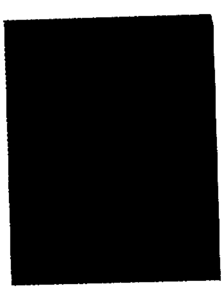
International Potato Center

PROGRAM REPORT

1995-96

The International Potato Center (CIP) is a not-for-profit, autonomous scientific institution established in 1971 by agreement with the Government of Peru. CIP is one of 16 international research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank, and comprises more than 45 countries, international organizations, and private foundations. The information and conclusions reported in this publication reflect the views of CIP.



Cover art based on a 9x12-inch mixed pastel titled *Partnership* by Josephine Dell'Orco Prain

PROGRAM REPORT 1995-1996

INTERNATIONAL POTATO CENTER

International Potato Center
Apartado 1558
Lima 12, Peru
cip@cgnet.com
http://www.cipotato.org

International Potato Center
Program Report
1995-1996

ISSN 0256-6311

September, 1997, 2 M

The International Potato Center. 1997.
Program Report 1995-1996. Lima, Peru. 323 p.

Contents

Providing Better Access to CIP Research

CIP's Program Report, published every two years, takes on a new look for 1995-96, and is more comprehensive than ever before. Previous reports covered scientific projects so that they could be reviewed quickly, but required many readers to request follow-up information. In presenting this new report, our intention is to provide research partners with a fuller understanding of CIP science, so that our work can be more easily replicated. The new format is intended to be more useful to a broader spectrum of scientists, including our traditional partners in national agricultural research systems, and researchers in advanced laboratories and the private sector. Together with our science reports, we have included regional overviews of CIP work worldwide, which provide some of the needs assessment and rationale for our research strategy. Presented here in published form, the entire report is also accessible through CIP's home page (http://www.cipotato.org) on the World Wide Web.

Technically, our Program Report covers CIP research conducted in 1995-96 under the able leadership of Dr. Peter Gregory, former Deputy Director General for Research. Readers should keep in mind, however, that CIP research is in a period of transition following our 1995 external review and because preparations for the initiation of the Center's 1998-2000 Medium-Term Plan were advanced by one year. These events, combined with more comprehensive impact assessment and priority setting, have led us to make some strategic adjustments in our research programs.

For example, readers may note that this report contains more articles in the area of biotechnology, particularly in our Disease Management and Germplasm Management and Enhancement Programs. This represents a shift in CIP research emphasis brought about by the recommendations of an external review and by a recognition among CIP scientists of the urgent need to avert a late blight emergency in developing countries. In addition, readers can examine the progress being made in virology, as CIP scientists are employing genetic engineering in their work to incorporate naturally occurring virus resistance into advanced breeding lines.

The 1995-96 report also points to how CIP will conduct its research under its next

Medium-Term Plan. As we gear up for a streamlined project portfolio that will begin in January 1998, the Center is adjusting its work programs, physical plant, and budget and management systems to accommodate new priorities and initiatives. The Medium-Term Plan—which received high marks from the CGIAR Technical Advisory Committee—gives high priority to late blight, the development of sweetpotato cultivars with higher dry matter content, and virus diseases.

In keeping with the Center's mission, these priorities are heavily weighted to those regions of the developing world with large numbers of poor people. Without exception, the research covered in the report favors low-income—especially women—farmers, labor-intensive technology that encourages rural employment, and urban consumers with limited funds for purchasing enough nutrient-rich foods. CIP research emphasizes work in and for those regions where agricultural productivity is threatened by environmental degradation and, conversely, where inappropriate farming practices threaten the natural resource base on which agriculture depends. I believe that our new reporting format will assist our many research partners, and will help bring into greater focus the need to meet these challenges.

Hubert Zandstra
Director General

Introduction: Alleviating Poverty Through Research Partnership

The 54 papers presented in this program report document a large segment of the major research initiatives conducted at CIP in 1995-96. Center scientists from each of our six program areas—together with representatives from the consortia and advanced laboratories with whom we conduct our research—share authorship for these reports.

The papers present various aspects of the Center's research agenda, particularly those elements of our program focused on environmentally friendly production systems and the many yield-reducing factors that affect root and tuber crops. CIP's research also emphasizes developing technologies that provide farmers with greater access to more diversified markets and, at the same time, protect endangered upper watershed ecologies.

Potato and Sweetpotato

In pursuit of these goals, CIP began to shift a higher percentage of its resources into upstream research in 1995. The blending of conventional and molecular approaches in CIP's breeding program, for example, illustrates the important changes taking place throughout much of the Center's research portfolio. In the case of late blight disease, our number-one priority, this includes a program of recurrent selection and multilocational testing of host-plant resistance, complemented by diploid prebreeding, marker-assisted selection, and direct gene transfer.

The feasibility of this approach was illustrated over the past two years by Center virologists working with partners in advanced research laboratories. As a result of their collaboration, we now have available a genetic map that provides the precise location of resistance genes for several key potato viruses. Projections indicate that the cloned genes can be successfully introduced into advanced breeding lines and varieties and made available for testing within three years.

In the case of sweetpotato—now the world's seventh-ranking food crop—CIP research was directed toward a significant, but more limited, number of objectives. CIP social scientists, working closely with colleagues at the International Food Policy Research Institute and in China, estimated that sweetpotato production in developing countries will increase at an average annual rate of 1 percent for the period 1990-2020. This calculation is consistent with long-term trends and emerging evidence from several countries, which indicate a bottoming-out in the decline in area planted or, as in the case of sub-Saharan Africa, a sharp increase in production.

After more than five years of diagnostic work in genetics, production and food systems, and socioeconomics, CIP researchers formulated a renewed sweetpotato research agenda. The new strategy is based on the hypothesis that production and use in subsistence farming systems are constrained by varieties that are poorly adapted and low in dry matter. In response, CIP scientists began to use the high-dry-matter accessions found in Center-held collections for varietal improvement targeted at poor countries in sub-Saharan Africa and Southeast Asia, and the poorer provinces of China. This work should produce high-quality sweetpotato cultivars suitable for direct consumption and for use as animal feed, starch, and flour products.

In addition, CIP scientists began to screen cultivars suitable for production in areas subject to drought. A major objective of this work is to make sure that farmers, particularly in the harsher environments of sub-Saharan Africa, have enough seed cuttings for planting once the rainy season begins. The Center's sweetpotato breeding program in Africa also reflects the crop's potential to offset the impact of cassava mosaic virus and black Sigatoka, diseases that now threaten food production in much of eastern and central Africa's most populated areas.

Genetic Conservation

The work reported here on genetic diversity analysis is the first use of molecular markers at CIP to fingerprint an entire cultivated potato collection (*Solanum phureja* Juz. et Buk.). CIP scientists also developed a cost-effective protocol for genotyping large germplasm collections using RAPD techniques, or randomly amplified polymorphic DNA. Integrating these and other molecular methods of germplasm management—together with more conventional conservation methods—could lower germplasm maintenance costs 30-40 percent, and allow greater investment in evaluation and utilization.

Along similar lines, cryopreservation research begun in 1995 should provide long-term solutions to the problem of maintaining vast numbers of traditional root and tuber varieties in conventional gene banks. CIP continued its work through national systems to safeguard nine exotic Andean crop species for farmers working in marginal areas, especially in the highlands. By the year 2000, Center scientists believe it will be possible to reduce investments in conservation and shift emphasis to research on utilization and marketing.

CIP has also begun efforts to support community groups that wish to conserve their germplasm *in situ*, and works to improve local varieties through participatory plant breeding programs. We expect these initiatives to reduce pressure on conventional gene banks, encourage natural evolution, and contribute to genetic diversity.

Natural Resources Management

Though less advanced than our work on potato and sweetpotato, conservation of lesser-known Andean genetic resources is conducted through CONDESAN, the Consortium for the Sustainable Development of the Andean Ecoregion. In 1995-96, CONDESAN involved work by more than 100 public-sector organizations, universities, and NGOs from seven Andean countries. One particularly important study completed in 1995 presents startling information on the health risks associated with insecticide use and provides policymakers with new methods for assessing the tradeoffs between agricultural productivity, environment, and health.

CONDESAN, working in the established traditions of other CIP-coordinated research networks and consortia, is also a key element of the CGIAR's Global Mountain Program. The Program's goal is to compare land use patterns and provide technological options that can be used across the world's great mountain systems. As with all CIP research, the overriding objective is to seek technological solutions that help alleviate poverty through increases in productivity and the enhancement of natural resources.

We ask readers to recognize that CIP scientists work from the premise that the poor should benefit proportionally more from Center research and training activities than do others. Implicitly, gender and poverty concerns strongly overlap with this goal. Although the reports presented here may not always explicitly express these concerns, the research behind them is geared exclusively toward improving the lives of the rural and urban poor in ways that are effective, equitable, and ultimately sustainable.

Overview of CIP Work in Latin America and the Caribbean

Fernando Ezeta[1]

Potato production in Latin America has grown at an average annual rate of 2% over the past 30 years. This expansion of the total output resulted mainly from improved productivity since the area in potato remained stable at nearly 1 million hectares for the region. But the aggregate regional figures do not reflect important differences among subregions and countries. Productivity gains have been greater in the Southern Cone countries and Central America than in the Andean region. Expansion of area was observed in Colombia, Cuba, Ecuador, and Mexico only, whereas in most other countries of the region potato area decreased or remained the same.

Among the technological interventions that have led to remarkable productivity gains are better varieties, access to quality seed, and improved agronomic practices, including dose and timing of fertilizer application. In spite of the obvious progress in potato agriculture observed over the past few years, average yields per unit area remain well below productivity levels in industrialized nations. Several constraints could be removed to increase overall potato output, basically via increased productivity. Over the next few years, CIP will concentrate efforts in developing technology and assisting Latin American and Caribbean NARS in improving potato pest and disease management, improving seed quality, and introducing processing attributes to new varieties.

1 Regional Representative, Lima, Peru.

Disease Management

Late blight (LB) is the main constraint to potato production in most of Latin America and the Caribbean (LAC). CIP's breeding program for resistance to LB with testing in Peru, Mexico, and Colombia (Ríonegro), which led to population A, has produced several LB-resistant varieties for the region. In Costa Rica, three clones of population A, introduced in 1991, were released as varieties in 1996. About 50% of the potato area in Costa Rica is now planted to these new varieties that are rapidly replacing cultivars Granola and Atzimba, which are extremely susceptible to LB. In Panama, two varieties selected from population A were released by IDIAP[1]. One of them, named IDIAFRIT, has excellent attributes for the french fries industry. In the Andean countries, CIP's LB-resistant clones have been released in Bolivia, Colombia, Ecuador, Peru, and Venezuela. In the Southern Cone, clones of population A have been used as progenitors in breeding programs. Direct adaptation of clonal selections from Andean environments to the growing conditions of the Southern Cone has been limited by the demand there for earliness and good tuber appearance.

The spread of a new, more aggressive population of the LB causal agent, *Phytophthora infestans,* together with growing environmental concerns have triggered regional efforts to support the Global Initiative on Late Blight, sponsored by CIP. The principles of searching for durable resistance without R genes and integrated disease management (IDM) are widely accepted all over the region. Argentina is actively screening R-gene-free populations adapted to long daylength. Other Southern Cone countries are equally interested in early screening of R-gene-free populations in the search for well-adapted, early LB-resistant materials. It is expected that PICTIPAPA and the potato research networks of the region will support research for durable resistance in their subregions.

The introduction of virus resistance is also of high priority in the region. Several breeding programs are making intensive use of CIP's PVX- and PVY-resistant populations to introduce resistance into their populations through conventional breeding. In Uruguay, variety IPORA, generated by INIA, incorporates PVY resistance from CIP's PVY-resistant population. The introduction of virus resistance is likely to have a remarkable impact on seed renovation rates, especially among low-income potato producers.

Bacterial wilt continues to be an important constraint to potato production throughout the region. Movement of large quantities of seed from infected areas seems to be the main dissemination mechanism. Over the past three years, CIP has organized workshops to alert research institutions and government plant health services to the problem. These workshops provided the opportunity to recommend actions to reduce, or possibly eliminate, the problem through IDM, quarantine, and the production of healthy seed.

Pest Management

Progress on integrated pest management (IPM) in LAC has been outstanding. In the Andes, pilot projects for control of the potato tuber moth (PTM) and the Andean potato weevil have proven the viability of the integrated approach to keep these pests below economic threshold levels. Technology components developed at CIP have been tested in farmers' fields to evaluate not only the technology itself but also training and communication materials. The program had a strong training component that reached technicians as well as potato farmers at the community level. In Peru, incorporating NGOs into the program increased the dissemination of IPM practices through extension services.

The successful application of IPM technology to the sweetpotato weevil (*Cylas formicarius*) in Cuba and the Dominican Republic must be highlighted. The sweetpotato weevil had gotten out of control in Cuba until the IPM program began. Now, the program is expanding rapidly, thanks to a well-orga-

1 Acronyms cited in this section can be found written out in the section *Acronyms*, p. 320.

nized extension service and well-defined individual control components. Among the components are effective sex pheromones that attract males into traps where they are eliminated by physical methods or by localized pesticide applications.

Significant progress has been made in controlling the leafminer fly (LMF) through IPM. In the central coast of Peru, where potatoes are grown in the winter, farmers have been able to reduce multiple insecticide applications to only two by adopting IPM practices. The use of yellow traps to catch adult flies dramatically reduces LMF populations. At the same time, the reduction in pesticide application favors biological control, which has proven to be extremely efficient.

Planting Materials

Although seed production technology is quite well disseminated in the region, the progress of seed production systems is below expectations. Public efforts to create a certified seed system have been unsuccessful in most cases because of the strong informal seed systems that supply seed to commercial growers. Nevertheless, in recent years the seed business has attracted the interest of the private sector. Private seed growers are adopting modern seed technology for rapidly multiplying healthy seed stocks. The progress made in pathogen detection of viruses and viroids is also a major contribution to improved seed quality standards. In summary, thanks to private efforts, local capacity for seed production in LAC has expanded in recent years.

True potato seed (TPS) as an alternative source of healthy planting material has been successfully used in Nicaragua and Peru. Other countries in Central America are exploring its potential. In Nicaragua, potato production depends on imported seed, which is expensive and physiologically immature. The experience with TPS has been rapidly assimilated into the production system of Nicaragua with good market acceptance. In the Peruvian highlands, the experience with Chacasina, a hybrid of a Peruvian variety and CIP clone 104.12 LB, has been so successful that farmers now have 200 kg of TPS as a source of seed for the coming years. Chacasina is a high-yielding TPS progeny with good acceptance among the consumers of this remote highland region, where good-quality clonal seed was extremely difficult to get before the project started.

Changing Markets

All over Latin America there is a growing interest in improving the processing quality of potatoes for chips and fries. The rapid expansion of the fast-food business in the region has created a demand for precooked frozen fries that, with few exceptions, is being met with Canadian imports. Most countries, however, would like to substitute locally produced potatoes for imports. Dry matter content and frying quality of advanced clones have been considered as important selection attributes in most breeding programs of the region. With the present rate of development of the potato processing industry in LAC, varietal acceptance is likely to be closely linked to processing quality in addition to agronomic traits and pest resistance.

Globalization and free-market economics are introducing important changes in potato production systems and markets of LAC. The progressive removal of trading barriers between countries within subregional common markets is increasing trade and competition among them. This more competitive environment poses a threat to small farming units and favors large-scale, high-input production units.

On a more global scale, LAC potato agriculture may face severe competition in the future from producers in industrialized countries. Production costs in most LAC countries are usually higher than in North America, an issue of major concern as LAC economies open up and reduce trading tariffs.

Collaboration

Collaborative potato research networks in LAC (PRECODEPA, PRACIPA, and PROCIPA) have confirmed their validity as mechanisms for the horizontal transfer of technology among members. Although at present only PRECODEPA counts on external funding, the links established between researchers in PROCIPA and PRACIPA continue to facilitate the exchange of research results.

Electronic communication is essential in today's research and development efforts. CIP is therefore fostering the consolidation of an electronic information network, INFOPAPA, that aims to link potato researchers of all research networks within LAC. We expect INFOPAPA to accelerate the exchange of knowledge and information among members efficiently and inexpensively.

Overview of CIP Work in the Middle East and North Africa

Aziz Lagnaoui[1]

The close proximity to Europe, the relative wealth of the Middle East and North Africa (MENA) region, and the strong commercial appeal of potatoes make this commodity more of a cash and export crop. Up to 75% of Dutch seed exports, out of Europe, are destined to countries in the MENA region. These same countries are in turn potato exporters during the winter months, mainly to the United Kingdom, France, and Germany. The special trade arrangements between the European Community and several MENA countries will certainly continue to influence this trend. CIP's comparative advantage is the potential to increase yields by concentrating on crop and pest management research.

Our Regional Action Plan and priority-setting for 1995-96 focused on reducing environmental hazards of potato production systems by developing and disseminating biological control methods for major pests. CIP has a clear comparative advantage in these activities and research results can be effectively used immediately. CIP showed impact in activities and places where a staff scientist was posted to work closely with counterparts in the national program. In response to our challenge to "focus on fewer things in fewer places," areas that held uncertain promises of success were avoided and promising research was continued to avoid a dilution of effort. The research team concentrated on integrated pest management (IPM), true potato seed (TPS), and healthy sweetpotato planting material.

With the strong belief that IPM is at the foundation of sustainable agricultural development, we continued to implement CIP's IPM strategy through participatory research and training, promoting public awareness of the benefits of IPM, and involving policymakers.

1 Regional Representative, Tunis, Tunisia.

Integrated Pest Management of Potato Tuber Moth

Our IPM strategy was to implement a process whereby potato growers in the MENA region could begin to substantially reduce their dependence on toxic pesticides for control of the potato tuber moth (PTM). Over the past few years, CIP and its partners in the Tunisian national program have developed effective practices for controlling PTM, the insect pest most responsible for significant losses in the region. Implementing the PTM management strategy was basically reduced to an educational process.

Recognizing the considerable opportunity to alter present PTM control practices in both Tunisia and Egypt, we invested our efforts in

- demonstrating advanced IPM technologies on-farm;
- promoting national policies that support the use of IPM; and
- training national scientists and extension specialists to implement IPM on a large scale.

By capitalizing on the soundness of the IPM strategy in Tunisia, we achieved a gradual shift in priorities as the Tunisian national program was encouraged to begin the large-scale implementation of IPM. We worked to determine the best way to extend IPM practices on a larger scale and to accelerate adoption.

In Tunisia, adoption of improved control practices has all but eliminated unnecessary insecticide sprays for PTM control in fields. The adoption of *Bacillus thuringiensis* (Bt) and granulosis virus (GV)-based insecticides is steadily increasing.

Complementary research focused on enhancing GV activity by formulating it with various compounds to put an additional stress on the insect. That should reduce the time required for the virus to kill PTM and lower the pathogen dose needed.

Improving traditional storage structures was also deemed necessary, so we called on CIP storage specialists to design an improved traditional storage facility. The Tunisian Ministry of Agriculture is funding the construction of pilot storage units in the major potato-producing areas.

The involvement of policymakers, including the President of Tunisia, generated unprecedented excitement for IPM in the research and extension community. That is likely to accelerate the adoption of IPM. As anticipated, the success of the Tunisian project is providing the foundation for the adoption of IPM in the other potato-producing countries in the MENA region.

In Egypt, a ban on the most widely used pesticide for PTM control in storage precipitated interest in the use of *B. thuringiensis* and granulosis virus. As a result, mass production of GV and Bt is increasing and quality is improving. In addition, 400,000 capsules of PTM sex pheromone for use in pheromone traps have been produced. Off-farm implementation is a trend in newly reclaimed areas. Growers contract with agencies or companies to control PTM using Bt and GV. A similar system was used in the past in the cotton IPM program, which is mainly designed to protect farmers from crop losses.

Integrated Disease Management

Causal agents of soft rot and dry rot

A survey of potato diseases in fields and in summer rustic stores was conducted in Tunisia to identify the main pathogens responsible for storage losses.

No incidence of soft rot or blackleg was found, although *Erwinia carotovora* and *E. chrysanthemi* were isolated from imported seed lots. In traditional stores, watery wound rot (WWR), also called potato leak, caused by *Pythium aphanidermatum* and *P. ultimum,* was prevalent. Tubers exhibited a discoloration similar to the pink rot symptom. Although *Fusarium roseum* var. *sambucinum* was isolated from imported seeds, it was dry rot caused by *F. solani* that showed a high incidence in stores. Losses in summer rustic stores were correlated to the seed health status of the previous spring crop.

In the field, wilt was caused by soil pathogens such as *Verticillium dahliae* and *F. solani* var. *eumartii. P. aphanidermatum* was also isolated from wilted plants; losses at harvest were mainly due to WWR. Wilt incidence was not correlated to seed health status but to the cropping system (successive planting of solanaceous plants), thus showing the importance of soil infestation in the transmission of disease.

Watery wound rot management

Pythium aphanidermatum and *P. ultimum* were found to be seed-transmitted as well as persistent in Tunisian soils. Because of the high incidence of these pathogens on-farm and in large-scale stores of the Tunisian seed program, we investigated various components of integrated management of WWR.

Comparison of varietal susceptibility. We developed a method to assess susceptibility to WWR and tested several European varieties from the national list. Among these, only varieties Korrigane, Superstar, Safrane, and Yesmina were found to be moderately susceptible.

Biological and chemical control. Seed treatments with the antagonistic soil saprophyte *Trichoderma harzianum* or with fungicide solutions of Ridomil (metalaxyl 10%, mancozeb 48%), mancozeb, maneb, or hymexazol efficiently controlled WWR development in the laboratory.

Disinfecting soil by solarization. Populations of *Fusarium solani* and of *Pythium* sp. were significantly reduced by soil mulching. The benefit of the method on potato growth and weed control was demonstrated in experiment station and on-farm trials.

Baiting technique. A simple baiting technique using oat seeds to detect and quantify soil populations of *P. aphanidermatum* was established. A detection threshold of 1-10 oospores/g of soil will allow us to identify noninfested soils for local seed multiplication.

Research begun on the control of WWR will help to formulate effective integrated control recommendations for local seed multiplication.

All surveys and research efforts have been performed in collaboration with the staff of the Tunisian seed program and the Ministry of Agriculture. Extension specialists have been trained to improve their ability to diagnose storage disease. The identification of the main potato pathogens in Tunisia also permitted us to establish tolerance thresholds for certification schemes and importation agreements more appropriate to local conditions.

Furthermore, these findings will greatly assist scientists in formulating integrated disease management (IDM) approaches for potato soft and dry rots.

Sweetpotato in Egypt

Newly released varieties Kafr El-Zayat I and Kafr El-Zayat II, varieties Jewel and Beauregard, and the selected advanced clone A193 were produced in large quantities in the newly constructed screenhouses at CIP's Kafr El-Zayat station. So far, 300,000 healthy plantlets were produced at the CIP station and distributed to farmers by the national program for on-farm evaluation; over 2 million plantlets were produced by the private sector. A similar operation is being set up in Syria (spinoff effect), where local planting material is degenerating. We will continue to emphasize the quality of planting material and promoting wider use of the crop.

True Potato Seed

The performance of TPS hybrids and recent advances in TPS use led to greater transfer of this technology to Egyptian farmers. A number of entrepreneurial farmers started to produce seedling tubers from TPS at 50% the cost of locally produced seed tubers. Our liaison office in Egypt is catalyzing interactions with the private sector and government organizations. Already a spinoff effect is taking place in neighboring countries as Syria has begun experimenting with promising progenies.

The Future

Over the years, CIP has ensured greater impact on-farm by strengthening the research capabilities of our national partners, by encouraging farmer participation, and by enhancing communication between the research and implementation institutions. In the years ahead, we will focus on the transfer and implementation of acquired knowledge on IPM and IDM to ensure greater impact on-farm and contribute to the sustainability of production systems in key countries in the region (Egypt, Tunisia, Morocco). We will also seek to promote linkages with institutions in countries of the Middle East (Jordan, Yemen, Syria).

Persistent challenges in the region are the ever-increasing threats posed by potato tuber moths, whiteflies, and leafminer flies as a result of intensified potato cropping in several MENA countries. Furthermore, special emphasis should be placed on the evaluation of the potential contribution of biotechnology to potato and sweetpotato production in the region. In accordance with IPM principles and biosafety guidelines, transgenic material will be carefully evaluated for its effectiveness and effects on nontarget species before deployment.

The most important challenge is to ensure long-term continuity of CIP's work in the region and to respond to new requests while maintaining a minimal physical presence. One way of meeting that challenge is to develop special country projects as needs are identified and defined.

Overview of CIP Work in Sub-Saharan Africa

Peter T. Ewell[1]

Sub-Saharan Africa is a large and diverse region. Of its 47 countries, 36 report potato and/or sweetpotato production to the FAO. In the aggregate, food production has failed to keep pace with population growth, and per capita production has declined. Chronic deficits are made up with imports and food aid. According to the World Bank, 21 of the 30 poorest countries in the world—with GNP per capita per year below $430—are in sub-Saharan Africa. Natural environments, cultures, and economic conditions vary markedly among countries. Vast regions are sparsely populated deserts and forests. Semi-arid lands, subject to periodic droughts, account for large areas. Both potato and sweetpotato are grown primarily in densely populated, intensively cultivated highland and mid-elevation zones. They play important, contrasting roles in the food systems of the region.

Potato and Sweetpotato in Africa

Potato is a short-season, high-value crop, grown as a cash crop and for household consumption. According to the FAOSTAT database on the Internet, about 400,000 hectares are harvested in sub-Saharan Africa. Potato production reported in Africa as a whole has nearly tripled over the past 35 years, from 1.3 million tons in the early 1960s to 3.7 million tons in 1996. This growth has been consistently and significantly higher than that of the population. This reflects the crop's growing importance as a food in rapidly growing urban areas.

Broadly speaking, there are three major potato systems:

1. In the densely populated, high-potential highland areas (1,800-2,750 m) of eastern and central Africa, potatoes are grown by small farmers (0.5-2 ha) both for the market and for home consumption. Yields vary between 5 and 20 t/ha, with a mean of 8-10 t/ha. Rates for chemical fertilizer and fungicide use vary widely among countries and production areas, but are generally low because farmers cannot afford chemicals and supplies are unreliable. Seed is obtained primarily from informal, local sources and average seed quality is low. Late blight and bacterial wilt, as well as viruses, cause chronic, significant yield losses.

2. In southern Africa, particularly in South Africa, potatoes are grown on a relatively large scale in the modern farming sector. Irrigation is becoming more important, good-quality seed is available, inputs are used intensively, and average yields are high—from 15 to over 25 t/ha in South Africa.

3. In Cameroon and Nigeria, potatoes are an important smallholder crop in higher areas. Elsewhere in West Africa, the crop is grown on a very small scale as a high-value vegetable, usually under irrigation.

Sweetpotato is an important food security crop grown in almost every country on the continent. Approximately 1.5 million hectares are planted, primarily in rural areas for home consumption. Although the overall growth rate in reported production has fallen behind total population growth, sweetpotato has significant potential for increased use.

Sweetpotato is a low-input crop, easily propagated from vine cuttings, that is grown under a wide variety of conditions, from intensive irrigation to commercial rainfed fields

1 Regional Representative, Nairobi, Kenya.

and to millions of small plots in and around fields of other crops, along roadsides, in backyard gardens, and in urban plots. The crop is most important in eastern and central Africa, including Cameroon, in densely populated, intensively cultivated mid-elevation (1,200-1,800 m) areas, slightly lower than where potatoes are grown in most of the same countries. Elsewhere in eastern and southern Africa, sweetpotato is an important secondary food in diets featuring maize and other cereals. The crop is important in certain regions and periods of the year, such as in the "hungry months" when stores are exhausted and the next grain crop awaits harvest. Diets in the lowlands of West Africa are dominated by cassava, yams, and other staples, and sweetpotato plays a minor role.

Research in Partnership with National Institutions

CIP set up its regional program in sub-Saharan Africa in the mid-1970s. The goal has been to work with national potato and sweetpotato research programs and other partner institutions on key issues facing increased production and use. In 1996, nine CIP international and regional scientists were working in the region: five in Kenya, three in Uganda, and one dividing time between Cameroon and Nigeria. These scientists were directly involved in core-funded, collaborative research with national scientists in Kenya, Uganda, Cameroon, Ethiopia, Tanzania, and Nigeria.

Strong links were maintained with other potato and sweetpotato programs through the PRAPACE[1] network for central and eastern Africa and the SARRNET network for the SADC countries of southern Africa. These networks provided the context for CIP's participation in seed relief and program rehabilitation projects in war-torn Rwanda and Angola. More limited contacts are maintained with countries that are not network members, for the distribution of information and germplasm.

Collaborative research is concentrated in six major project areas:

1. Potato late blight. Late blight is the single most important potato disease in the region, particularly in the tropical highland environment of central and eastern Africa. Temperatures in the major production zones (1,800-2,750 m) are relatively even. The rainfall pattern is bimodal, and inoculum is almost continuously present. Farmers do not have the income to spray fungicides regularly, and the disease causes serious yield reductions in most years. The disease is less significant in the drier areas of southern Africa.

Over the past 20 years, blight resistance has been the principal trait of new varieties adopted by farmers in countries throughout the region. Several advanced clones are near release and are expected to do well, although R genes are present and their resistance is likely to break down eventually. Sets of genotypes from population B, with better horizontal resistance, are in the early stages of selection in Kenya, Uganda, and Ethiopia. As the Global Initiative on Late Blight develops, CIP and its national partners will increase their investments in research, particularly to promote integrated disease management on-farm.

2. Farmer-based potato seed systems in Kenya, Uganda, Ethiopia, and Cameroon. Farmers need healthy seed, which is available on their farms at planting time, in the right physiological state, at a price they can afford. Centralized systems for seed multiplication and certification modeled on those in Europe and North America have proven difficult to implement and maintain in public-sector institutions in Africa. An alternative is to provide selected farmer-multipliers with clean starter seed stock, and support them to become specialized in the multiplication of seed for sale to other farmers in their area. This also provides a mechanism to get new varieties to farmers.

The facilities that CIP developed over many years in collaboration with the Plant Quarantine Station in Kenya for the intro-

1 Acronyms cited in this section can be found written out in the section *Acronyms*, p. 320.

duction and testing of germplasm for regional distribution have been converted into a seed unit. The best available varieties are multiplied in vitro as "starter stocks" for seed programs in target countries. Linkages have been developed with NGOs with contacts in pilot potato-producing communities to facilitate selection of suitable farmers, training in seed techniques, and support for constructing diffused-light stores.

3. Integrated disease management for potato. IDM is the only practical approach to bacterial wilt, as the disease organism persists in the soil, is carried by infected seed tubers, and cannot be controlled with chemicals. In Uganda, CIP is collaborating with NARO, the national research institute, in the African Highlands Initiative, an ecoregional program linked with the Global Mountain Initiative. Its purpose is to take a multi-institutional, multicommodity approach to improving resource management in the intensively cultivated high-potential areas of the highlands.

One project is the integrated management of diseases associated with increasing land use intensity and decreasing soil fertility. Bacterial wilt is one of four diseases being investigated. A full-time regional scientist attached to CIP to work on the project has shown that a package of improved rotation, clean seed, tolerant varieties, and improved on-farm sanitation reduces losses, even on very small farms. Strategies for improved management provide an entry point, to encourage farmers to improve their land use management, with immediate payoff in increased potato yields and longer-term payoffs in stable soil fertility.

4. Sweetpotato improvement. From the late 1980s, CIP's regional program has imported advanced sweetpotato cultivars from throughout the world for distribution and evaluation. At the same time, true seeds produced from crosses made by Uganda's national program and from elsewhere are being tested at a few locations.

Farmers grow diverse combinations of locally adapted varieties, which tend to be late-maturing and low-yielding. Planting material is exchanged informally among relatives and neighbors, and only a few introduced varieties have become established in sub-Saharan Africa over the past 25-30 years. African farmers are interested in new varieties if they meet certain criteria: high yield, earliness, and persistence of plants in fields so that planting material is available for the next season. Drought-tolerant varieties would permit the expansion of sweetpotato cultivation in drier areas and drier periods in the year. Good taste is very important both for home consumption and for sale in the market. Consumers like roots with high dry matter (usually at least 27-28%) and moderately sweet taste. Resistance to or tolerance of viruses, weevils, and other pests and diseases could help expand the range of the crop and increase yields.

New varieties for new or expanded uses also have significant potential. Most African consumers prefer roots with white or cream-colored flesh. Orange-fleshed varieties can provide significant quantities of vitamin A, which is critically short in the diets of many rural people, particularly children. Preliminary evidence shows that mothers will grow, prepare, and serve new varieties, if they understand the implications for the health of their families. Sweetpotato vines are high in protein and are an excellent forage for animals, particularly for weaning calves and kids. They are currently fed as a by-product, but dairy farmers will plant new varieties with high forage yields specifically for this purpose. Varieties for processing will be planted if secure markets become available.

5. Integrated sweetpotato crop management. The most widespread and damaging pest in eastern and southern Africa, particularly in dry areas and in dry years, is sweetpotato weevil (*Cylas* spp.), a focus of CIP's collaborative research. A number of other insects, viruses, and fungal diseases are important in certain areas. Collaborative research in Uganda and Tanzania, with assistance from the Natural Resources Institute, has isolated sex pheromones of all three species found in Africa, and is testing their use for monitoring and possibly mass-trapping. Several cultural practices, such as maintaining an adequate separation between sweetpotato fields, careful hilling, and removal of all residues from plots after harvest, have been shown to reduce damage.

Pilot projects are being established in Uganda to work with farmers to see how these components can be adjusted and combined to provide effective protection against weevil damage. Most successful IPM programs have been adopted by farmers because they help to reduce pesticide applications, thereby reducing costs. As pesticides are not used on sweetpotato except by a small minority of farmers, the challenge is to develop packages that increase yields sufficiently to justify the increased labor, cash costs, and management attention. Broadening the approach to include additional key constraints in an integrated *crop* management package is a key to success.

6. Expanded postharvest use of sweetpotato. In Africa, sweetpotato roots are consumed almost exclusively in fresh form; most are usually just boiled. In other parts of the world, particularly in Asia, use of sweetpotato as a raw material in the production of processed foods, feed, and industrial products has increased significantly over the past 40 years. The adaptation of known products and processes to African conditions could open up new markets for farmers. The use of a locally grown, low-input crop in processed products could also reduce the countries' need for food imports to meet the needs of rapidly growing cities.

Collaborative research in Kenya and Uganda has demonstrated that a ready market exists for homemade products such as flat bread (*chapatis*) and doughnuts (*mandazis*), which substitute cooked and mashed sweetpotato for a certain proportion of the usual wheat flour. Farmers in some areas cut roots into chips and dry them in the sun to preserve them. These processes are being improved so that the dried chips can be ground into a high-quality flour, which can be easily stored and transported, and used in mixtures with wheat and other flours in baked goods.

Other Activities

CIP's regional office provides a link between scientists working in national institutions and research throughout the world. Courses, short-term attachments, and study tours provide training in research and analytical techniques. CIP scientists act as advisors for many student thesis projects. Support for networks and a number of bilateral, regional, and multi-institutional projects help ensure that research responds to the needs of potato and sweetpotato farmers in Africa.

Overview of CIP Work in South and West Asia

Sarath Ilangantileke[1]

The largest potato producer in the South and West Asia (SWA) region is India, followed by Bangladesh, Nepal, Pakistan, Sri Lanka, and Bhutan. Sweetpotato production is mainly in India, Bangladesh, and Sri Lanka; production in other countries is localized and of little significance.

Potato

The SWA region produces about 21 million tons of potatoes on 1.3 million hectares. In the past decade, total potato production in India has increased rapidly, with comparatively slower increases in Bangladesh, Bhutan, Nepal, Sri Lanka, and Pakistan. Increases in total production in countries other than India and Bhutan are attributed more to a gradual expansion in area than to significant yield increases. Among the six regional countries, India currently has the highest national yield average (16 t/ha), whereas Nepal has the lowest (8.3 t/ha).

Potato is used mainly for the fresh market. However, local and multinational snack and fast-food industries are developing rapidly in the region, and India is striving to provide potato for the domestic processing industry. Estimates indicate that about 9,000 tons of the crop are now processed annually in the unorganized sector alone in India. Trade within the region in seed and ware potato is expected to increase in the future with new trade agreements between the SWA countries. Demand for selected processing and high-yielding varieties will therefore increase steadily.

Problems of cultivation in the region, although similar, are location and ecoregion specific. A major problem is the availability of high-quality local seed for ware and processing. Countries outside India depend on either imported seed or low-quality local seed. But late blight and bacterial wilt significantly affect yields in all SWA countries. Postharvest problems of storage and marketing already exist and may become more pronounced with increased production and future trade in the region. The intensities of problems differ significantly.

As a regular major activity, potato germplasm was distributed from CIP-Lima and the regional office to NARS, networks, NGOs, and private-sector organizations in the SWA region. This catered to the increased demand for germplasm for specific breeding requirements such as processing and disease resistance.

Development of healthy seed material is an important activity. Increased interest among farmers in TPS technology has resulted in a remarkable increase in crop production area in different agroecological regions of India. In addition to domestic use, large quantities of TPS produced in India have been exported to Vietnam, Egypt, Indonesia, and the Philippines outside the SWA region, and to Bangladesh, Nepal, and Sri Lanka within the region.

Regular farmer training programs and extension activities by NARS in collaboration with CIP have helped increase TPS production and use in Bangladesh. TPS demonstration projects and farmer training on location-specific agronomic practices in Nepal have resulted in increased use of TPS in the mid-hills and lowlands (Terai region). Although production of true seed in Nepal is

1 Regional Representative, New Delhi, India.

limited, use of TPS from India has shown an upward trend. The Asian Development Bank TPS project in Sri Lanka has provided assistance in evaluation and farmer demonstration trials. Research on TPS continued for developing earliness and disease resistance.

Training in the region has been dominated by TPS-related training, a major reason for the rapid increase in TPS use. An interregional workshop on TPS production and use held in India had participants from China, Vietnam, Sri Lanka, Indonesia, the Philippines, Nepal, Bangladesh, and India, as well as scientists from CIP-SWA and the ESEAP region. The private sector, progressive farmers, and NGOs were also represented. CPRI and CIP-SWA jointly gave field training on TPS production and use to scientists from Sri Lanka and Bangladesh. Individual and group training activities on TPS in the region included training on hybrid TPS production and use for research workers, farmers, agricultural officers, field assistants, and NGOs in India, Bangladesh, and Nepal.

The search for new areas for potato production in India has resulted in the use of riverbeds to cultivate potato in Orissa, with assistance from CIP. We have already observed an increase in production area. This technology targeted specifically to resource-poor farmers and to the use of underused land resources is gaining popularity and has provided significant increases in potato yields.

Seed and ware potato storage performs an important function in the production and marketing of the crop in the region. In India, large quantities of potato are stored in cold stores immediately after harvest. Farmers unable to avail themselves of cold-store facilities store the produce on-farm until prices begin to increase two to three months after harvest. Storage in heaps and in traditional structures results in losses. Research on an alternate method of storage using rustic evaporative cool stores was continued in three large potato-producing districts. A national workshop on problems of potato storage in India was held for scientists, farmers, policymakers, and cold-store owners as a way to identify future strategies for storage research.

In the future, CIP needs to address several potato activities in the SWA region: varietal improvement for end use, disease resistance, and productivity; availability of high-quality seed and efficient seed systems; postharvest and marketing; and development of human resources.

Sweetpotato

The SWA region produces about 1.6 million tons of sweetpotato on 0.2 million hectares. India accounts for 68% of the total production, followed by 27% in Bangladesh and about 5% in Sri Lanka. Sweetpotato is an important crop for Sri Lanka and occupies 1.1% of the total cropped area, followed by 0.5% in Bangladesh and less than 0.1% in India.

Although production area in Pakistan is insignificant, yields of more than 10 t/ha are reported, followed by 9.5 t/ha in Bangladesh, 8.3 t/ha in India, and 6.5 t/ha in Sri Lanka. In India, yields have improved since the mid-1980s, whereas yields in other countries have declined gradually after the respective peak yield years.

Use is limited to consumption as a vegetable in all SWA countries, with an insignificant quantity of processed snack food, limited to India, followed by Bangladesh. Industrial use is nonexistent.

A major problem is the availability of ideal varieties for different agroecologies and different cropping systems in the region, where crop duration influences yield potentials. High incidences of sweetpotato weevil and other pests and diseases limit achievement of maximum yields, while a lack of postharvest utilization methodology and marketing chains limits enthusiasm to elevate the crop beyond its present status as a "poor man's" crop.

The production and use of sweetpotato in the diets of people of South and West

Asia are expanding. The striving to popularize the use of sweetpotato in diets has resulted in the exchange of germplasm from neighboring countries. Sweetpotato germplasm distribution was done in vitro and as stem cuttings, as requested by NARS of Bangladesh, Nepal, and Sri Lanka; networks of different organizations; and NGOs and private-sector organizations in the region. Varieties having high carotene content were supplied to a USAID nutrition project in Nepal. CIP-SWA supported travel and attendance at international seminars and conferences.

Sweetpotato breeding in collaboration with NARS of India has resulted in a transfer of advanced clones for evaluation to Bangladesh and Sri Lanka, and to research organizations in the sweetpotato-growing areas of India. A sweetpotato production and weevil control course in India for farmers and agricultural officers of Goa was held to encourage increased production. Such activities will be increased to help popularize the crop.

Like for potato, varietal improvement for end use, increased availablity of high-quality planting material, and postharvest/marketing and development of human resources are important activities for CIP-SWA in developing sweetpotato production in the region.

Collaborating Institutions

Research was done in collaboration with NARS. In India, with the Indian Council for Agricultural Research and its institutes—the Central Potato Research Institute and the Central Tuber Crops Research Institute (for sweetpotato), the Department of Horticulture, state universities, NGOs, farmers, and private-sector organizations. In Bangladesh, collaboration was with the Bangladesh Agricultural Research Institute's Tuber Crops Research Center. A notable feature in Bangladesh was NGO interactions to help diffuse TPS.

Regular training programs and travel grants were provided to NARS scientists. CIP provided MSc and PhD programs for researchers in Bangladesh and India on TPS technology and on sweetpotato varietal selection and evaluation, respectively. Outside funding sources were solicited through the GBF (Society for Biotechnological Research) for NARS scientists for a three-month training in biotechnology in Germany.

Expected Accomplishments

Potato and sweetpotato are important crops in the diet of people in the SWA region. Activities conducted by CIP are expected to lead to sustainable seed and planting material systems in countries with needs. CIP will also work toward marketing and postharvest strategies that will result in seed self-sufficiency and a production environment with economic benefits for potato and sweetpotato farmers.

Overview of CIP Work in East and Southeast Asia and the Pacific

Peter Schmiediche[1]

Potatoes account for roughly half of the world's annual output of all roots and tubers and, since the early 1960s, the increase in area planted in developing countries has been higher than for any other major food crop. Annual world production currently totals 274 million tons on 18 million hectares, and China and India alone produce 22% of this total.

The potato sector worldwide is in transition. Europe and the former Soviet Union account for the bulk of production, but the situation is changing rapidly. In the early 1990s, about 30% of the global potato output was produced in developing countries, up from 11% in the early 1960s. If this trend continues, in less than a generation, most of the world's potatoes will be harvested in Asia, Africa, or Latin America. As a result, potato is becoming an increasingly important source of food, rural employment, and income for the growing populations in these regions.

Over the past three decades, Asia has experienced the world's highest annual growth rate in potato production. With its short cropping cycle, potato fits well into Asian food production calendars, and is particularly compatible with fast-growing hybrid cereals. The expansion of cold storage, the rapid emergence of processing facilities for the fast-food industry, and the indirect influence of improved rice and wheat irrigation systems have also contributed to the expansion of potato production in Asia. Low prices relative to cereals combined with the economic impact of improved storage systems have stimulated greater demand. This trend is continuing strongly in all Southeast Asian potato-growing areas, particularly in those that feed the rapidly expanding urban concentrations and megametropolises of this region. Demand is strongest for processed potatoes that supply the fast-food industry in these urban centers where processed potato products fetch top prices, thus converting this tuber into a highly profitable cash crop. This increasing demand puts strong pressure on national and international breeding institutions to produce high-quality processing varieties that are well adapted to the wide array of agroecological conditions in Southeast Asia.

Even if more and more varieties with the required processing and culinary qualities become available, the lack of adequate seed systems is the single most important impediment to the development of the crop. A profitable crop starts with high-quality seed, but unfavorable agroecological conditions interfere with the production of such seed in most Southeast Asian potato-growing areas.

One solution to the seed problem is the use of botanical or true seed instead of conventional propagation from tubers. True potato seed (TPS) has promise in several agroecological niches of Southeast Asia. One such area is the Red River Delta (RRD) around Hanoi, Vietnam, where several thousand hectares of potatoes will be grown from TPS during 1997-98 to avoid the disease problems associated with traditional tuber plantings. The hybrid seed grown in Vietnam was developed in CIP-sponsored projects in India, where seed production is now in the hands of the private sector. The TPS project in Vietnam is sponsored by the Asian Development Bank, and this project

1 Regional Representative, Bogor, Indonesia.

is in the process of revolutionizing potato culture in the RRD, where more than 90% of Vietnam's potatoes are grown. It is also introducing hybrid TPS production in the RRD and in the highland area around Dalat in south Vietnam. In addition, Vietnam is using numerous introductions of CIP potato germplasm to great effect. Several varieties or potential varieties have been selected for those areas where the TPS technology is not yet in use.

According to Chinese sources, CIP potato germplasm has boosted China's successful breeding program since the early 1980s when it had stalled because of the lack of genetic variability. Potato variety CIP-24 now occupies more than 250,000 hectares in China. Results of CIP's basic phytopathology research have been successfully used in China's seed potato program and in the integrated control of late blight and bacterial wilt. Apart from transferring technology, CIP has assisted with numerous training events for groups and individuals inside and outside China.

Because potato is affected by more pests and diseases than any other food crop, it has become a heavy user of pesticides, with the associated negative effect on the environment. To reduce pesticide use, programs of integrated pest management (IPM) have been developed for this region. CIP's ESEAP researchers collaborate with governmental and nongovernmental organizations to promote integrated pest and disease management based on four principles originally developed by the FAO Intercountry IPM Program for Rice:

- grow a healthy crop,
- conserve the natural enemies of pests,
- monitor fields frequently and, through training and hands-on experience,
- farmers become expert practitioners of integrated pest management.

In sweetpotato culture, the most important issue to be resolved in this region is that of sweetpotato use. The problem of use is closely followed by the need to control the sweetpotato weevil, the most important sweetpotato pest in Southeast Asia. Efforts to control the weevil with classical IPM methods have evolved into a comprehensive package of integrated crop management (ICM) since national programs will not, as a rule, implement an isolated IPM solution that does not address other related problems of raising a successful sweetpotato crop. As already indicated for potato, in Asia, the first principle of ICM is "grow a healthy crop," implying the central position of IPM within an approach of integrated crop management. Successful ICM depends on coupling the classical activities of deploying host-plant resistance, using biological control, reducing pesticide use, enhancing and protecting natural enemies, and deploying sex pheromones with equally classical agronomic measures. Moreover, ICM can only be successful if individual farmers and the farming community understand and participate in these measures. This has been achieved through a series of highly successful Farmer Field Schools in Indonesia. The concept of ICM and Farmer Field Schools is now spreading to other countries in this region, particularly Vietnam, where it will be applied to both potato and sweetpotato culture.

A special project funded by Swiss Development Cooperation (SDC) concentrated on the collection, classification, and use of sweetpotato biodiversity in Indonesia, combined with a pioneer effort to document the associated indigenous knowledge of this germplasm to facilitate its rapid use. This project was designed to identify sweetpotato germplasm that would meet specific needs, initially of Indonesian sweetpotato cultivators and later of growers in other areas of Asia. Exploration of *in situ* conservation techniques for sweetpotato is under way in Indonesia and the Philippines.

China's principal sweetpotato-breeding institutions have worked closely with CIP's regional sweetpotato breeder in the use of a wide array of germplasm to develop cultivars with high dry matter content. A highly visible and successful program, using virus-free sweetpotato planting material in Shandung

Province, has been acknowledged to have benefited from basic virus research and associated training activities conducted by CIP.

Sweetpotato processing, as it relates to the use of starch for noodle production, is another area in which great advances have been made in China, particularly in Sichuan Province—the largest area of sweetpotato production in China. Research on sweetpotato pig-feeding systems in that province is an area of enormous potential, with spillover possibilities for other provinces of China.

A major CIP-UPWARD[1] initiative on the use of sweetpotato and canna in north and central Vietnam completed a detailed assessment of research needs, and sweetpotato is now being introduced as an alternative source of starch for noodles and as an improved source of pig feed. Vietnam's strength in potato and sweetpotato research is in no small part the result of highly active ongoing CIP-sponsored and CIP-mediated training efforts during the past 15 years.

CIP's impact in the Philippines has been achieved through four institutional structures that developed and implemented a series of projects to address the needs of potato and sweetpotato culture in that country: (1) the UPWARD network, which, although regional in scope, has been particularly active in its host country; (2) the regional ASPRAD[2] network, which implemented a significant number of highly successful potato and sweetpotato projects through its active coordinating office in Los Baños; (3) the SANREM[3] watershed-based, natural resources management activities in Mindanao; and (4) potato seed research and development, implemented through CIP's seed unit in Baguio and through ADB-financed TPS research in Luzon and Mindanao.

1 UPWARD (Users' Perspectives With Agricultural Research and Development).
2 This network used to be known as SAPPRAD (Southeast Asian Program for Potato Research and Development) before it was renamed ASPRAD (Asian Sweetpotato and Potato Research and Development). Its Australian funding terminated on December 31, 1996.
3 SANREM (Sustainable Agricultural and Natural Resource Management).

Production-level impacts are promising through the diffusion of CIP-derived potato germplasm via formal and informal seed channels in the conventional potato production areas, and through the use of TPS in Mindanao.

Significant takeoff is already evident in the use of Farmer Field School approaches to the integrated management of bacterial wilt. Urban home gardens research in northern Philippines is now showing payoffs with large-scale expansion in the use of improved sweetpotato germplasm and other technologies. Institutional impact has been achieved through the adoption of participatory approaches to research by many institutions, involving farmers, farming communities, and other end users of potato and sweetpotato in research. For example, participatory variety evaluation procedures developed by ASPRAD have been adopted in the Philippines and in other countries. Interagency research partnerships developed by UPWARD are now practiced by local institutions. Filipino agricultural research institutions have highly trained individuals and, through UPWARD and ASPRAD, Filipino scientists have been able to make a significant research impact in other countries of this region through short-term consultancies.

In Indonesia, research has concentrated on the introduction and testing of new potato germplasm, the use of TPS as an alternative seed system, the integrated management of bacterial wilt, the integrated crop management of sweetpotato through development of the Farmer Field School model, and the preservation of sweetpotato biodiversity and indigenous knowledge associated with sweetpotato biodiversity. CIP has also contributed in significant ways through PhD training to the pool of agricultural research expertise in potato.

In summary, CIP has responded flexibly and with the prudent use of scarce human and financial resources to the needs of this region. Results and impact are apparent and the foundations for further advances have been laid.

Production Systems

Thomas S. Walker[1]

Since the last Program Report (for 1993-94), the Production Systems Program has continued to emphasize work in three areas: (1) characterization of constraints and production opportunities in potato and sweetpotato, (2) adaptation and integration of potato and sweetpotato production technologies, and (3) assessment of the impact and sustainability of potato and sweetpotato production technologies.

Research and training highlights in these three areas are presented for 1995-96, and implications of the *Medium-Term Plan 1998-2000* for program activities are described. In particular, the management of natural resources is an emerging area of emphasis as CIP responds to environmental concerns in shaping its portfolio of activities.

Characterization of Constraints

Characterization of production constraints and opportunities is an area of declining importance. Several studies were completed in 1995-96. In potato, lessons from five years of participatory farmer selection of late-blight-resistant varieties were drawn and reported in Bolivia. Diagnostic research explaining yield variation in farmers' fields in Bolivia is presented later in this report. The comparative advantage in potato production across the three main producing regions of Ecuador was assessed. Surveys of national agricultural research systems (NARS) provided data for documenting present levels of investment in potato crop improvement programs and for prescribing resource allocation, given the importance of potatoes in national

1 Program Leader, CIP, Lima, Peru.

production and assumptions on expected effects.

In sweetpotato, the last of five country characterization studies in eastern and central Africa was completed for Tanzania. Prospects for intensifying and sustaining sweetpotato production in response to increasing population pressure were also examined at three benchmark sites in southwestern Uganda.

The agroecological characterization of sweetpotato production systems was reviewed in Asia. Institutionalizing a participatory approach in root crop research was the focal point for both research contracts and training workshops for NARS partners in China, Indonesia, Nepal, the Philippines, and Vietnam.

In the medium term, characterization research will be merged with impact assessment into one project for potato and another for sweetpotato. Priorities for potato include updating the perceptions, first elicited in 1987, of NARS scientists on constraints and opportunities; characterizing constraints and opportunities for production in the central Asian countries; and evaluating regional competitiveness in production. For sweetpotato, the global synthesis of information from investments in characterization research in the early and mid-1990s is still the main priority.

Technology Adaptation

Advanced varietal testing and release figured prominently in technology adaptation. In potato, several virus-resistant, heat-tolerant varieties with good processing traits were released for early and late planting in coastal Peru. These varieties will extend the length of the growing season and hence reduce seasonal price fluctuations.

Steady progress was made in the advanced testing of sweetpotato varieties. In Uganda, the most important producer of sweetpotato in sub-Saharan Africa, five varieties were released by the national program. Although CIP was not intimately involved in the breeding or selection of these varieties, their release established an institutional precedent for the distribution of promising CIP-related material.

In 1998, research on varietal adaptation will take place in self-contained projects in other CIP programs. Work on adapting virus-resistant potato varieties will become part of the project on potato viruses. Similarly, adaptive trials on advanced sweetpotato material will be subsumed into the project on sweetpotato dry matter and adaptation.

Impact Assessment

Turning to the area of impact assessment, a monograph documenting the impact of nine CIP-related technologies was published in 1996. Two priority-setting exercises, which used information from the impact case studies, were also carried out and reported. These laid a firm foundation for CIP's *Medium-Term Plan 1998-2000.*

Among CIP-related technologies, true potato seed (TPS) received the most scrutiny. Results from several years of on-farm trials formed the building blocks for an ex ante assessment in Egypt, India, and Indonesia.

In the future, selective case studies of ex post impact will still be conducted. However, we will place more emphasis on evaluating the effects of improved technology on poverty and the environment. Some of this work will be carried out in the framework of the recent CGIAR initiative on impact assessment. Examining the effects of cyclical price instability on potato production and consumption is a policy-related area targeted for intensive study.

Natural Resources Management

Organizationally, Production Systems is the locus for much of CIP's increasing investment in research and training in natural resources management. Selective investments in systems modeling, soil fertility management, and natural resources economics supplied CIP with a critical mass to tackle issues related to land use in the Andes and to intensive potato-cropping systems. Research addresses the common theme of interactions between land productivity, technological change, policy intervention, and environmental improvement or degradation. This work is highly complementary to CIP's potato research as potato cropping systems are usually pivotal to the sustainability of land use systems in tropical mountain environments. Modeling approaches, featuring widespread participation from developing-country NARS and mentor institutes, are used to overcome problems of site specificity, which erode the transferability of research results.

CIP's contribution to research on the sustainability of land use in the Andes is conducted within the CONDESAN network and is embodied in two research and training activities.

The first activity, DME-Norte, marries biophysical and economic models to examine technology, policy, and environmental scenarios. It draws on and extends models developed in recently completed research on groundwater contamination as a consequence of the heavy use of pesticides in potato production by small farmers. Potatoes rotated with pastures is the land use of interest for modeling.

The second project, DME-Sur, combines satellite imagery with biophysical models to assess frost, drought, and salinity risk in crop and livestock production. We are also evaluating technological and policy options to mitigate the severity of these abiotic stresses in one of the largest and poorest regions of the Andes.

Production Systems also houses natural resources management research carried out in the Global Mountain Initiative (GMI) convened by CIP, ICIMOD, and ICRAF. This initiative stimulates research and synthesis across the three most important tropical and subtropical mountainous regions of the world. Priority research areas include agroecological characterization, integrated nutrient management, agricultural intensification in response to population pressure, the fate of investments in soil conservation, and dairy policy.

The sustainability of intensive potato-cropping systems is the third area of natural resources management for program activity. This project begins in 1997 and focuses on sustainability of rapidly expanding potato production in the Indo-Gangetic Plain of South Asia. Initially, attention will be directed at the intensive rice-potato-rice system in regions that have witnessed spectacular growth in potato production since 1985. This project will be executed under the umbrella of the CGIAR's Rice-Wheat Program.

Looking ahead, Production Systems is rapidly evolving into a natural resources management program. The name of the program will likely be changed to recognize this shift in emphasis.

Prospects for Sustaining Potato and Sweetpotato Cropping Systems in Southwest Uganda

Jan W. Low[1]

Many of the most productive agricultural systems in sub-Saharan Africa are located in the densely populated highlands of Eastern and Central Africa. Kabale District in southwest Uganda is representative of the highlands in this part of the world. Potato figures prominently as a cash crop, and sweetpotato is an important food crop.

Kabale District provides an opportunity to examine the dynamic roles of potato and sweetpotato in an area of intensifying agricultural production in response to increasing population pressure and market demand. Moreover, CIP participated with the National Agricultural Research Organization of Uganda in re-establishing potato research and seed production activities at the Kalengyere research station in Kabale District from 1989 to 1994.

This study has two main objectives: (1) to obtain baseline data on current production practices in representative sites so varietal change and other technology-related issues can be monitored over time, and (2) to assess the prospects for the intensification and sustainability of potato and sweetpotato production.

To address these objectives, we undertook field research in three phases. In February 1995, we visited potential sites, defined as a distinct valley with surrounding hillsides, held group discussions with farmers, conducted informal market surveys, and made final site selections.

Subsequent field work combining structured household surveys with agronomic observations on potato and sweetpotato plots was done in September 1995 and February 1996. In total, we interviewed 134 potato producers and 89 sweetpotato growers. All the sweetpotato growers were women; the majority of the potato producers were men. Figure 1 shows the geo-referenced survey data.

Of 17 potential field sites, 3 were selected to provide a range of agroecological conditions in the production of potatoes in a valley or neighboring hillside where sweetpotato is also an important crop. Kalengyere is a high-altitude area (2,100-2,500 m) of intensively cultivated, steeply sloped hills. Bukinda (at 1,700-1,900 m) is lower than Kalengyere and much warmer. Therefore, conditions are less favorable for potato production. However, both potatoes and sweetpotatoes are widely grown on the hillsides and in the valley bottom. Kicumbi (at 1,800-2,100 m) is somewhat higher, and its most notable feature is the huge, flat Katuna valley. Parts of the valley floor are dominated by larger fenced landholdings for pasturing dairy cattle. In other parts of the valley, wall-to-wall potato is seen during the dry season. Extensive sweetpotato ridges with deep drainage canals dominate the hillside landscape.

Changing Roles of Potato and Sweetpotato as Income and Food Sources

Growers were asked to assess whether the importance of potato and sweetpotato had been increasing or decreasing, or had remained the same, during the past five years, both as a food for home consumption and as

---

1 Formerly at CIP Sub-Saharan Africa regional office, Nairobi, Kenya.

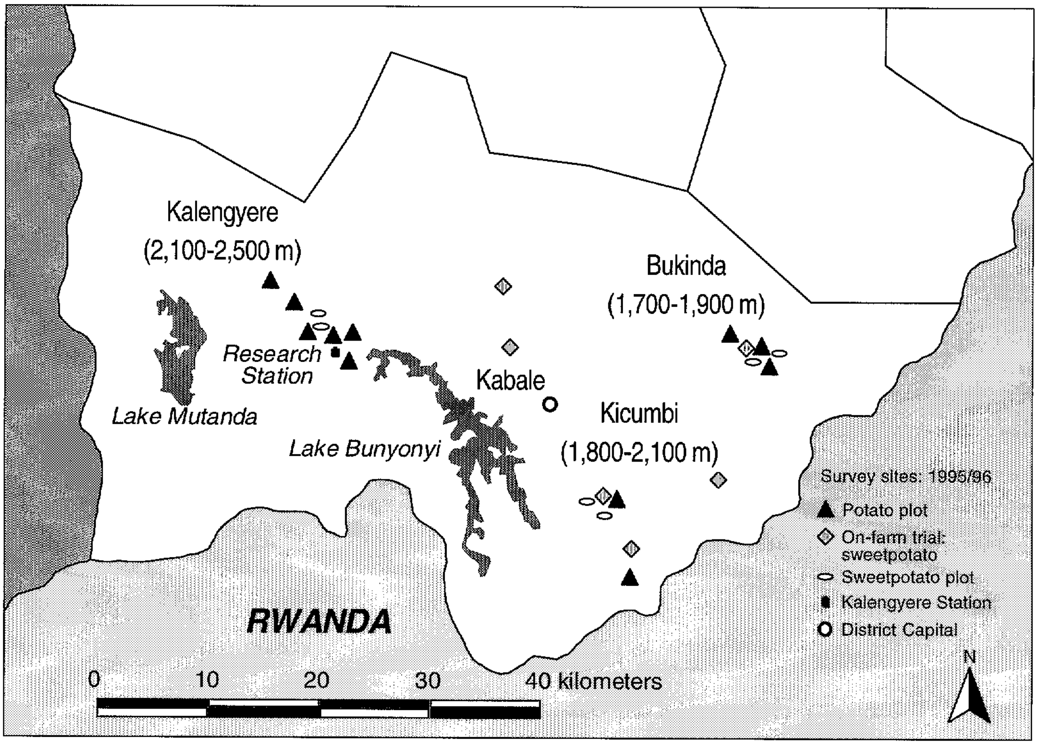


Figure 1. Research sites in Kabale benchmark survey.

a source of income (Table 1). Over half the growers reported that potato was increasing in importance as a source of cash and as a food for home consumption.

They cited two major reasons for this increase: increasing demand in the marketplace and the high productivity of the crop, in part because of new varieties. Potatoes as a food are also becoming more popular. Greater home consumption is in part a reflection of their greater availability at the household level as a by-product of planting more of the crop for cash sale.

In spite of the better market for potatoes, some farmers reported a decline in the importance of potato as a cash source during the past five years. The overwhelming reason for this tendency was declining yields. Farmers cited poor soil fertility or disease as contributing factors. Yield decline also figured prominently in the minority perception that potatoes were diminishing in importance as a food crop.

Sweetpotato, on the other hand, has never been an important cash crop in Kabale District. Therefore, the 32 households noting an increasing significance of sweetpotato as a cash crop is of interest. This increase was attributed primarily to increasing demand for the crop, particularly near urban centers such as Kabale, and for feeding students in boarding schools.

Many more respondents stated that the importance of sweetpotato as a cash crop was declining because of decreasing market demand as well as declining yields. These farmers complain that because everyone grows sweetpotato and there is no market for the crop outside of the local area, it is demanded locally only when other foodstuffs are in short supply.

Declining yield has also contributed to a reduction in the role of sweetpotato for home consumption. That is a disturbing trend, given the traditional year-round reliance on sweetpotato as a food security crop in Kabale.

In higher-elevation areas, such as Kalengyere, sweetpotato is also losing ground to potato as a food for home consumption. In group discussions, Kalengyere mothers often remarked that children preferred potatoes to sweetpotatoes. Older household members retained their preference for sweetpotato as a staple food. In contrast, the eroding role of sweetpotato in home consumption in Bukinda and Kicumbi, where preference for sweetpotato over potato remains high, is almost exclusively attributed to declining yields.

Sustainability of Potato Production

Results from on-farm yield assessment of potato production indicate that farmers in Kalengyere are, in general, obtaining excellent yields (29.5 t/ha). It would be highly desirable to sustain these yields, albeit with lower production costs. At the other end of the spectrum, potato yields for Kicumbi swampland farmers are already low (7.7 t/ha). The system is fragile and yield increases are urgently needed. Sustaining mean yield levels of 19.6 t/ha at the lower altitudes (1,800-2,100 m) of Bukinda over time would mean that potato would remain an important cash crop within this area.

In interpreting these yield data, it is important to note that the mean potato plot size on these farms is small, ranging from a low of 560 m^2 in Bukinda to a high of 812 m^2 in Kicumbi. Thus, even the high yield of 29.5 t/ha in Kalengyere translates into 2.0 t (ap-

Table 1. The perceived changing importance of potato and sweetpotato as cash and food crops in Kabale District, Uganda, 1995-96.

Trend	Potato		Sweetpotato	
	Cash	Food	Cash	Food
Increase in importance[a]	**122**	**121**	**32**	**76**
Increasing yield	61	41	10	18
Increasing market demand	76	1	23	—
Increasing family size	—	47	—	43
Increasing food preference	—	33	—	7
Increasing area planted	2	7	—	8
More land	2	1	—	2
Other	1	1	—	—
Decrease in importance	**85**	**57**	**77**	**88**
Declining yield	60	27	20	48
Declining market demand	9	5	35	—
Decreasing area planted	6	10	6	14
Declining food preference	—	7	—	18
Decreasing family size	2	5	10	4
Less land	2	2	—	2
Other	6	1	2	4
No change	**15**	**44**	**113**	**58**

a. Number of respondents. A few respondents gave more than one reason for a perceived trend; therefore, the totals for reasons exceed the total for trends.

proximately 19 bags) of potatoes from an average plot size of 699 m^2.

Several encouraging signs point to sustained production of potato in Kabale District. They include (1) high demand for potatoes in Kampala, the capital city, (2) improved road infrastructure, (3) increasing entrepreneurship, (4) increasing input use, and (5) the existence of late-blight-tolerant varieties.

The greatest threat to sustained potato production in Kabale District is the increasing incidence of two major diseases: late blight caused by *Phytophthora infestans* and bacterial wilt caused by *Pseudomonas solanacearum*. Farmers lack knowledge of recommended control practices so their ability to employ them is severely constrained. Although farmers can recognize the symptoms of both diseases and know the association between high humidity and late blight, knowledge of the causes of bacterial wilt is extremely limited (Table 2).

Moreover, their awareness of nonchemical approaches to dealing with late blight is scanty (with the exception of delayed planting to avoid heavy rains). Knowledge of how to prevent the spread of bacterial wilt and deal with an infected field is marginal to nonexistent. The introduction of some agronomic practices, such as roguing volunteer potato plants, may encounter considerable resistance, in that many farmers perceive these re-emergent plants as an important source of food.

Although the use of animal manures and crop residues on potato fields is increasing, steep terrain and limited availability make manure application a labor-intensive process. That encourages farmers to keep re-using plots for potato cultivation nearer to home. The preferred management strategy is to wait until yields have fallen to unacceptably low levels, then graze livestock on the fallow plot so that manure transport is not an issue.

The unavailability of inorganic fertilizers is a major constraint. It is unlikely that given Uganda's landlocked status, and the distance of Kabale from Kampala, that fertilizer use could be undertaken on a large scale without being subsidized.

Yet another serious constraint to implementing proper agronomic practices is the lack of sufficient quantities of clean seed available to farmers. High-quality seed from Kalengyere is sold cheaply to a limited number of contact farmers in the area at a subsidized rate. In theory, these farmers multiply seed and sell it to other farmers in the area. In practice, most of the next harvest is sold off as ware potatoes for consumption or retained by the contact farmer for replanting. Only a few other farmers purchase the new varieties for seed.

In addition to having insufficient quantities of good-quality seed to start with, farmers lack knowledge of how to select and properly store seed. To ensure that the skin of the potato does not easily peel during storage, stems of the potato plant should be cut off a week or so before harvest. Many farmers fear doing this, however, as cut stems advertise to potential thieves that potatoes are ready for harvest. Without significant investments in farmer education and improved distribution of high-quality seed, current potato yields are not sustainable.

Sustainability of Sweetpotato Production

While farmers widely recognize declining soil fertility as a problem, little evidence exists linking deficiencies in sweetpotatoes with poor soil fertility. Preliminary research on nutrient deficiencies in sweetpotatoes and concurrent soil fertility was conducted in February 1996. Leaves were evaluated for critical amounts of macronutrients and micronutrients. Soil samples were also taken from the base of each deficient plant at a depth of 15-30 cm.

The major findings from the leaf analyses were:

- Phosphorus deficiency was very common.
- Nitrogen, potassium, and sulfur are also generally suboptimal.

Table 2. Farmer beliefs about late blight and bacterial wilt symptoms, causes, and prevention, Kabale District, Uganda, 1995-96.

Symptoms, causes, and steps[a]		Percentage of all farmers interviewed
Symptoms of late blight	Tubers do not enlarge	70
	Leaves dry	61
	Leaves blacken	37
	Tubers usually rot	11
	Plant rots & breaks	3
	Low to no yields	6
Causes of late blight	Excessive rain	86
	Cold weather	18
	Loss of soil fertility	7
	Growing potato on same plot several times	5
	Lack of spraying	2
	Aphids	2
	Poor seed quality	1
	Does not know	1
Steps taken to avoid late blight	Sprays chemicals	97
	Wants to spray, but lacks funds	2
	Adds manure	1
Symptoms of bacterial wilt	Plant dries up ("wilts")	90
	Tubers rot	76
	Stunted growth	1
Causes of bacterial wilt	Does not know	38
	Infected seed	17
	Loss of soil fertility	13
	Overcultivation	9
	Insects in soil	9
	Planting potato after potato	6
	Soil unsuitable for particular potato variety	6
	Infected soil	4
	Seed left in rain	2
	Using damaged or cut seed	2
	Poor land management	3
	Planted in dry season	1
	Premature seed	1
	Too much rainfall	1
	Coldness	1
Steps taken to avoid bacterial wilt	Uproots infected plants	48
	None	37
	Crop rotation	10
	Fallowing	4
	Harvesting in dry weather	1
	Sells infected seed and buys new seed	1
	Adds manure	1
	Proper seed selection	1

a. n = 99 farmers.

- Boron concentrations were low to very low at all but two sites.

Soil analyses frequently showed deficiencies in P, K, and Ca. Although these results are preliminary, because of the limited degree of sampling, they reinforce the perception that sweetpotato is increasingly relegated to soils of declining fertility. Even though something is produced, yields continue to decline. Moreover, there is an association between increasing severity of the fungal disease *Alternaria solani* and declining soil fertility.

The growth of potato in importance as a cash crop and for home consumption has, in the higher elevations of Kabale, displaced sweetpotato in the diet to a certain extent and pushed the crop into more marginal production areas. However, three facts assure that sweetpotato will continue to remain an important food security crop in Kabale:

- Sweetpotato is the cheapest source of calories available year-round.
- Sweetpotato outperforms other crops on soils of declining fertility.
- Sweetpotato is an important rotation crop for sorghum, maize, beans, and peas.

There are warning signs that sweetpotato yields will continue to decline. In areas with little or no demand for commercial sweetpotatoes, farmers are unlikely to invest many resources in improving the fertility of marginal soils on which they prefer to plant sweetpotato. Problems with *Alternaria* spp. are likely to increase, particularly at the higher elevations, because of the worsening nutritional status of the plant. Although periodic outbreaks of sweetpotato butterfly (*Acraea acerata)* are likely to continue, they tend to be local and farmers take group action when severe infestations occur.

Prospects for market demand to increase beyond Kabale District are limited. Sweetpotato is widely grown throughout Uganda and higher-quality production areas surround Kampala and other major urban centers. Increasingly, valley bottom lands and swamplands are being targeted for potato or vegetable production during the dry season. In the past, sweetpotato was planted in the moist valley bottom lands to assure adequate supplies of planting material for hillside production the following season.

The evidence suggests that sweetpotato will continue to be grown in large quantities on better soils as part of rotation schemes. In addition, it will be grown on marginal soils where other crops fail, in spite of continual mean yield declines. Overall, yield declines can be reversed only if non-labor-intensive solutions to increasing soil fertility are found or sweetpotato becomes commercially important, hence increasing the benefit-cost ratio of increased input use.

Research Implications

Declining soil fertility is a major constraint of increasing importance to all crop production in Kabale District. Policy research needs to be conducted on the cost-effectiveness of importing and subsidizing appropriate inorganic fertilizers. It is clear that the limited availability of organic manures and the labor to apply them are likely to remain significant constraints in the long term. Research efforts should also concentrate on testing green manure crops that are adapted to higher altitudes and that could be planted on fallow fields.

Unlike the major effort that has been made on potato, there has been no systematic involvement in adaptive testing of sweetpotato varieties in southwest Uganda. However, given that varietal tolerance of low P levels and *Alternaria* spp. exist, it would make sense to test sweetpotato varieties bred by the Rwandan national program. During the past two decades, the Rwandan program has bred many varieties adapted to higher altitudes. Those should still be available.

Finally, the investment in a baseline survey is fully realized only if sites are periodically revisited. Although the selected sites are excellent for monitoring input use, disease intensification, and potato yields, farmers at these sites do not possess a significant number of plots with volcanic soils. An additional site should be added in the following round that would include these volcanic soil types that are highly suitable for potato production.

Risk Analysis of Potato Production in the Altiplano: Quantifying Farmers' Beliefs

R. Valdivia Alatrista[1], R. Quiroz[1], R. Valdivia Fernández[1], and V. Choquehuanca[2]

The Altiplano of Peru and Bolivia is home to many very poor farm families for whom agriculture is the main source of income. Potatoes are the staple food crop, and production risk, usually in the form of drought and frost, is pervasive.

The incidence and productivity consequences of risk are difficult to assess because historical data on the productivity of fields and farms are not available. Nonadoption of improved technologies is often attributed to risk, but both subjective and more objective information is usually lacking to document the relative riskiness of competing technologies.

Nor has the effectiveness of different methods to assess risk been established. In this study, yield and net revenue risk of native and improved varieties are examined in three ways: (1) estimated yields from samples taken in potato fields, (2) elicited information on farmer beliefs about varietal productivity, and (3) simulated yield estimates from process-based, crop-growth models.

Site and Methods

This research was conducted in Santa María, a community in the Department of Puno, Collao District, Peru. It is situated at about 3,900 m above sea level. Land is privately and communally farmed.

Potatoes are a dryland crop grown from October to April in the main growing season. Mixing native and improved potato varieties in the same field is common. Native varieties include bitter (Ruqui, Pinaza, Lok'a, Luki, and Ajanhuiri) and nonbitter (Ccompis, Imilla Negra, Sacampaya, Imilla Blanca, and Choquepito) cultivars. Improved varieties are represented by Andina, Tomasa Condemayta, Mariva, and Mi Perú.

Yield samples in farmers' fields were collected during six growing seasons from 1987 to 1992. Stratified sampling by elevation was used to generate estimated yields for native and improved varieties. About 10 fields were sampled in each of the 6 yr.

Farmers were interviewed in 1996 when information on the incidence and consequences of risk was canvassed. Farmers recognize four classes of years for potato productivity: bad, normal, good, and very good. Beliefs on varietal yield were assessed using a triangular method where the respondent provided information on the highest, modal, and lowest observations. By multiplying the frequency of the four productivity events by the results from the triangular elicitation procedure by varietal type, we generated yield distributions for native and improved varieties.

Daily weather data and soils information figured as inputs into a process-based, crop-growth model to simulate potato yield. Genetic coefficients on potential leaf and tuber expansion rate, degree of determinacy, photoperiod sensitivity, and temperature sensitivity for Imilla Negra and Andina were used to simulate the performance of the bitter and nonbitter varietal types.

1 CIP-CONDESAN (Consortium for the Sustainable Development of the Andean Ecoregion).
2 CIRNMA-CONDESAN (Centro de Investigaciones de Recursos Naturales y Medio Ambiente, Peru).

Table 1. Measured, elicited, and simulated potato yields in Puno, Peru, during the period 1987 through 1992.

Variety	Yield (t/ha)		
	Measured	Elicited	Simulated
Native	8.28 (0.85)[a]	9.77 (1.21)	8.76 (0.88)
Improved	12.04 (1.24)	13.23 (1.50)	9.80 (0.85)
Mixed	10.03 (0.84)	10.25 (0.61)	8.99 (0.85)

a. Numbers in parentheses are standard errors of means.

Results

We determined risk by comparing yield and net revenue of native, improved, and mixed varietal groups.

Yield comparisons

Productivity of the native, improved, and mixed varietal groups is compared for each of the three methods of estimation (Table 1). The yield for the mixed varieties was calculated as the average field proportions of native and improved varieties across the 6 years.

All methods give productivity estimates substantially higher than the departmental average yield of about 5 t/ha for Puno. The difference between estimated and officially reported yields partially reflects the impact of technological change introduced by the Proyecto de Investigación de los Sistemas Agropecuarios Andinos in 1985. Healthier seed, improved fertilizer, and other crop management practices played a role in this change.

The simulated results in Table 1 are especially noteworthy because estimates from such models are often several orders of magnitude higher than yields in farmers' fields. In our case, the crop simulation accurately reflects reality.

The measured and elicited estimates are similar. Indeed, regressing the elicited on the measured yield data for the 6 years accounts for about 98% of the variation in the measured productivity estimates.

Improved varieties were also characterized by the highest mean yields. Differences between the improved and native varietal types were most apparent with the measured and elicited methods. In contrast, the simulated results gave more or less the same results for each varietal type.

Figure 1 shows the tradeoffs in risk and productivity and presents the estimated cumulative distribution function of yields by varietal type for each of the three estimation methods. The cumulative probability reflects the likelihood of obtaining a yield less than or equal to a stipulated level. For example, in Figure 1A, the chance that native varieties produce less than 4 t is only about 3%; the expectation of this very low yield for the improved varieties is 10 times more likely at 30%.

Crossing curves imply tradeoffs in risk, that is, native varieties are less prone to both low and high yields (Figure 1A). The crop-cut method gives results highlighting the stability of native varieties and the yield responsiveness of improved varieties to good weather. In contrast, the farmers' subjective beliefs (Figure 1B) show almost no conflict between risk and expected productivity. For almost all yield levels, improved varieties dominate. The cumulative probability for a stipulated yield level is everywhere higher for

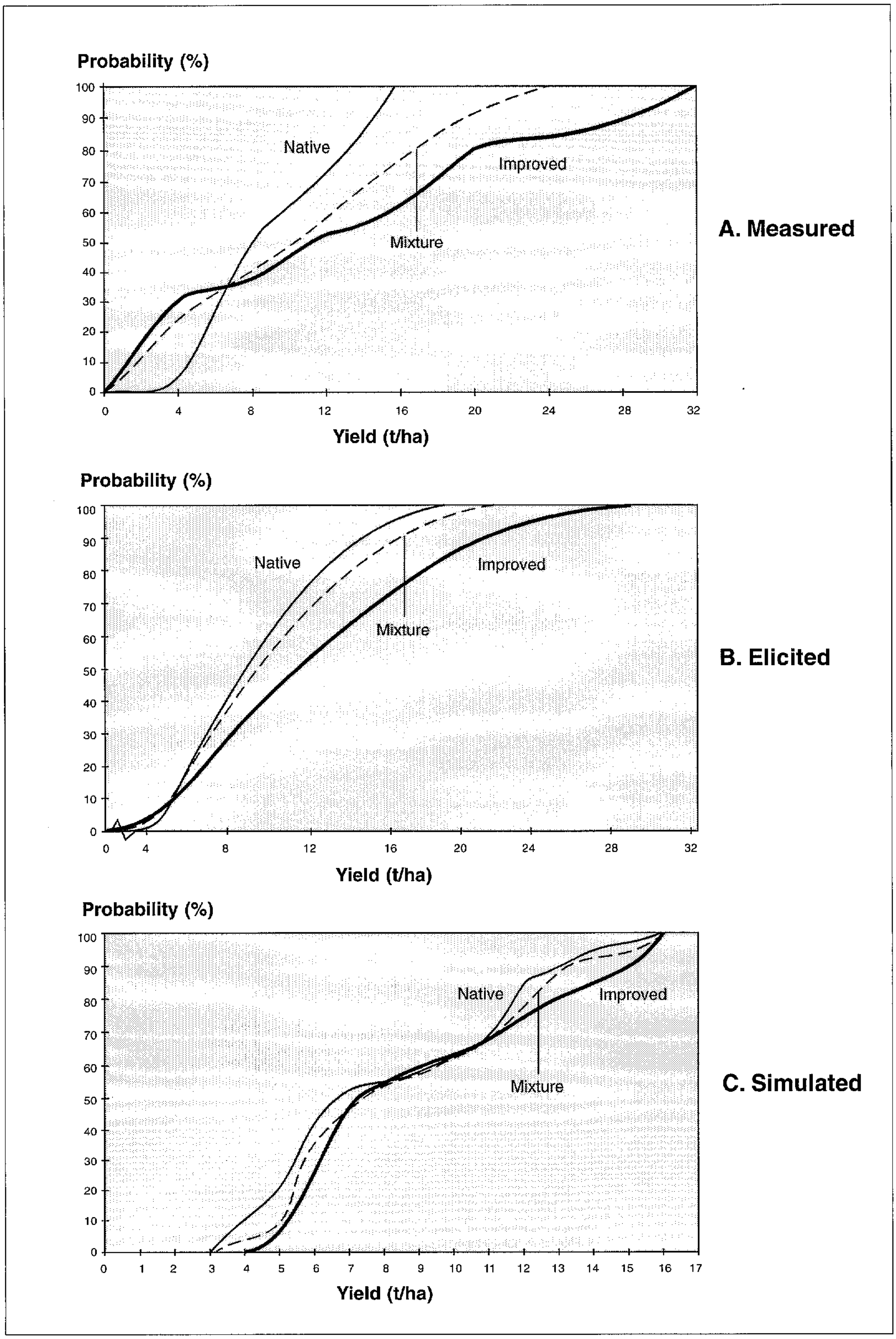


Figure 1. Estimated cumulative distribution of yield by estimation method. CIP, 1996.

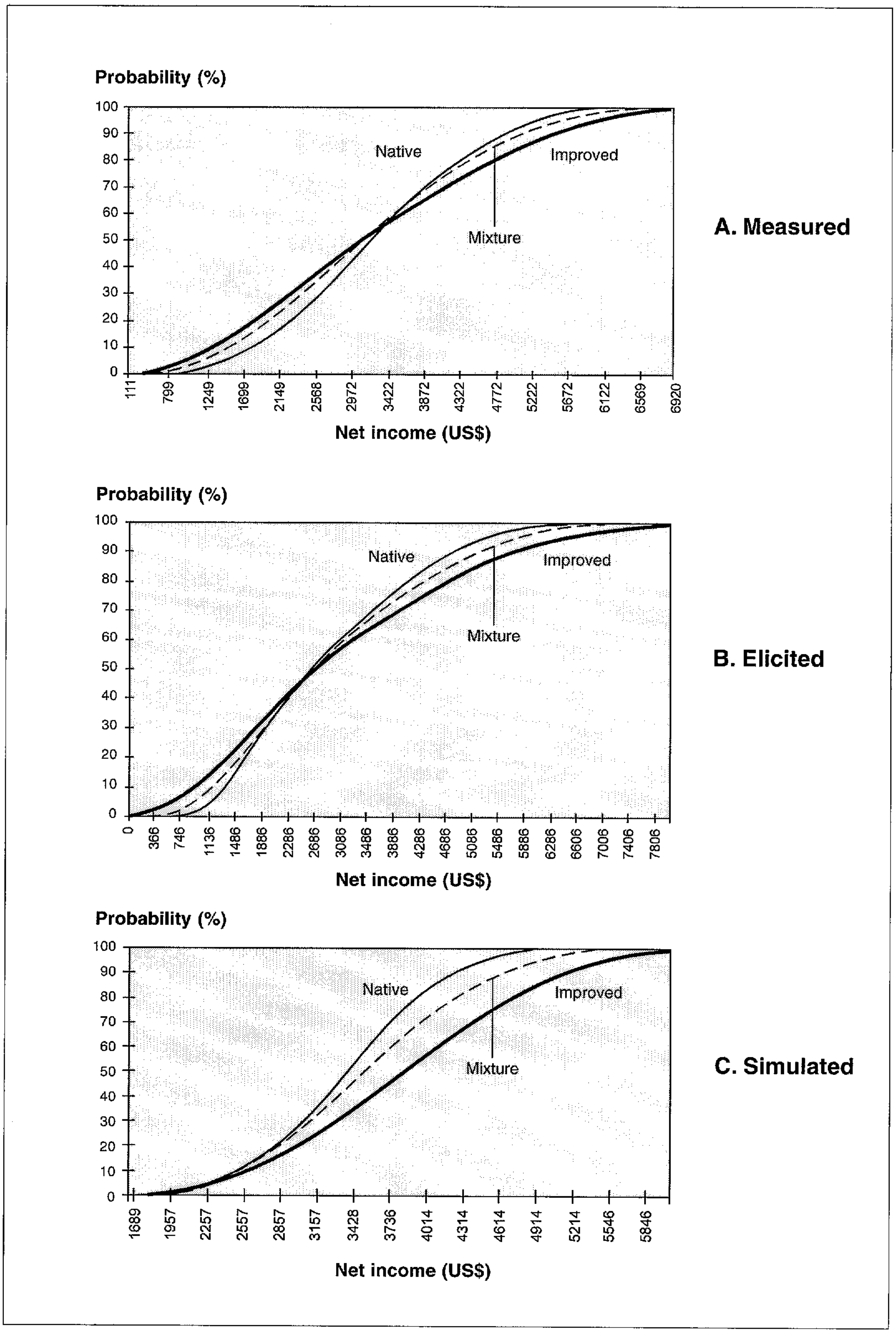


Figure 2. Estimated cumulative distribution of net revenue by estimation method. CIP, 1996.

native compared with improved varieties. Hence, the two methods generate different results: in Figure 1A, risk matters; in Figure 1B, it does not.

The distributions of the simulated results are not that informative. Improved varieties dominate at almost all yield levels (Figure 1C) and the yield distributions are almost the same. This similarity suggests that the crop simulation model is not sufficiently well-developed to assess varietal-specific risk.

Net revenue comparisons

The higher productivity of improved varieties (Figure 1) does not necessarily translate into higher net returns. Native varieties command a higher price, and improved varieties are more intensive users of costly inputs. Price differences between native and improved varieties are sharper in better production years when the improved varieties give higher yields.

Figure 2 charts tradeoffs between risk and expected profitability. The measured and elicited results show a slight advantage of native varieties over mixtures and improved varieties in lower-yielding years. The opposite occurs in better years when pure stands of improved varieties are superior to native varieties or mixtures.

Conclusions

Direct elicitation of the subjective incidence and severity of risk in potato production was useful in incorporating farmers' knowledge. It also gave results comparable to the more tedious objective method of sampling yields over time. This result suggests that farmers' knowledge might be successfully used to estimate potato yields over time with acceptable precision. Moreover, the estimated variance of the reported yields appears to be reliable and useful for assessing production risk.

Simulation models also gave results consistent with mean levels of productivity, but such tools are still too immature to describe variety-specific risk, the subject of this study. Experimentation in both bad and good years is needed to recalibrate these models to reflect the reality of the harsh production conditions of the Altiplano.

More research is also needed to understand the dynamics of varietal mixtures in risk-prone environments. In general, our results suggest that risk is an important issue for potato producers in the Altiplano. Native varieties are more profitable in lower-yielding years, and improved cultivars are more profitable in better years.

Analyzing Potato Productivity in Farmers' Fields in Bolivia

F. Terrazas[1], V. Suárez[2], G. Watson[3], G. Thiele[1], T. Walker[2], and A. Devaux[1]

Potatoes are the staple food crop in the Andes of Bolivia. Potato production and postharvest activities are a major source of rural employment and household income. Assisted by funding from the government of Switzerland, the government of Bolivia in 1989 strengthened its commitment to potato crop improvement, which was institutionally reborn in the form of the Proyecto de Investigación de la Papa (PROINPA).

Diagnostic research on constraints to and opportunities to increase potato production was symptomatic of the renewed vigor of the national potato program in the 1990s. Production surveys in the early 1990s were an important part of this diagnostic effort. Because of their broad coverage in more than 1,000 communities and because of their detailed, highly focused questions on potato production practices, these surveys are a rich source of information on potato productivity in farmers' fields.

The population of interest in this study on potato productivity in farmers' fields encompasses potato producers in four departments of Bolivia: Cochabamba, Chuquisaca, Potosí, and Tarija. These departments were the areas where PROINPA was most active in the early 1990s. Cochabamba was surveyed in 1990, 1991, and 1992, Chuquisaca in 1990 and 1991, Potosí in 1990 and 1991, and Tarija in 1992, 1993, and 1994.

The production surveys were conducted by research and extension staff of both governmental agencies and nongovernmental organizations in March, April, and May during the harvest from the main growing season, or *siembra grande*, which is planted in October and November at the beginning of the rainy season. Information was elicited in a questionnaire on potato production practices, and two yield samples from a field ready for harvest were taken. The multiyear data set contains 1,897 field and farmer observations distributed across 1,250 communities in 36 provinces.

Assessing Potato Productivity

The mean sample yield was 10.5 t/ha ranging from 400 kg to a maximum of 40 t/ha (Figure 1). The intervals between 2.5 and 10.0 t/ha accounted for the bulk of the observations in Figure 1. The empirical distribution of yields in Figure 1 is positively skewed, which is typical of semisubsistence smallholder agriculture in rustic production conditions.

The crop-cut estimates imply a fairly low level of productivity, but they are about twice as high as official departmental estimates, which varied from 4.5 to 6.5 t/ha in the early 1990s. Crop-cut estimates also convey substantially higher levels of productivity than multiplication ratios of output harvested to tuber seed planted, which is the way small farmers usually express productivity in potatoes. When asked how much production they expected per unit of seed planted in the sampled field, farmers most frequently gave multiplication ratios of 2.0 to 6.0. If we assume a seed rate of 1.5 t/ha, then a mean estimated yield of 10.5 t/ha is consistent with a multiplication ratio of 7.0.

---

1 PROINPA, Cochabamba, Bolivia.
2 CIP, Lima, Peru.
3 Formerly PROINPA.

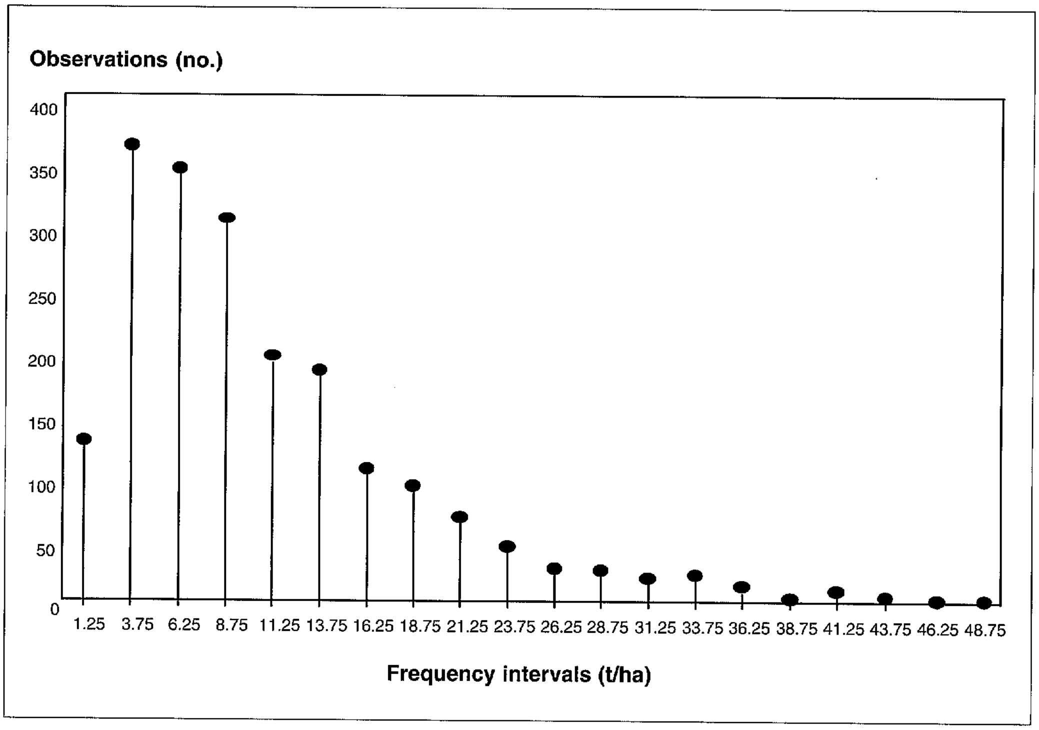


Figure 1. Frequency distribution of estimated yields. Numbers on x axis indicate midpoints of each frequency interval. For example, the first interval contains observations from 0.00 to 2.49, the second from 2.50 to 4.99, etc.

The difference in the size of these two productivity measures is probably attributed to potato quality. In crop cuts, all potatoes are harvested and weighed. When farmers express multiplication ratios, they may be focusing on production of a specified size and shape. They may also be discounting potato damaged by Andean potato weevil *Premnotrypes* spp. Nonetheless, the crop-cut data indicate that farmers' yield estimates are likely to be substantially lower than actual productivity.

Describing Potato Production

Potato production in Bolivia in the early 1990s was still very much a semisubsistence activity. Small farm households cultivated potatoes in very small fields with a low level of agricultural intensification. About one-half of the respondents stated that the production of the field was exclusively for household consumption. Only about 15% indicated that the bulk of production would be sold.

Estimated field size ranged from tiny, almost garden-size, to relatively small. The median size was between 0.10 and 0.25 ha; only about 10% of the fields exceeded 0.50 ha.

Potatoes are grown in Bolivia high in the Andes, often on steeply sloping fields. The median elevation was between 3,000 and 3,500 m; about one-third of the sampled fields were above 3,500 m. The most frequent slope category was between 3% and 20%, but many fields (33% of the sample) were on slopes exceeding 20%.

Although potatoes are mainly a dryland crop, about 30% of the fields were reported to have benefited from irrigation during the growing season. The incidence of irrigated fields was higher than expected, but irrigation should not convey the image of large-farm, commercial potato production.

Irrigation is negatively associated with field size. About 35% of the 346 fields estimated to be smaller than 0.10 ha were irrigated; only 14% of the 127 fields estimated to be larger than 0.50 ha were irrigated.

Nine of ten potato fields received manure. Sheep droppings were the dominant source of organic amendment. The importance of manuring is underscored by the observation that about one-quarter of the fields benefited from two kinds of livestock manure.

Fewer but still a majority (63%) of farmers applied inorganic fertilizer, usually in the form of NPK 18-46-0 or urea. Chemical fertilizer was used sparingly, never more than a few bags per field.

Fallowing land three or more years before planting potatoes occurred on 36% of the sampled fields. Potato monoculture, featuring three prior consecutive potato crops, was rare. In general, the farmers' responses on crop rotation support the conventional wisdom that potato is often the first crop to be planted following a period of fallow.

Pesticides are not used intensively in potato, but about two-thirds of the fields were sprayed or dusted. The modal number of applications was two to three on those fields. Only 5% of the fields received more than four sprays.

The formal sector did not loom large as a seed source. Nor was the incidence of specialized seed producers high. Nine of ten farmers stated that they planned to produce seed for their own use from the sampled field. Relatively few respondents (6%) said that production from the field would be sold as seed.

The dominant clones planted in the sampled fields were local varieties, which are overwhelmingly *Solanum andigena* (short-daylength Andean) types. About 1 field in 10 was planted to an introduced variety, such as Revolución (Peru) or Alpha (the Netherlands via Chile).

Although information on varietal choice conveys a rich array of varietal diversity, a relatively few varieties accounted for a substantial proportion of the dominant varieties in the crop-cut fields. For example, Waych'a was listed as the leading variety in 220 fields, and Sani Imilla was recorded as the dominant variety in 200 fields. The fields were about evenly split between those in which varietal monoculture was practiced and those in which more than one variety was planted.

Explaining Yield Variation

Differences in yield in the sample fields reflect variation in household resource endowments, institutional access and participation, field attributes, management practices, weather during the growing season, biotic and abiotic stresses, and cropping history. Figure 2 illustrates these relations. The boxes denote predetermined variables that influence yield not only directly but also indirectly through the intervening variables described in circles. Quantifying the relations in Figure 2 is a complex undertaking that requires information on the timing of production processes.

In an exploratory analysis, the bulleted variables in Figure 2 were correlated with yield in a multivariate regression framework. Figure 3 presents the statistically significant ($P<.05$) results in a productivity gap format, which depicts the change in estimated yield with a change in the variable of interest, while all other variables are held constant.

Changing the base conditions one at a time for the statistically significant management variables gives incremental yield increase estimates from a base yield of 6.8 t/ha to the highest forecast yield of 18.6 t/ha.

Figure 3 is based on an analysis of the full data set pooled across the departments of Cochabamba, Chuquisaca, Potosí, and Tarija. The estimated response of several of the independent variables varied significantly by department; therefore, Figure 3 summarizes only information on general tendencies.

Of all the potential variables in Figure 2, the impact of pesticides on productivity was

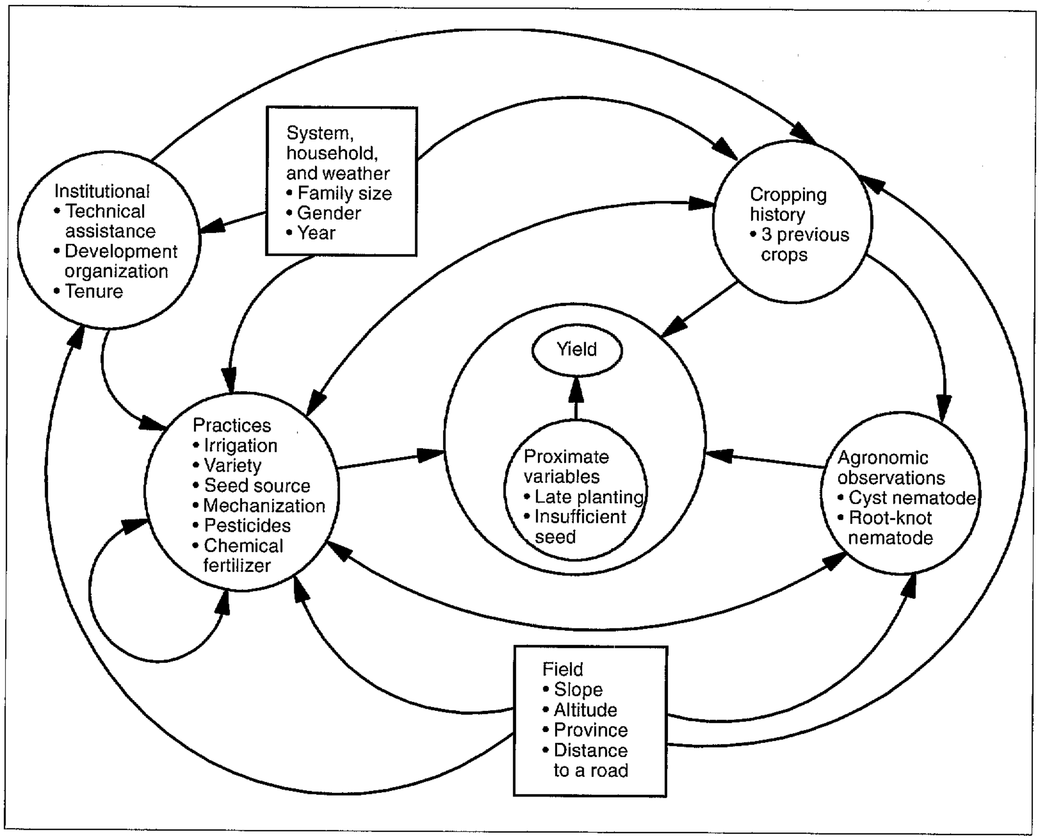


Figure 2. Schematic representation of interrelations determining productivity with data from the Bolivian potato production survey.

the most consistent across the four departments. Pesticide application was accompanied by a 2.6 t/ha increase (Figure 3). At levels of intensification in the early 1990s, few potato growers overused pesticides. But with such transparent productivity benefits, the use of such chemicals will likely expand in the future.

More analysis of the effects of different pesticides showed that systemic insecticides and fungicides and nonsystemic insecticides made an important and statistically significant contribution to yield. Nonsystemic fungicides did not significantly change productivity. This finding points to the potential for more effective use of chemicals in the integrated management of late blight caused by the fungus *Phytophthora infestans*, the target of the bulk of fungicide application in potato production in Bolivia.

About one-quarter of the farmers said that they received technical assistance in potato production in the form of training and information, credit, or access to inputs. The estimated effect of technical assistance was 2.5 t/ha (Figure 3).

In an effort to better understand the nexus between technical assistance and potato productivity, credit-related technical assistance was grouped separately from non-credit-related technical assistance. When technical assistance was disaggregated into these two groupings and the regression model was re-estimated, the coefficients suggested that technical assistance was broadly effective in increasing potato productivity independent of the type of service offered. Although those farmers who received technical assistance may have had higher yields than other farmers for reasons other than technical assistance

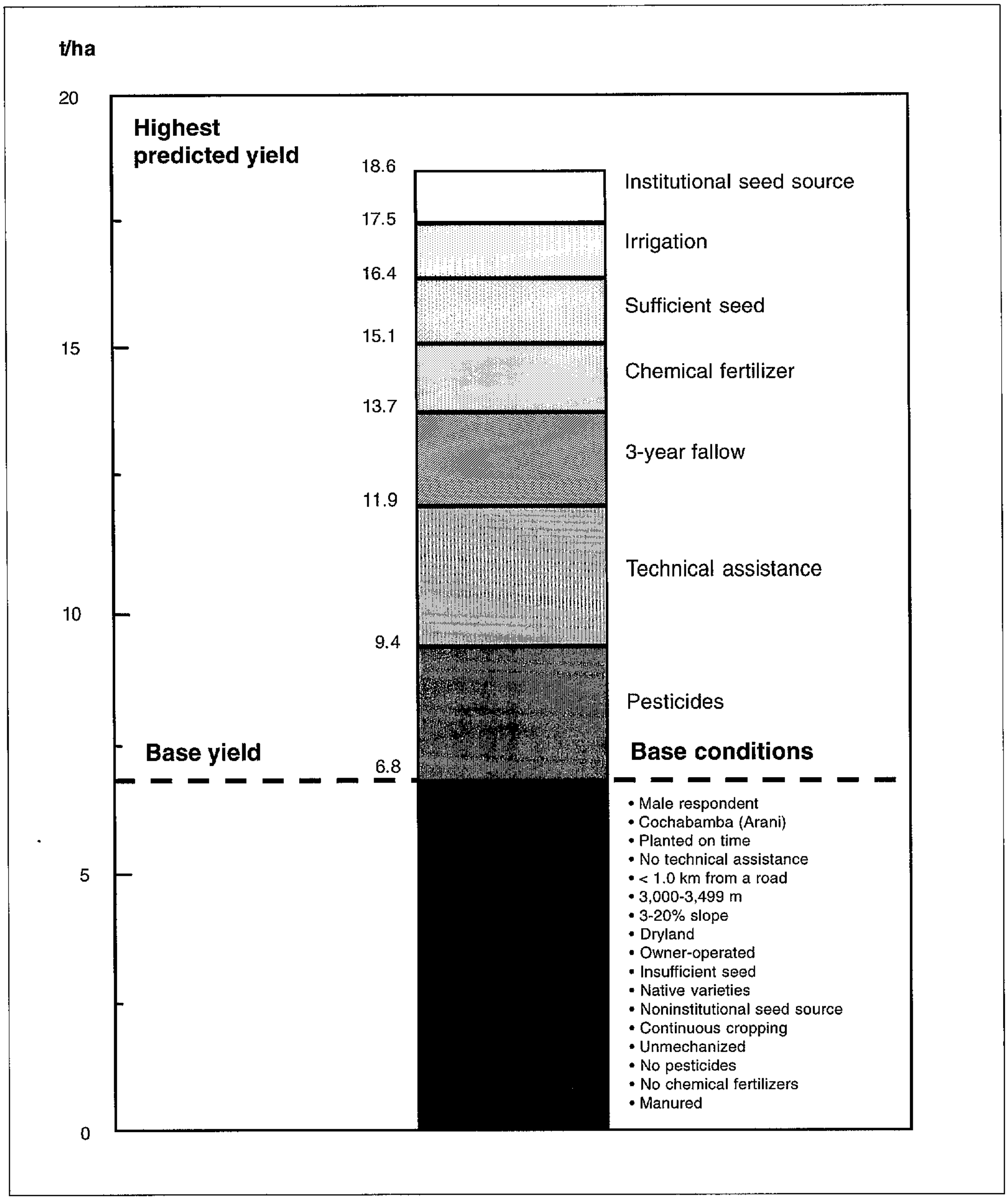


Figure 3. Sources of variation in potato productivity in farmers' fields in Bolivia.

per se, the results support the case for investing in extension programs designed to enhance potato productivity.

Fallowing two or more years was associated with a large and statistically significant yield advantage over continuous cropping (Figure 3). The productivity effects of a longer fallow were especially marked in Tarija and Cochabamba.

Most farmers who used pesticides also used chemical fertilizer, but its impact on yield was not as strong as that of pesticides. The use of chemical fertilizer was associated with a yield increase of only 1.4 t/ha. Low rates of application may partially explain this less-than-expected yield response.

Farmers who believed that they had sufficient seed to plant their planned potato area had 1.3 t/ha higher yields than those who believed that they did not have enough tuber seed. Although this question was cast in terms of seed availability, the strength of the results suggests that the responses are indicative of seed quality.

About 10% of the farmers benefited from an institutional supply of seed, which was the original source of the variety planted in the field. Switching from an informal to an institutional source of the variety was accompanied by a statistically significant 1.1 t/ha yield increase. This effect was most pronounced in Cochabamba. Collectively, the results on seed sufficiency and institutional seed source point to productivity benefits of improving seed quality and availability.

The impact of irrigation on potato productivity was not nearly as large as anticipated. Irrigation increased potato yield by only 1.1 t/ha. The positive productivity impact of irrigation is largely driven by the results in Chuquisaca where yields in irrigated fields were 2.5 t/ha higher than in nonirrigated fields. No data were taken on the intensity of irrigation; therefore, it is hard to explain the interdepartmental variation in this result.

The consequences for productivity of several other variables, which are described in Figure 2 and subsumed in the baseline scenario in Figure 3, warrant comment. Estimated yields in fields farmed by women were not significantly different from estimated yields in fields farmed by men. Owner-operator fields were characterized by a yield advantage of about 1.0 t/ha compared with fields farmed by groups. This yield difference is net of the effect that fields being farmed by a group were more likely to be planted later than fields cultivated by a single household. Fields planted after mid-November yielded 1.0 t/ha less than those planted before that date. A group was also more likely to perceive a seed shortage.

Summing Up

Like other survey-based research, this work has begged more questions than it has answered. For example, reasons for the absence of an anticipated strong productivity response between supplementary irrigation and chemical fertilizer use need to be investigated. Moreover, gathering more household-specific information, particularly on assets, could have contributed to a deeper understanding of explanations for variations in productivity across farmers' fields.

Nonetheless, the production surveys were cost-effective in generating insight into the level and determinants of potato production in Bolivia. They also provide a valuable benchmark for impact assessment of technologies generated by PROINPA. Combining crop cuts and focused surveys with broad geographic coverage should receive more emphasis in diagnostic research on productivity constraints and opportunities.

Preferences of Urban Consumers for Andean Roots and Tubers in Ecuador

P. Espinoza A. and C.C. Crissman[1]

Limited and declining demand by urban consumers is often cited as a major constraint to expanding the use of ulluco (*Ullucus tuberosus*), arracacha (*Arracacia xanthorrhiza*), oca (*Oxalis tuberosa*), and mashua (*Tropaeolum tuberosum*). Like potatoes, these are root and tuber crops domesticated in the Andes. Of the lesser-known Andean root and tuber crops (ARTC), the first three are the most important economically in Ecuador. But their consumer acceptance in large metropolitan areas in general, and the scope for identifying market niches to increase consumption in particular, have not been investigated. Ecuador, like the rest of the Andean countries where these crops are part of the diet, is already a predominantly urban country and will become even more so in the future.

To address these issues, two types of inquiries were carried out. First, 770 consumers, selected randomly and stratified by wealth, were interviewed about their consumption of and preferences for ulluco, arracacha, oca, and mashua.

Respondents were residents of Quito, Guayaquil, and Cuenca, the three largest cities, which account for 30% of the population of this country of 11 million inhabitants. Second, consumer panels of 160 residents of Quito were formed to test the acceptability of distinct types of ulluco and arracacha.

Urban Consumption of Andean Roots and Tubers

Over 90% of the respondents in each of the three cities recognized and had previously consumed ulluco and arracacha. In contrast, knowledge of and prior experience with mashua was negligible. Most respondents from the Andean cities of Quito and Cuenca had consumed oca, but few from the coastal city of Guayaquil had ever eaten it.

Urban Ecuadorians consume a variety of root and tuber crops. Table 1 shows estimated annual purchases per person; this includes potato, cassava, and sweetpotato. Across the three cities, ulluco and arracacha rank third and fourth in per capita annual purchases of root and tuber crops, but they are a distant third and fourth in quantity purchased. Potato occupies a dominant position in Quito and Cuenca, and potato and cassava are the most economically important root and tuber crops in Guayaquil.

Surprisingly, per capita purchases of ulluco and arracacha are higher in coastal Guayaquil, which is farther from their source, than in the Andean cities of Quito and Cuenca.

The lesser-known ARTC are usually associated with poverty in both production and consumption. Poorer respondents tended to purchase proportionally more ulluco and oca. In contrast, the wealthiest respondents bought relatively more arracacha, which is especially prized by richer consumers in Guayaquil.

The survey results also support the conventional wisdom that consumer preference for these crops is declining (Table 2). Substantially more respondents stated that in the past they had consumed more ulluco, arracacha, and oca, compared with potato, than they do now. Moreover, preferences for these crops varied by age. On average, the highest preference scores were given by the oldest group of respondents and the lowest

1 CIP, Quito, Ecuador.

Table 1. Annual per capita purchase (in kg) of root and tuber commodities (n=770) in three Ecuadorian cities, 1994-95.

Commodity	City		
	Quito	Guayaquil	Cuenca
Potato	120.0	49.7	80.4
Cassava	17.3	49.3	14.8
Ulluco	9.6	12.8	11.2
Arracacha	8.1	8.9	2.7
Sweetpotato	5.4	7.4	2.8
Oca	3.5	0.6	1.8
Total	163.9	128.7	113.7

by the youngest. This pattern did not prevail in potatoes, where average preference scores were uniformly high across age groups.

These lesser-known ARTC are also viewed as being cheaper than potatoes. Indeed, the results of the survey support this perception among respondent households.

Potatoes were perceived to be dearer than other root and tuber crops. But market information suggests the opposite: ulluco, arracacha, and oca all cost more per kilogram than potato. Perhaps consumers confused expenditure with unit prices in responding to the question on relative prices.

Positive and negative characteristics, which condition consumer preferences, are unique to each of the three crops (Table 3). Ulluco was negatively associated with a high incidence of mucilage. Oca took too long to prepare. Negative aspects related to smell and taste eroded consumer preferences for arracacha. On the plus side, the three crops were widely viewed as nutritious. The easy digestibility of arracacha leads to its frequent use as baby food or for nursing mothers.

Morphotype Variability in Consumption

The limited availability of morphotypes is a severe constraint to expanding urban con-

Table 2. Variation in consumption of roots and tubers over time by commodity in percent (n=770), CIP-Ecuador, 1994-95.

Commodity	Consumption (%)		
	More before	More now	Same
Ulluco	28.9	12.2	57.9
Oca	51.4	11.5	36.3
Arracacha	32.5	13.6	53.6
Potato	10.0	6.8	83.1

Table 3. Positive and negative characteristics that condition preferences for lesser-known Andean root and tuber commodities, CIP-Ecuador, 1994-95.

Commodity	Characteristics			
		Positive		Negative
Ulluco	1	Nutritious	1	Mucilage
	2	Tasty	2	Expensive
	3	Habit	3	Hard to get
	4	Healthy	4	Fattening
Oca	1	Tasty	1	Long time to prepare
	2	Nutritious	2	Hard to get
	3	Healthy	3	Bad taste
	4	Habit	4	Don't know how to prepare
Arracacha	1	Nutritious	1	Bad taste and smell
	2	Digestible	2	Very perishable
	3	Tasty	3	Hard to get
	4	Healthy	4	Expensive
	5	Habit	5	Fattening

sumption of ulluco and arracacha. The majority of consumers in Quito identified ulluco with the dominant yellow form (Table 4). They had never seen other morphotypes. In Guayaquil, the red ulluco prevailed, and in Cuenca yet a third type dominated the market.

A similar situation occurred in the consumption of arracacha, which is identified with the white morphotype. Urban consumers had never seen yellow and purple morphotypes.

Is the absence of these other morphotypes in the market attributable to poor consumer acceptability or lack of availability? To answer that question, consumer panels were given an array of morphotypes of ulluco and arracacha to consume and evaluate in the ways they normally would prepare them.

The results (Table 5) indicate that the pink morphotype is broadly acceptable in ulluco and that the yellow morphotype is competitive with the white one in arracacha. The strength of the pink ulluco was its lower mucilage content; the yellow arracacha was preferred for its bright color, which it kept when cooked. There were no significant differences in acceptability for yellow and pink ulluco.

For arracacha, differences in perceived characteristics between the top two ranking morphotypes were not as marked as in ulluco. Consumers were impressed with the bright color of the yellow morphotype, and they rated its taste, smell, and consistency on a par with the white one.

Implications for Expanding Urban Consumption

Protecting the biodiversity of these lesser-known ARTC requires the maintenance of existing markets and the development of new markets. Like most Latin American countries, Ecuador is predominantly urban. Urban markets are therefore essential to the survival of

Table 4. Consumer preference for ulluco morphotypes in three Ecuadorian cities.

Preference ordering	Quito		Guayaquil		Cuenca	
	Preference	(%)	Preference	(%)	Preference	(%)
1	Yellow	85.4	Red	60.3	Gallo Lliro	96.7
2	Pink	10.6	Gallo Lliro	23.3	Red	*
3	Gallo Lliro	2.2	Yellow	8.9	Gallito	*
4	Gallito	1.1	Gallito	4.0	Pink	*
5	Red	*	Pink	*	Yellow	*

* Less than 1%.

these crops. This urban population is growing rapidly from natural birth rates and from rural-urban migration. Most migrants come from lower economic strata and bring with them their ARTC consumption habits. However, notable was the fact that preferences for ulluco and arracacha by the upper economic strata exceeded those of the lower strata. These two crops do not need to be consigned to market niches for poor people. By taking advantage of the knowledge of the urban population of these crops and preferences for them, new niches can be found that can help assure the survival of distinct morphotypes.

Based on the survey and subsequent consumer panel results, implications for increasing urban consumption are specific to each crop. Oca is still widely appreciated in rural regions, yet is largely unknown in the cities. We can draw on the experience of reintroducing quinua in several countries in Latin America and sweetpotato in Chile for a promotion strategy for oca. Promoting it as an exotic and organic product to richer consumers first would appear to be the most suitable strategy to increase urban demand, which eventually would percolate to poorer consumers.

Table 5. Mean acceptability scores of different morphotypes of ulluco and arracacha[a].

Morphotype		Treatment average[b]
Ulluco	Yellow	6.68 (a)
	Pink	6.56 (a)
	White	6.06 (b)
	Red	5.97 (bc)
Arracacha	White	6.71 (a)
	Yellow	6.60 (a)
	Purple	5.19 (b)

a. Results of Duncan's multiple range test are presented in parentheses.

b. On a scale of 1 to 9 where 1 = I dislike very much and 9 = I like very much.

Many respondents, particularly younger people in Quito, reject ulluco because of the high mucilage content of the yellow morphotype, which is the only one marketed in the city. The results of the consumer panel showed that a market niche exists for a pink morphotype with less mucilage.

In general, consumers prefer bright-colored morphotypes that are low in mucilage and that keep their color during preparation. These types should be promoted so that consumers can select between ulluco morphotypes that are high and low in mucilage content.

Similarly, most consumers know only one morphotype (white) of arracacha. Again, the consumer panel study pointed to the market potential of the yellow morphotype, which was praised for its color and taste. Additionally, improving the transport and packing of arracacha destined for the Guayaquil market could lead to an increase in consumption in response to a better presentation and longer shelf life.

For more details on these crops, including recipes, see: Espinosa and Crissman, *Raíces y Tubérculos Andinos en Ecuador*, Ediciones Abya Yala, Quito, Ecuador, in press, and P. Espinosa, R. Vaca, J. Abad, and C. Crissman, *Raíces y Tubérculos Marginalizados en Ecuador: Limitaciones en Producción,* Ediciones Abya Yala, Quito, Ecuador, 1997. 179 p. Both are available through CIP.

Selection of New Sweetpotato Varieties for High Dry Matter Content in Indonesia

Il-Gin Mok, Lisna Ningsih, and Tjintokohadi[1]

Increasing dry matter (DM) content is the primary objective for sweetpotato breeding for Southeast Asia. Since 1990, many CIP pathogen-tested clones have been evaluated in Bogor and at other sites in Indonesia. However, their low DM content or poor adaptability outweighed their good agronomic characters. We are now combining this CIP germplasm with locally important cultivars in a recurrent selection scheme for long-term population improvement in Indonesia.

Meanwhile, botanical seeds introduced from various sources, including CIP-Lima and CIP's regional breeding programs, and from breeding programs in China, Japan, and the Philippines (Table 1), have been intensively evaluated and selected at Bogor. From 1993 to 1995, about 90 advanced clones were selected for high DM content and high yield at Bogor. These clones were tested at Lembang and Malang to select the most suitable variety for starch production for Southeast Asia. These advanced clones also maintain many useful traits such as resistance to scab (caused by *Elsinoe batatas*), white or cream flesh, and good storage-root shape. These advanced clones were a result of many years' efforts to select a variety for high DM content.

Materials and Methods

Lembang is situated at about 1,600 m above sea level. Because the average temperature is low (16-24°C), the sweetpotato growing season is 5-6 mo from planting to harvest. Nitrogen fertilizer was applied at the rate of 60 kg/ha. Malang is situated at about 500 m, where the growing season is about 4 mo. Farmers use high levels of N fertilizer (100 kg/ha). At Malang, we used farmers' fields, and asked them to manage the crop according to their own practices, to minimize any influence from us except for our providing planting material. The climate at Bogor is hot and humid, and soil fertility is low. We did not apply fertilizer, relying instead on residual fertility from the previous crop. Yield and DM content were compared at all three sites.

DM content was measured by selecting five medium-size storage roots from each plot, and chopping them into thin strips. One hundred g of sample were oven-dried at 105°C until weight remained constant.

Storage roots harvested from Lembang were used to measure starch content. A simple method was used to extract starch in the laboratory. The storage root was chopped, ground in a blender, sieved through a 150-200 mesh screen, and allowed to sediment for 3-4 h before drying.

Results and Discussion

Storage-root yield

Although clones used in the study were initially selected at Bogor for high DM content and high yield, many of them also had high yields at Lembang and Malang. At Lembang, the average yield of the check BIS 183 was about 20 t/ha. Therefore, clones selected for Lembang had to yield more than 20 t/ha, and have DM content above 35%, which commercial processors prefer. At Malang, cv. Pak Ong yielded 32 t/ha. Only a few clones yielded as high as or higher than Pak Ong, but all were higher in DM content. DM content of Pak Ong was only 24.5%.

1 CIP-ESEAP regional office, Bogor, Indonesia.

Table 1. Origin of advanced clones selected at Bogor in 1993-95. All materials were initially introduced as botanical seed.

Source[a]	Families evaluated at Bogor (no.)	Advanced clones selected from source (no.)
AVRDC	42	1
XSPRC, GAAS, China	62	16
NARC, Japan	15	31
Philippines (ASPRAD)	53	1
MSU, USA	18	0
CIP-HQ	63	37
CIP-SSA	38	5
CIP-ESEAP	78	4
CIP-SWA	5	0
Total	374	95

a. Acronyms cited in this section can be found written out in the section *Acronyms*, p.

Since Pak Ong is used to make ketchup and sambel (chili paste made from sweetpotato and hot pepper), there is a strong demand for a variety with higher DM content.

Dry matter content

Figure 1 shows the frequency distribution of DM content for advanced breeding clones evaluated at Lembang and Malang. At both sites, many advanced breeding clones had high DM content. Most of the clones tested had DM content above 30%. The number of clones with DM content above 35% was 21 at Lembang and 17 at Malang. The result indicates significant progress in breeding for high DM content.

There is a highly significant correlation between DM content in different environments. The correlation coefficient for DM content between Lembang and Malang was 0.536 (with df = 30, significant at the 0.01 probability level). If a clone is high in DM content at Lembang, it is likely to be high at Malang as well, although their environments differ considerably.

Starch content

Starch content varied from 20% to 30% (Figure 2). Most clones tested had between 20% and 25% starch content. Seven clones were in the range of 25.1-27.5%; one clone had a starch content of 30%. Starch content on a dry wt basis ranged from 58.9% to 77.9%, av 69.1%. The correlation coefficient between DM content and starch content was 0.689 in Lembang, which is highly significant at the 0.01 probability level.

Based on overall performance, the four best clones (Table 2) were selected for starch processing. AB94001.8 is a selection from Japanese seed families; the other three clones are from CIP's seed families. All are high yielding, and are high in DM and starch content. They are highly or moderately resistant to scab, which is important in Southeast Asian countries.

We estimate that the clones would produce 4.6-6.6 t/ha of starch at Lembang, and 6.6-7.7 t/ha at Malang (Table 3). Assuming an extractable starch content of 25%, and yield

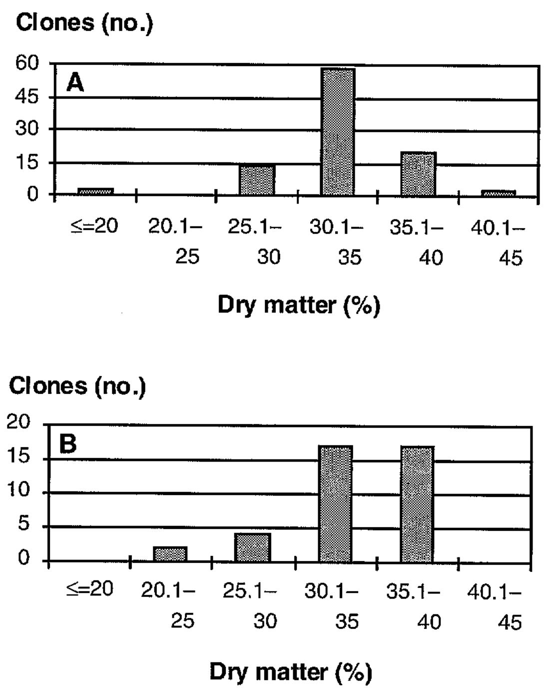


Figure 1. Frequency distribution of dry matter content for advanced breeding clones evaluated at (A) Lembang (1600 m) and (B) Malang (500 m), Indonesia, 1996.

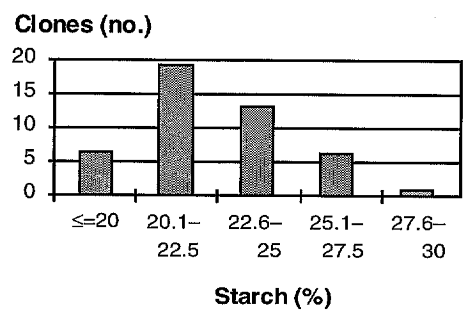


Figure 2. Frequency distribution of starch content for advanced breeding clones evaluated at Lembang (1600 m), Indonesia, 1996.

of 20 t/ha, 5 t of starch could be produced from 1 ha in 4 mo. That would be competitive with other crops in the starch processing industry in Southeast Asia.

Conclusions

There is a very high correlation between starch content and DM content. Heritability

Table 2. Four best-performing clones selected from 90 advanced clones for high dry matter content and yield, Indonesia, 1996.

Clone	Root yield (t/ha)			DM content (%)			Starch content (%)	Skin color	Flesh color
	Malang	Bogor	Lembang	Malang	Bogor	Lembang	Lembang		
AB94001.8	30.4	14.1	25.9	37.8	34.8	37.1	25.4	Cream	White
AB94065.4	27.5	15.6	24.3	37.2	37.3	33.8	0.0	Cream	White
AB94078.1	26.2	18.5	18.4	39.4	40.4	36.7	25.1	Red	White
AB94079.1	28.6	14.8	17.9	38.7	38.8	36.0	27.0	Cream	White

Table 3. Starch productivity at Lembang and Malang calculated from starch content of clones grown at Lembang, Indonesia, 1996.

Clone	Yield at Lembang (t/ha)	Yield at Malang (t/ha)	Starch content (%)	Starch production	
				Lembang (t/ha)	Malang (t/ha)
AB94001.8	25.9	30.4	25.4	6.58	7.72
AB94065.4	24.3	27.5	—	—	—
AB94078.1	18.4	26.2	25.1	4.62	6.58
AB94079.1	17.9	28.6	27.0	4.83	7.72

content is also high. Therefore, it is reasonable to expect rapid enough genetic advance to select for high starch content in a short period.

Because we are dealing with diverse environments, we are using polycross and recurrent selection to rapidly accumulate useful genes for high starch content into a population. Botanical seeds from the population are then distributed to collaborating institutes for further selection in each country.

Collaborative Sweetpotato Breeding in Eastern, Central, and Southern Africa

E.E. Carey[1], S.T. Gichuki[1], P.J. Ndolo[2], G. Turyamureeba[3], R. Kapinga[4], N.B. Lutaladio[5], and J.M. Teri[6]

Over the past few years, sweetpotato research and development efforts in eastern, central, and southern Africa have intensified markedly. This regional effort is carried out largely by national programs under the auspices of two regional research networks, the Programme Régional de l'Amélioration de la Culture de la Pomme de Terre et de la Patate Douce en Afrique Centrale et de l'Est (PRAPACE) and the Southern Africa Root Crop Research Network (SARRNET), with technical assistance from CIP. Varietal improvement programs aim to enhance the value of the crop for food security through the selection and dissemination of early high-yielding varieties with acceptable quality adapted to the major sweetpotato-producing environments in the region. Breeding efforts also link to postharvest research and development efforts aimed at diversifying uses of sweetpotato to expand income-generating opportunities for farmers and processors.

This report focuses on recent progress and current approaches to sweetpotato variety selection and dissemination activities in the region. For illustrative purposes, emphasis is given to data collected in Kenya.

Principal breeding objectives and strategies are discussed, and areas and approaches for future emphasis are proposed. First, we place regional breeding efforts in context by reviewing some aspects of current sweetpotato production and constraints.

Status of Sweetpotato Production and Constraints in the Region

In eastern, central, and southern Africa, sweetpotato is generally grown for household food, with minimum use of inputs other than labor. It is usually a women's crop. In addition to providing food, it is also often sold in local markets to generate small amounts of cash. In a few areas, the crop is grown commercially on a relatively large scale for sale to urban markets. Low-input production practices, however, are still the norm because of risks associated with low prices caused by market gluts at harvest.

The crop is grown principally for its storage roots, which are usually harvested either piecemeal or progressively, and eaten fresh, either boiled or steamed. In much of southern Africa, including Tanzania, the leaves are also eaten as a vegetable.

In eastern Africa, particularly in densely populated areas of Kenya with high production potential, vines are sometimes fed to cattle. In some dry areas of Tanzania and Uganda, sun-dried products made from storage roots provide a seasonally important dietary staple. There is essentially no use of the crop as a source of marketable products such as starch, flour, or animal feed.

Farmers in the region grow a large number of varieties, principally disseminated through informal farmer-to-farmer exchange.

1 CIP, Nairobi, Kenya.
2 Kenya Agricultural Research Institute (KARI), RRC-Kakamega, Kakamega, Kenya.
3 National Agricultural Research Organization, Namulonge Agricultural and Animal Production Research Institute (NAARI), Kampala, Uganda.
4 Agricultural Research Institute-Ukiriguru, Mwanza, Tanzania.
5 Programme Régional de l'Amélioration de la Culture de la Pomme de Terre et de la Patate Douce en Afrique Centrale et de l'Est (PRAPACE), Kampala, Uganda.
6 Southern Africa Root Crop Research Network (SARRNET), Lilongwe, Malawi.

Many have probably been selected by farmers from chance seedlings, which develop frequently because many sweetpotato varieties flower readily under short-daylength tropical conditions. The informal nature of variety dissemination and the lack of information on varieties grown by farmers make it difficult to determine the extent to which relatively recent introductions or escapes from breeding programs contribute to the mix.

Throughout the region, the crop is propagated using vine cuttings, principally obtained from previous crops or in drier areas from multiplication plots maintained in swampy areas or in the shade of trees.

Only in South Africa and Zimbabwe are there schemes for the relatively limited dissemination of pathogen-tested planting material of selected varieties to commercial farmers.

In general, farmers attempt to select healthy-appearing planting material of known varieties. But in times of scarcity, they go some distance to obtain planting materials of unknown varieties of possibly poor health status. The general lack of attention by farmers to the storage-root production of the plants from which they select planting materials may contribute to the degeneration of some varieties and the relatively rapid turnover of varieties observed in some areas.

Sweetpotato is grown over a wide range of environments in the region, but most is grown at mid-elevations between 800 and 2000 m. These mid-elevation production areas may be roughly divided into three major agroecological zones (AEZ), each having a different set of commonly occurring constraints to increased production. The major AEZ, their major areas of distribution, and constraints are shown in Table 1.

Generally adequate levels of resistance to sweetpotato virus disease (SPVD) and Alternaria stem blight caused by *Alternaria* spp. occur in most important varieties in AEZ where these constraints are important. The importance of these constraints usually becomes especially apparent during the selection of new varieties.

Some constraints are common to sweetpotato across all AEZ. The prevalence of late-maturing, low-yielding varieties grown by farmers is widely considered to be a major constraint to increased production. Limited forms of use and the perishability of fresh roots also seriously limit demand for sweetpotato in the region. The potential for diversification of sweetpotato uses has not

Table 1. Distribution of major sweetpotato agroecological zones in eastern and southern Africa, and associated production constraints.

Agroecological zone	Major area of zone	Principal constraints
Moist-warm environments (bimodal rainfall)	Major production zones of Kenya, Uganda, W. Tanzania, Rwanda, Burundi	SPVD, moles
Dry-warm environments (unimodal rainfall)	Northeastern Uganda, parts of Kenya, Tanzania, and southern Africa	Weevils (*Cylas* spp.), drought, scarcity of planting material
Moist-cool environments—higher elevations (bimodal rainfall)	Highland production zones, southwestern Uganda, Rwanda, Burundi, eastern Zaire	Alternaria disease, low soil fertility

been as widely recognized by farmers and researchers in Africa as in a number of Asian countries. Where use is diversified, sweetpotato has gone from being predominantly a food security crop to being an income generator as a raw material for human food and animal feed products. Similarly, low or declining soil fertility is widespread across large areas of eastern, central, and southern Africa where sweetpotato is grown. It is especially severe in the densely populated central African highlands.

Current Approaches and Selected Results

During the past few years, there has been an increasing sweetpotato research effort in eastern, central, and southern Africa. The work has largely been conducted under the auspices of PRAPACE and SARRNET, with support from CIP, through a regionally based team of scientists in key countries. The CIP team includes a plant breeder, an entomologist, a postharvest specialist, and socioeconomists. The breeding component of the effort, which is still evolving, is highly collaborative, principally involving shared breeding trials with the national programs of Kenya, Uganda, and Tanzania, and broader regional evaluations through the networks.

Key elements of the regional breeding strategy include: (1) the introduction and testing of elite varieties and seed populations from outside of Africa; (2) the cleanup, distribution, and testing within Africa of varieties identified as promising or important by individual national programs; (3) breeding in key AEZ to generate new varieties for the region; and (4) the participation of farmers and extension and nongovernmental organization (NGO) partners in the selection and dissemination of new varieties.

Within each network, some countries play more active roles than others in sweetpotato variety development. Thus, in PRAPACE (a network of Burundi, Eritrea, Ethiopia, Kenya, Rwanda, Uganda, and Zaire), Kenya, Ethiopia, Uganda, and Zaire have taken variety selection, particularly for virus resistance and earliness, as their main area of focus. In SARRNET, an 11-country network of Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe, breeding new varieties is the focus of Malawi, Mozambique, South Africa, Tanzania, and Zambia. Other countries, both within and outside of the networks, principally receive and test proven varieties identified by the lead network countries.

In recent years, CIP has been the principal provider of pathogen-tested sweetpotato clones for distribution in the region. International distribution of seed populations is another important means of introducing sweetpotato germplasm for selection by breeding programs.

Principal sources of sweetpotato seed populations distributed recently in the region have included the CIP breeding programs in Peru and Indonesia, the Chinese programs at Xuzhou and Guangzhou, and programs at Mississippi State University and the United States Department of Agriculture Vegetable Research Laboratory at Charleston, South Carolina. Until 1994, the Institut des Sciences Agronomiques du Rwanda maintained a crossing block, which was an important source of seed for distribution within and outside of Africa. More recently, the breeding program at Namulonge, Uganda, has become the principal source of seed in the region.

Table 2 presents information on the distribution of sweetpotato germplasm by CIP to national programs in the region since 1993. The types (either clones or seeds) and numbers of clones or families distributed to individual programs reflect the capacities and interests of national programs, and the role of those programs in the regional breeding strategy.

The lead countries in the networks have tended to receive more clones and seed families for testing than others. Kenya, as the base of the regional CIP breeder, is the primary site for the introduction and evaluation of germplasm, and so has received the most

Table 2. Distribution of sweetpotato germplasm as clones or seed families by CIP to countries in eastern, central, and southern Africa for evaluation and selection (January 1993 to February 1997). Number of clones shipped is given by region of origin, and number of shipments to each country is given in parentheses.

Country	Source of clonal germplasm by region[a]				Total no. of clones shipped	Seed families[b]
	Latin America	North America	Asia	Africa		
Angola (4)	16	4	10	11	41	—
Burundi (3)	2	—	—	4	6	24
Botswana (2)	17	4	6	7	34	—
Congo (1)	5	1	3	2	11	—
Eritrea (2)	6	1	8	5	20	—
Ethiopia (4)	38	17	24	17	96	13
Kenya (13)	73	41	127	44	285	265
Lesotho (3)	17	4	7	10	38	5
Madagascar (3)	14	7	10	13	44	—
Malawi (6)	19	8	10	7	44	97
Mozambique (4)	24	18	14	16	72	—
Namibia (1)	6	—	2	3	11	—
Rwanda (7)	34	21	22	19	96	92
South Africa (6)	6	1	2	3	12	89
Sudan (2)	6	4	5	6	21	—
Swaziland (2)	17	4	7	9	37	—
Tanzania (8)	28	7	20	20	75	149
Uganda (8)	83	34	75	41	233	117
Zaire (3)	20	17	18	18	73	—
Zambia (5)	11	3	6	10	30	93
Zimbabwe (3)	16	4	8	10	38	—
Total numbers	99	54	133	57	343	447

a. Including varieties and experimental clones from: Latin America and the Caribbean—Argentina, Brazil, Colombia, Cuba, Ecuador, Mexico, Peru, Puerto Rico, St. Vincent, Venezuela, and CIP; North America—USA; Asia and Oceania—Australia, Bangladesh, China, Cook Islands, India, Indonesia, Japan, Korea, Myanmar, Papua New Guinea, Philippines, Sri Lanka, Taiwan, Thailand, Tonga, Vietnam, and AVRDC; Africa—Burundi, Cameroon, Egypt, Kenya, Madagascar, Rwanda, Uganda, South Africa, and IITA.

b. Seed families from sources including CIP, Indonesia, China, Uganda, and Rwanda.

clones and families. Kenya is also the principal regional site for the redistribution of clonal germplasm by CIP from the Plant Quarantine Station at Muguga.

The total number of clones and seeds introduced (as shown in Table 2) is not necessarily a true reflection of the number of genotypes that have made it to the field for testing. Losses frequently occur during the process of introduction and multiplication. That is particularly true for the introduction of clones as in vitro plantlets. Since 1995, most clonal germplasm distributed in the region by CIP has been shipped in the form of cuttings taken from pathogen-tested mother plants at the Plant Quarantine Station at Muguga, Kenya. Losses during transport and establishment have decreased markedly as a result.

Summary Results

Following introduction and initial multiplication in each country, trials are conducted to evaluate the performance of introduced genotypes and to select superior performers. Initial results of evaluations of introduced germplasm are beginning to appear in reports of national programs and networks, with promising performance reported for a number of introduced clones. Here we will mainly examine summarized results from evaluations of introduced clones and selections from seed families at sites in Kenya over the past few years to illustrate some preliminary conclusions about the performance of introduced germplasm in the region.

Clone performance

A total of 208 introduced clones were evaluated at six sites covering a range of Kenyan sweetpotato production zones between 1994 and 1996. Table 3 gives summary results of the 22 highest yielding clones, along with information on the performance of a few local checks and farmers' varieties.

The yield performance of clones in each trial was ranked by quartile, and for each clone the number of trials in which the clone performed in the first, second, third, or fourth quartiles was counted (Table 3). This information was used to derive a weighted mean of performance for each clone over all trials in which it was evaluated. Mean root dry matter (DM) content for each clone from trials in which that was evaluated is also given. Clones were not always evaluated in the same number of trials at the same number of sites. Therefore, results do not necessarily indicate broad adaptation over all sites, and the results for different clones may not be strictly comparable, particularly when the number of trials was low.

Clones from diverse sources had high, stable yields in Kenya. The large number of clones from the International Institute of Tropical Agriculture (IITA), selected through multilocational trials at humid and subhumid lowland sites in Nigeria, was noteworthy, thus indicating the value of multilocational selection programs.

The root DM content of the stable, high-yielding introduced clones was usually below 30%, whereas that of the local check varieties was over 30%. But several introduced clones did have DM contents above 27%, indicative of acceptable taste. Several of the clones listed in Table 3 have been selected for further testing at sites in Kenya and have been widely distributed to other countries in the region for further testing. A number of these clones, such as Naveto (440131) and Yan Shu 1 (440024), are reported to be performing well at various sites. Zapallo (420027), with relatively low DM, but high provitamin A content, and an apparent capacity to produce well under drought, has also been widely distributed for testing. Santo Amaro (400011) yielded in the top quartile in eight out of nine trials and will be widely distributed.

In contrast to the performance of introduced clones at most sites in Kenya, virtually all exotic clones introduced and evaluated at the Namulonge Agricultural and Animal Production Research Institute (NAARI) in Uganda have succumbed to SPVD. This indicates that high levels of resistance to this disease are rare or absent in germplasm introduced from outside the region. In contrast, frequency of

Table 3. Summary of yield performance and root dry matter content of the best performing introduced clones and local check varieties over trials in Kenya from 1994 to 1996 (out of 208 introduced).

CIP number	Name	Origin	Number of trials in which clone ranked by quartile: 1	2	3	4	Total no. trials	Weighted mean	Root DM content (%)	(n)
188001.1	LM88.002	CIP	3	5	0	1	9	1.89	25.03	3
188001.2	LM88.014	CIP	4	2	1	2	9	2.11	28.13	3
188004.3	LM88.113	CIP	4	5	3	0	12	1.92	27.00	3
400011	Santo Amaro	Brazil	8	1	0	0	9	1.11	27.36	7
420027	Zapallo	Peru	10	3	3	2	18	1.83	23.34	6
440004	W-119	USA	8	2	1	2	13	1.77	29.58	4
440005	W-151	USA	1	4	2	0	7	2.14	24.33	3
440024	Yan Shu 1	China	10	2	2	3	17	1.88	27.06	5
440057	TIB 11	IITA	5	1	0	0	6	1.17	22.15	6
440069	TIS 5125	IITA	2	1	0	0	3	1.33	20.63	3
440074	TIS 8524	IITA	5	3	1	1	10	1.80	23.35	4
440076	TIS 9291	IITA	2	6	1	0	9	1.89	25.99	8
440077	TIS 9465	IITA	7	0	1	0	8	1.25	20.03	4
440078	TIS 70357	IITA	4	0	2	0	6	1.67	30.00	5
440098	TIS 8164	IITA	5	4	1	0	10	1.60	23.69	9
440131	Naveto	Papua NG	13	2	2	5	22	1.95	25.78	11
440144	IRA 502	Cameroon	3	3	0	0	6	1.50	22.45	6
440154	Xiang Shu 6	China	4	4	0	0	8	1.50	20.88	6
440164	K51/3251	Rwanda	3	1	0	0	4	1.25	23.50	4
440185	LO-323	USA	6	1	4	0	11	1.82	22.06	7
440228	CARI 9	Sri Lanka	4	6	3	1	14	2.07	23.41	8
440243	L 312	Papua NG	6	6	2	0	14	1.71	23.93	8
	Jayalo	Kenya	3	0	1	0	4	1.50	30.25	2
	KEMB 10	Kenya	4	2	1	7	14	2.79	30.08	12
	KEMB 36	Kenya	0	1	1	9	11	3.73	31.33	9
	KSP 20	Kenya	7	3	0	1	11	1.55	25.74	9
	SPK 013	Kenya	3	2	0	0	5	1.40	32.80	1
Means			1.7	1.7	1.6	1.6	6.6	2.54	26.25	4.18

resistance is high in local farmers' varieties from Uganda and in clones bred by the breeding program at NAARI. Fortunately, sites where high levels of resistance to SPVD are essential are relatively few in this region.

Seed family performance

The performance of seed families introduced from outside the region, or from seed collected from introduced clones at Nairobi, Kenya, is reported in Table 4. The 31 clones surviving from a 2-yr process of selection at Kakamega were evaluated in a preliminary yield trial with two replications. Clones derived from several hundred seedlings were initially evaluated for appearance, high yield, and resistance to SPVD (disease pressure is moderately severe at Kakamega).

Mugande, a variety recently introduced to Kenya from Rwanda, was included as a check. Mugande was among the top yielders and had high root DM content. Although many of the experimental clones yielded well, root DM content was consistently low, thus indicating a low likelihood of taste acceptability. At NAARI in Uganda, no clones selected from the same batches of introduced seed survived more than two seasons under the high SPVD pressure in the field there.

The preponderance of clones with IITA parentage among them indicates that widely adapted progenitors tend to yield a high frequency of widely adapted selections. The low DM content of almost all selected clones, however, indicates a need for using regionally adapted parental clones, such as Mugande, with a high DM content. In fact, the experience of the breeding program at NAARI, which emphasizes the use of Ugandan and regionally important clones as progenitors, shows a high frequency of clones

Table 4. Performance of top-yielding seedling-derived clones selected from introduced seed in a preliminary yield trial at Kakamega, Kenya, 1996, long rains.

Clone	Pedigree	Source	Root dry matter content (%)	Large storage-root yield (t/ha)	Total dry matter yield (t/ha)
192101/107	TIS 70357 x PC HA*	CIP	17.9	55.4	10.9
192102/101	LM 88.114 x PC HA	CIP	24.5	49.9	12.2
Mugande	Check	Rwanda	31.0	47.7	14.7
192100/103	TIS 9465 x PC HA	CIP	26.6	47.4	12.8
192082/103	DLP 2004 x PC HA	CIP	29.5	46.8	13.8
192101/113	TIS 70357 x PC HA	CIP	27.0	45.2	12.1
440010/101	W-215 x OP	Kenya	25.6	43.4	11.2
192043/101	Tainung 57 x PC HDM	CIP	22.2	40.4	9.2
420020/113	Huarmeyano x OP	Kenya	27.8	39.6	10.9
192045/103	TIS 1487 x OP	CIP	16.4	36.6	6.3
192045/102	TIS 1487 x OP	CIP	21.8	33.3	7.3
192101/101	TIS 70357 x PC HA	CIP	23.3	31.6	7.2
440038/102	TIS 2498 x OP	Kenya	32.4	30.3	9.8
Mean (n=32)			25.8	25.7	6.6
LSD (0.05)			1.50	17.2	5.2
CV			11.3	32.9	38.4

* HA = highland adaptation, HDM = high dry matter, PC = polycross of clones with similar characteristics, OP = open-pollinated seed.

reaching the advanced trial stage with the regionally important variety, Tanzania (SPN/O), as their female progenitor.

Conclusions and Future Focus

Results of evaluations of introduced, elite sweetpotato germplasm in eastern, central, and southern Africa are promising. Trials in Kenya have identified several clones with high and stable yields over production environments with the range of regionally important production constraints. Also, in contrast to the majority of local varieties, which are white-fleshed, a number of introduced clones have orange flesh, due to a high content of provitamin A.

Introduced clones have demonstrated considerable potential for increasing sweetpotato yields at several sites throughout the region, and are already being adopted by farmers in Kenya and Zaire.

Local farmers' varieties have also shown considerable value, particularly with respect to root DM content, which is closely related to eating quality. A number of farmers' varieties, such as Mugande, have also demonstrated early, high, and stable yields. Several promising African farmers' varieties are already on the CIP list of pathogen-tested clones. More clones are cleaned up for addition to the list as they are identified.

In environments where SPVD pressure is high, as in the moist-warm sweetpotato production areas of southern Uganda, most introduced clones do not have the high levels of resistance required to survive. Local germplasm must serve as the principal source of resistance. The Ugandan breeding program at NAARI has recently made extensive use of this local germplasm in breeding new clones that are now reaching the final stages of selection.

Initial results of the evaluation and selection of clones from introduced seed populations at sites in Kenya and Uganda were not very promising. The breeding focus has shifted to the combination of exotic and local germplasm sources in the regional crossing block at NAARI. Testing and selection of progenies from this program are conducted at sites in major sweetpotato-producing zones covering a range of regionally important agroecological conditions in Uganda, Kenya, and Tanzania.

At this stage of sweetpotato improvement for eastern, central, and southern Africa, each of the three approaches outlined above—introduction of exotic clones, use of local farmers' varieties, and breeding of new varieties—can make a contribution to sweetpotato variety selection. With time, and the success of current breeding efforts, we can expect a shift to greater reliance on the products of the regional breeding program.

The major objectives of our regional breeding effort are to select varieties with acceptable characteristics that are important now or have potential importance in the region. These are:

- taste acceptability/dry matter;
- high DM content and orange flesh (to combat vitamin A deficiency);
- suitability for improved farm-level processing (high DM content, attractive appearance, and properties for commercial products, particularly flour); and
- production of vines for animal feed.

Within the overall context of use objectives, secondary objectives will be fine-tuned as necessary on the basis of further testing in the major production environments. Important areas of focus include assessing:

- earliness vs. in-ground storability;
- drought tolerance—planting material persistence, establishment, yield;
- nutrient efficiency (P and K in southwest Uganda); and
- improved techniques for selection for SPVD resistance.

Results to date of regional sweetpotato breeding efforts are encouraging. We are confident that our breeding efforts and regional approach will do much to enhance the role of sweetpotato as an important food security crop in this region, and to help transform the crop into an important income generator for the region's farmers.

Tradeoffs in Agriculture, the Environment, and Farmer Health

C.C. Crissman[1], J.M. Antle[2], and S.M. Capalbo[2]

Over the past two decades, sustainability has come to mean for many the maintenance and improvement in human living standards, standards that are affected by changes in the environment and in human health and economic status. Incorporating sustainability criteria into the mandate of CIP implies that the Center should critically examine not only the productivity but the potential environmental and health effects of its research. In the heterogeneous and frequently fragile environments that are among the priority regions for CIP, there are considerable tradeoffs between productivity gains and their potential environmental and health effects. This paper reports on a general approach to measure the economic, environmental, and health tradeoffs associated with agricultural technologies and how those tradeoffs may be altered through technology or policy changes. The research reported here demonstrates this approach in a study of the environmental and health consequences of pesticide use in potato production in Ecuador.

An Integrated Agriculture/Environment Model

Policy analysis is typically undertaken nationally or regionally. The analysis frequently uses secondary data that reflect aggregates. However, policy analysis with sustainable agricultural development objectives must include environmental effects that are location-specific. Policy analysis in the heterogeneous biophysical setting of the tropical mountains of Ecuador suffers serious deficiencies from the averaging effects of using data that are not location-linked. One objective of the research on pesticide effects is to improve the potential for policy analysis with sustainable agriculture criteria by developing and implementing a framework that links macrotype policy to microtype effects.

The method used here is to define a common unit of measurement valid to the different disciplines and predict the effects of technological or policy changes on those units. In this case, the unit is a farm field. By describing the population of these units statistically and estimating effects on each unit, it is possible to aggregate those effects to a level useful for policy analysis. Using this information, one can define aggregate tradeoffs between economic and environmental or health outcomes in the form of a tradeoff curve.

Figure 1 depicts a model of land use and crop management decision-making. The upper part of the figure pertains to the analysis of a unit of land at the farm level. Prevailing prices, policies, technologies, and the physical attributes of the unit of land affect the farmers' management decisions on land use and input use. These decisions affect agricultural production, but also may affect the environment and human health through two distinct but interrelated mechanisms. Farmers first determine which units of agricultural land are put into production—the land use decision. Then, on the land in production, farmers make management decisions that determine the application rates of chemicals, water use, and land management practices—the input use decision. Physical relationships between the environmental attributes of the land in production and the management practices then jointly determine the agricultural output, and human health and environmental effects as-

1 CIP, Ecuador Liaison Office.
2 Montana State University, Bozeman, Montana, USA.

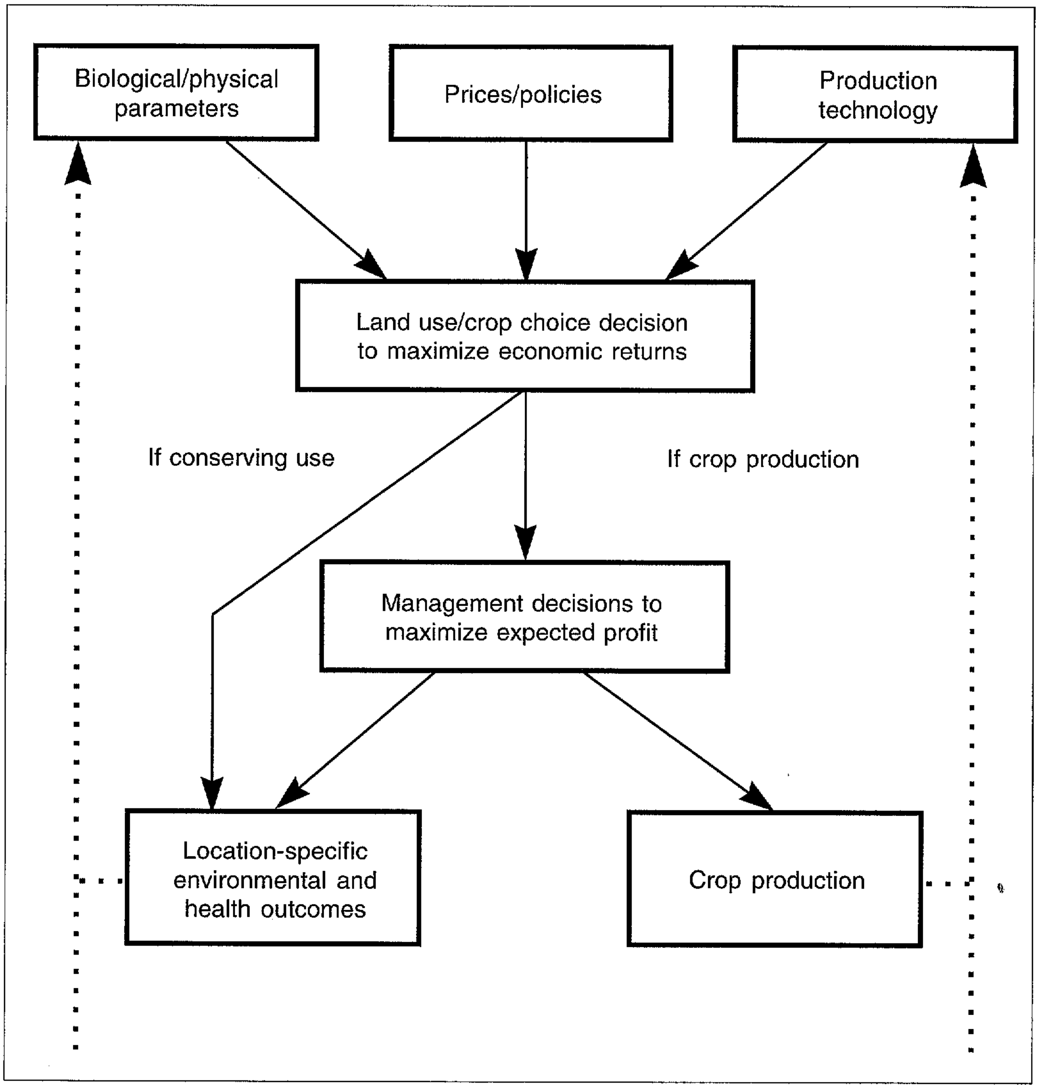


Figure 1. An economic model of land use and crop management decision-making.

sociated with the particular unit of land in production. Thus, the land use and input use decisions of farmers form the linkage between policy and technology and the environmental and health consequences.

The Pesticides Effect Study

The case study

The case study was conducted in a 70-km^2 watershed in the principal potato-producing zone of Ecuador. Production data were collected in a farm-level survey on 40 farms. Because crops are planted and harvested continuously throughout the calendar year, data were collected for parcels, where a parcel is defined as a single crop cycle on a farmer's field. Detailed parcel-level data were collected monthly. Potato production in Ecuador is management-intensive, and there are as many as 20 distinct operations during the 6-month crop cycle.

Late blight caused by *Phytophthora infestans* is the principal disease, and the tuber-boring Andean weevil (*Premnotrypes vorax*) and several foliage-damaging insects are the principal pests affecting production.

They are controlled with dithiocarbamate fungicides and neurotoxin insecticides from the organophosphate and carbamate families.

The case study focused on groundwater contamination through leaching and the occupational health issue of the pesticide applier's exposure as the expressions of environmental and health consequences of pesticide use.

The simulation model

The decision-making model of Figure 1 is embedded into a simulation model (Figure 2) for empirical application. The simulation model is based on econometric revenue and production models, a soil pesticide leaching model, and a health effects model. Figure 2 illustrates the flow of the economics, pesticide leaching, and health portions of the simulation model. A policy or technology scenario is imposed on the economic model where the unit of analysis is a parcel of land. The economics portion consists of four components. First, the model is initiated by sampling the economic and physical characteristics of the fields in the study watershed. Second, we obtain net returns distributions of the principal crops in the rotation (potatoes and pasture for milk production), which determine the land use decision. In the third component, a potato production model produces estimates of the quantity and frequency of pesticides used. The fourth component is a restricted revenue function used to predict the value of production. As shown in Figure 2, the economic model generates three types of outputs that are used in the subsequent portions of the simulation model.

The leaching model is a detailed process model that uses soils and other physical data from the watershed, the chemical characteristics of the pesticides, the pesticide applications from the economics portion of the model, and more than two decades of daily rainfall, temperature, and evapotranspiration data from weather stations in the area. The leaching model predicts the downward movement of pesticide active ingredients through the different soil horizons.

The health component of the simulation model consists of an estimated health production function that specifies health as a function of the total number of pesticide applications, total quantity of applied neurotoxic substances to which an individual was exposed, and other factors. We measure health as an individual's mean neurobehavioral score, an index constructed from a series of neurobehavioral tests. Neurobehavioral tests measure specific aspects of cognitive function such as attention span, visuospatial memory, and reaction time, which are important for decision-making and daily performance of farm work. We also measured poisoning rates to establish the size of the problem.

Because we use mutually compatible data sets, the three separate disciplinary models produce results that are linked. As the last box in the figure shows, we use the linked results to compare the tradeoffs in gains and losses among farm revenues, water table contamination, and applicator health.

Note that the model is stochastic. At several points, the model samples distributions that are derived from physical and economic data. Thus, any two runs of the model are not expected to produce precisely the same results. This is advantageous in two ways. First, since economic and physical processes are stochastic, the model can produce all outcomes in addition to the expected average outcomes. Second, by using distributions constructed from the sample data, you can appeal to rules of aggregation to obtain summary statistics for the group. Reasonable assumptions about the structure of production permit statistically valid extrapolation beyond the data collection site, an important implication for policy analysis.

Presentation of Results

Use of tradeoff curves

To facilitate interpretation of the model results, the tradeoffs between agriculture, health, and the environment are presented in a series of pairwise comparisons. The hypo-

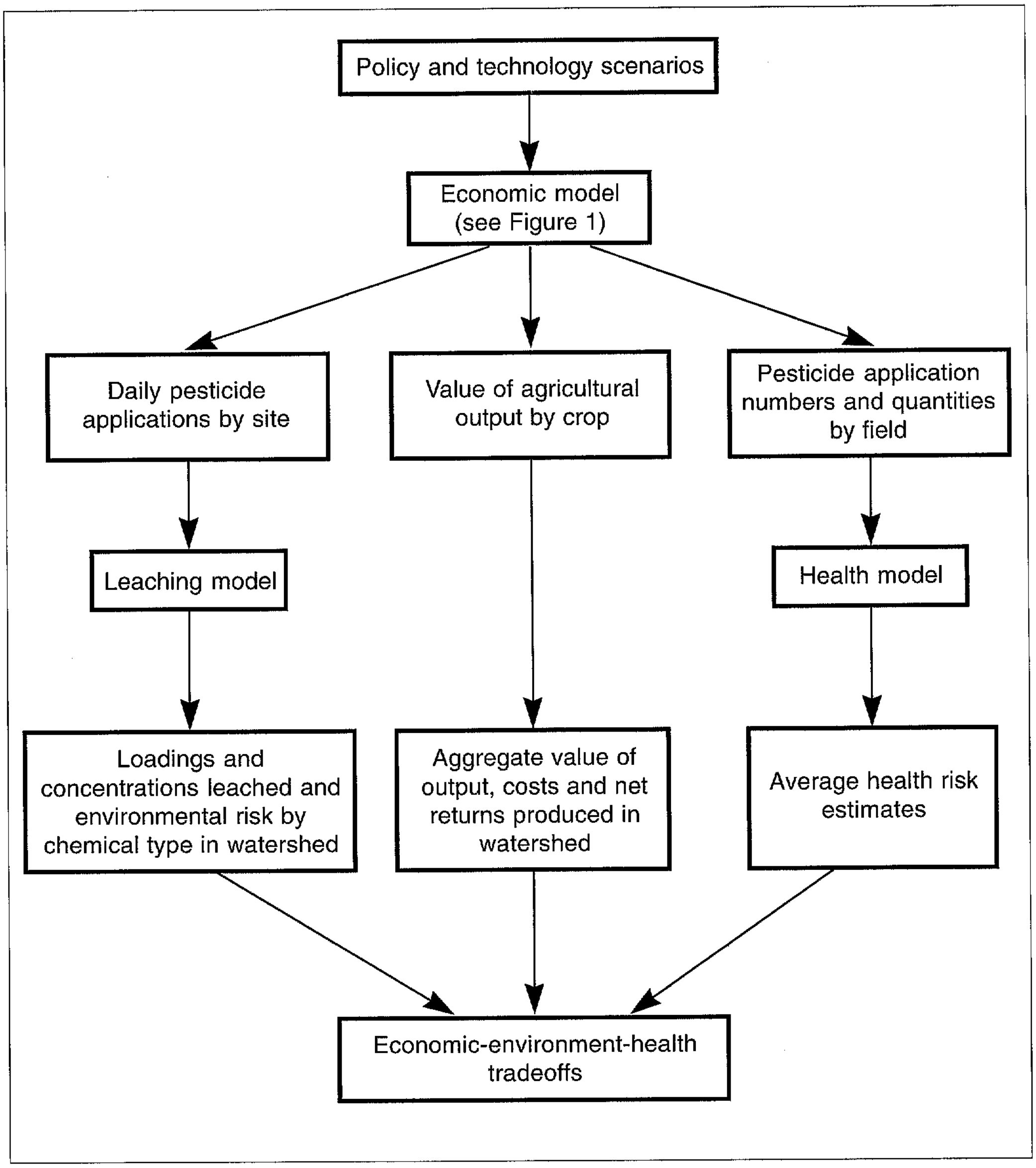


Figure 2. An integrated simulation model for tradeoff analysis.

thetical tradeoff curves in Figure 3 illustrate the tradeoffs between agricultural output and environmental effect. The tradeoff curve represents all the possible pairs of outcomes for a given technology. Thus, different curves are available for different technologies. The move from T_1 to T_2 shows a change in technology that everywhere maintains output while reducing environmental effect. The slope of the tradeoff curve provides information about the opportunity cost of environmental quality in terms of lost output. As curve T_3 shows, different technologies may be more or less damaging at different levels of output.

Construction of an empirical tradeoff curve

An empirical curve is constructed by imposing different policy scenarios on the model. Figure 4 is a scatter diagram of the comparison that relates the level of fungicide leaching with the value of agricultural production. The squares are the base case produced with simulations using the actual data

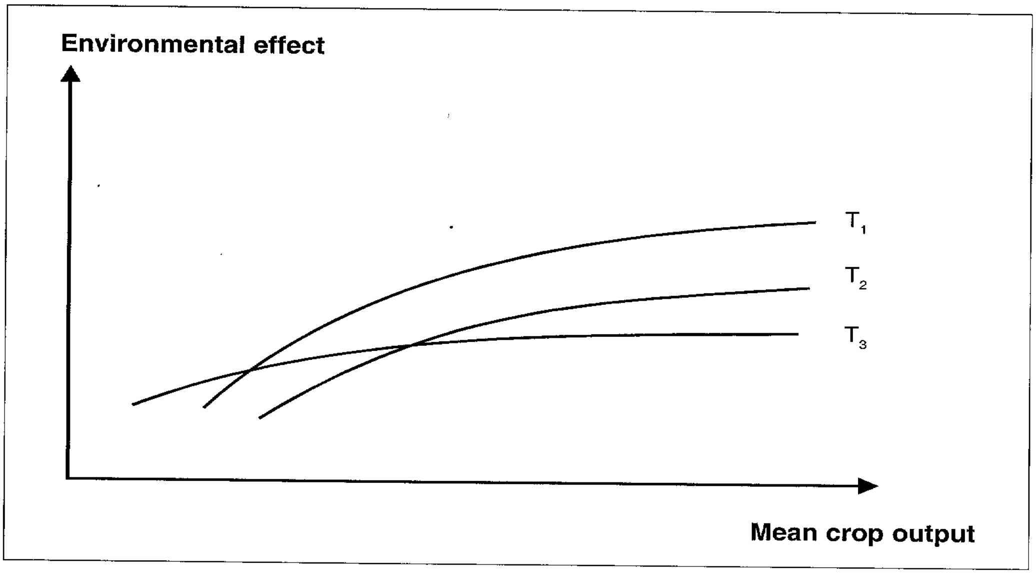


Figure 3. Output-environment tradeoffs associated with alternative technologies.

set. Each square represents the average outcome of 30 fields each with 5 production cycles. This is repeated 30 times. Changing relative prices causes movement along a curve. For example, when the levels of fungicide tax are imposed on the model, there is a reduction in fungicide use with a consequent reduction in fungicide leaching and the value of agricultural production.

The reduced value of potato production comes from two sources. First, farmers leave more area in pasture, which produces less revenue than potatoes; second, they use less fungicide on potatoes, which reduces yields. The figure also depicts increases in potato prices. Higher prices increase profitability, thus causing farmers to plant more area to potato and to use more fungicides. That in turn increases fungicide leaching and the value of production.

Implications for Policy/Technology Analysis

Several issues relevant to policy analysis can be addressed by tradeoff curves. Politicians implicitly use tradeoff curves every day. By the nature of their jobs, they are concerned with winners and losers resulting from policy decisions. The tradeoff curve is simply a concrete expression of what is usually a mental calculation. In the example, the politician or analyst can readily see what the sacrifice of a single unit of environmental quality will gain in units of agricultural production. Whether the size of the sacrifice is acceptable becomes a political decision.

Case study results

First, because of the short half life of the pesticides in use, the fixation of these pesticides to the organic matter in the soil, and the frequent but light rainfall that moves the pesticides slowly downward, water contamination from pesticide leaching is not significant. At four parts per billion, carbofuran contamination of the water table is a full magnitude below the USEPA tolerance limit of 40 ppb. Second, at 171 per hundred thousand inhabitants, the rate of work-related pesticide poisonings ranks among the highest recorded in the world. Third, the health effects of chronic exposure severely depress the neurobehavioral performance of a large segment of the applicators and farm families. Fourth, our economic efficiency analysis shows that farmers are not overspending and applying pesticides irrationally.

These results run counter to public perceptions in Ecuador. Farmers are thought to make

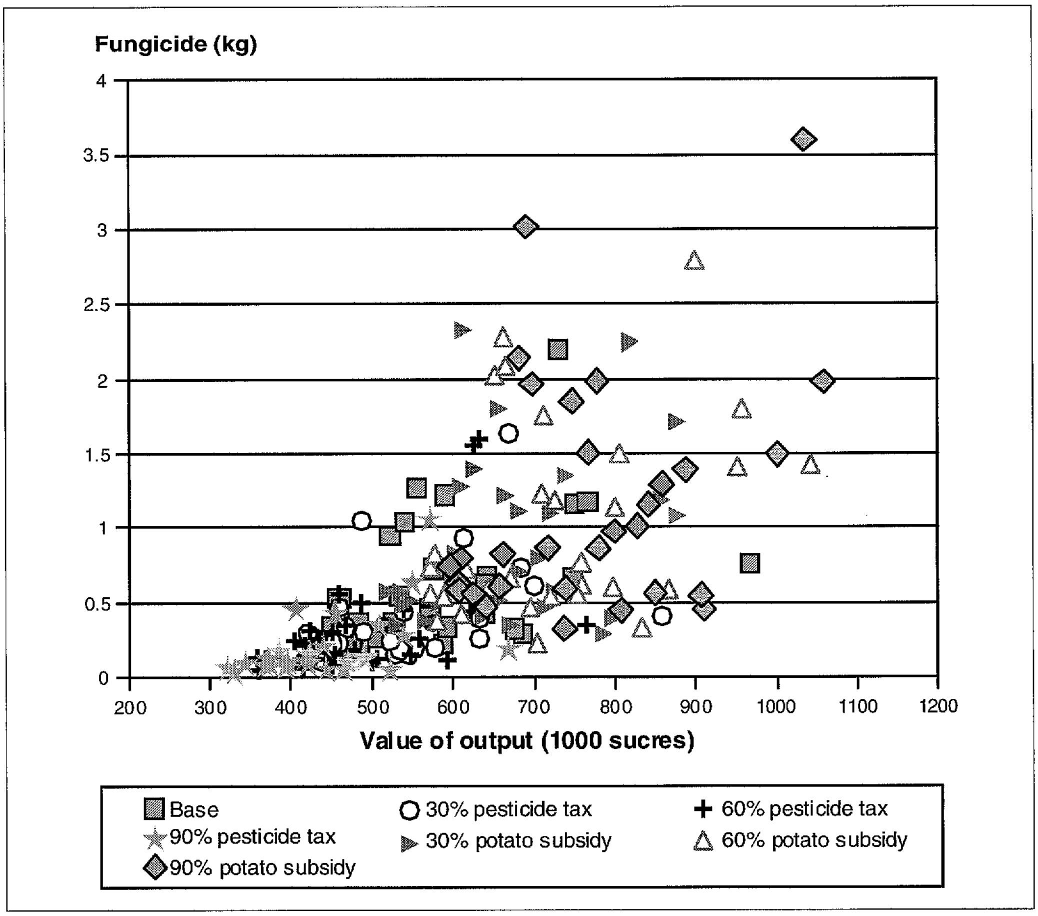


Figure 4. Pesticide leaching-output tradeoffs for base technology.

irrational, excessive use of pesticides with resulting widespread environmental contamination. Environmental lobbyists put forward proposals to ban certain classes of pesticides, including carbofuran, based on the presumption of environmental contamination. However, the research shows that a ban on carbofuran would reduce potato production, but would only minimally improve the environment.

The worker-safety lobby in Ecuador is not nearly as well organized as the environmental lobby, so there is little public discussion about occupational health issues. With pesticide use an essential part of efficient potato production, the policy debate should be centered primarily on the safety of the pesticide applicator and farm families and integrated pest management (IPM) techniques.

Heterogeneity of environment

Policy analysis that incorporates environmental effects must also consider the variability of the impact of the policy itself. The research watershed was classified into four microregions (Figure 5) where we plot lines through the scatter plots to simplify their interpretation. Three of the microregions have similar low-leaching characteristics; the fourth zone is much more susceptible to leaching. There is considerable heterogeneity present even in small areas. We can differentiate such phenomena by linking environmental data to economic data. With such differentiation, regulations to improve the environment could be based on agricultural zoning rather than on taxes or broad-based prohibitions on pesticides that uniformly affect all production zones.

Technology effect analysis

The current technology to control the Andean weevil relies on applications of carbofuran. CIP entomologists have developed a set of IPM technologies that reduce the reliance on carbofuran. Here we simulate the effect on health risk of an 80% adoption of IPM practices that reduce carbofuran use by 40%, combined with a worker education program for safe handling practices (Figure 6). Health risk is the percent chance of a one standard deviation decrease in neurobehavioral score below the mean score of the nonfarming urban control population. The analysis suggests that the combination of IPM and improved safety practices could reduce health risk by 50% or more.

Conclusions

Including sustainability criteria into policy decisions in both developed and developing countries has spurred substantial changes in the mandates of agricultural research institutions and the manner in which research is conducted. One outcome of these changes is an increased emphasis on systems modeling. A weak link in most systems modeling work is the lack of economic criteria in the models.

The research reported in this paper developed a conceptual model that provides linkages between macropolicy and microtype effects. The linkage is provided by including a farmer decision-making model. That model shows how farmers react to policy or technology changes through adjustments to land use and input use decisions. The simulation model produces results that can be aggregated for extrapolation beyond the actual case study area, thus making the model useful for policy analysis. Tradeoff curves are introduced as an analytical tool for summarizing large amounts of data and for illustrating the multiple effects of a given technology.

Although the conceptual model is applied in an economics, pesticide leaching, and health study of pesticide effects, the model is flexible and can be applied to other research questions such as fertilizer use, erosion, or output price adjustments. Since the model is statistically based, it can use data sets generated from various sources.

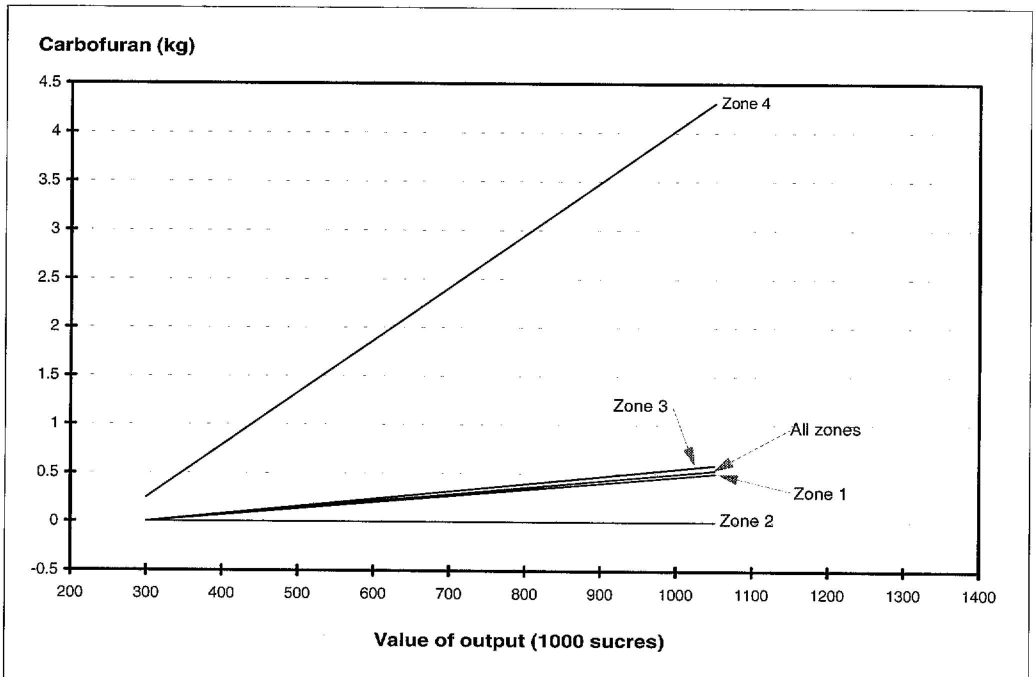


Figure 5. Carbofuran leaching-output tradeoffs.

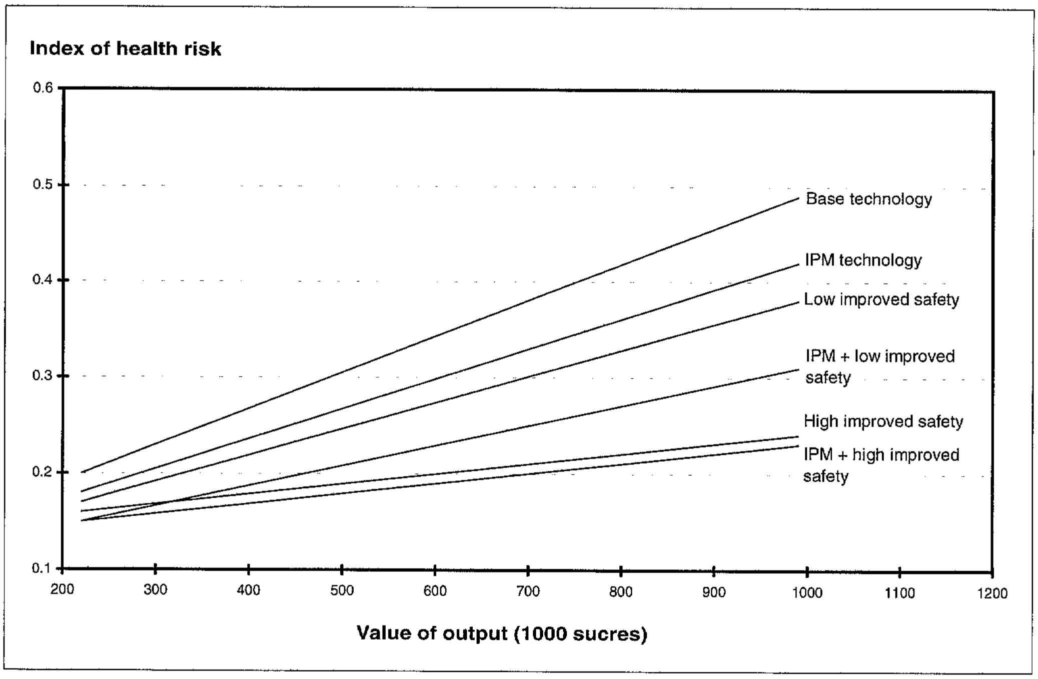


Figure 6. Health-output tradeoffs for carbofuran IPM and improved safety practices.

Selected Reading

Antle, J.M., S.M. Capalbo, and C.C. Crissman. 1994. Econometric production models with endogenous input timing: An application to Ecuadorian potato production. J. Agric. Res. Econ. 19(1):1-18.

Antle, J.M., C.C. Crissman, R.J. Wagenet, and J.L. Hutson. 1996. Empirical foundations for environment-trade linkages: Implications of an Andean study. In: M.E. Bredahl, N. Ballenger, J. Dunmore, and T.L. Roe (eds.). Agriculture, trade, and the environment: Discovering and measuring the critical linkages. Boulder, Col.: Westview Press. p. 173-197.

Crissman, C.C., D.C. Cole, and F. Carpio. 1994. Pesticide use and farm worker health in Ecuadorian potato production. Am. J. Agric. Econ. 76(3):593-597.

Germplasm Management and Enhancement

Ali Golmirzaie[1]

Genetic resources worldwide are being evaluated to preserve and improve them for future generations. Program 2 has played an important role in the conservation of CIP's mandate crops (potato, sweetpotato, and Andean root and tuber crops—ARTC). During 1995-96, we worked to conserve, characterize, and evaluate these crops, using conventional and nonconventional approaches. We used these approaches in-house or in collaboration with research institutes in developed and developing countries. The Program focused on: (1) increasing seed of wild potato and sweetpotato species; (2) identifying duplicates and determining genetic diversity of potato, sweetpotato, and ARTC collections; (3) developing and applying a cryopreservation method for potato; and (4) selecting a core collection for potato and sweetpotato.

Program 2 works closely with CIP's five other programs, whose breeding activities used genetic resources from Program 2 to develop advanced clones. Program 2 was also an active partner in the CGIAR's Systemwide Genetic Resources Program and in global approaches. It has contributed to an international effort to develop plans that will integrate *in situ* and *ex situ* conservation of plant genetic resources, in accordance with the Convention on Biological Diversity.

The future emphasis of Program 2 will be on determining the true biodiversity of CIP's mandate crops and their wild relatives, by classical and modern methods, to more effectively and efficiently conserve the maximum diversity in each collection and in designated core subsets.

1 Program Leader, CIP, Lima, Peru.

Potato

CIP continued the process of selecting a core potato collection. The largest number of potato cultivars in the collection corresponds to the tetraploid *Solanum tuberosum* subsp. *andigena.* Therefore, a core subset comprising 534 of the most diverse *andigena* cultivars has been selected from 2,644 cultivars of this species in the collection. We selected cultivars in the core subset on the basis of their geographic origin, morphological characterization, and isozyme diversity for 9 loci.

The *S. phureja* collection at CIP contains 170 accessions collected from the warm Andean valleys on the eastern side of the Andes of Venezuela, Colombia, Ecuador, Peru, and Bolivia. We performed a genetic diversity analysis in this collection using the randomly amplified polymorphic DNA (RAPD) technique adapted for low cost and high throughputs.

We conducted cluster analysis on 131 genotypes at 93 RAPD marker loci, which led us to two conclusions: no geographic clustering exists and this material appears to be a single homogeneous population. In the process of selecting a core collection, we compared two sampling methods: a marker-assisted sampling that takes the marker-based clusters as "stratas" and systematically selects accessions from each stratum to maximize the genetic distances in the samples, and the random sampling. Our analysis showed that marker-assisted sampling gave higher molecular variance values (i.e., genetic diversity) than the random sampling. We found that as few as 16 genotypes could constitute the *S. phureja* core collection.

CIP has also increased the in vitro potato collection with the addition of 1,605 clones from breeding programs at CIP. These clones include ones with resistance to late blight, viruses, nematodes, insects, or bacterial wilt. In addition, we have precleaned 1,588 Andean potato cultivars using in vitro thermotherapy followed by meristem culture. Serological testing confirmed that the cultivars are free of the six most important potato viruses.

At CIP we preserve shoot tips in liquid N at -196°C using a cryopreservation by vitrification method developed at Cornell University, USA. Since adopting this method, CIP has put 183 potato accessions in liquid N, with a high percentage of recovery (70%). For recalcitrant accessions that do not respond to this method, we modified the protocol and have obtained 75% recovery after conservation. Currently, 143 accessions are being maintained by cryopreservation.

We have continued to emphasize seed increase of the wild potato collection. The seed lots of many accessions are more than 25 years old; either few seeds are in stock or their viability is low. About 300 accessions have been rejuvenated at three sites in Peru (Huancayo, Cusco, and Cajamarca) by sib crosses with manual pollination. About 63% of the collection has fresh seeds.

CIP has moved rapidly to meet the goals of the Systemwide Information Network for Genetic Resources (SINGER). In April 1996, CIP became the first center to replicate its data at the SINGER Network Operations Center at CGNET in Palo Alto, California, USA. In May 1996, CIP staff helped conduct a workshop in Nairobi, Kenya, to train staff from other centers in new information systems technology for the SINGER computer systems. Participating centers were ICARDA, ICRAF, IITA, INIBAP, ILRI, and WARDA.

CIP's accession, cooperator, transfer, and characterization data for about 13,000 accessions of potato, sweetpotato, and other Andean root and tuber crops are now on-line for access by the world's scientific community on the Internet.

Sweetpotato

Polymerase chain reaction-based fingerprinting is routinely used for identifying duplicates to reduce redundancy in our sweetpotato (*Ipomoea batatas*) germplasm. This is the first step in constructing a sweetpotato core collection. Duplicate identification within Peruvian sweetpotato accessions has so far reduced the number of clones maintained in the field gene bank from 1,939 to 909.

We compared the methods of duplicate identification based on morphological characterization and DNA fingerprinting. Results so far show that when the duplicate groups comprise morphologically identical accessions, no differences are found in their DNA fingerprints.

The second step for core collection construction is to assess genetic diversity. A set of sweetpotato cultivars from Papua New Guinea, considered to be a secondary center of sweetpotato diversity, was compared with a set of sweetpotatoes from South America. Based on the DNA fingerprint information, we calculated the genetic distance between the two groups of cultivars. This study suggested that the PNG cultivars can be distinguished from the South American cultivars. The average genetic distance between South American cultivars is significantly greater than that in Papua New Guinea. This could indicate that the Asian cultivars are a subset sample of South American cultivars. These studies are continuing using larger samples of sweetpotatoes from Asia and South America.

CIP has increased the sweetpotato pathogen-tested list with 20 other cultivars cleaned of viruses during 1995 and 1996. In addition, a new conservation medium that extends the period between subcultures to 1 year in the in vitro sweetpotato collection has been tested in 500 different cultivars. Survivability was 100% in the new medium.

From 359 sweetpotato cultivars in the pathogen-tested list, 60 have been selected as early maturing. A 7x7 lattice experiment with 48 cultivars, using cv. Jewel as a control, showed 21 cultivars with yields between 19 and 30 t/ha 90 d after planting (DAP). Jewel produced 17 t/ha. Twenty-nine cultivars had yields ranging from 33 to 53 t/ha 120 DAP. Jewel yielded 33 t/ha.

CIP has improved techniques to increase the seed stocks of wild *Ipomoea* species and increased seed set considerably. The Center has produced more than 500,000 seeds from 90 accessions of 7 wild species related to the sweetpotato, and almost 600,000 seeds from 122 accessions of 32 other *Ipomoea* species. During the process of seed increase of *Ipomoea* wild species classified outside Series Batatas, we found self-pollination in 22 species.

Germplasm enhancement through conventional breeding is an important activity. Wide genetic diversity collected at CIP is being assembled through this breeding scheme. First, we randomly mated a large number of clones in nurseries. Recurrent selection to combine high dry matter content with other desirable traits has been practiced for three generations. After progeny testing, the promising progenitors with diverse genetic background will be identified and made available to NARS and regional programs. This is an efficient way to speed up germplasm diffusion.

Andean Root and Tuber Crops

CIP is maintaining a collection of 1,266 accessions of Andean root and tuber crops (ARTC) (oca, 482; ulluco, 446; mashua, 92; arracacha, 91; achira, 65; yacón, 44; maca, 33; mauka, 5; *Pachyrhizus*, 8; and 90 of their wild allies) to protect them from genetic erosion. So far, of 506 accessions we have identified 146 morphotypes of oca, 92 of ulluco, 51 of mashua, and 31 of arracacha.

Additional investigations on the same arracacha material through RAPD resulted in the identification of 32 arracacha genotypes, suggesting an almost perfect congruence between morphological and molecular characterization. Thus, our results on arracacha indicate that 51% of the Peruvian arracachas maintained by CIP are probably duplicates, and should thus undergo conservation by means of seeds.

The *ex situ* conservation of ARTC is complemented by activities to study the *in situ* management of these crops in 21 microcenters of diversity (14 in Peru and 7 in Bolivia). Factors that contribute to the increase or loss of genetic diversity of these crops are being studied as well as the main constraints to expanding use of these crops.

Descriptor lists for oca, ulluco, and arracacha are in the final stage of development in close cooperation with Andean NARS. They will be published in 1998. Descriptors for mashua, yacón, and achira are also being tested. Andean germplasm banks maintain about 9,800 ARTC accessions. The development of descriptor lists for ARTC will help to identify duplicates and optimize their *ex situ* conservation.

Advances in Potato Cryopreservation by Vitrification

A.M. Golmirzaie and A. Panta[1]

One way to safeguard plant genetic resources against erosion is to use cryopreservation —storing plant material at ultralow temperature (-196°C) in liquid nitrogen (N).

Cryopreservation has been applied to more than 80 plant species and is considered a safe and less labor-consuming conservation method than in vitro maintenance. Stored material can be conserved indefinitely without genetic erosion. Because all chemical reactions cease in liquid N, no cell division occurs and cell degeneration or genetic changes cannot take place.

Potato cryopreservation work began in 1977. It has been carried out with excised meristems, pollen, shoot tips, cell cultures, and protoplast-derived cell colonies. Entire plants capable of undergoing normal tuberization have been obtained from cultures cryopreserved for 4 yr. These findings justify the application of cryopreservation to the long-term conservation of potato.

The in vitro Potato Base Collection (PBC) held at CIP contains more than 6,000 accessions and is increasing rapidly with new, improved material developed by geneticists. To reduce the cost and labor involved in maintenance, in 1995, in a United Nations Development Program collaborative project with Cornell University, CIP started testing cryopreservation by vitrification, a method developed by P. Steponkus. With this method, shoot tips (the meristem dome with several leaf primordia) are dehydrated by exposure to concentrated solutions of sugars and cryoprotectants, and are then frozen rapidly, thus preventing intracellular ice formation.

1 CIP, Lima, Peru.

The use of shoot tips has an advantage over other tissues because they can be regenerated into plants that are more faithfully identical to mother plants.

This article describes attempts to cryopreserve 183 potato genotypes and to assess the feasibility of this approach for storing the PBC.

The Cryopreservation Technique

In vitro growth of mother plants

The following genotypes to be cryopreserved were taken from the PBC: *Solanum tuberosum* subsp. *andigena* (61), *S. chaucha* (1), *S. phureja* (38), *S. stenotomum* (57), *S. goniocalyx* (9), natural hybrids of *S. goniocalyx* x *S. stenotomum* (10), and *S. stenotomum* x *S. goniocalyx* (4), plus 3 other accessions whose species determination is under way. This material is now being conserved in in vitro long-term storage by slow growth at low temperature in a medium containing sorbitol as an osmotic growth retardant. Plants from long-term storage were micropropagated by single-node stem segments in tubes containing an MSA medium (Murashige-Skoog salts, 0.4 mg/L thiamin, 2 mg/L glycine, 0.5 mg/L nicotinic acid, 0.5 mg/L pyridoxine, 0.1 mg/L gibberellic acid, 2.5% sucrose, and 4 g/L SIGMA phytagel).

Improving in vitro growth of mother plants

We did this work with recalcitrant accessions—those that after being frozen two or three times did not survive. Plants coming from long-term storage were subcultured two or three times in magenta jars containing semisolid MSA propagation media and covered with a transparent polypropylene film with a filter (SIGMA, C6920) to increase exchange of air. The phytagel, the gelling agent of the MSA medium, was replaced by agar. The medium was poured into magenta jars in two layers: first a semisolid MSA medium (15 ml) containing agar, and then liquid MSA medium (10 ml). Plants were propagated by placing 9 single nodes on the medium in each jar. Several subcultures were required to increase the vigor of weak genotypes.

Cryopreservation by vitrification

The vitrification method, based on Steponkus's method, involves removing axillary shoot tips (1.5 mm long) from plantlets grown in vitro for 30-45 d. The shoot tips consist of 4-5 leaf primordia and the apical dome.

They are first precultured in a modified Murashige-Skoog medium (supplemented with 0.04 mg/L kinetin, 0.5 mg/L indoleacetic acid, and 0.2 mg/L gibberellic acid) containing 0.09 M sucrose for 24 h under proper incubation conditions for micropropagation. Next they are incubated in the same medium containing 0.06 M sucrose for 5 h at room temperature. The shoot tips are dehydrated by placing them in a vitrification solution containing ethylene glycol:sorbitol:bovine serum albumin (50:15:6 wt%) for 50 min at room temperature.

The shoot tips are then transferred to 0.25-ml propylene straws with 150 µl of vitrification solution, and the straws are rapidly quenched in liquid N. Following storage in liquid N, the shoot tips are thawed, expelled from the straws into a hypertonic (1.5 osmolal) sorbitol solution at room temperature, and incubated for 30 min.

The shoot tips are then plated on a semisolid potato meristem medium containing Murashige-Skoog salts supplemented with 0.04 mg/L kinetin, 0.1 mg/L gibberellic acid, and 25 g/L sucrose, and maintained under normal incubation conditions for micropropagation. After 4-6 wk, survival was evaluated by counting plantlets growing from shoot tips.

With this procedure, all 183 selected genotypes were frozen and stored in liquid N. For each genotype 120 shoot tips were stored (Figure 1), and for dehydration control 20 shoot tips were loaded into straws (2 repetitions of 10 samples), where they continued to thaw without freezing.

One day after freezing, 2 straws containing 10 shoot tips each were removed from the liquid N and the shoot tips were thawed. Survival was evaluated 6 wk after thawing (Figure 2). For accessions that did not respond even when evaluated three times, the stored shoot tips were discarded and the assay was repeated once or twice more, using dehydration times of 45, 55, and 60 min.

Post-thaw recovery

Survival of 80 genotypes was evaluated by thawing 2 repetitions of 10 shoot tips of each genotype 3 mo after freezing. Shoot tips were thawed at room temperature and transferred to a recovery medium. After 6 wk, survival

Figure 1. Tank used at CIP for storage of cryopreserved potatoes. Tank capacity is 4,800 cryovials of 2 ml.

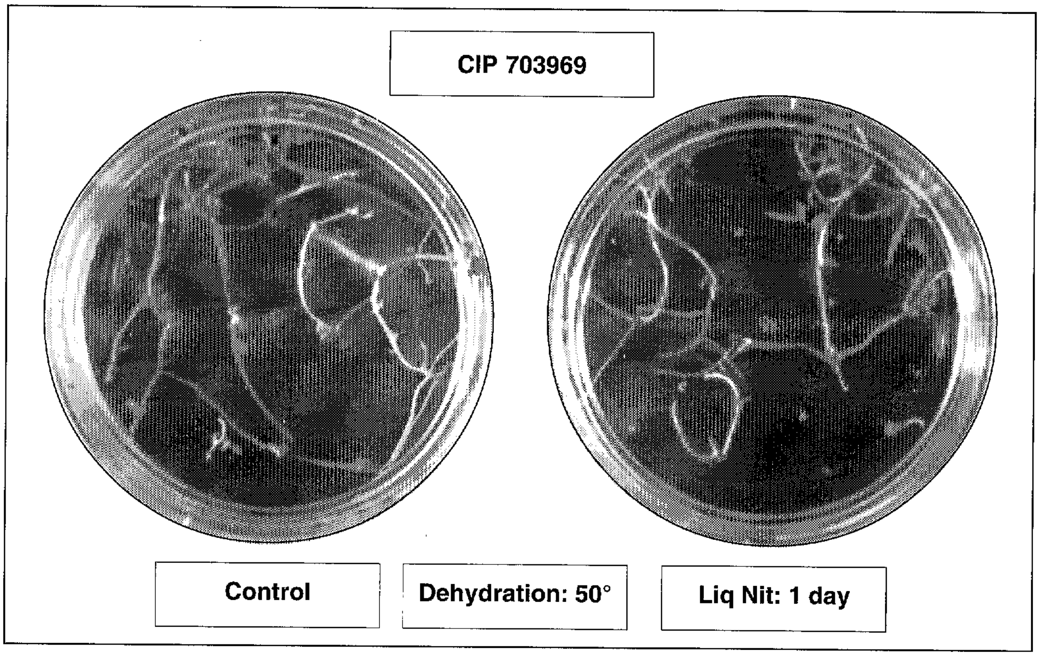


Figure 2. Plantlets of S. *tuberosum* subsp. *andigena* genotype after 6 wk of plating. Left: plate showing 70% survival from dehydrated shoot tips and shoot tips not frozen. Right: plate showing 60% survival after post-thaw of shoot tips.

was evaluated by counting the number of regrowth plantlets. The plantlets were then transferred to an MSA medium.

Cryopreserving apical shoot tips from vigorous in vitro plants

Seven genotypes chosen randomly were micropropagated by several subcultures of apical tips in magenta jars. The growth time between subcultures was 3 wk. After 7 subcultures, 140 apical shoot tips from vigorous plants of each genotype were isolated. They were processed by the vitrification method using 50 min of dehydration.

Results

In vitro growth of mother plants

Some genotypes that were propagated in tubes containing a semisolid MSA medium showed symptoms of weakness, especially those that showed 0-20% survival after vitrification. They grew slowly, plantlets were thin, and leaves were small. Some showed a loss of apical dominance after 3 wk of propagation. The lack of vigor of these plants could be due to the sorbitol content in the medium used for long-term storage, which could have affected the plants' hormone balance. This assumption needs more research to be confirmed. After culturing these genotypes in magenta jars, using at least 3 subcultures, plants were more vigorous, stems were stronger, leaves were bigger, and the lack of apical dominance was disappearing.

Post-thaw recovery

With thawing after 1 d of freezing, 69% of the genotypes tested were successfully recovered. Different survival levels were observed, which could be related to the vigor of mother plants or genotype dependence (Figure 3). With shoot tips isolated from more vigorous mother plants and with minor changes in dehydration time, the percentage of surviving genotypes increased to 75%. This increase resulted from changes in dehydration times (45, 55, and 60 min) for the recalcitrant accessions.

We obtained 10 more surviving accessions by making these modifications. Table 1 shows

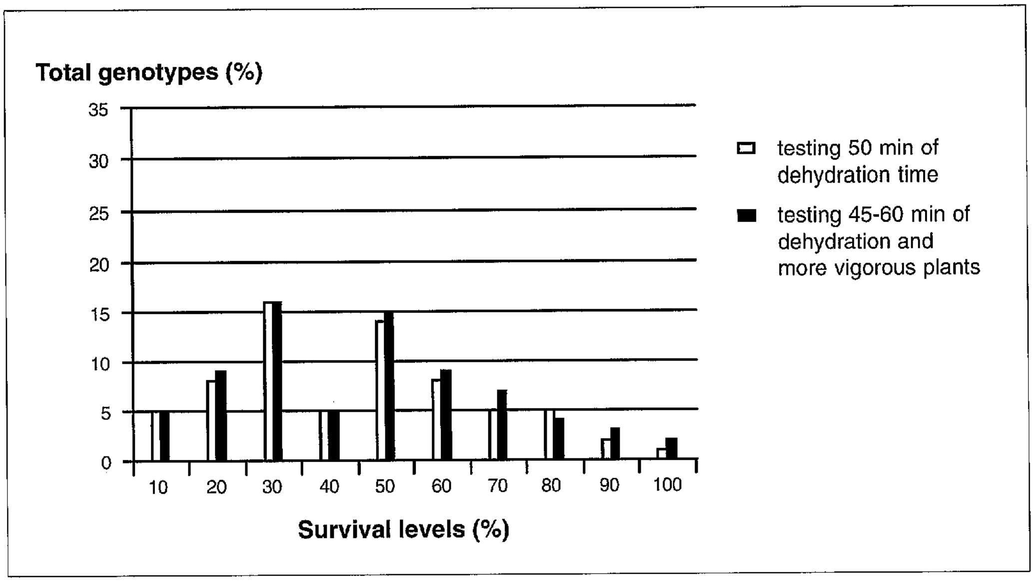


Figure 3. Survival percentage of potato shoot tips of 183 genotypes comparing the vitrification method using 50 min of dehydration vs. testing other periods of dehydration (45, 55, and 60 min) and more vigorous plants, CIP, 1995-96.

survival expressed by species or genotype group. The percentage of surviving genotypes varies from 72 to 80. The lowest average survival rate (29%) was found in *S. tuberosum* subsp. *andigena* and *S. goniocalyx* genotypes. The highest (47%) belonged to the natural hybrid *S. goniocalyx* x *S. stenotomum.* More research is needed to confirm whether this

Table 1. Survival percentage of 183 genotypes and recovery rate of each species or group after cryopreservation by the vitrification method, CIP, 1995-96.

Genotype	Ploidy	Genotypes evaluated (no.)	Surviving genotypes (%)	Average survival rate (%)
S. tuberosum subsp. *andigena*	4x	61	74	29
S. phureja	2x	38	74	41
S. stenotomum	2x	57	72	33
S. goniocalyx	2x	9	78	29
S. chaucha	3x	1	—[a]	30
Natural hybrids				
S. goniocalyx x *S. stenotomum*	2x	10	80	47
S. stenotomum x *S. goniocalyx*	2x	4	75	45
Undetermined species		3	—[a]	50
Total		183	75	

a. Because of the low number of genotypes evaluated, survival percentage was not considered.

Table 2. Survival percentage of seven potato genotypes after cryopreservation by the vitrification method, comparing the use of axillary shoot tips with apical shoot tips from vigorous plants, CIP, 1995-96.

Species	Genotype (CIP number)	Survival percentage using: Axillary shoot tips [a]	Apical shoot tips from vigorous plant [b]
S. tuberosum subsp. *andigena*	703859	50	88
S. tuberosum subsp. *andigena*	700874	10	45
S. phureja	703579	30	70
S. phureja	703596	80	90
S. phureja	703600	0	55
S. stenotomum	703446	0	65
S. stenotomum	702586	50	55
Average		33	67

a. Survival evaluated by number of regrowth shoot tips from 2 repetitions of 10 frozen shoot tips.

b. Survival evaluated by number of regrowth shoot tips from 4 repetitions of 10 frozen shoot tips.

variation is due to differences between species.

We evaluated 80 genotypes for survival 3 mo after freezing. In the first evaluation (1 d after freezing), the average survival was 46%; after 3 mo it was 40%. This difference was not statistically significant. Theoretically, the survival rate should not change even if the plant material were stored for many years. To confirm this hypothesis, we plan a third evaluation after 1 year of freezing.

Cryopreserving apical shoot tips from vigorous in vitro plants

After we froze about 100 accessions, it became evident that plant vigor is a bottleneck in the cryopreservation process, and that the survival rate obtained by using axillary shoot tips varies by genotype. With apical shoot tips from vigorous plants, seven genotypes tested showed higher survival percentages (Table 2). The survival of two recalcitrant genotypes was over 50%, and the average survival rate increased from 31% to 67%. We planted five plants recovered from each genotype to evaluate phenotypic characters under greenhouse conditions.

Conclusions

The success obtained in this work shows the feasibility of applying cryopreservation techniques to the long-term storage of a wide range of potato genotypes. In this work, survival was evaluated strictly by the number of regrowth shoot tips; in other works, recovery has been evaluated by including leaf expansion without regrowth.

We also demonstrated that survival rate can be dramatically increased by improving the pregrowth conditions of plant material and by using apical shoot tips. Studies on the influence of different phenotypic and physiological characters of plants on the freezing process would help enhance their viability.

CIP is now cryopreserving 145 potato accessions and trying to recover 100% of the genotypes to be cryopreserved. To reach this goal, we are improving the vitrification method and testing other methods, such as dehydration and encapsulation, and droplet methods that have been tested by other researchers with a wide range of crops.

We expect to be able to safely store the Potato Base Collection (approx. 4,000 accessions) using cryopreservation. Since this germplasm will eventually form a foundation for potato breeding work for future generations, we plan to emphasize genetic stability studies.

Selected Reading

Bajaj, Y.P.S. 1987. Cryopreservation of potato germplasm. In: Bajaj, Y.P.S. (ed.). Biotechnology in agriculture and forestry. Vol.3: Potato. Springler-Verlag, Berlin. p. 472-486.

Benson, E.E., M. Wilkinson, A. Todd, U. Ekuere, and J. Lyon. 1996. Developmental competence and ploidy stability in plants regenerated from cryopreserved potato shoot-tips. Cryo-Letters 17:119-128.

Steponkus, P.L., R. Langis, and S. Fujikawa. 1992. Cryopreservation of plant tissues by vitrification. Adv. Low-Temp. Biol. 1:1-16.

Genetic Diversity Analysis in a Cultivated Andean Potato, *S. phureja* Juz. et Buk.

M. Ghislain, D. Zhang, D. Fajardo, Z. Huamán, and R. Hijmans[1]

The gene bank held at CIP maintains 3,527 accessions of cultivated potatoes (*Solanum* spp.) collected from throughout the Andes. This potato collection provides a long-term safeguard for the otherwise rapidly depleting genetic diversity in this crop and related species. The large size of this collection, together with limited funding, restricted the characterization and evaluation of these materials and hindered their use for breeding.

An increasingly popular solution is to construct a small core collection from a large collection. An ideal core collection should represent the greatest part of genetic diversity in the large collection. Information provided by molecular genetic variation is useful in creating such smaller, but genetically representative, core collections. First, molecular marker data can be used to reduce the redundancy in the collection. Second, the large collection can be rationally stratified into small groups based on molecular variation, so that samples can be taken from each stratified group to form a core. Third, the marker data can be used to assess genetic diversity in a collection composed of preexisting groups formed on the basis of other criteria (e.g., ecogeographic data).

Solanum phureja is a diploid cultivated potato. It is important in potato breeding because many accessions of this species have valuable resistance to several important biotic and abiotic stresses (e.g., late blight (LB), bacterial wilt (BW), and nematodes) and produce tubers that have good culinary properties. The precise site of origin of *S. phureja* is unknown. Today, the species is distributed in a long, narrow strip along the eastern slope of the Andes from Colombia to Bolivia (Figure 1). The *S. phureja* collection maintained at CIP contains 170 accessions collected from the warm Andean valleys on the eastern side of the Andes of Venezuela, Colombia, Ecuador, Peru, and Bolivia at an altitude of 2,000-3,700 m. It has been assembled through several collecting expeditions and germplasm donations. Within this collection are 25 accessions that were labeled as *S. phureja* but whose morphological characters suggest that they are closer to *S. tuberosum* subsp. *andigena*.

Because of the small size of the collection and its importance in potato breeding, we chose *S. phureja* as a model collection to test how molecular marker data can provide additional information to improve germplasm management. Here we present our work of genetic diversity analysis in *S. phureja* using the randomly amplified polymorphic deoxyribonucleic acid (DNA) (RAPD) technique adapted for low cost and high amount of samples processed. The results not only led to an increase in our understanding of the genetic diversity in *S. phureja*, but are relevant to the construction of core collections in other cultivated potato species as well.

The work reported here is the first report on the use of molecular markers to fingerprint an entire cultivated potato collection. We show an assessment of the genetic diversity revealed by molecular data, and identify a genetically representative, marker-assisted sample of this potato collection.

Materials and Methods

We used a total of 163 accessions, presumably belonging to *S. phureja*, for this research. We took leaf samples from in vitro-grown plants and from greenhouse collections. We

1 CIP, Lima, Peru.

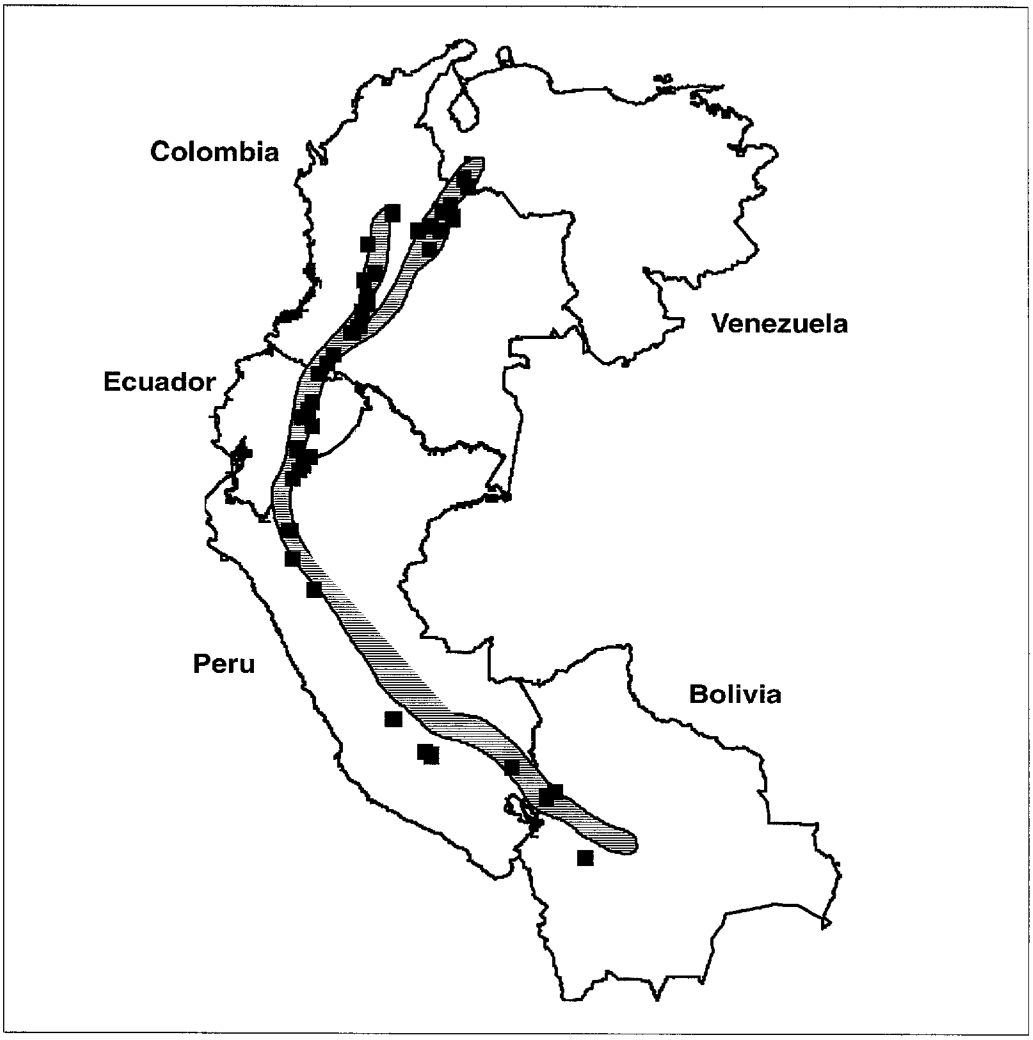


Figure 1. Geographic distribution of 129 *Solanum phureja* accessions of the germplasm collection held at CIP. Squares indicate collection sites; the shaded area, the geographic area of *S. phureja*.

used a miniprep DNA extraction. DNA quantity was standardized by agarose gel electrophoresis using highly purified DNA. We separated amplification products on agarose gels and recorded them with a video image analyzer. Genotypes were scored for the presence (1) or absence (0) of each band. From these data, we calculated a matrix of pairwise genetic distances (Jaccard's distance) using Jaccard's similarity coefficient. We also used multidimensional scaling (MDS) to present the relationships between accessions. The statistical analysis used in the numerical taxonomy analysis was done using the NTSYS-PC 1.80 software.

RAPD amplifications were performed following a cost-effective protocol that we developed for genotyping large germplasm collections at reasonable costs. The overall cost of RAPD fingerprinting has been reduced by several measures such as reducing sample volumes, recycling agarose gels, re-using microplates, digitizing gel images, etc. The running cost is about US$0.17/reaction following the protocol of CIP's molecular biology laboratory. DNA extraction and quantification are still by far the most expensive cost item (US$1.47/sample). These estimates do not include staff salaries, equipment amortization, and overhead.

Results and Discussion

RAPD primer selection and marker characterization

We have screened a total of 106 primers and selected the 12 most informative ones (Table 1), which generated 93 RAPD markers with a broad range of allele frequencies. Three criteria were considered for primer selection: (1) reproducibility, (2) number of polymorphic loci per assay, and (3) levels of polymorphism detected in a specific population. Reproducibility is an intrinsic property of a particular primer sequence, and hence can be addressed only experimentally. The other two aspects can be quantified, and we propose a single parameter to measure the informativeness of a particular primer for genetic diversity studies in an outcrossing species.

Polymorphic bands. Each RAPD primer produces different numbers of polymorphic bands. We selected the RAPD primers with the highest number of polymorphic bands among the 106 screened. Each produced at least six polymorphic bands.

RAPD marker index. To characterize the capacity of each primer to reveal or detect polymorphic loci in our germplasm, we use the polymorphic index content (PIC) = $1\text{-}SP_i^2$, where P_i is the allele frequency of the i^{th} allele.

Each RAPD marker locus is expressed as two alleles: presence and absence of the band. PIC values ranged evenly from 0.01 to 0.50. The higher the PIC value, the more informative is the RAPD marker. This parameter is useful to estimate the genetic distances of two accessions in a large population or germplasm collection. The PIC values for the RAPD markers generated by the same primer were cumulated and have been named RAPD marker index (Table 1). This index reveals the information content of the RAPD primer per assay. Therefore, primers OPR9, OPR13, OPZ4, and OPD20 (the four highest index values) will be used in subsequent fingerprint research.

Genetic diversity assessment of the *S. phureja* collection

Cluster analysis grouped the 163 accessions into several large clusters at a high similarity level. Of these, 25 *S. phureja* accessions fall mostly in one distinct group. This result supported the morphological observation that these 25 accessions are genetically different from the rest of the *S. phureja* accessions. Re-

Table 1. Selected RAPD primers for the *Solanum phureja* germplasm survey.

Primers	Sequence	Polymorphic bands	RAPD marker index
OPD20	ACCCGGTCAC	8	2.06
OPM4	GGCGGTTGTC	6	1.38
OPM5	GGGAACGTGT	6	1.47
OPR3	ACACAGAGGG	6	0.92
OPR7	ACTGGCCTGA	8	1.78
OPR9	TGACGACGAG	13	3.21
OPR12	ACAGGTGCGT	8	1.88
OPR13	GGACGACAAG	9	2.64
OPZ4	AGGCTGTGCT	8	2.38
OPZ6	GTCTACGGCA	9	1.56
OPZ11	CTCAGTCGCA	6	1.92
OPZ13	GACTAAGCCC	6	1.48

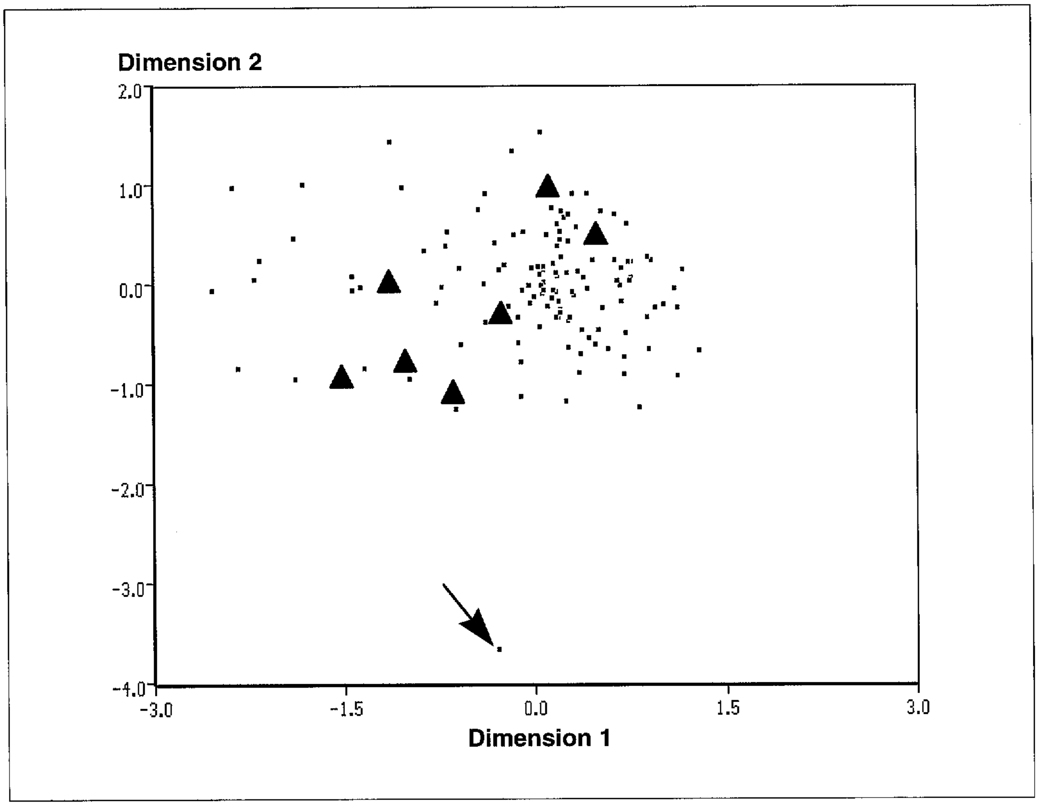


Figure 2. Multidimensional scaling of the 131 *Solanum phureja* accessions. Solid triangles indicate doubtful species assignment.

examination using morphological and passport data led to the conclusion that they were actually from other *Solanum* species, mainly from *S. tuberosum* subsp. *andigena.*

The cluster analysis was redone on the remaining 131 genotypes using Jaccard's similarity coefficient. The coefficient ranged between 0.53 and 1 and was used to develop a phenogram. The goodness of fit test for the cluster analysis resulted in a low correlation (r=0.76), suggesting that the cluster is poorly defined. In general, there is no correlation between the marker-based grouping pattern and the geographic origin.

Accessions collected from Colombia scattered across almost every cluster. So did the accessions collected from Peru and Ecuador. This result indicates that it is not very useful to subgroup these 131 *S. phureja* accessions based on their geographic origin.

The *S. phureja* accessions make up a relatively homogeneous group. The multidimensional scaling (MDS) analysis (Figure 2) displays a rather homogeneous distribution with little indication of subgrouping. We labeled the accessions in the MDS plot according to their geographic origin at the level of departments (provinces) and found little accord between geographic origin and genetic relationship. This further supports the conclusion that *S. phureja* is a single, homogeneous cultivated species that is different from other wild relatives of potato. It has a long history of domestication in the Andes, which may have kept this native crop relatively isolated.

In the collection of 131 genotypes, seven accessions were classified doubtfully as *S. phureja* based on morphology. The MDS plot shows that at least three of the seven were distributed at the outer layers (Figure 2). Careful taxonomic examination is recommended for these three clones as well as the one marked with an arrow in Figure 2 to determine their species identity.

Morphological data available for 106 accessions did not allow us to clearly separate 5 genetic groups of *S. phureja* accessions, which we therefore considered as suspected duplicates. RAPD data resolved genetic differences between these clones in all cases. A separate analysis confirmed these results (Figure 3). However, out of the 131 genotypes fingerprinted, two were found to be indistinguishable for 93 RAPD markers. Hence, the number of suspected duplicates went down from 5 groups of 12 genotypes to only 1 group of 2 genotypes.

Molecular data and core collection

Based on molecular marker data, we used the 131 accessions of *S. phureja* as a model to compare sampling methods for a core collection. Two sampling methods were compared: (1) random sampling, and (2) marker-assisted sampling, which takes the marker-based clusters as stratas and systematically selects accessions from each stratum to maximize the genetic distances in the samples.

We divided the phenogram at 0.65 and 0.70 values of Jaccard's similarity coefficient, which resulted in 16 and 35 clusters from which one genotype was chosen at random. The diversity level in the selected sample was measured by RAPD marker variance

$$V_m = S\,(npq)/(n-1)$$

where n = number of individuals, and p and q are the frequencies of the presence or absence of a RAPD marker (Figure 4).

The analysis shows that in both cases (sample size of 16 and 35), marker-assisted sampling has higher molecular variance values (i.e., genetic diversity) than random sampling (Figure 4). The value of V_m increased by 17% when 16 accessions were sampled, and by 15% when 35 accessions were sampled. This result demonstrated the advantage of using marker data to construct a core collection when the collection can be assimilated into a single population.

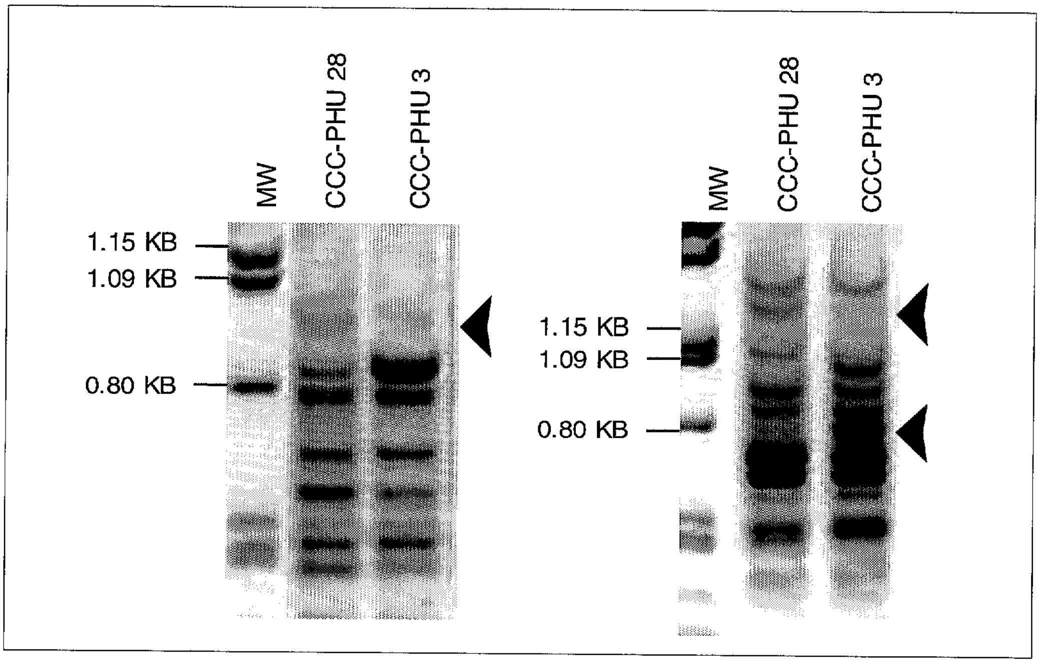


Figure 3. Morphological duplicates of the *Solanum phureja* collection resolved by molecular assays: polymerase chain reaction amplification with primer OPR3 on the left and OPZ4 on the right. Arrows indicate differential markers.

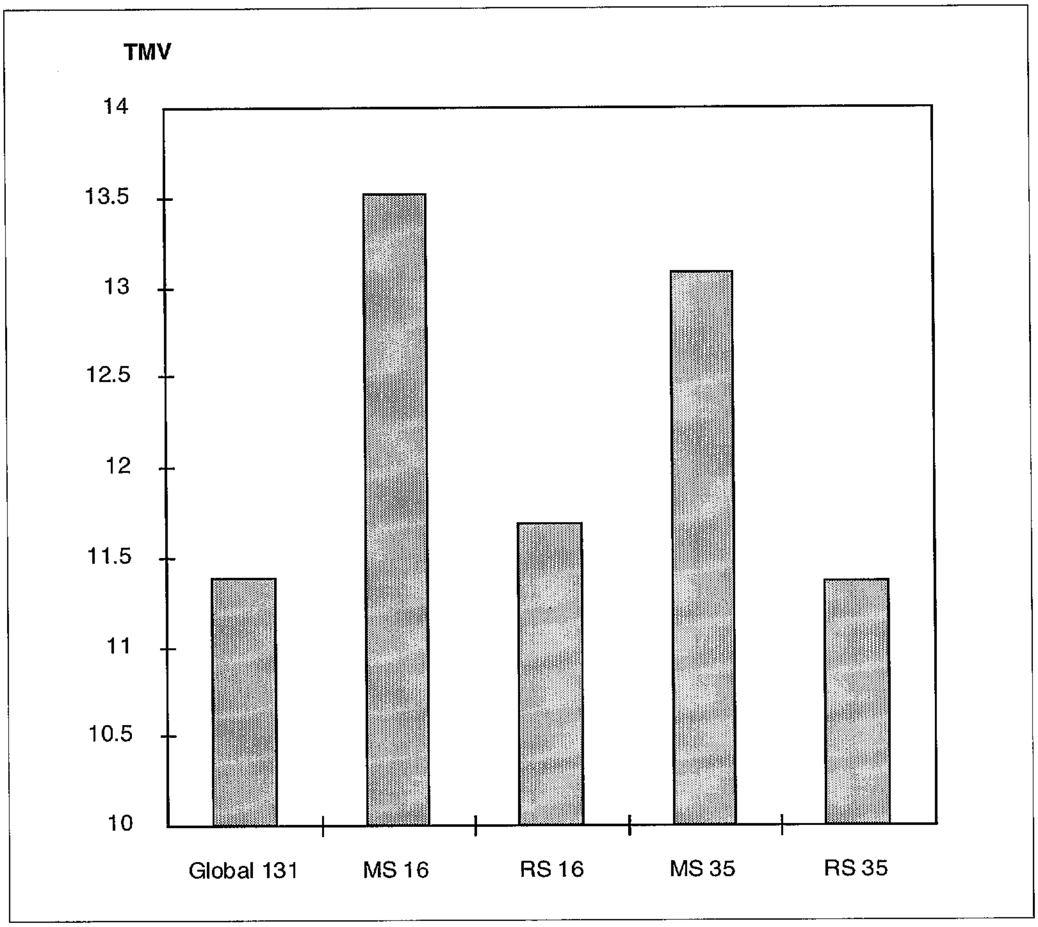


Figure 4. Total marker variance (TMV) for random (RS) vs. marker-assisted (MS) sampling of the *Solanum phureja* collection using 16, 35, and 131 genotypes.

Conclusions

To form a core collection, the large potato collection held at CIP should first be sampled and stratified based on molecular marker data. Then a sample should be taken from each stratum to represent each marker-differentiated group.

Also, the number of core accessions should be decided based on the retention of the maximum number of alleles. This procedure will lead to a core subset covering the maximum genetic diversity in the large collection. Based on this subset, curators and breeders could add certain genotypes known to possess important agronomic traits.

The designated core collection will then be systematically evaluated for major agronomic traits so that the gene variation in the collection will be better understood. These core accessions will then be cleaned and made available to germplasm users. This core collection approach would allow us to better use our limited resources for rationalized management of the potato germplasm collection.

Selected Reading

Hawkes, J.G. 1992. Biosystematics of the potato. In: The potato crop. P. Harris (ed.). Chapman & Hall, London. p.13-64.

Nienhuis, J., J. Tivang, and P. Skroch. 1994. Analysis of genetic relationships among genotypes based on molecular marker data. In: Proceedings of the symposium Analysis of Molecular Marker Data. p. 8-15.

Ochoa, C.M. 1990. *Solanum phureja*. In: The potatoes of South America: Bolivia. Cambridge University Press. p. 315-334.

DNA Markers for the Introgression of Late Blight Resistance in Potato

M. Ghislain, B. Trognitz, C. Herrera, A. Hurtado, and L. Portal[1]

Resistance to Late Blight in Potato

A major challenge in breeding for resistance to late blight caused by *Phytophthora infestans* in potato is to fully exploit tuber-bearing *Solanum* germplasm as a source for resistance to the disease. Indeed, germplasm used by breeders has a narrow base compared to the potential available in *Solanum* germplasm.

Two types of resistance to late blight (LB) exist in this germplasm: vertical (governed by a specific gene-for-gene interaction) and horizontal (governed by several genes whose interactions are still largely unknown).

CIP´s breeding strategy is to use horizontal resistance from novel sources to make resistance in potato to LB less dependent on pathogen races and hence more durable. Quantitative inheritance and the high load of unfavorable genes in wild and native potatoes, however, have impeded the broad use of this type of resistance to develop new potato cultivars.

Unraveling the Genetics of Horizontal Resistance to Late Blight

Researchers explained some of the genetics of horizontal resistance to LB in the early 1990s. Potato scientists have characterized horizontal resistance in several *Solanum* species and in interspecific hybrid progenies. A molecular genetics study has even been developed with a preliminary genetic map of quantitative resistance to LB from an intraspecific *S. tuberosum* cross. This type of resistance is thought to be the result of several independent mechanisms that are constitutively expressed and induced upon pathogen infection.

At CIP, we have been applying molecular techniques to unravel the genetics of horizontal resistance to LB in tuber-bearing *Solanum* species, especially *S. phureja* and *S. verrucosum*. Developing detailed genetic linkage maps using molecular markers will help us explain the genetic control and architecture of this quantitative trait. This knowledge and molecular tools will improve the efficiency of the introgression of valuable resistance and defense genes from *Solanum* germplasm into the cultivated potato.

Materials and Methods

We have developed populations of diploid potatoes that segregate for LB resistance from three accessions of a native cultivated potato, *S. phureja*. This diploid species was selected for its high levels of horizontal resistance to LB (leaf resistance), favorable tuber characteristics and culinary quality, and crossability with dihaploid potatoes. We are analyzing the three populations (VP, PD, and PP) at CIP for phenotypic segregation of resistance using a complex race of *P. infestans* (Table 1).

We have worked in close collaboration with scientists Rhonda Meyer and Robbie Waugh from the Scottish Crop Research Institute, and Susana Marcucci and Esteban Hopp of the Instituto Nacional de Tecnología Agropecuaria, Centro de Investigación en Ciencias Veterinarias, in Argentina. Molecular markers have been developed to analyze hybrid populations, parental heterozygosity, and simultaneous segregation with phenotypic scores. These tools are polymerase chain reaction (PCR)-based deoxyribonucleic

1 CIP, Lima, Peru.

Table 1. *Solanum* germplasm used to map horizontal resistance to late blight.

Population code	Individuals (no.)	Female parent		Male parent	
		Identification	Resistance	Identification	Resistance
VP	102	*S. verrucosum* PI-116163	Vertical and horizontal	*S. phureja* CCC81 cv. Yema de Huevo	Horizontal
PD	246	*S. phureja* CHS-625	Horizontal	*S. tuberosum* dihaploid PS-3	Susceptible
PP	305	*S. phureja* PI-225678.52	Horizontal	*S. phureja* PI-320362.57	Susceptible

acid (DNA) markers—randomly amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), and microsatellites—and have been used on the first two populations only. The markers have proven the hybrid nature of the VP and PD populations, a prerequisite for a breeding strategy based on molecular genetics. The segregation of these markers in the progeny is indicative of the level of heterozygosity of the parents.

Results

Characterization of DNA markers

DNA markers were scored separately for each of the parents, leading to the definition of two parameters: heterozygosity index (*Hi*) and a marker value (*Mv*). The heterozygosity index of each parent is calculated here as the ratio between segregating bands and nonsegregating scorable bands that correspond to either one of the two parents in the progeny. The marker value is the average number of informative DNA markers (polymorphic and segregating) per assay. The analysis of more than 50 RAPD primers indicates by means of the *Hi* value that the dihaploid *S. tuberosum* clone is the most heterozygous of the four (Table 2). In contrast is the *S. verrucosum* parent, which barely shows any marker segregation.

The marker value helps us select an appropriate marker system for a particular cross and allows us to predict costs in terms of time and assays of building a genetic map. Again, the dihaploid (D) parent will on average produce 2.7 scorable marker loci per RAPD assay, whereas more than 20 are necessary for the *S. verrucosum* (V) parent. Therefore, the DNA marker analysis led us to conclude that the genetics of LB resistance in the VP population will be studied more efficiently with a subsequent backcross in which the female marker loci will segregate.

DNA markers in diploid hybrid potato populations

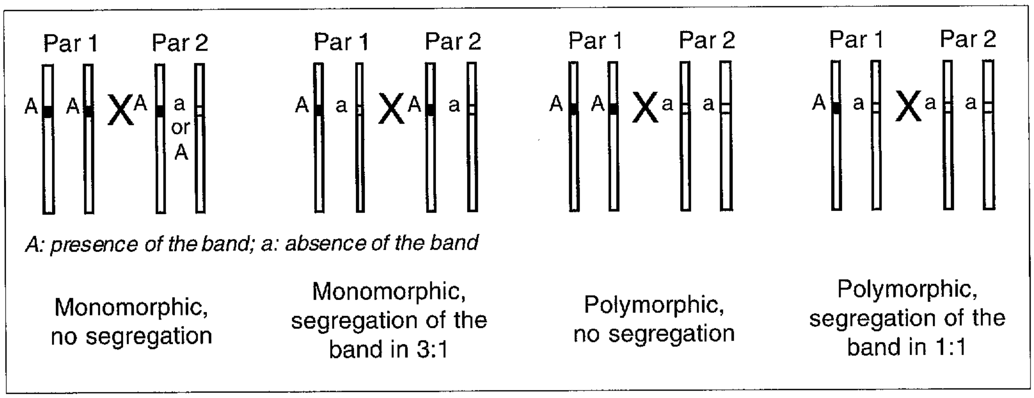
The segregation of DNA markers in hybrid populations has been analyzed separately for markers that derive from each parent following a backcross model. All DNA markers have been treated as dominant markers in which each segregating band in the hybrid population is expected to have a 1:1 segregation ratio for presence-absence. This model allows us to analyze the data with MapMaker v3.0 software and to develop two genetic linkage maps, one for each parent.

VP. In the VP (*S. verrucosum* x *S. phureja*) population of 102 individuals, we scored several RAPD and AFLP markers that derive from both parents (Table 3). Chi-square (χ^2) tests for goodness of fit to the monogenic ratio 1:1 revealed a high degree of distortion of segregation from the female parent of VP. Only eight markers (22% of the female parent markers) from the female parent showed unskewed Mendelian 1:1 segregation.

Of the 122 RAPD and AFLP markers scored in this population from the male parent, 84 (69%) did not deviate significantly from the expected monogenic ratio. Linkage analysis between the 84 unskewed markers deriving from the male parent led us to define five linkage groups (using the default values of MapMaker). The highly distorted segregation for markers deriving from the female parent prevents a genetic analysis of the resistance coming from the *S. verrucosum* parent. We plan to analyze this source of resistance in the offspring of the resistant hybrids.

PD. We also analyzed LB resistance genetically on the other diploid potato population, PD (*S. phureja* x dihaploid *S. tuberosum*). We are now building genetic maps for the parents using 164 RAPD and 151 AFLP markers, and 16 microsatellites (Table 3) on 94 PD hybrids. In contrast to the VP population, 81% of the female parent markers and 68% of the male parent markers show Mendelian 1:1 segregation in this interspecific hybrid progeny. Linkage analysis of the unskewed markers, 118 female and 127 male, led us to define 13 linkages for the female map and 16

Table 2. Characterization of diploid potato populations: segregation of dominant markers in hybrid progenies, heterozygosity index of parents, and marker value assessed by RAPD markers.



Parent	Primers	Total bands	Mono-morphic	Poly-morphic	Locus AA	Locus Aa	*Hi*[a]	*Mv*[a]
	(no.)		(no. of bands)		(no.)			
V PI-116163	58	301	113	188	181	7	0.037	0.121
P CCC81	58	353	113	240	130	110	0.458	1.897
P CHS-625	63	550	382	168	50	118	0.702	1.873
D PS-3	63	586	382	204	34	170	0.833	2.698

a. *Hi* = heterozygosity index, *Mv* = marker value.

Table 3. DNA markers scored in the offspring of diploid potato interspecific crosses and association with late blight resistance.

Population	Markers	Female parent			Male parent		
		Total markers	Unskewed markers[a]	Putative LB markers[b]	Total markers	Unskewed markers[a]	Putative LB markers[b]
VP	RAPD	7	4	—	94	65	2
	AFLP	30	4	1	28	19	4
PD	RAPD	57	50	6	107	76	7
	AFLP	82	62	3	69	45	1
	Micro-satellite	6	6	—	10	6	—

a. χ^2 test at $P<0.01$.

b. Student's t-test at $P<0.05$.

for the male map. As a result of this analysis and earlier phenotypic evaluations, this PD population displays the expected features of a genetic material adequate for mapping horizontal resistance to LB.

DNA markers for resistance to late blight

We applied single-marker analysis to detect linkages between genotypic classes (presence or absence of the band) and their respective phenotypic values (LB resistance vs. susceptibility) using a two-sample Student's t-test. This test detects whether the means of the phenotypic values for two genotypic classes differ significantly.

VP. We have identified 7 DNA markers out of a total of 92 unskewed markers in the VP population that are associated ($0.01<P<0.05$) with contrasting phenotypic classes (Table 3). The trait values are the means of 3-yr field evaluations with indigenous complex races. This weak association can be explained by the genotype x environment interaction and changes in race complexity from year to year. One marker is from the female parent, whereas the other six are from the male parent. Five of the six markers from the *S. phureja* parent fall into three of the five linkage groups by two-point analysis (Table 4).

PD. Applying the single-marker loci analysis for linkage with phenotypic classes on the PD population resulted in the identification of 17 DNA markers (Table 3). Nine markers from the female parent and eight from the male parent are associated ($0.001<P<0.05$) with significant effects on resistance to LB observed in a screenhouse assay. As expected for a polygenic trait, each of these DNA markers correlates with small differences in phenotypic values. Several markers fall into the same linkage group (Table 4).

We hope to confirm this preliminary identification of DNA markers associated with the segregation of quantitative resistance to LB by extending the analysis to the entire PD population of 254 individuals. Likewise, we will collect phenotypic data from field trials in 1997. We plan to finish constructing the genetic map simultaneously for both parents and carry out a quantitative trait loci (QTL) analysis by interval mapping methods, using

Table 4. Linkage analysis of DNA markers associated with significant differences in means of late blight scores by Student's t-test.

Markers	Coupling (C) or repulsion (R) phase to late blight resistance loci	P<	Marker linked to group
From *S. verrucosum* female in VP			
e73m67.8	R	0.05	Independent
From *S. phureja* male in VP			
E35m42.1	R	0.05	LG 1
e73m67.5	R	0.05	LG 1
e73m67.7	C	0.05	LG 4
e73m67.4	C	0.05	LG 4
Z4.680	R	0.05	LG 5
R4.900	C	0.05	Independent
From *S. phureja* female in PD			
Z10.550	C	0.01	LG 1
R9.1200	R	0.05	LG 9
S18.500	R	0.05	LG 9
G3.1020	R	0.05	LG 9
E45M42.13	C	0.01	LG 14
E45M42.3	C	0.05	LG 14
B6.1400	C	0.05	LG 15
S8.940	C	0.05	Independent
From dihaploid male in PD			
B17.1750	R	0.05	LG 2
B2.2500	C	0.05	LG 5
S7.2050	C	0.05	LG 10
S4.600	R	0.05	LG 12
B8.1850	R	0.01	LG 13
Z6.400	R	0.01	LG 13
G3.1000	C	0.01	Independent
E45M42.6	R	0.05	Independent

the chromosomal region between two markers instead of a single marker.

Conclusions

This preliminary QTL analysis of two diploid potato populations will be refined by high-resolution genetic analysis and by looking at differences in the expression of QTL for resistance under different environments and after exposure to different races of the pathogen. Confirmation of the value of each DNA marker will be an important step in developing new varieties with improved resistance to LB. In this respect, the PP population (Table 1) will be useful for testing the congruence of LB resistance markers in *S. phureja* germplasm.

This will be achieved by selective genotyping of the PP population with the PD-derived LB markers. By 1998, we will begin introgressing valuable QTL from the PD population by applying marker information to help select good parental clones. We plan to make new crosses at the diploid stage to verify cosegregation of these DNA markers with horizontal resistance to LB. In the medium term, we will transform DNA markers that tag resistance QTL into an easy-to-use tool to select new potato varieties with LB resistance QTL with an *S. phureja* origin.

Selected Reading

Colon, L.T., R.C. Jansen, and D.J. Budding. 1995. Partial resistance to late blight (*Phytophthora infestans*) in hybrid progenies of four South American *Solanum* species crossed with diploid *S. tuberosum.* Theor. Appl. Genet. 90:691-698.

Leonards-Schippers, C., W. Gieffers, R. Schäfer-Pregl, E. Ritter, S.J. Knapp, F. Salamini, and C. Gebhardt. 1994. Quantitative resistance to *Phytophthora infestans* in potato: A case study for QTL mapping in an allogamous plant species. Genetics 137:67-77.

Identifying Duplicates in Sweetpotato Germplasm Using RAPD

D.P. Zhang, M. Ghislain, Z. Huamán, F. Rodríguez, and J.C. Cervantes[1]

Sweetpotato (*Ipomoea batatas* (L.) Lam.) is a highly heterozygous hexaploid crop. Vegetative propagation is the only means to maintain its varietal identity. Maintaining a large gene bank of a vegetatively propagated crop is costly, and it is difficult to meet increasing user demands when faced with limited financial and physical resources. More comprehensive assessment of genetic identity is essential to reduce redundancy and save management and operating costs of the germplasm bank held at CIP. Accessions considered redundant could be bulked into botanical seeds, which are less costly to maintain. Identification of duplicates is also the first step in developing a core collection to represent the genetic variability available within the sweetpotato gene pool and to make the germplasm more accessible to users.

Duplicate accessions of sweetpotato have been routinely identified at CIP based on CIP-AVRDC-IBPGR[2] sweetpotato descriptors. Duplicate identification within Peruvian sweetpotatoes maintained in the field gene bank held at CIP has so far reduced the size of the collection from 1,939 to 909 accessions. These duplicates were identical both in their morphology and in their electrophoresis banding patterns of proteins and esterase.

The introduction of polymerase chain reaction (PCR)-based DNA fingerprinting offers a novel tool for cultivar identification. The advantage of this technique is its sensitivity, simplicity, speed, and low cost. PCR-based DNA fingerprinting has been applied to cultivar identification in many other crops. Its potential for sweetpotato, however, has yet to be assessed.

Three criteria were considered essential for any method to identify duplicates. First, the method should generate maximum intervarietal variation to ensure discrimination between cultivars. Second, it should detect minimal intravarietal variation so that clones of the same cultivar would have a highly homogeneous identity. Third, it should have good environmental stability and little technical error.

Large intervarietal variation in sweetpotato had been found using randomly amplified polymorphic DNA (RAPD) fingerprinting. But whether RAPD would reveal minimal intravarietal variation was not clear. Identifying duplicates in sweetpotato is complicated by the fact that somaclonal mutation is frequent in this crop. Visible morphological changes such as skin and flesh color of storage roots are common. Therefore, it is essential to understand whether these mutations are detectable by RAPD. And if they are, what amount of difference is acceptable for a group of accessions to be considered duplicates?

The reproducibility of the RAPD assay is of concern when applying RAPD to the identification of duplicates. It is known that most errors occur when cross-lab, cross-plate (amplification), and cross-gel comparisons are made.

In our case, the highest number of suspected duplicates in the sweetpotato gene bank held at CIP is 20 accessions per group. Therefore, all within-group comparisons can

1 CIP, Lima, Peru.

2 IBPGR = International Board for Plant Genetic Resources, AVRDC = Asian Vegetable Research and Development Center.

be made on the same plate and with the same gel, which greatly minimizes error. However, errors associated with quality and quantity of template DNA, which occur mostly during leaf sampling and DNA extraction, still need to be characterized.

Here we report our study of applying RAPD for identifying sweetpotato duplicates. We assessed the inter- and intravarietal RAPD variation within a group of sweetpotato cultivars, characterized the error source, and developed a procedure for identifying duplicates in the sweetpotato germplasm collection. This study shows how molecular marker techniques play an important role in sweetpotato germplasm management at CIP.

Materials and Methods

Suspected duplicate accessions

We used 66 suspected duplicate accessions in 15 groups for this study (Table 1). These accessions were originally collected from Bolivia and maintained in the gene bank at CIP.

We grouped the suspected duplicates based on morphological observation, meaning that the accessions in the same group are morphologically identical, or so similar that the descriptors cannot distinguish one from another. Their passport data, however, indicate they were collected from different geographic locations. Fifteen accessions, one from each suspected duplicate group, were chosen to assess intervarietal variation (Table 1).

Plant material for measuring intravarietal variation

Two common U.S. *Ipomoea batatas* cultivars, Jewel and Beauregard, were collected from three sources: U.S. Department of Agriculture, Regional Plant Introduction Station, Griffin, Georgia; the sweetpotato breeding program of North Carolina State University, Raleigh, North Carolina; and the in vitro gene bank held at CIP. These cultivars were used as true duplicates to assess intravarietal variation.

The in vitro plants were first transferred to propagation media for 2 wk and then to the screenhouse. No morphological variation could be detected between accessions of the same cultivar from any of the three different origins.

A transgenic sweetpotato, Chogoku, obtained from the molecular biology laboratory of CIP, was used as a simulated mutation clone. An intron-β-glucuronidase (GUS) gene was introduced into its genome via *Agrobacterium rhizogenes*. The insertion was confirmed by a GUS assay and Southern blot. The transgenic Chogoku is also morphologically distinguishable from the untransformed control because of dwarfing induced by the transformation (Figure 1).

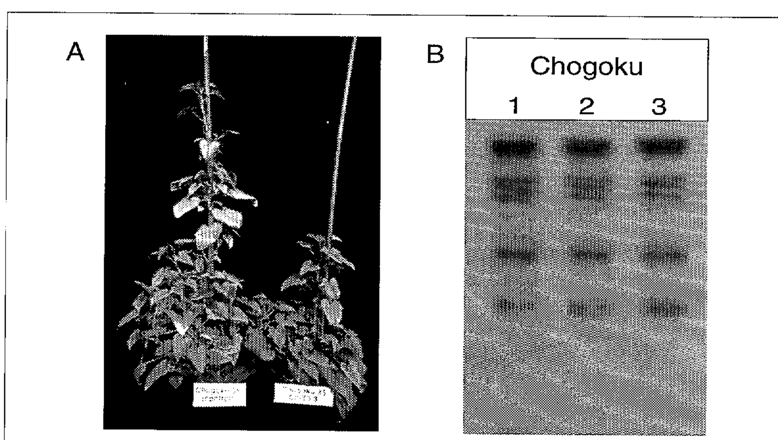


Figure 1. Transgenic Chogoku sweetpotato with dwarf mutation (A). Southern blot of transgenic Chogoku sweetpotato (B) confirmed the insertion of the intron-GUS gene into the genome.

Table 1. List of 66 suspected cultivar duplicates in a Bolivian collection.

Collection number	Native name	Duplicate group	Collection number	Native name	Duplicate group
DLP 1332	Unknown	2001[a]	DLP 1373	Unknown	2009[a]
DLP 1387	Blanco	2001	DLP 2723	Carne Amarilla	2009
DLP 1658	Camote Blanco	2001	DLP 1627	Ojiri	2010
DLP 1384	Amarillo	2002[a]	DLP 1600	Amarillo	2010[a]
DLP 1377	Oglliri	2002	DLP 1360	Unknown	2011
DLP 1383	Blanco Pintado	2002	DLP 1363	Amarillo	2011
DLP 1382	Amarillo	2002	DLP 1376	Morado	2011[a]
DLP 1370	Apichu	2002	DLP 1362	Blanco	2011
DLP 1380	Oriental	2003	DLP 1368	Morado	2011
DLP 1637	Morado	2003	DLP 1622	Amarillo	2011
DLP 1638	Japonés	2003	DLP 1621	Morado	2011
DLP 1366	Cruzeña	2003	DLP 1619	Blanco	2011
DLP 1602	Brasilero	2003	DLP 1356	Peruano	2012
DLP 1626	Japonés	2003	DLP 1359	Rosado	2012
DLP 2704	Colorado	2003[a]	DLP 1375	Unknown	2012
DLP 1634	Camirino	2003	DLP 1352	Guindo	2012
DLP 1618	Colorado	2003	DLP 1374	Unknown	2012[a]
DLP 1348	Rojo	2004	DLP 1378	Aguela Manuchia	2012
DLP 1354	Amarillo	2004[a]	DLP 1372	Amarillo	2012
DLP 1353	Rosado	2004	DLP 1381	Quebradeño	2012
DLP 1355	Blanco Papa	2004	DLP 2733	Morado	2012
DLP 2721	Tarijeno	2005	DLP 1379	Morado	2012
DLP 1349	Amarillo	2005	DLP 2708	Morado	2012
DLP 1347	Camote	2005	DLP 2726	Colorado	2012
DLP 1350	Amarillo	2005[a]	DLP 1669	Rosado	2013
DLP 1660	Unknown	2006	DLP 1650	Rosado	2013
DLP 1662	Blanco Larco	2006	DLP 1668	Rojo	2013
DLP 1636	Blanco	2006[a]	DLP 1666	Blanco	2013[a]
DLP 1649	Blanco	2006	DLP 1333	Unknown	2014[a]
DLP 1327	Huila Apichu	2007[a]	DLP 1340	Unknown	2014
DLP 1328	Apichu Amarillo	2007	DLP 1334	Guindo	2014
DLP 1635	Corridor	2008[a]	DLP 1652	Morado	2015
DLP 1612	Blanco	2008	DLP 1659	Morado	2015[a]

a. Accessions selected for assessing intervarietal variation.

Material for characterizing error source in RAPD

Three factors associated with consistency of RAPD profiles—age of leaves, sample contamination, and template DNA concentration—were characterized. Cultivar Jewel was used for these tests. To assess the effect of leaf age on RAPD fingerprints, leaves from node 3 or above were compared with leaves from node 6 or older.

To test the contamination effect, four young leaves from pathogen-tested plants were compared with those of field-grown plants. Five levels of template DNA concentration ranging from 1 ng/µl to 20 ng/µl were used to test the effect of DNA concentration.

Gel scoring and data analysis

Different fragments produced with each primer were numbered sequentially and the presence or absence of fragments in each individual was scored. Individuals from the same row on one gel were compared with each other. Fragments with the same mobility on the gel but with slight differences in intensities were not distinguished when accessions were compared with each other. The similarity between accessions is calculated as:

$$2 \times NAB/NA + NB$$

where NAB is the number of bands shared by individuals A and B, and NA and NB are the number of bands in individuals A and B, respectively. The chance of finding two individuals with the same fragment pattern can be calculated as the mean similarity (S) to the power of the mean number of bands (N).

Results and Discussion

Primer selection

A total of 80 Operon decamers were screened on 10 accessions of sweetpotato. A set of 24 primers was ultimately selected based on (1) the number of easily detectable and well-resolved polymorphic bands produced and (2) the reproducibility of the same fragment pattern over repeated tests. We used these 24 primers to amplify a total of 164 polymorphic fragments from among all 15 accessions that had provided original data for calculating their genetic similarities. We also used these 24 primers to assay the true duplicates and transgenic plant. We used only seven of the most informative primers for genotyping the 66 suspected duplicates (Table 2).

Intervarietal variation

Large intervarietal RAPD variation was detected. Any one of the 24 selected primers

Table 2. List of seven primers used for identifying the 66 suspected duplicates and the number of bands they amplified.

Primers	Oligonucleotide sequence 5′ to 3′	Polymorphic fragments scored (no.)	Fragments amplified (no.)
B 8	GTCCACACGG	11	17
B18	CCACAGCAGT	6	12
B19	ACCCCCGAAG	7	11
M11	GTCCACTGTG	7	13
M18	CACCATCCGT	15	18
R17	CCGTACGTAG	15	17
R19	CCTCCTCATC	14	16
Total		75	104

unambiguously differentiated all of the 15 cultivars (Figure 2). The genetic similarity was calculated for all the possible pairwise combinations of the 15 cultivars. It ranged from 0.44 to 0.69, with a mean of 0.61. Each primer produced eight bands in this case, so when one primer is applied, the probability of misidentification (two different cultivars by chance possessing the same RAPD profile) is 0.61^8 , that is, 0.0192. When three primers are applied, the chance of misidentification becomes negligible (7.05×10^{-6}).

Even when a group of 20 suspected duplicates is compared (180 pairwise comparisons), the chance of misidentification is 3.89×10^{-4}. This simplistic calculation shows that RAPD is extremely efficient in detecting intervarietal variation in sweetpotato. That is because sweetpotato is a highly heterozygous outcrossing crop and great genetic difference exists between cultivars.

Identifying suspected duplicates

To test whether three primers would be enough to identify duplicate cultivars with acceptable accuracy, the seven most informative primers were sequentially applied to the 15 groups of suspected duplicates (Figure 3). The first primer identified 58 duplicates out of the 66 accessions. The second primer improved the result by discriminating 1 more accession, thus reducing the total of duplicates to 57. The result remained constant even as more primers were used, indicating that three primers will give enough accuracy for identifying duplicate accessions in sweetpotato.

That is not to say that these identified duplicates are genetically identical. One can never prove that two accessions are genetically identical unless the sequence of the entire genome is known. We based our designation as duplicate on the average genetic

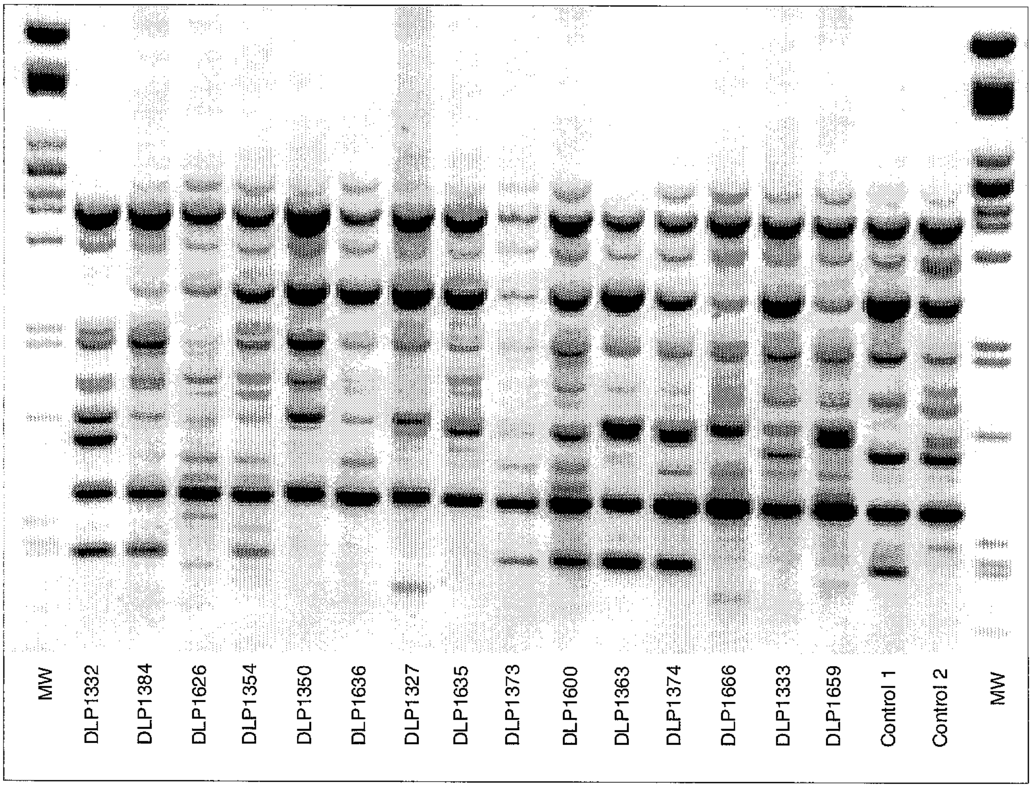


Figure 2. RAPD revealed intervarietal variation of 15 Bolivian cultivars by oligonucleotide primer B14. Lanes 1 and 19 are a 1 kb DNA ladder. Lanes 17 and 18 are controls.

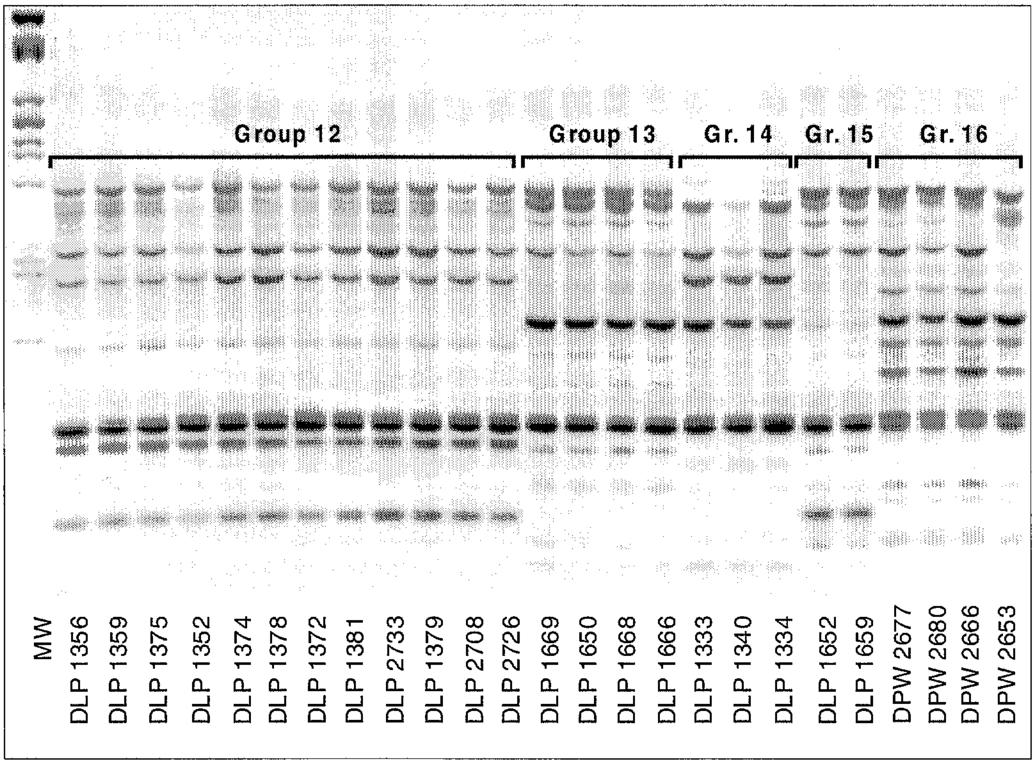


Figure 3. RAPD fingerprints of suspected duplicate groups generated by oligonucleotide primer B8. The molecular weight standard (MW) is a 1 kb DNA ladder. Table 1 describes the groups. Accession DPW 2653 in group 16 was not found to be a duplicate.

distance between cultivars from the same geographic origin. For that reason, the identified duplicates will not be eliminated. They will be planted in a crossing nursery and converted into botanical seeds, with only one of them being conserved as a unique cultivar in vegetative form.

Intravarietal variation

With 24 primers and 125 polymorphic bands, neither Jewel nor Beauregard showed any intravarietal RAPD variation. Clones collected from the three sources all revealed the same profiles. Moreover, these polymorphic markers revealed no differences between the transgenic Chogoku and the untransformed control, even though the transgenic plant was taller. This result suggests that although somaclonal mutation is frequent in sweetpotato, intravarietal variation is not readily detected by RAPD.

Sweetpotato has a DNA content of roughly 2c=5.0 picograms (pg) as estimated by flow cytometry. One pg of DNA is approximately equivalent to 965 million base pairs. Therefore, sweetpotato should have a genome size of roughly 8.04×10^5 kb. Assuming each primer can score 2 kb, the 24 primers used in this study scored at most 48 kb of the 8.04×10^5 kb sweetpotato genome. In addition, the complete sequence of the amplified product of RAPD is not known. A primer may produce identical-size products in two genotypes, but possible divergence within the internal sequences cannot be detected. In the case of the transgenic Chogoku plant, one would need to apply 4×10^5 primers on average to be able to detect the mutation, assuming it is caused by a single insertion. Thus, it is unlikely that RAPD will be useful for detecting intravarietal variation resulting from somatic rearrangements.

This result also suggests the important and complementary role of morphological identification. To identify duplicates, one should always use morphological characters first. Application of DNA fingerprints should be based on sound work of morphological identification.

Error and repeatability

There were visually detectable differences between older leaves (node 6 or older) and young leaves (node 3 or above). The RAPD assay using older leaves gave less satisfactory results, such as faint bands or inconsistent band intensity (data not presented). The effect of tissue age on RAPD banding pattern may be due to the polysaccharides present in older leaves, which affect DNA quality. Thus, it is necessary to sample young leaves for DNA extraction.

The leaves sampled from the field gene bank did not give a different RAPD profile from that of the in vitro plant. Our experience shows that one can take samples directly from the field, as long as healthy young leaves are sampled.

A difference in RAPD banding pattern was found in the template DNA concentration test. A low concentration (1-5 ng/μl) tends to result in missing bands of low molecular weight. It is difficult to avoid such error, because the DNA quantification is usually not accurate. In fact, this is the only significant error for duplicate identification. We recommend repeating the RAPD test with different DNA if the suspected duplicate accessions only show differences in one or two low molecular weight bands, whereas the rest of the bands are the same.

Conclusions

Several conclusions can be drawn from the present study. First, RAPD offers a reliable method for sweetpotato cultivar identification. It has distinct advantages over many biochemical methods such as isozyme and protein assays, which are susceptible to environmental and developmental variations. A combination of three selected primers can unambiguously confirm duplicates in the germplasm bank held at CIP.

Second, morphological identification should always be the first step in grouping suspected duplicates. RAPD can then be applied to verify the morphological result. Based on good morphological characterization, the RAPD comparison can be conducted on a limited number of accessions so that the comparison can be made in the same gel. That makes the operational error negligible, because cross-plate and cross-gel comparisons are avoided.

Third, RAPD is unsuitable for assaying intravarietal variation in sweetpotato. Therefore, it cannot be used to monitor clonal genetic stability in the gene bank or to detect somaclonal mutation in sweetpotato.

Using RAPD for identifying sweetpotato duplicates is now routine at CIP. We estimate that about 30-40% of the 5,400 sweetpotato accessions are duplicates. The identification of redundancy will eventually save about 30-40% of the maintenance cost of the gene bank. The downsized collection will also provide a much better base for constructing a core collection. Minimum redundancy is the first requirement for a meaningful core subset.

Selected Reading

Bailey, D.C. 1983. Isozyme variation and plant breeders' rights. In: S.D. Tanksley and T.J. Orton (eds.). Isozymes in plant genetics and breeding, part A. Elsevier, Amsterdam. p. 425-441.

CIP, AVRDC, IBPGR (International Potato Center, Asian Vegetable Research and Development Center, International Board for Plant Genetic Resources). 1991. Descriptors for sweetpotato. Huamán, Z. (ed.). International Board for Plant Genetic Resources, Rome, Italy.

RAPD Variation in Sweetpotato Cultivars from South America and Papua New Guinea

D.P. Zhang, M. Ghislain, Z. Huamán, A. Golmirzaie, and R. Hijmans[1]

It is commonly accepted that sweetpotato (*Ipomoea batatas* (L.) Lam.) is of Central and South American origin, with its center of diversity in northwest South America. Sweetpotato was dispersed to the Old World during the sixteenth century, except for a suggested prehistoric spread from South America to eastern Polynesia in 400 A.D. The crop's outcrossing nature, combined with vegetative propagation, has created a vast number of cultivated genotypes around the world since then, in spite of the relatively short dispersal period.

Nearly 8,000 accessions of sweetpotato have been collected and maintained at various gene banks around the world, with the majority of them maintained at CIP. Knowledge of the distribution of genetic diversity is essential for rational germplasm conservation. Information on diversity distribution is also crucial to constructing core collections. Core collections are a limited subset of accessions, from a large germplasm collection, chosen to represent the genetic spectrum in the whole collection. Maximum genetic diversity is the key to establishing a good core subset.

Sweetpotato cultivars in Oceania, particularly those in New Guinea (including Papua New Guinea and Irian Jaya Province of Indonesia), have long attracted curators' attention. This area was suggested as part of the secondary diversity center of sweetpotato. There is evidence from ancient forest clearance that sweetpotato might have reached the New Guinea highlands some 1,200 years ago. More than 5,000 cultivars have been developed under these isolated ecological conditions. The island is the only place in the world where sweetpotato can be found growing at altitudes of up to 2,800 m. As a result, CIP and Indonesian scientists at the Root and Tuber Crops Research Center, Cenderawasih University, are conducting an *in situ* conservation project in Irian Jaya (the western half of New Guinea).

As a preliminary step in the genetic diversity assessment, we recently compared Oceanian and South American sweetpotato germplasm to answer two basic questions:

1. Is Oceanian sweetpotato necessarily different from that of South America?
2. What is the genetic diversity level in the Oceanian gene pool?

In this study, genetic variation is based on DNA sequence variation revealed by randomly amplified polymorphic DNA (RAPD). Assuming that all the RAPD fragments are randomly located on the sweetpotato genome and are selectively neutral, the genetic difference in two groups of genotypes can be statistically tested by the analysis of molecular variance (AMOVA). The genetic diversity in a group of genotypes can also be measured by the mean genetic relationship between all possible pairs of individuals within that group. This survey should shed more light on the distribution of sweetpotato diversity and help to rationalize our sweetpotato germplasm collection.

Materials and Methods

Plant materials

Thirty-six sweetpotato cultivars from Colombia, Ecuador, Peru, and Papua New Guinea (PNG) were used in this study (Table 1).

1 CIP, Lima, Peru.

Table 1. Name and code of 36 sweetpotato cultivars from two geographic regions.

Name	Collection no.	Origin
Unknown	DLP 1873	Colombia
Unknown	DLP 1898	Colombia
Morado	DLP 1001	Colombia
Blanco	DLP 1705	Colombia
Tijereta	DLP 1735	Colombia
Dedulce (A)	DLP 1149	Ecuador
Unknown	DLP 1257	Ecuador
Blanco	DLP 1453	Ecuador
Moradosal	DLP 1493	Ecuador
Dedulce (B)	DLP 1207	Ecuador
Unknown	DLP 1223	Ecuador
Morado	DLP 1404	Ecuador
Chilpe	DLP 953	Peru
Japones	DLP 2008	Peru
Morado	DLP 3309	Peru
Amarillo	ARB 488	Peru
Unknown	DLP 2213	Peru
Oreja de Galgo Blanco	RCB IN 49	Peru
Mea	I00442	Papua New Guinea
Mania	I00450	Papua New Guinea
Mena	I00462	Papua New Guinea
Wawambo	I00475	Papua New Guinea
Gorohakowe	I00524	Papua New Guinea
Aiva	I00561	Papua New Guinea
Kivep	I00618	Papua New Guinea
Merenge	I00846	Papua New Guinea
Koitaki 2	I00928	Papua New Guinea
Dakasum	I01361	Papua New Guinea
Narunmitang	I01367	Papua New Guinea
L312	I01369	Papua New Guinea
Saras	I00601	Papua New Guinea
Kombo Nomongambo	I00509	Papua New Guinea
Ilmo 1	I00934	Papua New Guinea
Hapamunto	I00497	Papua New Guinea
Faiv-Mun	I00849	Papua New Guinea
Yunpi	I00453	Papua New Guinea

The plant materials were obtained from the sweetpotato gene bank held at CIP. Healthy young leaves were collected from each accession maintained in a screenhouse and in vitro culture. The leaf tissue was immediately quick-frozen in liquid nitrogen, then freeze-dried. The freeze-dried leaf tissue was then used for genomic DNA isolation using a miniprep procedure.

DNA amplifications

We screened 80 random decamer oligonucleotides as single primers for the amplification of RAPD sequences. Amplification was performed in volumes of 15 µl containing 1.5 µl of the 10x buffer, and 100 µM each of dNTP, 0.4 µM primer, 25 ng genomic DNA, and 1 unit of polymerase. The reaction mix was overlaid with 50 µl mineral oil. Amplification was performed in 96-well microtest plates using a Teche PHC-3 thermal controller programmed for 41 cycles of 1 min at 93°C, 1 min at 33°C, and 2 min at 72°C. Amplification products were analyzed by horizontal gel electrophoresis in 1.5% agarose gels in 1x TBE buffer at 100 v for 5 h and detected by ethidium bromide staining. Gels were photographed using the Stratagene system.

Scoring and data analysis

We treated different fragments produced with each primer as a unit character, and then numbered them sequentially. We scored genotypes for the presence (1) or absence (0) of each fragment. Only those fragments with medium or high intensity were taken into account. Fragments with the same mobility on the gel but with different intensities were not distinguished from each other when cultivars were compared. Monomorphic fragments were not scored.

From these data, a matrix of pairwise genetic distances based on simple matching coefficients (SM) was calculated as $D_{ij} = 1 - SM$.

The AMOVA procedure was used to estimate variance components for RAPD phenotypes. Variation was partitioned among individuals (within regions) and between regions. The variance components of interest were extracted and tested using nonparametric permutational procedures.

Multidimensional scaling (MDS) of NTSYS-PC was used to present the relationships between the 36 cultivars.

The genetic diversity within PNG and South American cultivars was measured by the mean genetic distance and total marker variances.

Results

Of the 80 primers screened in this study, 15 were selected because they all revealed multibanded fingerprints, which are clearly scorable (Table 2). All 36 cultivars can be differentiated by any one of the selected primers (Figure 1). Their replicability in amplification was verified by three runs of polymerase chain reactions (PCR) using template DNA from five sweetpotato cultivars. These reactions are highly consistent. Since the results were consistent between replications, amplifications with all 36 cultivars were repeated for each primer only when obvious problems with the PCR procedure occurred.

The 15 selected primers yielded 89 polymorphic and clearly scorable fragments across the 36 cultivars. On average, approximately six polymorphic bands were observed for each primer (Table 2). Of the 89 scored markers, only eight are region-specific (present in one region but absent in another). The rest of the markers vary in frequency between regions.

The between-region variance contributes only 10% of the total molecular variance; the within-region variance accounts for 90%. Nevertheless, using a nonparametric test with 1,000 permuted matrices, we found that the between-region difference was significant (Table 3). This indicates that there is a substantial difference between PNG cultivars and their South American counterparts in RAPD variation.

The genetic diversity within Papua New Guinea and South American groups, mea-

Table 2. List of primers used in the RAPD analysis and their respective oligonucleotide sequence.

Primers	Oligonucleotide sequence 5′ to 3′	Polymorphic fragment scored (no.)	Fragments amplified (no.)
OPB-08	GTCCACACGG	6	14
OPB-13	TTCCCCCGCT	4	9
OPB-14	TCCGCTCTGG	5	13
OPB-16	TTTGCCCGGA	9	11
OPM-04	GGCGGTTGTG	7	9
OPM-07	CCGTGACTCA	4	8
OPR-11	GTAGCCGTCT	10	13
OPR-15	GGACAACGAG	4	10
OPR-17	CCGTACGTAG	5	12
OPR-19	CCTCCTCATC	6	12
OPS-02	CCTCTGACTG	6	11
OPS-09	TCCTGGTCCC	4	10
OPS-13	GTCGTTCCTG	8	14
OPS-19	GAGTCAGCAG	4	13
OPS-20	TCTGGACGGA	7	13
Total		89	172

sured by the total marker variance and the mean genetic distances between all possible pairs of individuals within a region, is also significantly different. South American cultivars had a significantly greater diversity than PNG cultivars (Table 4).

The difference between these two groups of cultivars in terms of genetic constitution and genetic diversity is also reflected in the MDS plot (Figure 2). The PNG cultivars are grouped together in a much smaller range,

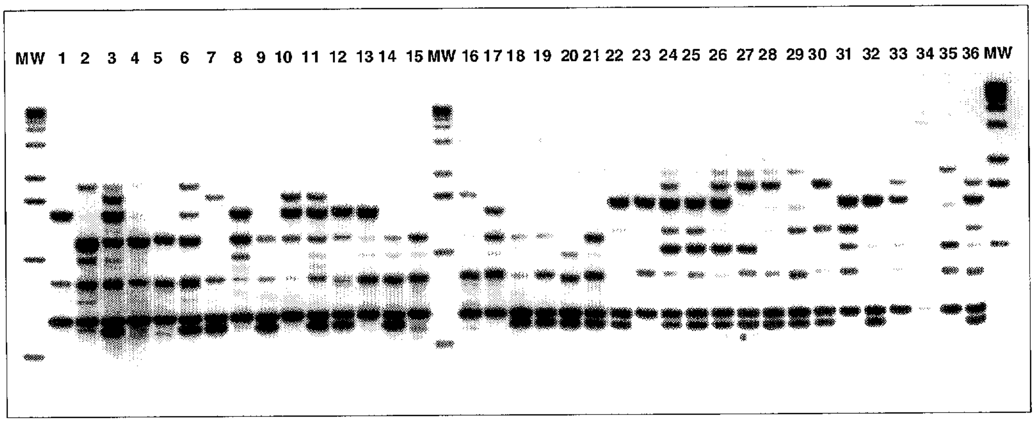


Figure 1. RAPD fingerprints of 36 sweetpotato cultivars generated by oligonucleotide primer B16 (the nucleotide sequence is given in Table 2). The numbers on top refer to the sweetpotato cultivars listed in Table 1. The molecular weight (MW) standard is 1 kb DNA ladder.

Table 3. Analysis of molecular variance (AMOVA) for RAPD variation between South America and Papua New Guinea (PNG).

Source of variation	df	MSD[a]	E(MSD)[b]	Variance component	Total[c] (%)	P value[d]
PNG vs. S. America	1	0.569	$\sigma^2_b + 18\,\sigma^2_a$	0.0212	10	<0.001
Individuals within regions	34	0.188	σ^2_b	0.1882	90	

a. Mean square deviations.

b. Expected mean square deviations.

c. Percentage of total molecular variance (0.2094).

d. Probability of obtaining a larger component estimate. Number of permutations = 1000.

whereas the South American cultivars are more widely scattered in the plot.

Discussion

A high degree of variability in RAPD markers was observed in sweetpotato. All 36 cultivars evaluated can be differentiated with a single primer. It appears that enough markers can be generated by a few selected primers to enable a comparison of different cultivar groups. This high resolution power, in contrast with the very low level of allozyme and protein polymorphism observed earlier, demonstrates the effectiveness of using RAPD to identify cultivars and assess genetic diversity in sweetpotato.

Replicability is one of the primary concerns in using RAPD as a DNA fingerprint. Our results show that with properly selected primers and optimized amplification conditions, results are highly replicable. When a large collection of germplasm needs to be assessed for genetic diversity, RAPD is certainly one of the most cost-effective and user-friendly tools.

Although the prehistoric existence of sweetpotato cultivation in Papua New Guinea

Table 4. Total marker variance, mean genetic distance and nonparametric test of variances for Papua New Guinea and South American sweetpotato cultivars.

Origin of cultivars	Individuals (no.)	Total marker variance[a]	Mean genetic distance among individuals within population
South America	18	17.974*	0.412
Papua New Guinea	18	15.523	0.362
Siegel-Tukey test[b]		1.157*	

a. Total marker variance = $\Sigma (n^*p^*q)/(n-1)$, where n = number of individuals in a population and p and q refer to the frequency of the presence or absence of a band, respectively.

b. Siegel-Tukey test of variance homogeneity.

* Significantly different.

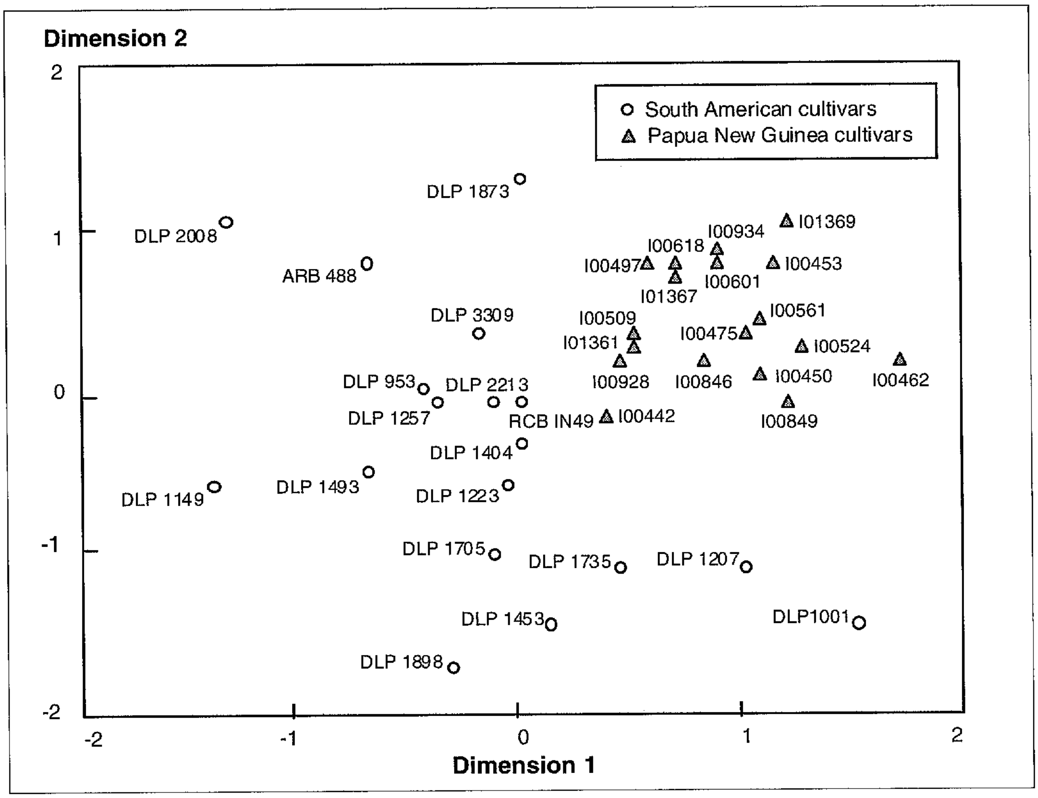


Figure 2. Multidimensional scaling plot of 36 sweetpotato cultivars based on simple matching coefficients from RAPD markers.

has yet to be proved, sweetpotato has become a staple food there. The crop is cultivated extensively in the highlands of New Guinea, unlike in the rest of the world where it is mostly a lowland crop. This study shows that there is a substantial difference between PNG and South American cultivars, although the difference is small relative to the large differences between individuals within each region.

Sweetpotato is an outcrossing hexaploid; variation because of sexual reproduction and somatic mutation can be fixed by its vegetative propagation. It is not surprising then to see such large variation between individual cultivars. When AMOVA is used to partition regional differences against a background of among-individual (within-region) polymorphism, it quantifies the cumulative impact of the difference in frequency of polymorphic markers between PNG and South American cultivars. Results suggest that Papua New Guinea cultivars, after many years of independent evolution and selection in an isolated environment, are indeed genetically distinguishable from their ancestors in South America.

Our other major interest, besides the genetic differences between PNG and South American cultivars, is the genetic diversity level within PNG and South American genotypes. The significantly lower diversity level within PNG cultivars, compared with South American samples, is not unexpected since South American cultivars sampled were from Peru, Ecuador, and Colombia—the center of origin of sweetpotato. The Oceanian gene pool, in contrast, is a comparatively recent arrival from a more ancient distribution.

Assessing diversity is also important for the construction of a core collection. A stratified sampling method can be used when establishing a core subset. RAPD data, which partially reflect the distribution of diversity, can therefore be used as one criterion to help assign accessions to appropriate groups.

Conclusions

Several conclusions can be drawn from the present study. First, PNG cultivars, after many years of independent evolution in an isolated agroecological environment, are substantially different from their ancestors in South America.

Second, the genetic diversity level in PNG cultivars is significantly lower than that in South American cultivars.

Third, the RAPD technique or DNA markers in general can reveal useful information about the genetic relationship and genetic diversity in sweetpotato, which morphological markers cannot detect. Therefore, it should be used as a major tool for the assessment of genetic relationship and genetic diversity in sweetpotato germplasm.

This is our first experiment in assessing global sweetpotato diversity. More research with a larger sample size, involving different important sweetpotato gene pools, is under way at CIP. We believe that these results will provide us with the information needed for rational management of global sweetpotato germplasm.

Selected Reading

Austin, D.F. 1988. The taxonomy, evolution and genetic diversity of sweetpotatoes and related wild species. In: P. Gregory (ed.). Exploration, maintenance, and utilization of sweetpotato genetic resources. CIP, Lima, Peru. p. 27-60.

Excoffier, L., P.E. Smouse, and J.M. Quattro. 1992. Analysis of molecular variance inferred from metric distances among DNA haplotypes: Application to human mitochondrial DNA restriction sites. Genetics 131:479-491.

Nienhuis, J., J. Tivang, and P. Skroch. 1994. Analysis of genetic relationships among genotypes based on molecular marker data. In: Proc. Analysis of Molecular Marker Data. Joint Plant Breeding Symp. Ser., Am. Soc. Hort. Sci. and Crop Sci. Soc. Am. Minneapolis, Minn. p. 8-14.

Sweetpotato Breeding Strategy and Germplasm Testing in Southeast Asia

Il-Gin Mok[1], Tjintokohadi[1], Lisna Ningsih[1], and Tran Duc Hoang[2]

Sweetpotato (*Ipomoea batatas*) has long been used as food and feed in Asia. It grows well under relatively poor fertility and low soil moisture. Sweetpotato produces the highest amount of energy (194 MJ/ha per day) of all crops. Production, however, is decreasing with economic development in the region. Through processing, the crop will become a value-added commodity. Most varieties now cultivated have low dry matter (DM) content (25-30%), too low to be used as raw material in the processing industry, which prefers DM above 35%.

We already know, from heritability estimation and additive gene action, how to increase DM content. The CIP regional breeding program, however, targets many countries (or locations) in the region. We must therefore maintain various useful genes for yield, storage-root quality, and pest resistance while increasing mean DM content in each selection cycle.

Wide adaptability is also important for the regional breeding program. To achieve that goal, we adopted and modified a breeding scheme already used by maize breeders in the United States—the convergent-divergent selection scheme. The convergent-divergent scheme for sweetpotato breeding involves (1) maximizing the use of diverse genetic resources, (2) promoting collaboration among breeders (CIP region and national agricultural research systems), and (3) selecting varieties for wide adaptability. Heritability can be used as an indicator for selecting a specific trait in breeding programs. Both broad (H) and narrow (h^2) sense heritability have been estimated by many researchers in temperate countries. For the tropics, we need to estimate h^2 again to predict the progress of a selection cycle.

While evaluating various introductions from many countries, we realized that seed families from Japan produced a large number of progeny with very high DM content. Obtaining botanical seed from Japan was difficult, because seed production by hand-pollination was expensive. Moreover, all of the recently released varieties, which are frequently used for hybridization, are protected under Japan's Breeders' Rights Law.

To overcome the limitations to using Japanese breeding material, shuttle breeding was suggested. Hybrid seeds produced by a trainee working with the national breeding program in Japan could be sent to the CIP regional office in Bogor, Indonesia, for evaluation and distribution to countries in the region.

The Breeding Strategy

Explanation

To take advantage of CIP's decentralized breeding activities, we modified the convergent-divergent selection scheme for sweetpotato improvement.

Convergent-divergent selection and clonal pool

We receive seeds from various regions or sources to form a base population (Figure 1). Seeds are planted and superior clones are selected and intercrossed. Small packages of seeds of the F_1 population are returned to each site where selection continues. Clones selected at each site are intercrossed, and seeds from those populations are sent again to the

1 CIP-ESEAP regional office, Bogor, Indonesia.
2 Vietnam Agricultural Sciences Institute, Hanoi, Vietnam.

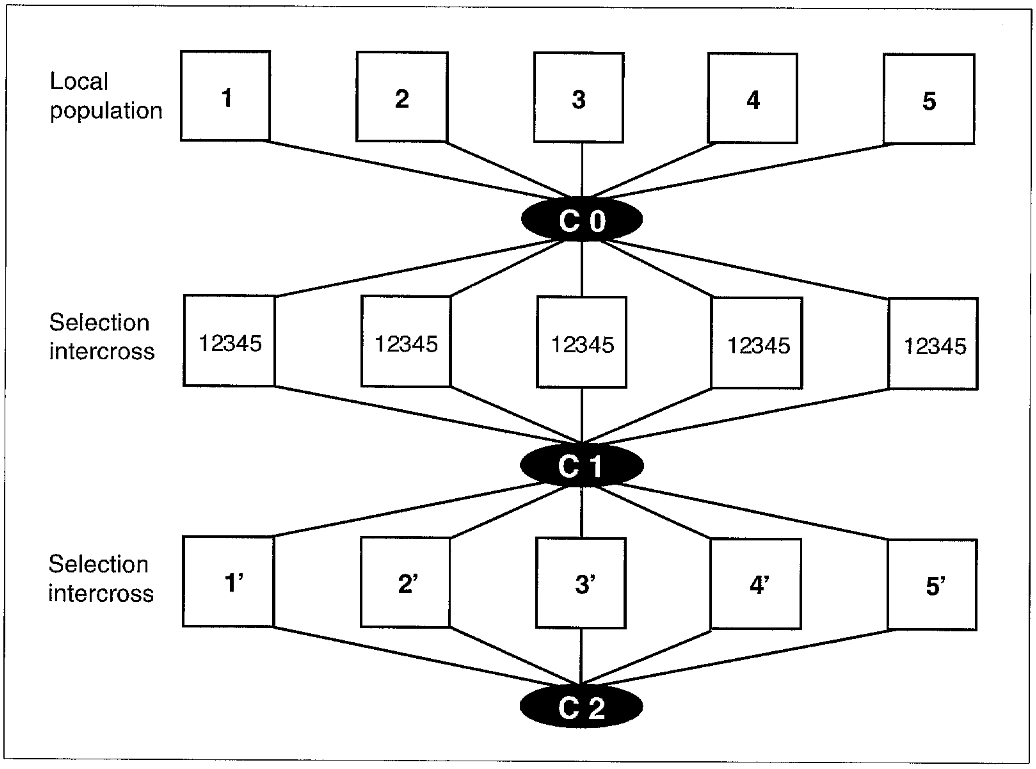


Figure 1. Convergent-divergent selection scheme, which maximizes the efficiency of decentralized breeding programs.

coordinating site. During selection cycles and intercrossing, each region can add newly acquired elite germplasm for introgression of specific genes. This method adapts well to sweetpotato breeding at CIP, whose breeders are based at many sites around the world.

Sweetpotato seed families introduced from many countries as part of the modified convergent-divergent breeding scheme were first planted at Bogor for evaluation. Clones were selected for high DM content and reasonably high yield. Most clones have light-colored flesh varying from white to yellow. Because the objective of this program focuses on industrial use, skin color was not a selection criterion.

We plan to maintain about 100 clones continuously as a clonal pool to provide good material for further selection at different sites. As new clones are selected from seedling evaluation → observational evaluation → preliminary evaluation, poorer performing clones will be replaced with better ones to ensure that the clonal pool always contains the best possible clones.

Some of the clones in the clonal pool will be used to make crosses. Seeds will also be provided to collaborating breeding programs as improved material. Some clones from the clonal pool will be ready to distribute after meristem culture and pathogen testing.

Evaluation of new introductions

New introductions from CIP, Japan, and China were evaluated at Bogor for adaptability and DM content. CIP440049 (cv. Mojave) and CIP440230 (cv. Satsumahikari) had the highest DM content and moderate yield. Satsumahikari was very susceptible to various diseases and may be useful only as a parental clone. CIP400004 and CIP400016 gave high yield, but DM content was low (~29%). Three introductions from Japan were very high in DM content (34-40%), but their yield was moderate or low. One of them, Hi-starch, a successful variety in Japan for starch processing, was very susceptible to weevil (*Cylas formicarius*). Many Chinese varieties were high yielding and had good adaptability, but all were low in DM content, far below that of the local checks.

Many CIP pathogen-tested clones were tested for DM content at Bogor for more than two seasons. A few clones varied in DM content, but the variation of most of them was within the acceptable range of about 2%. Among tested clones, CIP 440042 (cv. Macana), CIP440045 (cv. Toquecita), CIP440121 (cv. Naeshirazu), and CIP440146 (IRA-1592) gave high DM content over at least two seasons. CIP400004 (CEMSA 74-228) was also stable, yielding about 30% DM content over three seasons. These clones were chosen as parents for the convergent-divergent selection scheme.

Estimating Heritability for Dry Matter Content

Twenty-two parental clones were selected in preliminary experiments. Some were introduced from CIP-Lima; the others were collected in Indonesia. These parental clones have varied DM content, good flowering, and high yield. Parental clones were planted in a field isolated from other sweetpotatoes, and open-pollinated by natural vectors such as bees. Seeds were collected 30-35 d after flowering. Parental clones were multiplied by taking cuttings from existing plots. Viable seeds were obtained from 18 clones (Table 1). These seeds were used for the heritability study.

Parental clones and their offspring were evaluated for yield and DM content in a separate but adjacent field at Muara Experiment Station, Bogor, in 1995. The field was harvested 150 d after planting. The plot size was 5 m x 1 m, with two rows for each progeny family, and a single row for each parental clone. Both the offspring and parental clones were tested in a randomized complete block design with four replications. Five individual progenies were selected based on a storage root large enough for sampling DM content and free of disease or insect damage. Five storage roots were selected from each individual; each storage root was cut into four longitudinal sections. The longitudinal sections, each from 4 or 5 storage roots, were sliced into strips and mixed well. After 100 g of sliced strips were weighed, the sample was dried in an electric oven for 8 h at 80°C and 6 h at 105°C. DM weight was measured to calculate DM content.

Heritability was estimated by simple linear regression of the response of the maternal parents against the mean response of their half-sibling offspring. Estimation of h^2 was calculated by doubling the regression coefficient (b) for each parameter. Heritability was obtained for DM content, storage roots/plant, storage root weight/plant, storage root size, plant survival rate, and resistance to scab (caused by *Elsinoe batatas*).

The h^2 of the storage-root DM content was 61.2 for family and 58.6 for individual response (Table 2). The high h^2 of family and individual observations in this study agreed with the estimates of other researchers in temperate regions. Heritability of DM content is high enough to make rapid progress with phenotypic selection in a breeding program.

DM content of parent and offspring gave an interesting result. Frequency distribution of progeny according to the DM content of individual plants could be categorized into three groups (Figure 2). In group A, with family BB94505 as an example, most progenies were lower in DM content than their parental clone. In group C, most progenies were higher in DM content compared with their parental clone. In group B, the parental clone was about in the middle of the frequency distribution. Group A has three families, group B has seven, and group C has eight. This grouping indicates that just one cycle of recombination increased the family mean DM content, although there was no direct selection exerted toward high DM content. Parental clones of families BB94517, BB94518, and BB94514 had the lowest DM content of all parents (Table 1). DM content of BB94517 was 21.5%; BB94518, 23.9%, and BB94514, 26.8%. However, the mean DM content of

Table 1. Families and their parents used to estimate heritability in dry matter content of sweetpotato.

Parent	Mean DM content[a] (%)	Range of DM content (%)	Family	Mean DM content[a] (%)	Range of DM content (%)	Family from Figure 2
B0009	33.5 ab	30.8–35.4	BB94501	35.4 a	30.1–41.4	B
B0286	30.3 cd	28.8–31.5	BB94510	34.8 ab	27.1–40.7	C
B0298	30.6 cd	28.2–32.6	BB94511	34.1 abc	26.0–41.5	C
B0068-7	33.7 a	32.5–34.7	BB94507	34.0 abcd	28.4–39.6	B
B0316	35.1 a	33.3–36.6	BB94513	33.8 abcd	30.0–38.1	A
B0315	34.9 a	33.2–35.9	BB94512	33.6 abcd	25.1–37.9	B
B0068	34.5 a	33.7–35.3	BB94506	32.9 abcd	24.2–40.4	B
S0215	29.9 cde	29.2–30.4	BB94520	32.6 abcde	24.8–42.2	C
B0349	21.5 h	19.9–22.8	BB94517	32.3 abcdef	23.3–39.3	C
S0035	23.9 g	21.9–26.5	BB94518	32.3 abcdef	28.4–40.1	C
B0319	26.8 f	25.3–28.6	BB94514	32.0 bcdef	26.4–38.4	C
B0053	31.8 bc	30.6–32.4	BB94505	31.9 bcdef	24.3–35.6	A
B0337	28.0 ef	27.6–28.3	BB94516	31.8 bcdef	22.4–36.1	C
B0329	30.7 cd	30.0–31.5	BB94515	31.6 bcdef	24.2–39.9	B
B0052-5	29.3 de	28.7–29.6	BB94504	31.3 cdef	25.8–35.7	C
B0052-4	30.9 cd	30.0–31.6	BB94503	30.6 def	24.0–36.3	B
S0083	29.9 cde	28.4–32.1	BB94519	29.6 ef	25.2–35.0	B
B0088-11	30.7 cd	29.3–31.8	BB94509	29.1 f	21.5–39.9	A
Average	30.3			32.4		

a. In a column, means followed by the same letter are not significantly different at P≤0.05 by Duncan's multiple range test.

progeny was above 32% for all three families. Dominant genes probably control this trait. This, together with high h^2, is a very encouraging result for breeding high DM content.

Shuttle Breeding

Seven parental clones were selected for hybridization in Japan in 1996 as part of a shuttle breeding scheme. All had high starch content between 24% and 30%, and had white or yellow flesh. The yield of parental clones was about 25 t/ha in Japan. Twelve biparental crosses were made between the parental clones. Grafting was carried out to promote flowering using *Ipomoea nil* as rootstock. Parental clones grown in pots were placed in a greenhouse to isolate them from pollinating insects.

From 14,256 pollinations, 8,910 seeds were harvested. About one-third were sent to Vietnam; the rest were sent to CIP-Bogor. The seeds will be sent to breeding programs in other countries in the region to select high DM clones.

Conclusions

The modified convergent-divergent breeding program for sweetpotato has permitted de-

Table 2. Estimates of narrow-sense heritability in sweetpotato[a].

Trait	Family	Individual
Roots (no./plant)	47.8 ± 0.444	53.8 ± 0.254
Root weight (g/plant)	73.0 ± 0.402	64.8 ± 0.198
Dry matter content (%)	61.2 ± 0.390	58.6 ± 0.196
Root size	76.6 ± 0.296	73.4 ± 0.174
Harvest index	12.0 ± 0.701	
Scab disease	57.6 ± 0.264	

a. Heritability estimates calculated as twice the regression coefficient.

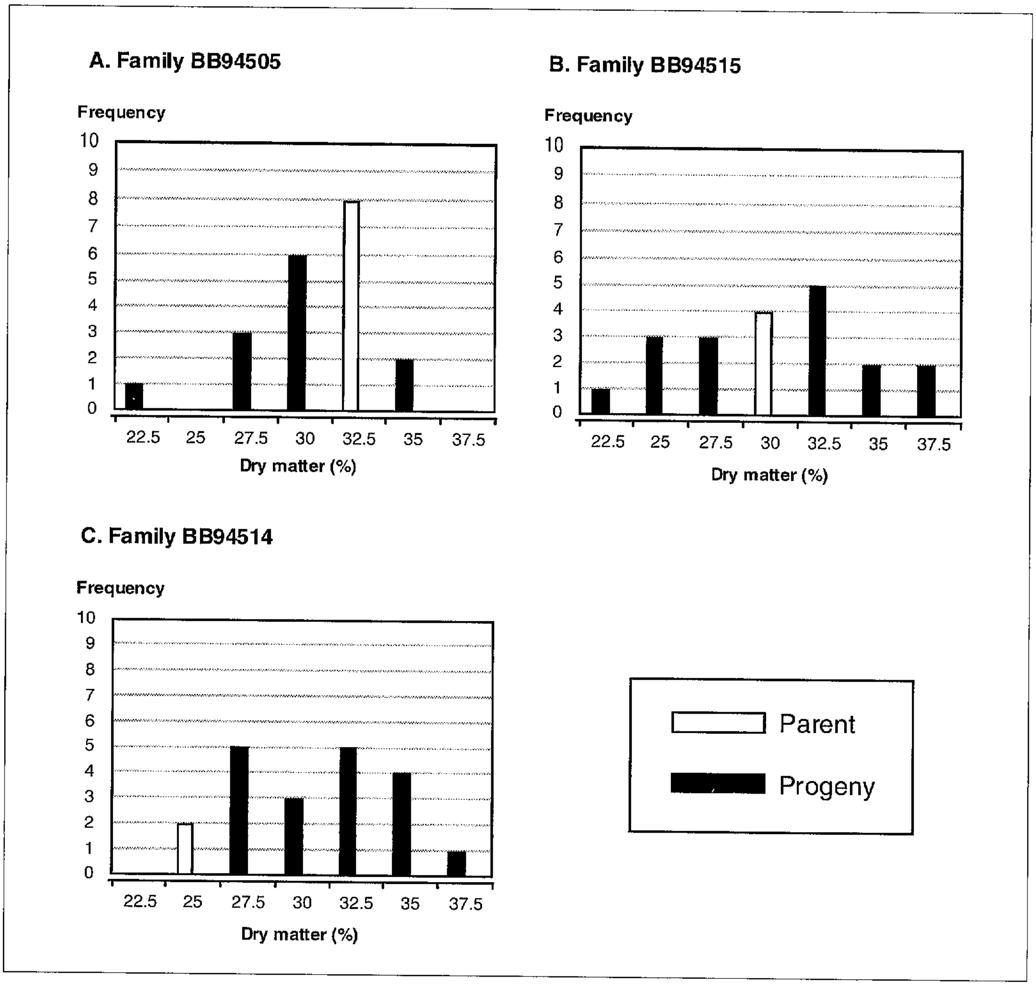


Figure 2. Representative frequency distributions of progeny and parent in 18 sweetpotato families used to estimate heritability of dry matter (DM) content: A, DM content of most progenies was lower than that of the parent; B, parent is in the middle of progeny DM content distribution; C, most of the progenies had higher DM content than that of the parent. CIP, 1995.

velopment of families with the high starch content preferred by processors. Shuttle breeding with Japan has allowed us to combine seed families with high DM content from Japan with local parents with other good agronomic characters. Now, the seed families resulting from the shuttle breeding program are being distributed to NARS, where they are being selected as advanced clones and parents for crosses.

Selected Reading

Carey, E.E., E. Chujoy, T.R. Dayal, H.M. Kidanemariam, H.A. Mendoza, and I.G. Mok. 1992. Combating food shortages and poverty: Sweetpotato breeding for CIP's client countries. CIP Circular 19:1-6.

CIP. 1989. Improvement of sweet potato (*Ipomoea batatas*) in Asia. Report of the workshop on sweetpotato improvement in Asia held at ICAR, India, October 24-28, 1988. 256 p.

Jones, A. 1986. Sweetpotato heritability estimates and their use in breeding. HortScience 21(1):14-17.

Lonnquist, J.H., W.A. Compton, J.L.Geadelmann, F.A. Loeffel, B. Shank, and A.F. Troyer. 1979. Convergent-divergent selection for area improvement in maize. Crop Sci. 19:602-604.

Advances in the Morphological Characterization of Oca, Ulluco, Mashua, and Arracacha Collections

C. Arbizu[1], R. Blas[2], M. Holle[1], F. Vivanco[3], and M. Ghislain[1]

At the beginning, any collection of ARTC is usually large. Morphological characterization is done to identify morphotypes. A morphotype is a group of plants showing morphological similarities, apparently of the same phenotype, but not necessarily of the same genetic constitution. Thus, molecular characterization can follow to identify genotypes.

At this stage, a curator has an efficient collection with a minimum of duplicates. Consequently, the collection is smaller than the original one. Studies on genetic diversity and evaluations such as agronomic characters, nutrition, reaction to biotic and abiotic factors, etc., can be carried out on this kind of material. Once that has been achieved, a core collection (basic sample of a germplasm collection representing the widest range of diversity in terms of morphology, geographical coverage, and genes) can be established. Systematic activities concerning a germplasm collection of Andean root and tuber crops (ARTC) are illustrated in Figure 1.

ARTC collections have been maintained in the Andean ecoregion since the pioneer work of Martín Cárdenas and coworkers in 1958. The number of accessions maintained by Andean germplasm banks has increased dramatically in the last 10 yr as a consequence of projects funded by the International Board for Plant Genetic Resources (IBPGR) in the 1980s and Swiss Development Cooperation (SDC) since 1993. More than 9,000 accessions of ARTC were reported by the Andean gene banks as of 1995. CIP maintains 1,356 accessions of ARTC, including some of their wild allies (Table 1).

Morphological characterization and preliminary evaluation of ARTC in the Andean ecoregion have continued since the time of Cárdenas (Table 2). Almost 6,500 accessions of oca, ulluco, mashua, arracacha, and achira have been morphologically characterized or have undergone preliminary evaluation in the last 38 yr. Most of the work, however, has concentrated only on determining the frequency of accessions for each character. Little has been done to identify morphotypes or duplicates. One of the main constraints for efficient morphological characterization has been the lack of standard descriptors for each crop.

In the present work, morphological characterizations of some Peruvian ocas, ullucos, mashuas, and arracachas were formulated in an attempt to answer the following questions:

1. Can a relevant descriptor list be formulated and tested for each of these crops?
2. Is it possible to identify the best morphological characters within each crop for characterization purposes?
3. What is the level of duplication in ocas, ullucos, mashuas, and arracachas maintained by CIP?
4. Is it feasible to have an efficient collection (minimum of duplicates) of oca, ulluco, mashua, and arracacha in the Andean ecoregion, with the material maintained by CIP?

To answer these questions, three stages of research were followed:

1 CIP, Lima, Peru.
2 Universidad Nacional Agraria La Molina, Lima, Peru.
3 Universidad Nacional del Centro del Perú, Huancayo, Peru.

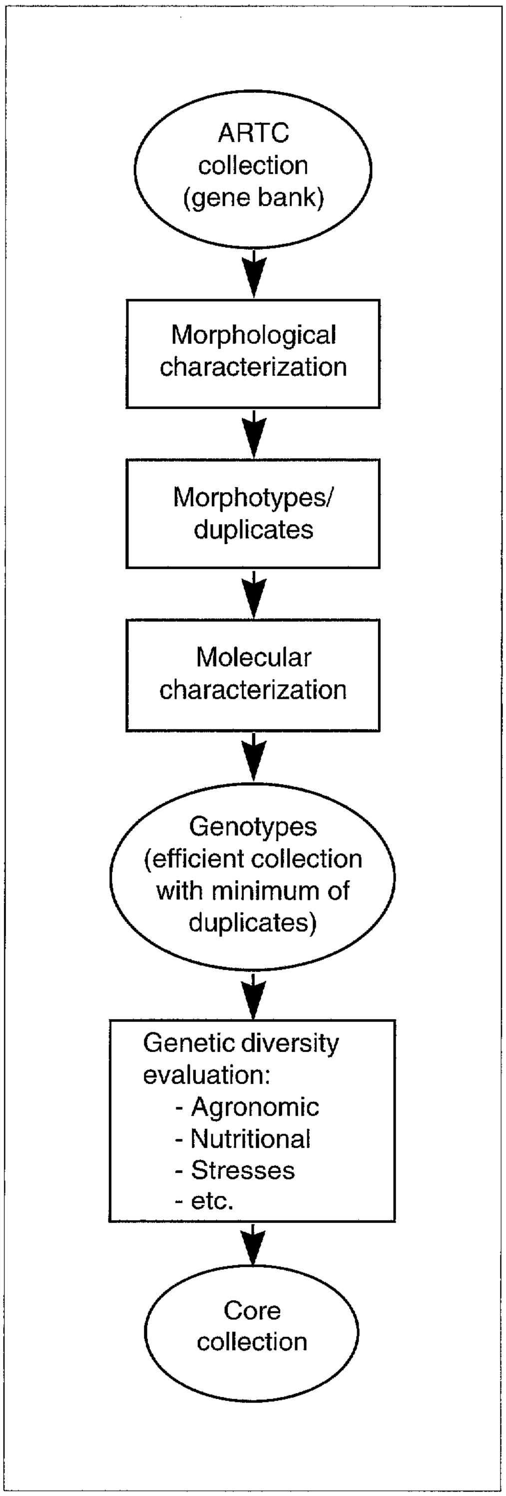


Figure 1. Strategy for handling collections of Andean root and tuber crops.

- Stage 1. Grouping accessions of oca, ulluco, mashua, and arracacha according to their morphological similarities to identify morphotypes.
- Stage 2. Recording the highly stable characters within each accession of the crop and analyzing the data by cluster analysis.
- Stage 3. Using molecular characterization to identify genotypes of arracacha.

Materials and Methods

In stage 1, 227 accessions of oca, 149 of ulluco, 66 of arracacha, and 64 of mashua, collected from different agroecological zones of the Peruvian Andes, were grouped visually into morphotypes according to their morphological similarities. This grouping was performed in Huancayo (3,200 m above sea level) during three cropping seasons (1993-95). The work on arracacha was conducted in La Molina (240 m) and Huancayo (3,200 m) from 1994 to 1996.

The work of stage 2 was performed almost simultaneously to the visual morphological grouping. We recorded 28 characters for arracacha, 24 for oca, 21 for ulluco, and 18 for mashua. For each accession, we recorded qualitative characters, which appear not to be influenced by environment and are supposed to give a better resolution of the groups. Characters of the aboveground parts were recorded at flowering or in the adult stage, whereas characters of the underground parts were recorded immediately after harvest. Color characters were recorded according to the Royal Horticultural Society Color Chart of 1995. Data were analyzed by cluster analysis.

In stage 3, we attempted molecular characterization on the 66 accessions of Peruvian arracachas using randomly amplified polymorphic DNA (RAPD) markers.

Results and Discussion

Grouping 506 accessions visually according to their morphological similarities resulted in

Table 1. Andean root and tuber crops maintained by CIP (Dec. 1996).

ARTC/origin[a]	Col	Ecu	Per	Bol	Arg	Chl	Bra	Total
Oca	–	–	337	81	57	7	–	482
Ulluco	4	2	320	81	39	–	–	446
Mashua	–	–	84	4	4	–	–	92
Arracacha	1	–	66	–	–	3	21	91
Achira	10	13	34	1	–	7	–	65
Yacón	–	2	37	4	1	–	–	44
Maca	–	–	33	–	–	–	–	33
Mauka	–	–	5	–	–	–	–	5
Ahipa	–	–	4	4	–	–	–	8
Wild allies of ARTC	–	4	84	2	–	–	–	90
Total	15	21	1,004	177	101	17	21	1,356

a. Col = Colombia, Ecu = Ecuador, Per = Peru, Bol = Bolivia, Arg = Argentina, Chl = Chile, Bra = Brazil.

Table 2. Morphological characterization or preliminary evaluation of Andean root and tuber crops[a]. CIP, Peru, 1996.

Crop	Accessions (no.)	Years	Reports (no.)	Investigators (no.)	Institutions[b]
Ulluco	2,168	1958-1996	16	18	IICA, INIAP, IBTA, INIA, UNA,UNALM, UNSAAC, UNSCH, UNCP, UNT
Mashua	955	1958-1996	15	17	IICA, INIAP, IBTA, INIA, UNA,UNALM, UNSAAC, UNSCH, UNCP
Oca	2,836	1958-1996	13	16	IICA, INIAP, IBTA, INIA, UNA,UNALM, UNSAAC, UNSCH, UNCP, URP
Arracacha	473	1965-1996	8	9	IICA, INIAP, INIA, UNC, CIP
Achira	64	1987-1995	3	3	UNSCH, CIP
Total	6,496	1958-1996	55	63	12 different

a. An archive of these characterizations is kept by the senior author.

b. IICA = Instituto Interamericano de Cooperación para la Agricultura, Ecuador; INIAP = Instituto Nacional de Investigaciones Agropecuarias, Ecuador; IBTA = Instituto Boliviano de Tecnología Agropecuaria, Bolivia; UNT = University of Turku, Finland; INIA = Instituto Nacional de Investigación Agraria, Peru; UNA = Universidad Nacional del Altiplano, Peru; UNSAAC = Universidad Nacional de San Antonio Abad del Cusco, Peru; UNSCH = Universidad Nacional de San Cristóbal de Huamanga, Peru; UNCP = Universidad Nacional del Centro del Perú, Peru; URP = Universidad Ricardo Palma, Peru; UNALM = Universidad Nacional Agraria La Molina, Peru; UNC = Universidad Nacional de Cajamarca, Peru; CIP = Centro Internacional de la Papa.

the identification of 146 morphotypes of oca, 92 of ulluco, 51 of mashua, and 31 of arracacha. The most important point, however, is that cluster analysis also identified the same morphotypes within each crop, that is, it confirmed the morphotypes identified by visual grouping.

Thus, 52% of the Peruvian arracachas, 38% of the ullucos, 36% of the ocas, and 20% of the mashuas maintained by CIP are probably duplicates. An example in which cluster analysis confirmed the identification of morphotypes is shown in the phenogram of arracacha (Figure 2). It can be seen that the 66 accessions of arracacha were clustered into 31 morphotypes and 4 groups at a taxonomic distance of about 1.5.

In stage 3, the morphotypes identified in stages 1 and 2 were further checked by applying RAPD marker analysis to the 66 accessions of arracacha. Fifteen RAPD primers were selected out of 31 because of their good reproducibility and polymorphism. These selected RAPD primers generated 75 RAPD markers polymorphic with the 66 accessions of arracacha. The markers resolved the 66 accessions of arracachas into 32 genotypes at a similarity coefficient of 0.88.

Only one morphotype did not match with the molecular clustering; it was split into two genotypes. The results of morphological (31 morphotypes) and molecular characterization (32 genotypes) suggest an almost perfect congruence. Therefore, these results demonstrate the value and accuracy of morphological characterization.

The lack of a perfect congruence could be explained by the fact that other qualitative and quantitative characters, not considered in the cluster analysis, were probably detected by RAPD. Thus, the genotypes of arracachas identified by molecular characterization suggested that 51% of the Peruvian arracachas maintained by CIP could be duplicates.

Table 3 presents the latent roots (variance on each axis) and their relative contribution to total variation of the principal component analysis. The first 18 principal components contributed to about 96% of the total variation of the ocas, 100% of the ullucos, 100% of the mashuas, and 99% of the arracachas. The first three components accounted for about 37% of the total variation in oca, 47% in ulluco, 49% in mashua, and 51% in arracacha. The first principal component appeared more important than the others in contribution to variation in ulluco and arracacha. No such demarcation was apparent between important and unimportant principal components in oca and mashua.

Table 4 presents the six main characters that delineated the accessions of oca, ulluco, mashua, and arracacha into separate morphotypes and groups in the first three principal components.

In oca, plant, inflorescence, and tuber characters such as petiole color, stem color, peduncle and pedicel color, sepal color, and predominant and secondary tuber flesh color were the most important discriminatory characters associated with the first component axis. But they did not indicate a clear demarcation between the ones that contributed substantially to the first principal component and those that did not.

Additionally, the first principal component accounted for only 15.7% of the variance (Table 3). The second principal component is comparable in importance to the first one in that it accounted for 12% of the variance (Table 3). Stem, peduncle, and pedicel color, all of which were important contributors to the first principal component, were also major discriminatory characters associated with the second principal component (Table 4). Other characters associated with the second principal component were predominant abaxial leaflet color, distribution of abaxial secondary leaflet color, sprout shape, and petal color. Secondary abaxial leaflet color and distribution of abaxial secondary leaflet color are characters that appear to contribute more than sepal color, depth of eyes, secondary tuber flesh color, and distribution of

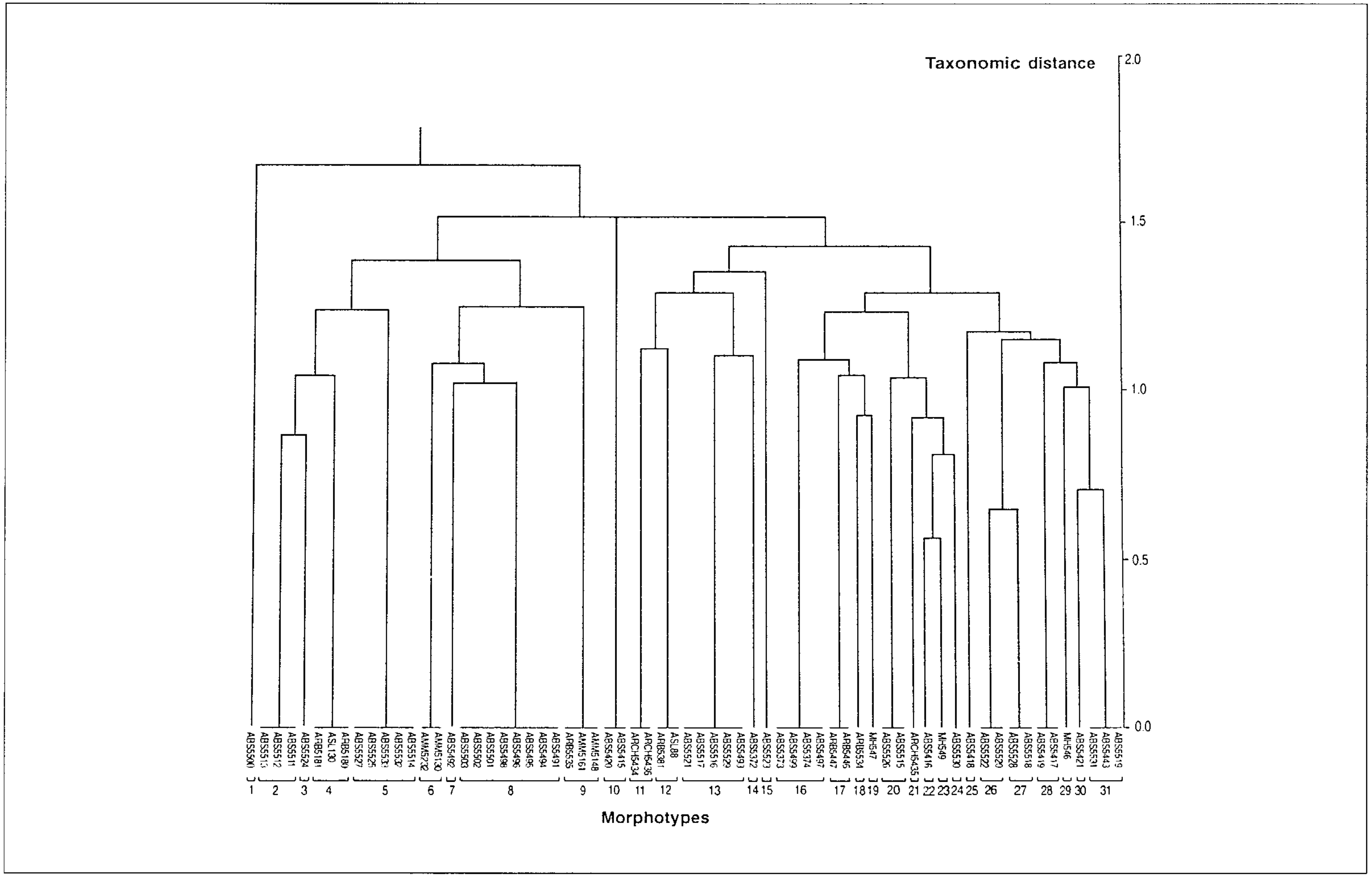


Figure 2. Phenogram clustering 66 accessions of Peruvian arracachas.

Table 3. Latent root and percentage of total variation of the first 18 principal component axes for the material studied. CIP, Lima, Peru, 1996.

Principal component	Oca			Ulluco			Mashua			Arracacha		
	Latent root (no.)	Variation (%)	Cumulative variation (%)	Latent root (no.)	Variation (no.)	Cumulative variation (%)	Latent root (no.)	Variation (%)	Cumulative variation (%)	Latent root (no.)	Variation (%)	Cumulative variation (%)
1	3.76	15.7	15.7	5.27	26.4	26.4	3.40	18.9	24.1	24.1	18.9	6.74
2	2.88	12.0	27.7	2.45	12.2	38.6	3.09	17.2	15.4	39.5	36.1	4.32
3	2.33	9.7	37.4	1.77	9.8	47.4	2.38	13.2	11.3	50.8	49.3	3.16
4	2.20	9.2	46.6	1.67	8.4	55.8	1.62	9.0	8.5	59.3	58.3	2.38
5	1.73	7.2	53.8	1.56	7.8	63.6	1.49	8.3	6.7	66.0	66.6	1.88
6	1.33	5.6	59.4	1.20	6.0	69.7	1.21	6.7	6.2	72.2	73.3	1.73
7	1.25	5.2	64.6	0.96	4.8	74.5	0.94	5.2	4.8	77.0	78.5	1.34
8	1.07	4.4	69.0	0.88	4.4	78.9	0.85	4.7	4.1	81.1	83.3	1.16
9	1.02	4.3	73.3	0.74	3.7	82.6	0.72	4.0	3.5	84.6	87.3	0.99
10	0.93	3.9	77.2	0.63	3.2	85.8	0.61	3.4	3.0	87.7	90.7	0.84
11	0.75	3.1	80.3	0.61	3.1	88.8	0.42	2.3	2.9	90.5	93.0	0.80
12	0.70	2.9	83.2	0.59	3.0	91.8	0.36	2.0	2.1	92.7	95.0	0.60
13	0.66	2.7	86.0	0.42	2.1	93.9	0.31	1.7	1.8	94.4	96.7	0.49
14	0.60	2.5	88.5	0.37	1.8	95.7	0.27	1.5	1.1	95.6	98.2	0.32
15	0.58	2.4	90.9	0.32	1.6	97.3	0.13	0.7	1.1	96.7	99.0	0.30
16	0.51	2.1	93.0	0.22	1.1	98.4	0.10	0.6	0.9	97.5	99.5	0.24
17	0.38	1.6	94.6	0.16	0.8	99.2	0.06	0.4	0.6	98.2	99.9	0.18
18	0.30	1.3	95.9	0.06	0.3	99.6	0.02	0.1	0.6	98.8	100.0	0.17

Table 4. Major characters[a] associated with the first three principal component axes of 227 accessions of oca, 149 of ulluco, 64 of mashua, and 66 of arracacha. Peru, 1994-96.

Crop	Principal component 1	Principal component 2	Principal component 3
Oca	Petiole color (0.719)	Predom. abaxial leaflet color (-0.644)	Sec. abaxial leaflet color (-0.714)
	Ped. and pedicel color (0.711)	Stem color (-0.633)	Distrib. sec. abaxial leaflet color (-0.707)
	Sec. tuber flesh color (0.659)	Sprout shape (-0.522)	Distrib. sec. tuber flesh color (0.522)
	Stem color (0.620)	Ped. and pedicel color (-0.476)	Sec. tuber flesh color (0.443)
	Predom. tuber flesh color (-0.593)	Petal color (-0.463)	Depth of eyes (0.386)
	Sepal color (0.551)	Distrib. sec. abaxial leaflet color (0.457)	Sepal color (-0.382)
Ulluco	Sec. tuber flesh color (0.888)	Sec. tuber skin color (0.540)	Plant type (-0.449)
	Distrib. sec. tepal color (0.818)	Distrib. sec. tuber skin color (0.516)	Leaf shape (-0.431)
	Distrib. sec. tuber flesh color (0.798)	Tuber shape (0.513)	Foliage color (-0.422)
	Sec. tepal color (0.792)	Tepal base color (0.465)	Sec. tuber skin color (-0.400)
	Predom. tuber skin color (0.714)	Depth of eyes (-0.441)	Intensity tuber skin color (-0.399)
	Tepal base color (0.555)	Predom. tuber flesh color (0.438)	Leaf size (0.355)
Mashua	Distrib. sec. stem color (0.770)	Intensity tuber skin color (-0.729)	Predom. tuber skin color (0.839)
	Predom. stem color (-0.768)	Sec. tuber flesh color (0.685)	Sec. tuber skin color (-0.641)
	Sec. stem color (0.745)	Distrib. sec. tuber flesh color (0.681)	Tuber shape (-0.450)
	Twining (-0.617)	Predom. tuber flesh color (-0.670)	Predom. tuber flesh color (0.423)
	Distrib. sec. tuber flesh color (0.527)	Sec. stem color (-0.531)	Sec. tuber flesh color (0.421)
	Mature leaf color (-0.502)	Predom. stem color (0.451)	Distrib. sec. tuber skin color (-0.407)
Arracacha	Acumen terminal leaflet (-0.769)	Foliage color (-0.743)	Stor. root shape (-0.613)
	Sec. stor. root surf. color (0.707)	Sec. abaxial leaflet color (-0.682)	Predom. propag. surf. color (-0.542)
	Leaflet margin color (0.687)	Distrib. sec. abaxial leaflet color (-0.670)	Predom. abaxial leaflet color (-0.538)
	Sec. propag. flesh color (0.681)	Sec. stor. root flesh color (0.621)	Wax on petiole (-0.487)
	Distrib. propag. flesh color (0.681)	Predom. petiole color (-0.600)	Distrib. sec. petiole color (-0.471)
	Predominant petiole color (0.651)	Sec. propag. flesh color (0.548)	Leaflet margin (0.469)

a. Distrib. = distribution, ped. = peduncle, predom. = predominant, propag. = propagule, sec. = secondary, stor. = storage, surf. = surface.

secondary tuber flesh color to the third principal component (Table 4), which accounted for 9.7% of the variance (Table 3).

For ulluco, tuber and tepal characters contribute to the first and second principal components, whereas plant and tuber characters are the important delineating characters in the third component. Tuber characters such as shape, predominant skin color, secondary skin color, distribution of secondary skin color, intensity of skin color, predominant flesh color, and secondary flesh color were reported by Finnish scientists to be stable characters. A number of Andean investigators have also been using ulluco tuber characters along with plant type, foliage color, leaf shape, and leaf size to study variation of ulluco in the ecoregion, but only some of them considered tepal features.

Mashua. Tuber and plant characters are important determining characters in the first, second, and third principal components in mashua. As in ulluco, the characters identified for mashua in the present work have been used to study morphological variation of the plant in the Andes, but have not been analyzed or interpreted appropriately.

Arracacha. Leaves, propagules, and storage-root characters were shown to be important determinants of morphotypes in arracacha. Leaf characters were the most highly variable in Ecuadorian arracachas. Four leaf characters and 3 storage root characters were also used by scientists in Ecuador to identify 17 morphotypes of arracacha. Four leaf characters were also used to characterize arracachas morphologically in northern Peru.

Conclusions

Morphological characterization by grouping accessions according to their morphological similarities and by cluster analysis proved to be accurate and reliable tools to identify morphotypes in ARTC collections. Molecular characterization in arracacha indicated that grouping and cluster analysis gave consistent results.

Our results suggest that Andean gene banks can use visual grouping alone to identify morphotypes and duplicates in their ARTC collections at relatively low cost. Cluster analysis, if it could be afforded, would confirm grouping results. Molecular characterization could be used only at an advanced stage following visual grouping and cluster analysis.

The grouping patterns of morphotypes in oca, ulluco, mashua, and arracacha show different geographical origin. Accessions from different agroecological zones of Peru were grouped by principal components into the morphotypes indicated above. Therefore, it is likely that ethnic groups were responsible for disseminating, maintaining, and using these crops in the Andean ecoregion.

The use of qualitative morphological characters (Table 4) resulted in an excellent resolution of the morphotypes for each crop. These characters could be the basis of descriptor lists for oca, ulluco, mashua, and arracacha for morphological characterization to optimize their handling and use in Andean gene banks.

Selected Reading

Cárdenas, M. 1969. Manual de plantas económicas de Bolivia. Imprenta Icthus, Cochabamba, Bolivia. 410 p.

León, J. 1964. Plantas alimenticias andinas. Boletín Técnico No. 6, Instituto Interamericano de Ciencias Agrícolas, Zona Andina. Lima, Perú. 112 p.

National Research Council. 1989. Lost crops of the Incas: Little-known plants of the Andes with promise for worldwide cultivation. National Academy Press, Washington, D.C. 415 p.

PROGRAM REPORT

Program 3

Disease Management

Luis F. Salazar[1]

The major activities of the Disease Management Program during 1995-96 included research on the control of late blight, bacterial wilt, and virus diseases of potato, sweetpotato, and Andean root and tuber crops (ARTC). The program's strategy is to combine basic and applied research, and this is carried out at headquarters or in collaboration with scientists in developed countries when required.

Late Blight

Late blight (LB) research saw major advances in the improvement of breeding populations (population B) that carry significant levels of non-race-specific and durable (horizontal) resistance to the causal fungus *Phytophthora infestans* due to their minor genes of quantitative inheritance. Three sets of population B (B1, B2, and B3) are now being tested for improved LB resistance. Population B1 was developed through several recombination cycles of resistance sources of *Solanum andigena*. Population B2 was obtained from crosses between *S. andigena* and *S. tuberosum* sources of resistance. Population B3, the most advanced source of horizontal resistance available at CIP, was selected from population A, a previous LB-resistant population carrying both quantitative and qualitative types of resistance. B3 contains mostly *S. demissum*-derived horizontal resistance improved mainly in an *S. tuberosum* germplasm background.

1 Program Leader, CIP, Lima, Peru.

Correlation studies conducted on LB evaluation results from Mexico and Colombia have shown that B3 resistance is stable under those two diverse physical environments and pathogen populations. Widening adaptation of the B3 population to long days in Argentina (at 38°S latitude) and China (at 40°N and 26°N latitude) is in progress.

Additionally, extreme resistance to potato virus X (PVX) and potato virus Y (PVY) from CIP genotypes that carry the genes for virus resistance in triplex (XXXxYYYy) is being introduced into population B3. Further improvement of B1 and B2 populations continues.

A new group of LB-resistant materials (population C) is at the prebreeding stage of development at CIP-Lima. This breeding stock now comprises 186 diploid potato hybrids that carry factors of resistance to foliage blight from 13 species of wild and native cultivated potato. The prebreeding effort aims at introgressing durable resistance to late blight into population C breeding stock. Population C will be a core collection of a wide range of diverse resistances in ready-to-use potato breeding clones.

CIP's major emphasis in LB research was until recently on building resistance to the fungus for use by NARS in integrated disease management (IDM). With the Global Initiative on Late Blight (GILB) now in operation, the IDM approach will receive high priority. Research on and application of other IDM components such as the use of appropriate agronomic practices, use of clean seed, or biological control will be encouraged.

Bacterial Wilt

Research on controlling bacterial wilt (BW) of potato, caused by *Ralstonia (Pseudomonas) solanacearum,* was particularly addressed to IDM components. The use of clean seed tubers, identified by the enzyme-linked immunosorbent assay, has proved an effective BW control measure in Indonesia. Because it has proven difficult to build genetic resistance to BW into acceptable genotypes, we reduced efforts on this approach. Remaining activities conducted in collaboration with some national agricultural research systems (NARS) were mainly directed to evaluating BW resistance of promising genetic materials generated in CIP. Some BW-resistant potato clones, also carrying acceptable levels of resistance to LB, have been selected in Indonesia and China.

In other studies on IDM components, preliminary experiments in China suggested good possibilities of using bacterial suspensions of two strains of *Bacillus* for the biological control of BW. Farmer participatory experiments in Uganda showed that improved IDM packages that include a resistant cultivar, clean seed, adequate planting space, roguing of volunteer potatoes, sanitation, and minimum cultivation increased yields up to 75%.

Virus Diseases

New virus diseases were found to threaten potato production in some countries. Among these, yellow vein in Ecuador and Colombia, Saq'o in Bolivia, deforming mosaic in Brazil, and rough dwarf or potato virus P (PVP) in Argentina and Brazil deserve mention. Yellow vein is by far the most important because of its effect on yield. Although the virus has not yet been identified, evidence indicates it is a virus with unusual characteristics. The putative virus is apparently prevalent in weeds and other crops and moves into the potato crop through its whitefly vector *Trialeurodes vaporariorum.* Studies on Saq'o suggested the involvement of an unusual strain of potato leafroll virus (PLRV). Other yet-unidentified phytoplasma-like microorganisms also appear to be implicated in the Saq´o disease. The other viruses mentioned are still under study in collaboration with scientists in Brazil and Argentina.

Deforming mosaic from Brazil appears different from that reported years ago from Argentina. It is probably a geminivirus, whereas rough dwarf in Argentina or PVP in Brazil is a carlavirus resembling the well-known potato virus S (PVS), which causes severe symptomatology in potato.

Phytoplasmas, formerly known as mycoplasmas, have also spread in recent years. They have caused severe damage, particularly to seed tuber production in Peru and Mexico. Because of the importance of these diseases, we have diverted limited funds to study these pathogens. Our major activities are directed toward developing sensitive detection technology for all these diseases.

Because pathogens usually interact in nature in a positive or negative manner, we are studying these plant-pathogen interactions in detail. An example of a negative interaction having epidemiological significance is transmission of the potato spindle tuber viroid (PSTVd) by aphids when PSTVd and PLRV co-infect potato plants. Molecular experiments showed the transmission to occur through encapsidation of the small PSTVd molecule in particles of the aphid-transmitted PLRV. Spread of the viroid through encapsidation has occurred in potato crops in China.

An important interaction among pathogens of the positive type is the significant reduction in the rate of *P. infestans* (LB) development in potato plants infected with PVX, PVY, or PVS. Virus-infected plants showed reduced penetration of zoospores and reduced sporulation of the fungus, thus reducing the number and size of lesions. With viruses such as PVS that have no significant effect on yield, this interaction will be further explored as a component of IDM.

Molecular approaches are seen as an important complement to traditional breeding for resistance to virus diseases. In collaboration with the Sainsbury Laboratory in the United Kingdom, molecular characterization of virus resistance genes in potato was continued. For the *Rx* gene (conferring extreme resistance to PVX), a BAC (bacterial artificial chromosome) library for the cloning of Ry_{adg} has already been developed and isolation of the *Rx* locus is under way. For *Ry* (conferring extreme resistance to PVY), molecular characterization of the Ry_{sto} locus is in progress at Sainsbury.

Virus-free planting materials were evaluated for the control of sweetpotato virus diseases. In China, virus-free planting materials outyielded farmers' seed by at least a factor of 2. Efficient virus detection technology is essential to produce virus-free planting materials. We are continuing virus identification and characterization studies. Several newly recorded viruses have been characterized. Studies on sweetpotato virus disease (SPVD) suggested that one of the two components, the whitefly-borne closterovirus (WBV), varies in its interaction with sweetpotato feathery mottle virus (SPFMV), depending on the region where SPVD occurs.

Our previous hypothesis that control of SPFMV was sufficient to control SPVD was not borne out in Uganda, where cultivars highly resistant to SPFMV degenerate with SPVD. Apparently WBV *breaks* the resistance to SPFMV and SPVD develops. Our new strategy calls for developing WBV resistance. If host-mediated resistance cannot be found in CIP sweetpotato germplasm or elsewhere, development of transgenic resistance will be attempted using virus-derived genes.

Andean Root and Tuber Crops

Research on ARTC diseases allowed us to develop a manual on ARTC diseases to be published soon. In addition to ARTC-specific viruses, there are some important potato viruses that also attack ARTC. From an epidemiological point of view, these findings are important for developing viral control measures in both potato and ARTC.

Developing Horizontal Resistance to Late Blight in Potato

J.A. Landeo[1], M. Gastelo[1], G. Forbes[1], J.L Zapata[2], and F.J. Flores[3]

Late blight (LB) disease in potato, caused by *Phytophthora infestans*, is one of the major diseases researched at CIP since its founding. It is a cause of serious potato production losses, particularly in less developed countries around the world. CIP scientists have always believed that host resistance could play an important role in the management of the disease, particularly in CIP's client countries. Therefore, breeding for resistance has been a major endeavor since its early days.

During the early 1980s, CIP researchers began to exploit their own breeding population assembled from *Solanum demissum*-derived advanced sources of resistance introduced into *S. tuberosum* subsp. *tuberosum*, *Neotuberosum*, and *S. tuberosum* subsp. *andigena* germplasm, and four-way hybrids between *S. acaule*, *S. bulbocastanum*, *S. phureja*, and *S. tuberosum* (ABPTs). Through a testing strategy that included Peru, Colombia, and Mexico, by the end of the decade some 300 clones with various levels of horizontal resistance to LB and good agronomic attributes, including quality, were selected. They were made available to client countries on all continents.

From 1990 to 1996, more than 30 LB-resistant varieties were released in 15 countries (Table 1). A particular feature of this breeding population is that horizontal resistance was improved in the presence of undesired, unknown major (R) genes for vertical resistance (population A). Their presence, rather than contributing to the overall resistance, made the recognition of true horizontal resistance and effective gene frequency upgrading more difficult.

Starting in 1990, following a LB strategy review at CIP, a new breeding strategy was designed to upgrade horizontal resistance in the absence of R genes (population B). The absence of R genes, or removing their interference in assessing true horizontal resistance, has already resulted in a more efficient breeding scheme. We are witnessing an increase in gene frequencies and higher levels of resistance along with traits of agronomic value.

The new strategy includes the development of three independent subpopulations to broaden the genetic diversity for resistance and maximize the use of horizontal resistance from cultivated germplasm. The first population is derived from a wide sample of native cultivars from *S. tuberosum* subsp. *andigena* (B1). The second is derived from the same source of *S. andigena*, but crossed only once to R-gene-free *S. tuberosum* cultivars to improve some agronomic traits lacking in *S. tuberosum* subsp. *andigena* (B2). The third, which is the most advanced agronomically, is derived from population A (B3).

Progress in developing population B3 is reported here since this breeding population receives major emphasis in CIP's research program. It has many desirable agronomic characters and good levels of horizontal resistance obtained from sources of population A.

Quantifying Horizontal Resistance in B3

Materials and methods

The experimental material included progenies obtained following a line x tester

1 CIP, Lima, Peru.
2 Corporación Regional del Instituto Colombiano Agropecuario (CORPOICA), Ríonegro, Colombia.
3 Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP), Toluca, Mexico.

Table 1. Varieties released from late-blight-resistant breeding population A, 1990-96.

Region	Country	CIP number	Local name
Latin America and the Caribbean	Bolivia	385240.2	Chaposa
	Colombia	382119.20	Unnamed
	Costa Rica	386040.9	Birris
		386056.7	Floresta
	Ecuador	384638.1	INIAP-Sta. Rita
		388790.24	INIAP-Fripapa
		382119.20 B	INIAP-Rosita
		388749.3	INIAP-Margarita
	Guatemala	382170.101	ICTA Xalapan
	Panama	381381.13	IDIAP 92
		381390.30	IDIAFRIT
		382171.10	PRECODEPA
	Peru	380389.1	Canchán-INIAA
		384866.5	Amarilis-INIA
		377744.1	Kori-INIA
		380496.6	Chagllina-INIA
	Venezuela	380013.2	Andina
Sub-Saharan Africa	Burundi	381381.9	Rukinzo
		381381.26	Ingabire
		382147.18	Jubile
	Cameroon	381381.13	Cipira
		381406.6	Tubira
	Ethiopia	378501.16	Sissay
	Kenya	381381.13	Tigoni
		381381.20	Asante
	Rwanda	381381.3	Nderera
		381395.1	Ngunda
		382120.14	Kigega
		383140.6	Mugogo
		386003.2	Mizero
		387233.24	Gikungu
	Uganda	381379.9	Kisoro
		381381.20	Victoria
	Zaire	378699.2	Kinigi
		380583.8	Baseko
		380606.6	Enfula
		386022.22	Nurula

mating design of a sample of R-gene-free clones.

Three clones were used as male testers. Quarantine-produced tuber families of the progenies obtained were arranged in incomplete simple lattice designs with two replications and sent for testing under local LB epidemics to two sites in Cajamarca, Peru, and one site each in Ríonegro, Colombia, and Toluca, Mexico, during the growing season. Percentage of leaf area infected was recorded for 6 consecutive weeks and average apparent infection rates per family were calculated to quantify horizontal resistance.

Likewise, family average total tuber weight per plant was used for yield. Analysis of variance was determined for the line x tester mating design, and the source of variance due to clones was used to calculate the general combining ability variance, which is associated with the additive portion of the total genetic variance. At each of the three sites, narrow-sense heritability for resistance and yield was estimated following standard procedures. Combined analyses were not attempted because different line samples and testers were used for Peru, Colombia, and Mexico.

Results

The mean squares for clones at all sites were highly significant for resistance and yield. Combining ability variances, calculated from the sources of variation of the clones, and heritabilities ranged from 0.41 to 0.71 for resistance and from 0.24 to 0.51 for yield (Table 2). These estimates indicate that both characters are at mid to high levels for a quantitative trait.

The values may be somewhat inflated, however, because of the contribution of the source genotype x environment interaction, which was not isolated from the main source of genetic variation. In this sampled population, additive genetic variances have magnitudes significant enough to ensure progress in breeding and selection for outstanding LB-resistant clones with attributes to become varieties.

Correlation Studies for Horizontal Resistance to Late Blight in B3

In the process of continuing improvement of population B3 at CIP, correlation studies for LB resistance were conducted in samples of this population for two consecutive years (1995 and 1996) at two LB endemic sites with contrasting ecologies and pathogen populations. The sites chosen were Toluca, Mexico, and Ríonegro, Colombia.

Materials and methods

The sample tested in 1995 was composed of 60 families from intercrosses between the first lot of R-gene-free parents (47 clones) and contained approximately 6,000 individuals. The sample tested in 1996 included another 60 families with approximately 8,000 individuals. They were both tested for LB resistance in the field at Ríonegro and Toluca, the samples being exact duplicates at each site. Families in the 1995 sample were not replicated, whereas families in the 1996 sample were replicated and arranged in the field in an incomplete simple lattice design. Six weekly readings on percentage of foliage infection were taken for every individual during the season at both sites in 1995; four

Table 2. Estimates of heritability for horizontal resistance to late blight and total tuber yield in a sample of clones free of R genes from population B3.

Trait	Peru		Colombia	Mexico
	Site 1	Site 2		
Late blight resistance	0.71	0.56	0.41	0.43
Total tuber yield	0.25	0.52	0.24	0.26

weekly readings were taken in 1996. The area under the disease progress curve (AUDPC) was calculated and used as a parameter for resistance. Averages of AUDPC per family were used to rank families at both sites and Spearman's rank correlation was performed.

Results

The combined analysis of variance for the 1996 sample (CV = 17%) indicated that the family source of variation was highly significant whereas the environment source of variation was not. However, the family x environment interaction was also significant. This indicates that family performance for resistance varies significantly and that some may have performed differentially at each of the two sites. After calculating the correlation coefficient, however, which was also significant and quite high ($r = 0.79$ for 1995 and $r = 0.82$ for 1996), it seems that there is a linear association between resistance performances of families at the two sites (Figure 1).

The coefficients of determination ($R^2 = 0.61$ for 1995 and $R^2 = 0.66$ for 1996) indicate that the linear association between the family performances at these two sites can be explained by about 60%. That leads us to conclude at this point that the expression of horizontal resistance to LB present in this improved source is rather stable and was not affected significantly by divergent environments. The genotype x environment interaction, although present, may not be as high as earlier suspected according to our results.

On the basis of these results, whereby testing was conducted under LB disease pressure of two endemic locations, we can conclude that horizontal resistance, under improvement in the B3 population, is in fact expressed effectively in a wide range of the pathogen and under contrasting environments. Toluca is noted for containing the most diverse pathogen populations of *P. infestans*, including both asexual and sexual stages of the fungus; in Ríonegro the disease pressure is more uniform and higher than in Toluca throughout the season, but less diverse. Thus, either site can be used to effectively test and select for stable horizontal resistance to LB.

Conclusions

Classical breeding approaches applied to population B as a continuation of population A improvement have been quite efficient in upgrading gene frequencies for horizontal resistance to LB, together with important agronomic traits. B3, the most advanced source of resistance, is at the stage of being readily used by breeding programs. It is also being further improved at CIP through recurrent selection with progeny testing.

Further improvement is foreseen in achieving higher levels of stable resistance, broadening its genetic diversity, increasing adaptability to a wider range of daylengths, and gradual combination with other important disease and pest resistance or tolerance. Marker-assisted selection, as it becomes applicable and practical, is contemplated to further increase accuracy and efficiency in the overall process of selection for horizontal resistance to LB.

Selected Reading

CIP (International Potato Center). 1973-74. Program planning conferences. Report of the program planning conferences held at CIP during 1973 and 1974. Lima, Peru. 384 p.

CIP (International Potato Center). 1989. Fungal diseases of the potato. Report of the planning conference on fungal diseases of the potato held at CIP, September 21-25, 1987. Lima, Peru. 216 p.

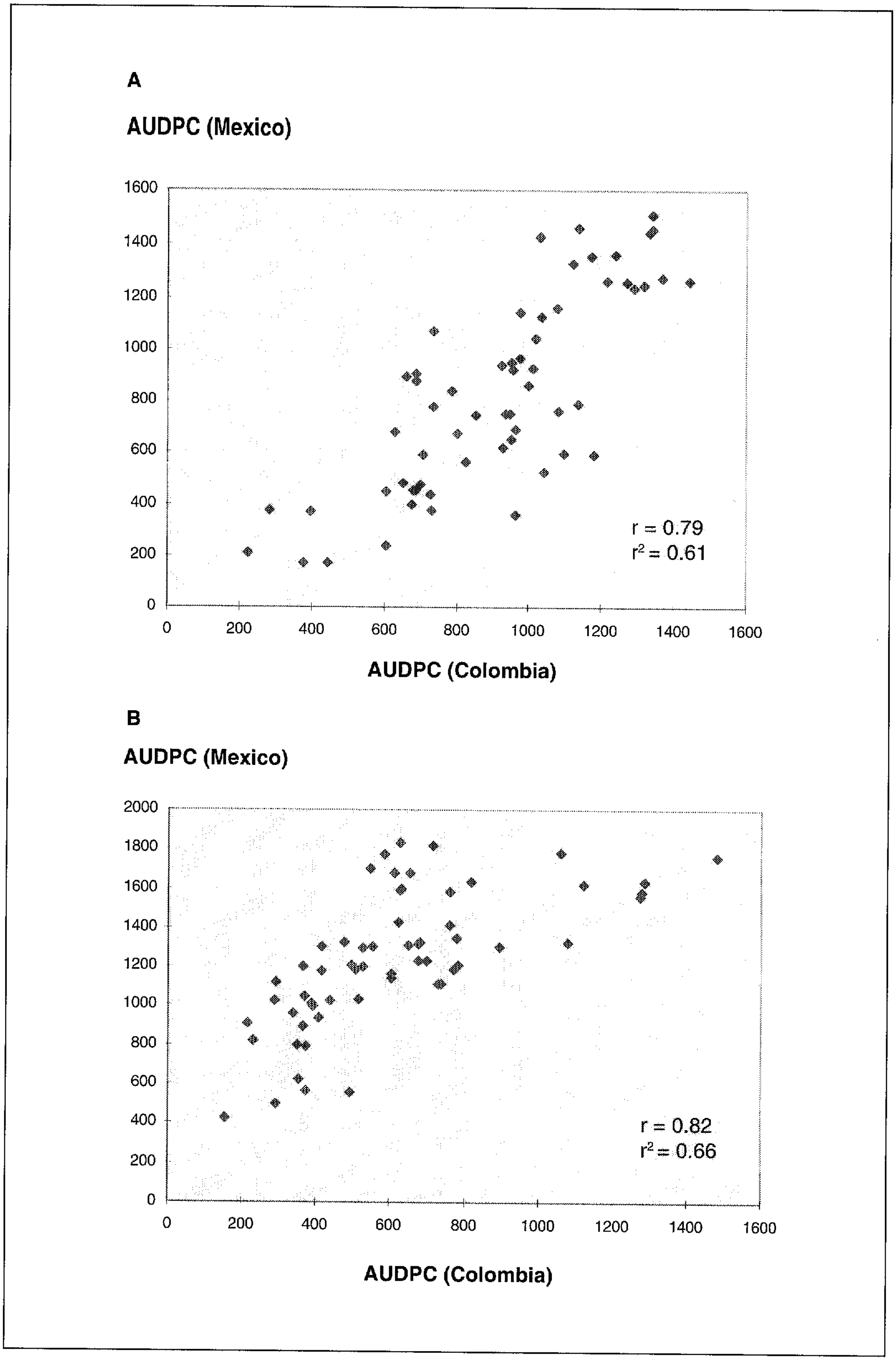


Figure 1. Simple correlation of AUDPC from Colombia and Mexico, 1995 (A) and 1996 (B).

Resistance to Late Blight from Diverse Wild Sources

B. Trognitz, M. Eslava, L. Portal, and P. Ramón[1]

Widening the gene pool of potato (*Solanum tuberosum*) to enhance the crop's resistance through the use of wild relatives has become a routine strategy. This is especially true for resistance to *Phytophthora infestans*, the causal agent of late blight (LB), for which resistance of the common potato is limited. Several wild relatives of potato have been used, but efforts are concentrated on only a few sources of resistance. Some of them have been used repeatedly over the past 50 years.

Because many improvement programs are in developed countries with moderate climates, the new hybrid potato stocks developed there may be of limited use in the tropical and subtropical environments of developing countries.

To more systematically exploit the large collections of wild potatoes maintained at CIP and in other potato gene banks, we investigated several lesser-known and underused potential sources of resistance to LB. We included South American wild species in the experiment because it was believed until only recently that these species would not possess major (R) genes for race-specific resistance to LB. The South American species, unlike several native species of Mexico, have been exposed to *P. infestans* relatively recently in their evolutionary history. But evidence is growing that R genes, each one of them conferring resistance against only a few strains of the pathogen, also occur in potatoes indigenous to South America. Therefore, we must also test our hybrids for the presence of R genes.

1 CIP, Lima, Peru.

Materials and Methods

Samples of botanical seeds of several accessions of diploid wild and native cultivated potatoes were grown. The accessions had been selected, based on their known or suspected resistance, from collections held at CIP; the Potato Introduction Station, Sturgeon Bay, Wisconsin, USA; and the potato gene bank at Gross Lusewitz, Germany. To detect possible race-specific interactions, detached leaflets were placed in petri dishes and inoculated with isolates of *P. infestans* of different virulences.

A quick and reliable test of foliage resistance under controlled conditions in the greenhouse was developed at CIP-Lima. For this test, stems with fully developed foliage are taken from adult plants and placed in milk bottles in a screenhouse equipped with mist irrigation to produce high air humidity and favorable conditions for blight development. A randomized two-block design is used, in which the experimental unit is a sample of three stems of a given genotype in a single bottle. The foliage is inoculated once after sunset with a suspension of 15,000 sporangia/ml of a virulent isolate representing a potato (*S. tuberosum*) race of *P. infestans* of a lineage common in the Andean region of Peru, Ecuador, and Colombia.

A polycyclic blight epidemic develops within 2 wk. Three readings of the percentage of foliage area affected are taken at 2-day intervals, starting when the susceptible check, Yungay, has an average of 30% foliage area affected. The average of the three readings over the two repetitions is then taken as a measure of the degree of resistance of a genotype. Data are analyzed by ANOVA for each group of clones assayed at a time. In this way, successful identification of LB resistance is possible throughout the winter period in Lima, from June to November.

Besides Yungay, four other checks with different levels of resistance are always included in the assay. Although the overall degree of infection varies between individual inoculation dates, the relative differences in resistance levels expressed by the checks are highly reproducible, with a correlation coefficient of r=0.70-0.99 between pairs of individual inoculation cycles. The average area of blighted foliage of the checks observed in five inoculation cycles in 1996 was (from highest to lowest level of resistance): CIP breeding clone 381381.26 (released as Ingabire in eastern Africa), 17.1%; Canchán INIAA (released in Peru), 21.2%; Atzimba (Mexican variety), 34.6%; Yungay (Peru), 48.5%; and Pimpernel (Netherlands), 50.6%. The ranking and the relative differences between the varieties' scores observed in this detached foliage test are the same as those observed in field experiments. Therefore, our resistance test using detached foliage is reproducible and gives a good estimate of the level of field resistance of the genotypes tested.

Detached leaflet assays revealed that clone 381381.26 does not sporulate after inoculation with the isolate used for the screenhouse inoculations. This indicates that 381381.26 possesses specific (R-gene-mediated) resistance to this isolate. We conclude therefore that R gene resistance is equivalent to readings of an average of 17% affected foliage area in the trial used. Therefore, the direct selection of highly resistant genotypes that do not express R gene resistance, by relying on the phenotype of a single clone in the screenhouse or field, appears to be impossible.

Selected LB-resistant clones of accessions of diploid wild species were crossed with potato dihaploids. The resulting hybrids have also been subjected to a series of tests for the level and race-specific or -nonspecific resistance inherent in them, as described above.

Results

One hundred and three individuals of 28 single-cross progenies were selected in Lima, and 70 individuals of 15 progenies in Quito, for their high levels of foliage resistance to LB. These selected hybrids include the resistances of 16 accessions of 13 wild and native cultivated *Solanum* species (Table 1). These hybrids are all diploid, and most of them produce unreduced pollen. This will allow them to be used in meiotic tetraploidization through pollinations of tetraploid varieties and breeding clones. For selected clones, the mechanism of formation of unreduced pollen will be elucidated through cytological means.

In addition, we used 13 clones with high levels of quantitative LB resistance, which were selected from a set of diploid hybrids of the former bacterial wilt breeding program at CIP, in crosses with potato varieties to obtain tetraploid hybrids. The tetraploidized genotypes were propagated clonally and tested for LB resistance. We have identified several highly LB-resistant, early to medium-late maturing genotypes expressing agronomically acceptable tuber characteristics.

Segregation of resistance in individual diploid hybrid populations was analyzed using the data of both the detached-leaflet and detached-foliage assays. In the inoculations of detached leaflets, sporulation was taken as a criterion for compatibility with the isolate used. Several hybrid populations screened expressed sporulation on leaflets of all genotypes with four isolates used. One isolate had no avirulence genes; the others possessed different combinations of avirulence genes interacting with the 11 known R genes of *S. demissum*. For a summary, see Table 1.

Segregation of the level of resistance in relation to the resistant check in a progeny of this race-non-specific reaction type is given in Figure 1. The segregation in the progeny of the cross of CIP dihaploid PS5 x *S. ambosinum*, OCH 11865, clone 24, is unimodal and fits a normal distribution. A progeny obtained from a self of dihaploid PS5 also showed a pattern of segregation that fit a normal distribution in the screenhouse test. All individuals expressed sporulation after inoculation of detached leaflets with all isolates used, suggesting that PS5 does not possess race-specific resistance alleles for any of these isolates.

Table 1. Accessions of wild and cultivated potato containing high levels of resistance to late blight that are used for introgression of resistance into potato.

Solanum species	Accession code, collector number	Resistant plants used (no.)	Resistance level	Race-specific reaction observed
acroglossum	CIP 761070, OCH 11297	2	Medium	Yes?[a]
ambosinum	OCH 11865	2	Medium	No
berthaultii	CIP selection, KV Raman	1	High	Yes
albornozii	CIP 761164, OS 11007	1	Medium	No
chiquidenum	CIP 761588, OCH 13345	1	Medium	Yes?
chomatophilum	CIP 761582, OCH 13325	1	Medium	Yes?
laxissimum	CIP 761028, O/S 11855	1	Medium	No
microdontum	PI 500041	1	High	Yes
phureja	INIAP, Ecuador, BOM 540	1	High	No
phureja	INIAP, Ecuador, CHS 625	1	High	No
phureja	PI 320376	2	High	No
phureja	PI 225678	1	High	No
piurae	CIP 761072, O/S 11615	2	High	Yes?
paucissectum	CIP 761243, OCH 11630	2	High	Yes?
santolallae	CIP 761691, OCH 13640	1	Medium	Yes
urubambae	OCH 11059	1	Medium	No

a. The question mark indicates that race-specific interactions observed in preliminary experiments must be confirmed in subsequent studies. A precondition is the identification of differential isolates for these materials.

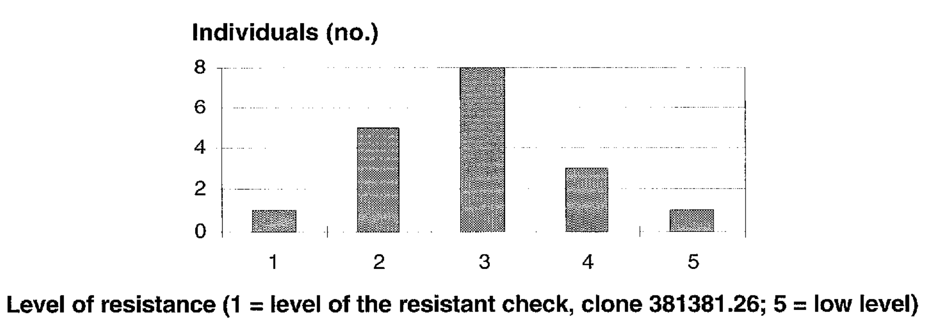


Figure 1. Histogram showing the segregation of resistance to late blight in a progeny of 18 individuals of the cross of dihaploid PS5 x *S. ambosinum*, OCH 11865, clone 24.

Several hybrid progenies, however, had a percentage of individuals that reacted with hypersensitivity or not at all to the inoculations of detached leaflets with a particular isolate. These populations also expressed segregation of the degree of resistance, as measured in the foliage assay in the screenhouse. An example is the progeny of the cross of dihaploid PS5 x *S. berthaultii*, clone 1 (provided by K.V. Raman, CIP, 1991), shown in Figure 2. Of 44 individuals tested in the screenhouse, 22 either had no infection or up to twice the affected foliage of the resistant check (clone 381381.26), resistance levels 1 and 2 in Figure 2.

The same resistant individuals did not sporulate after inoculations of leaflets with three individual isolates. Some of the susceptible individuals (Figure 2, resistance levels 3-7) were tested in the detached-leaflet assay. All showed sporulation with at least two of the three isolates used. The observed segregation into resistant and susceptible phenotypes perfectly fits a 1:1 ratio indicative of a single gene. However, the frequency distribution shown in Figure 2 is not bimodal, as would be expected for segregation of a single factor, but is unimodal and skewed. Therefore, a model of segregation of several dominant, race-specific resistance genes, each one contributing a distinct level of foliage resistance, can also be envisaged.

Further analysis of segregation in F_2 or backcross populations derived from this *S. berthaultii* hybrid progeny is necessary to elucidate the number of putative R genes involved and their type of action. It is possible that these genes contribute a durable, residual effect to the resistance, even when they are broken down.

Segregation into distinct resistance classes was observed in progenies carrying the resistances of the South American species *S. acroglossum*, *S. berthaultii*, *S. chiquidenum*, *S. chomatophilum*, *S. microdontum*, *S. paucissectum*, and *S. santolallae* (Table 1). Hybrids into which the race-specific resistances of these South American species were incorporated expressed intermediate to high levels of resistance in the screenhouse test.

Of the species contributing race-non-specific resistance, comparably high levels of resistance of hybrids were obtained only with *S. phureja*. This native cultivated potato reacts to infection by dropping diseased leaves through abscission at the petiole base. As such it represents a resistance phenotype different from *S. tuberosum*, in which diseased foliage

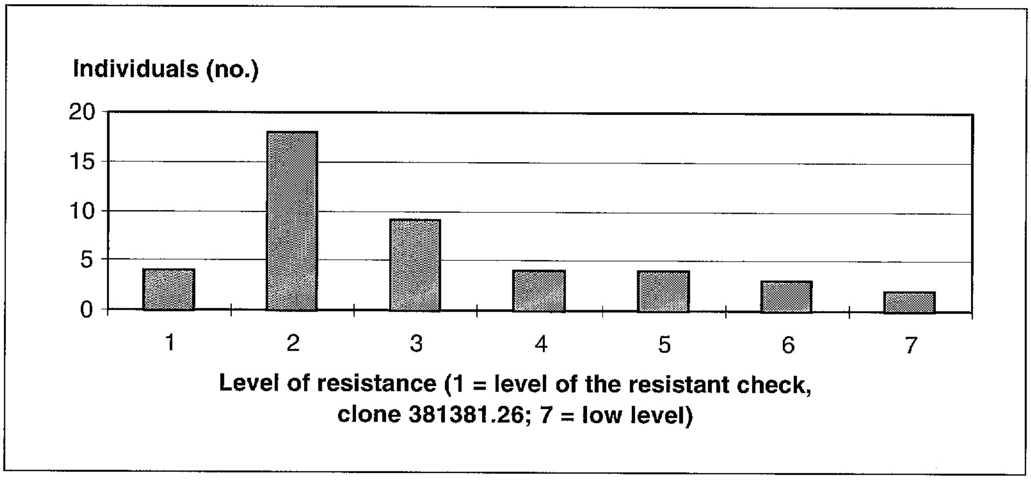


Figure 2. Histogram showing the segregation of resistance to late blight in a progeny of 44 individuals of the cross of dihaploid PS5 x *S. berthaultii*, clone 1.

remains on the plant. Abscission of infected leaves was observed in the field and on detached foliage tested in the screenhouse. This resistance type is also expressed by *S. urubambae*, and it is transmitted to the hybrids.

Conclusions

The total of 186 selected diploid hybrids described above represents the basic pool of LB resistance genes of a wide range of genetic resources. We are currently using this cohort of selected clones to develop tetraploids in interploidy crosses with advanced potato breeding clones. The tetraploid hybrids will then complement a set of progenitors—CIP's group C or population C—that carry the new resistances. We envisage group C as a core collection of a wide range of diverse resistances, in a ready-to-use form of potato clones that are acceptable to breeders because of their improved agronomic characters.

The hybrids will also be used for studies of the genetics and inheritance of resistance to LB. Segregating populations for genetic mapping of resistance factors will be obtained through F_2 or backcrosses for efficient introgression of these factors into potato breeding stocks and to isolate candidate resistance genes for plant molecular transformation.

Despite our observation that one-half of the wild potato species investigated possess race-specific resistance conferred by R genes, we will explore further the feasibility of breeding using R-gene-free materials. Nevertheless, wild species may harbor stable R genes that could provide durable protection against LB. We will survey the genetic material studied in this paper for its resistance genes through inoculations with *Phytophthora* isolates that represent a wide range of virulences and hosts.

Selected Reading

Toxopeus, H.J. 1964. Treasure-digging for blight resistance in potatoes. Euphytica 13:206-222.

Ross, H. 1966. The use of wild *Solanum* species in German potato breeding of the past and today. Am. Potato J. 43:63-80.

Ross, H. 1986. Potato breeding: Problems and perspectives. Advances in Plant Breeding, 13. Paul Parey, Berlin and Hamburg. 132 p.

Evaluation of Late Blight Resistance in Populations of Diploid Potato Hybrids for Genetic Mapping

B. Trognitz, M. Ghislain, G. Forbes, P. Oyarzún, M. Eslava, R. Herrera, L. Portal, P. Ramón, and G. Chacón[1]

Wild and cultivated relatives of the potato (*Solanum* spp.) carry valuable resistances to late blight (LB) that, when introgressed into potato, are thought to considerably reduce the crop's vulnerability to this devastating disease.

To increase the durability of resistance to LB, researchers seek forms of resistance that are effective against a broad range of pathogenic strains of *Phytophthora infestans*. Polygenic, additive resistance is the most promising. This resistance can be masked by monogenic, race-specific major (R) gene-mediated resistance when no races compatible with such an R gene are available. This is most important when the identity of R genes is not known.

Twelve R genes for resistance to LB have been identified. Differential potato clones to distinguish 11 of them are available. These 11 R genes originated in Mexican wild *S. demissum*, and this and other Central American potato relatives are assumed to have developed many more R genes. The Mexican wild potato *S. verrucosum* is reported to possess high levels of quantitative resistance besides R gene-mediated resistance. The successful use in resistance breeding of this and other wild and native cultivated potatoes therefore depends on knowledge of the occurrence and identity of R genes.

One strategy to avoid interference with R gene resistance could be to choose genotypes without R genes. Previously, it was hypothesized that potato relatives indigenous to South America would not possess R genes; all resistance expressed by them would be polygenic and quantitative. However, evidence is emerging that many South American species also employ R genes. Therefore, it is desirable to test every potential source of resistance for the occurrence of race-specific resistance genes, and it is reasonable to expect that additional R genes are yet to be identified.

Two sources of resistance to LB were investigated in two segregating populations of diploid potato hybrids. One population was a cross between highly resistant *S. verrucosum* and susceptible *S. phureja*, designated population VP. The other was a cross between resistant *S. phureja* and a susceptible *S. tuberosum* dihaploid, designated population PD. The PD population was selected for the study from nine diploid hybrid populations carrying high levels of resistance to LB.

This investigation had two objectives. One was to characterize the level of resistance of every individual of the two populations as a precondition for genetic mapping. The second was to test the populations for the occurrence and segregation of race-specific R genes.

Population VP

This population comprises 102 individuals, all of them late-maturing under the short daylength of Cajamarca, Peru. All genotypes form small, pear-shaped tubers of creamy-

1 CIP, Lima, Peru.

white flesh that sprout early. The entire population expresses a cytoplasmic male sterility (CMS) phenotype that is known as eclipse sterility. Although preliminary intrapopulation crosses were unsuccessful, it may be possible to use the VP individuals as females in crosses with pollen-fertile genotypes because female fertility is not affected by CMS.

VP field resistance

VP individuals were evaluated for resistance in the field at Cajamarca, Peru, under high infection pressure, in 1994, 1995, and 1996. The parents did not grow in the field or were not available and could not be included in the experiment. A randomized block design was used and the area under the disease progress curve (AUDPC) was calculated from weekly readings of the percentage of diseased foliage in plots of 10 plants per clone and block. The VP population had a high average field resistance (progeny mean, AUDPC=303, range 168–999; resistant standard Perricholi, AUDPC=410; susceptible standard Yungay, AUDPC=997). Its frequency distribution (Figure 1) deviated from the desired normal distribution typical for a quantitative trait.

Race-specific resistance of VP

We performed detached-leaflet tests to analyze the segregation of the discrete trait resistance to sporulation. The phenotype of R gene resistance in this test is a hypersensitive response of leaf tissue. Sometimes no symptoms or only weak infection is observed. Sporulation occurs rarely. We classified individuals as susceptible or resistant based on this variability of the expression of resistance. Individuals on which *P. infestans* sporulated were classified as susceptible; those that did not allow the pathogen to sporulate in any of the repetitions were considered resistant.

Ninety-nine individuals were inoculated with five isolates of *P. infestans*, each possessing a different level of virulence (Table 1). The experimental unit was a petri dish containing four lateral leaflets from different fully developed top leaves of one to three plants in bud or flowering. The plants were grown in pots in a greenhouse at Lima during the winter of 1995. Humidity was maintained by adding a sheet of moist filter paper to each petri dish. Readings of sporulation and area affected were taken 5 d after inoculation, or when the controls showed the expected symptoms. Tests were repeated one to three

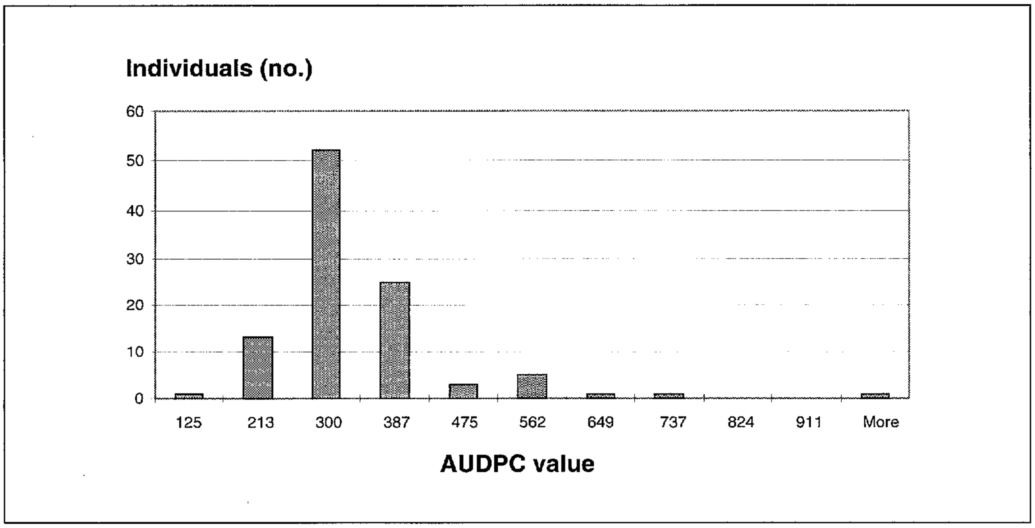


Figure 1. Population VP: frequency distribution of AUDPC measured on 99 individuals in 3-yr field trial, Cajamarca, Peru.

Table 1. Inoculations of detached leaflets of VP individuals with 5 isolates of *Phytophthora infestans*.

Isolate	Virulence	Resistant progenies (no.)	Susceptible progenies (no.)	Segregation observed	Segregation expected for single-gene resistance
275	1	36	63	1:1.75	1:1
P2	1.3.4.6.7.10.11	30	69	1:2.3	1:3
50	1.3.4.7.11	15	84	1:5.6	1:3
8	1	0	99	0:1	1:1
260	1.2.3.4.6.7.9.10.11[a]	0	99	0:1	0:1

a. Not tested against R8.

times and the accuracy of a test result was established by comparing it with the reaction of resistant and susceptible control cultivars.

The inoculum was applied with a spray bottle. The inoculum concentration was 5,000–15,000 sporangia/ml washed from mycelium grown on tuber slices. This high inoculum concentration was chosen to ensure that all susceptible individuals became infected.

Of 99 plants tested, none was resistant to isolates 8 and 260. With the remaining three races, segregation into resistants and susceptibles was obtained (Table 1). The ratios of resistant:susceptible individuals obtained with either race significantly ($P<0.001$) diverge from ratios expected for a model of single dominant genes of resistance. More feasible models were the complementary action of two or more resistance genes, or a resistance gene and a suppressor gene. In dozens of inoculations done over 5 yr, our controls carrying R genes always responded resistant to the respective avirulent isolates. None developed sporulating mycelium. Possibly the resistance genes of *S. verrucosum* break down under particular environments, thus resulting in an excess of susceptibles. Segregation results must be confirmed by testing the V and P parents and by analyzing backcrosses to the susceptible *S. phureja* parent.

A host-pathogen interaction scheme is presented in Table 2. The eight resistance patterns observed in the population indicate that the virulences of the isolates 275, P2, and 50 are different from each other. At least three factors of race-specific resistance must be assumed to segregate independently in the VP population. Isolates 8 and 275 share the avr1 gene for virulence on potato (*S. demissum*) gene R1 (Table 1), yet they have differing patterns of compatibility with the VP individuals. That result indicates that isolate 8 possesses more virulences either to R gene 8 (for which no differential was available) or to some other unknown resistance genes.

After 3 yr of resistance testing in the field, the AUDPC means of genotypes differing in their resistance to 0, 1, 2, or 3 isolates were compared by a series of t-tests (Figure 2). None of the means could be clearly separated. But the tendency of smaller AUDPC values to be associated with a higher number of isolate-specific resistances indicates a small but favorable residual effect of these factors on the expression of resistance in the field. Also, the mean AUDPC value (mean AUDPC=280) of all 36 individuals that were

Table 2. Response[a] of 99 VP plants to inoculation of detached leaflets with five isolates of *Phytophthora infestans.*

Isolate					Individuals resistant
275	P2	50	8	260	(no.)
S	S	S	S	S	43 susceptible
R	S	S	S	S	20
S	R	S	S	S	13
S	S	R	S	S	4
R	R	S	S	S	8
S	R	R	S	S	3
R	S	R	S	S	2
R	R	R	S	S	6

a. R = resistant to development of sporulating mycelium, S = susceptible.

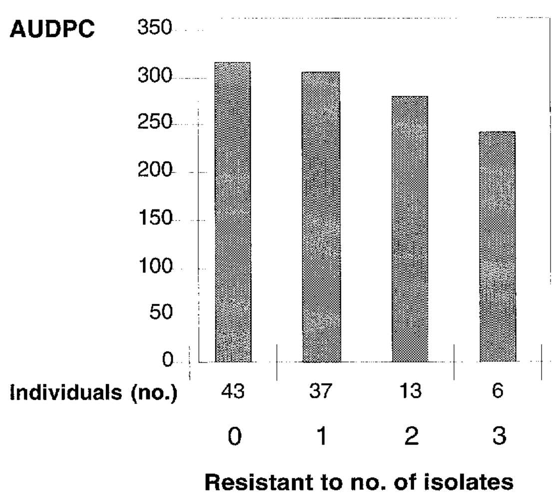


Figure 2. Mean AUDPC values of classes of VP individuals resistant to 0-3 isolates.

resistant to isolate 275 was smaller than that of the individuals susceptible to that isolate (mean AUDPC=317, 63 individuals).

Population PD

PD is the result of a seedling family selection process. A sample of accessions of wild and native cultivated potatoes as candidate sources of resistance to LB was screened at CIP-Quito, in 1992 and 1993. Resistant clonal selections were crossed with potato dihaploids to produce diploid hybrid progenies. A sample of nine early-maturing progenies was subjected to a 2-yr field trial for resistance. The cross CHS-625 x PS-3 performed best of all progenies. Its progeny mean of resistance (AUDPC=152, 50 individuals) was, of all nine progenies, closest to the value of the resistant standard, variety Catalina (AUDPC=98). The individuals had AUDPC values between 65 and 240, displaying a normal distribution. Twenty percent of the individuals had the same resistance as the standard, or a higher level. All individuals of this progeny are male- and female-fertile and 65% of them produce more than 2% unreduced pollen grains. This progeny also has smooth round and oval-shaped tubers with shallow eyes and yellow skin. The yellow-fleshed starchy tubers have good culinary quality. The cross of the parents was repeated in Peru to produce the PD mapping population.

All individuals of population PD are male- and female-fertile and flower profusely in the greenhouse at CIP-Huancayo, Peru. Plants are vigorous, but seem to be vulnerable to infection by mosaic viruses—a feature frequently observed in wild and native potatoes. Introgression of virus resistance in subsequent crossing generations will be necessary.

PD resistance in a controlled-environment test

PD plants and their parents were grown in pots in the greenhouse at Lima, during the 1996 winter season. Stems with complete foliage were used in a resistance trial in a screenhouse equipped with mist irrigation to constantly maintain high relative humidity and low temperature. A randomized 2-block design was used. The experimental unit was a milk bottle containing three stems of a PD genotype. The plants were inoculated at night with isolate 260 (complex virulence to *S. demissum* R genes, see Table 1), at a concentration of 13,000 sporangia/ml. The epidemic developed after 4-7 d and visual readings of the percentage of diseased foliage were taken three times at 2-d intervals. The experiment was repeated after 4 wk, and a two-factor ANOVA (factors PD genotype and block, nested in repetition) was run on the mean percentage of diseased foliage calculated over the three readings. There were significant differences between the PD individuals, although no groups could be separated by multiple comparisons of means. Based on the conditions of the screening facility, the overall level of disease was different for each block within each repetition.

Figure 3 shows the frequency distribution of diseased foliage for the PD individuals, which fits a normal distribution. The overall level of resistance of the PD population (27% diseased foliage) observed was higher than that of the resistant control, Canchán (4%). But it was much lower than that of the susceptible check, Yungay (33%).

Overall, high levels of resistance that vary gradually between sister individuals depict the image of true quantitative resistance

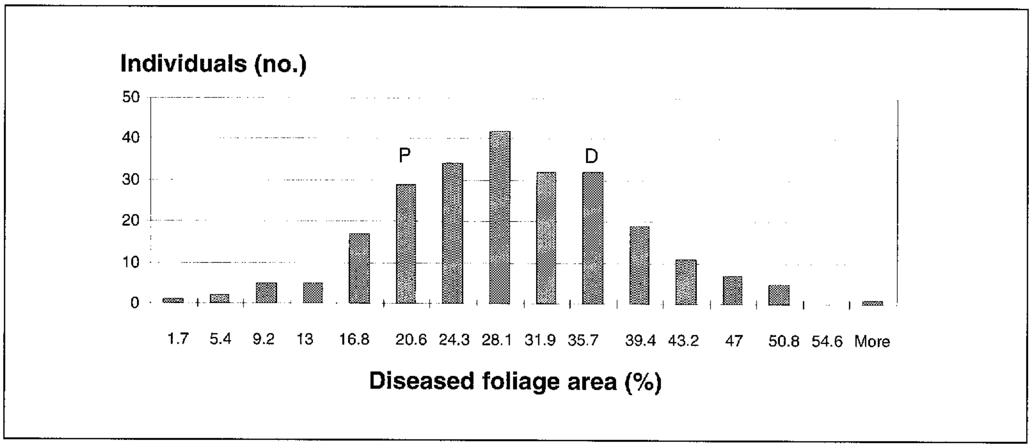


Figure 3. Population PD: frequency distribution of diseased foliage area (%) measured on 240 individuals and the P and D parents in 2 repetitions, Lima, 1996.

caused by many additive genes. Thus, the PD population is useful for molecular mapping of quantitative trait loci for resistance. More resistance studies must be done under actual field conditions and in different environments to elucidate the stability and sustainability of the resistance detected.

Testing for R genes in population PD

Most of the PD individuals developed foliage damage of more than 15-20% after inoculation with a virulent isolate of *P. infestans* (Figure 3). A small fraction of individuals exhibited less than 10% damage and preponderantly necrotic lesions. Therefore, it is preferable to test this population for the segregation of putative, isolate-specific resistance as well.

Two repetitions of a test for sporulation on detached leaflets of 218 PD individuals were done using the isolate P2 (Table 1). Of 218 individuals tested, 9 did not sporulate in one of the two repetitions, and 13 did not sporulate at all. No necrotic lesions developed, and the size of the lesions that did develop on these nonsporulating leaflets was similar to that on leaflets of other individuals on which the pathogen sporulated. Further tests with this and other isolates of *P. infestans* on the PD individuals and on progenies from crosses of sisters and backcrosses to the D parent are necessary to elucidate whether race-specific resistance is also segregating in this quantitatively LB-resistant material.

Conclusions

Population VP expressed high levels of resistance in the field, with little variation among genotypes. Besides the population's overall field resistance, race-specific interaction of individuals was detected in detached-leaflet assays. These race-specific resistances had a small favorable effect on resistance in the field.

We will use male-sterile individuals of the VP population as females in backcrosses with the susceptible P parent and with a dihaploid tester clone to obtain advanced backcross populations for further analysis of the resistance and use in breeding.

Population PD had a wide range of gradually different resistance levels in a repeated controlled-environment, foliage resistance assay, thus allowing the separation of most-resistant from most-susceptible individuals by statistical means. High levels of quantitative resistance to LB as well as good fertility and the production of unreduced (2x) gametes, earliness, yellow tuber flesh, and other good agronomic characteristics of the PD population make it a valuable material for breeding. Introgression of resistance to LB from this population into cultivated potato appears to be possible. To carry out this introgression efficiently, we will need to genetically map quantitative resistance loci as a precondition to marker-assisted selection.

Selected Reading

Malcolmson, J.F. and W. Black. 1966. New R-genes in *Solanum demissum* Lindl. and their complementary races of *Phytophthora infestans* (Mont.) de Bary. Euphytica 15:199-203.

Ramanna, M.S. and J.G.Th. Hermsen. 1974. Unilateral "eclipse sterility" in reciprocal crosses between *Solanum verrucosum* Schlechtd. and diploid *S. tuberosum* L. Euphytica 23:417-421.

Stewart, H.E. 1990. Effect of plant age and inoculum concentration on expression of major gene resistance to *Phytophthora infestans* in detached potato leaflets. Mycol. Res. 94:823-826.

Trognitz, B.R., G. Chacón, H. Pinedo, and M. Eslava. 1995. Screening for R genes causing race-specific resistance to late blight in wild potato species. Am. Potato J. 72:662.

Host Specificity of Late Blight Pathogen on Potato and Tomato in Ecuador

G.A. Forbes, P.J. Oyarzún, A. Pozo, and M.E. Ordóñez[1]

In Ecuador, potato and tomato are cultivated year-round. Late blight caused by *Phytophthora infestans* occurs in potato and tomato at any stage of plant growth after emergence, because of the continuous presence of inoculum. Potato and tomato are not generally grown in the same area, but production zones for the two crops can be within a few kilometers of each other or even contiguous. Occasionally, we have seen potato and tomato grown on the same farm, and on rare occasions in the same field. Host specificity has important implications for management of the disease, especially in areas where both crops are grown in the same vicinity. Farmers need to know whether their crops are threatened by nearby alternative hosts that are badly infected. Researchers and extensionists working on potato and tomato must coordinate efforts if the pathogen is equally aggressive to both hosts.

This study was begun to elucidate two aspects of *P. infestans* host specificity: whether potatoes and tomatoes are attacked by the same population of *P. infestans* in Ecuador, and what role specific virulence plays in determining host specificity.

Materials and Methods

Several markers were used to characterize both potato and tomato populations.

A total of 120 isolates, 60 from potato and 60 from tomato, were collected from central and northern Ecuador, between November 1994 and January 1996. Approximately equal numbers were taken from the two zones.

All isolates were inoculated on 11 potato differential plants containing 1 each of 11 known R genes for resistance and 4 tomato differential cultivars. Detached-leaf tests of aggressiveness were performed on 3 potato cultivars and 3 tomato cultivars using 7 isolates from each host. Isolate resistance was assessed on 10% V8 agar amended with 5 and 100 ppm metalaxyl.

The mating type test was performed by pairing isolates with known A1 and A2 genotypes on clarified rye A agar. The presence or absence of oospores was recorded after 15 d. Mitochondrial haplotype was determined with the polymerase chain reaction procedure using primers developed and provided by G.W. Griffith, University of Bangor, Bangor, Wales, U.K.

Isolates were cultivated in still culture of pea broth or on rye B agar for 7 d and gels were stained for glucose-6-phosphate isomerase (GPI) and peptidase (PEP). Eleven randomly selected isolates from tomato were analyzed for restriction fragment length polymorphism (RFLP) fingerprints using the moderately repetitive probe RG57 developed in the laboratory of W.E. Fry at Cornell University.

Results

Genetic description of *P. infestans*

All isolates from potato had the allozyme genotype of 96/100 for *Gpi* and 100/100 for *Pep* (Table 1), and the mitochondrial DNA haplotype of IIA. This multilocus genotype is identical to that found for the lineage EC-1, which was described as the dominant lineage on potato in Ecuador. Thirty genotypes were fingerprinted with probe RG57. Of these, 28

1 CIP, Quito, Ecuador.

Table 1. Genotype characterization of populations of *Phytophthora infestans* on potato and tomato in Ecuador.

Host	Number	*Gpi*[a]	*Pep*[b]	RFLP fingerprint[c]	Lineage
Tomato	1	86/100	92/100	10101000010011010	US-1
Tomato	2	86/100	92/100	10101010010011010	US-1
Tomato	8	86/100	92/100	10101010110011010	US-1[d]
Tomato	48	86/100	92/100	Not tested	US-1?
Tomato	1	96/100	100/100	Not tested	EC-1?
Potato	2	96/100	100/100	11111010000011010	EC-1
Potato	28	96/100	100/100	11111010010011010	EC-1[d]
Potato	30	96/100	100/100	Not tested	EC-1?

a. Glucose-6-phosphate isomerase.

b. Peptidase.

c. Underlined bands indicate polymorphism within lineages.

d. Indicates published RFLP and isozyme genotype, which define that lineage.

had the fingerprint of EC-1 and the fingerprints of the other 2 were similar to EC-1, but lacked band 10. All potato isolates were IIA mitochondrial haplotypes and A1 mating type.

All isolates from tomato, except for one, had the allozyme genotype of 86/100 for *Gpi* and 92/100 for *Pep* (Table 1), which is definitive for the globally distributed lineage US-1. Eight of 10 isolates fingerprinted had the US-1 genotype. Two were similar, but lacked band 9, and one isolate lacked both band 9 and 7. All tomato isolates but one were IB mitochondrial haplotypes, and all were A1 mating type.

Specific virulence

The specific virulence patterns of potato and tomato populations of *P. infestans* differed greatly. Isolates were generally highly virulent on their own host differentials, but not on the alternative host differentials (Table 2). In several cases, isolates from one host did not infect any of the other host differentials, even those free of known major genes for resistance.

Two race-specific genes in tomato were reported previously, but our data indicate that there is at least one more in the four differentials we used. Pieralbo, reportedly a major-gene-free isoline of the Ph2 differential Pieraline, should have behaved similarly to FMX-93, also putatively free of major genes. However, these two tomato cultivars interacted differentially with some isolates, thus indicating the interaction of a hitherto unknown major gene (Table 2).

Some isolates from potato did not infect any of the four tomato differentials. Similarly, some isolates from tomato did not infect any potato differentials, including those free of known R genes.

No relation between tomato and potato avirulence genes in *P. infestans* could be deduced from our results. Isolates that were avirulent on all potato differentials were virulent on all tomato differentials (Table 2). Therefore, all avirulence genes for tomato expressed in this study appear to be independent of all known potato avirulence genes.

Pathogenic aggressiveness

Results are presented as the average over all cultivars for each host and all isolates from each origin (tomato or potato). There was a very clear and statistically significant ($P<0.0001$) interaction between origin of iso-

Table 2. Specific virulence patterns of *P. infestans* isolates coming from potato or tomato and inoculated on major-gene differential plants of both hosts.

Isolates collected from potato			Isolates collected from tomato		
Potato differentials[a]	Tomato differentials[b]	Pathotype frequency	Potato differentials[a]	Tomato differentials[b]	Pathotype frequency
0,1,3,4,7,8,10,11	0,1	23	0,3,7	0,1,2,3	15
0,1,3,4,7,8,10,11	0,1,3	11	0,3	0,1,2,3	12
0,1,3,4,7,8,10,11	0	8	0	0,1,2,3	8
0,1,3,4,7,10,11	0,3	3	0,2,3	0,1,2,3	6
0,1,2,3,4,6,7,10,11	0,1	2	No infection[c]	0,1,2,3	5
0,1,2,3,4,6,7,8,10,11	0,3	2	3	0,1,2,3	3
0,1,3,4,7,8,11	No infection[c]	1	0,2,3,7	0,1,2,3	2
0,1,3,4,7,8,11	0	1	No infection[c]	2	1
0,1,3,4,7,8,11	0,3	1	No infection[c]	0,1,2	1
0,1,3,4,7,11	0,1	1	0,4	0,1,2,3	1
0,1,3,4,7,10,11	0	1	0,11	0,1,2,3	1
0,1,3,4,7,8,10,11	No infection[c]	1	0,3,7	0,1,3	1
0,1,3,4,6,7,10,11	0,1	1	0,10,11	0,1,3	1
0,1,2,3,4,6,7,10,11	0,1,3	1	0,1,3,7	0,1,3	1
0,1,2,3,4,6,7,8,10,11	0	1	0,1,3,7	0,1,2,3	1
0,1,2,3,4,6,7,8,9,10,11	0,3	1	0,1,3,4,7,8,10,11[d]	0,3	1
0,1,2,3,4,6,7,8,9,10,11	0,1,3	1			

a. Numbers represent major genes overcome by that pathotype.

b. Numbers represent four tomato differentials: 0 = FMX-93, 1 = Pieralbo, 2 = New Yorker, and 3 = Pieraline.

c. These individuals did not infect any of the differentials, including those considered free of major genes (0).

d. This tomato isolate that was highly virulent on potato belongs to the EC-1 lineage.

late (tomato or potato) and lesion diameter caused on either host (Figure 1). On the average, isolates from tomato caused lesions about 2 cm greater in diameter on tomato than on potato. Isolates from potato caused lesions about 1 cm greater in diameter on potato than on tomato.

Metalaxyl

There was a marked and statistically significant difference in three levels of sensitivity to metalaxyl between tomato and potato isolates (Table 3). More than half the isolates tested from potato (30 of 59) were resistant to metalaxyl, but only 3 of 43 isolates from tomato were resistant. In contrast, only 5 of 59 isolates from potato were intermediately resistant; 17 of 43 from tomato were intermediate.

Discussion

Our data amply address the first objective of the study, that is, to determine whether populations of *P. infestans* attacking potato and tomato differ in Ecuador. All our data indicate that the two populations are distinct. All isolates collected from potato for this study belong to the EC-1 lineage. All but one of 60 isolates from tomato belonged to the globally distributed lineage US-1. That single variant has the same dilocus allozyme genotype as EC-1 and probably belongs to that lineage.

We do not know whether the one EC-1 isolate found on tomato indicates the initiation of evolution toward aggressiveness on tomato, or simply represents a weakly patho-

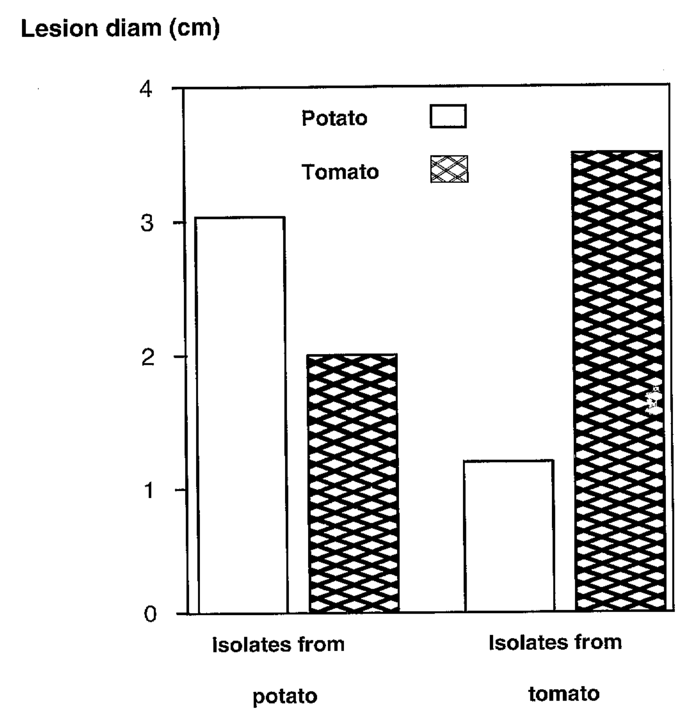


Figure 1. Pathogenic aggressiveness of *Phytophthora infestans* isolates from potato and tomato, inoculated on both hosts.

Table 3. Level of sensitivity to metalaxyl of isolates of *P. infestans* from potato and tomato in Ecuador.

Origin of isolates	Sensitivity level		
	Resistant	Susceptible	Intermediate
Potato	30	24	5
Tomato	3	17	23

Chi-square value for independence = 28.81, P = 0.001, 2 degrees of freedom.

genic isolate found by chance. Nor do we know whether the lesion was large or sporulating when taken from the field. Further monitoring is required to determine the significance of this finding.

In general, however, management of late blight is simplified in Ecuador. For all practical purposes, and until populations of *P. infestans* change, farmers do not need to worry about cross infection from nearby alternative hosts, at least until EC-1 is shown to be an aggressive pathogen of tomato. This management recommendation is supported by field observations we made where epidemics occurred in one of the hosts while nearby fields of the alternative host remained clean.

The second objective of the study, to elucidate the role of virulence in host specificity, was less well addressed by our results, but we believe that a working hypothesis can be developed. Our best interpretation is that host specificity is not determined by virulence, but rather by pathogenic aggressiveness.

None of the EC-1 potato isolates infected New Yorker, the tomato cultivar containing the Ph1 gene (Table 2). The existence of an avirulence gene for Ph1, which is costly for the pathogen to lose, would be an attractive model to explain host specificity. Unfortunately, we were not able to survey cultivars being used in Ecuador and we do not know whether Ph1 is common. We do not believe, however, that it occurs at a rate that would explain host specificity as seen in Ecuador and elsewhere.

We sampled extensively in the central and northern parts of the country and it is highly unlikely that all these fields had cultivars with Ph1. Separate populations of *P. infestans* are found on potato and tomato in Brazil, the Philippines, and parts of the Netherlands. Ph1 is also unlikely to be responsible for host specificity in those countries.

Pathogenic aggressiveness appears to be a more important factor than specific virulence in determining host specificity. There was a clear interaction between origin of isolates and their ability to infect tomato and potato (Figure 1). The isolates from potato infect potato more aggressively than tomato, whereas the opposite is true for isolates from tomato. That finding supports other studies that showed that host specificity was determined by quantitative rather than qualitative factors.

Our study also leads to other interesting observations regarding specific virulence.

Apparently, *P. infestans* has different avirulence genes for potato and tomato, at least among those that can be identified with existing differential cultivars of both hosts. We found that several isolates, which possess all known avirulence genes for potato, infect all four tomato differentials (Table 2). Therefore, avirulence genes for potato must not elicit a hypersensitive response in potato. Similarly, several isolates, which did not infect any tomato differentials, were highly virulent on potato (Table 2).

One aspect of host specialization that remains unclear is whether *P. infestans* can evolve into an aggressive tomato pathogen with no loss of aggressiveness on potato. There seems to be evidence for both sides of the argument. One study done recently in North America demonstrated that certain genotypes of *P. infestans* can infect both hosts with a high level of aggressiveness. It is not evident, however, that this phenomenon is universal. If dual aggressiveness were an inherent capability of *P. infestans*, and if adaptation to tomato aggressiveness occurred relatively quickly (>10 vegetative cycles), then it seems logical that the dually aggressive genotypes would quickly dominate both hosts.

That is not the case in Ecuador and other parts of the world, where distinct genotypes are found in close association with each host.

Our data do not conclusively demonstrate that aggressiveness to tomato results in a loss of aggressiveness on potato, because the two populations represent different lineages of the fungus. We could have addressed this point more clearly if we had studied tomato and potato populations with one lineage. In 5 years of sampling from potato in Ecuador, however, we have found only one isolate belonging to US-1, and it was isolated from the diploid potato species *Solanum phureja.*

One plausible explanation for the inconsistency between observations in North America and in other parts of the world is that genotypes outside North America do not have the genetic potential for developing high levels of aggressiveness on both hosts. The genotypes that do attack both hosts equally in North America were recently introduced from Mexico, the center of origin of the pathogen. If that is the case, the introduction of the North American genotypes to other parts of the world will have major implications for management, especially in areas where the two crops are grown in close association.

Selected Reading

Legard, D.E., T.Y. Lee, and W.E. Fry. 1995. Pathogenic specialization in *Phytophthora infestans*: Aggressiveness on tomato. Phytopathology 85:1356-1361.

Turkensteen, L.J. 1973. Partial resistance of tomatoes against *Phytophthora infestans,* the late blight fungus. Thesis. University of Wageningen, Netherlands.

Use of Natural Resistance Genes for Transgenic Resistance to Potato Viruses

M. Querci[1], G. Brigneti[2], J. García-Mas[2], and D.C. Baulcombe[2]

One of the principal threats to potato (*Solanum* spp.) cultivation is the susceptibility of potato to pests and diseases. Viral diseases in particular cause significant qualitative and quantitative crop losses. The most widely used strategies for control of virus diseases focus on methods to prevent infection or on genetic resistance. Resistance describes the general response of the plant in which the effect of virus infection is reduced or eliminated. This ranges from tolerance of or hypersensitivity to the most durable *extreme resistance* or immunity. Few sources of extreme resistance provided by dominant genes exist for some potato viruses. Examples of durable resistance genes so far include *Rx* and *Ry* genes conferring extreme resistance to potato virus X (PVX) and potato virus Y (PVY), respectively.

Breeding for virus resistance, a major component of most breeding programs, is generally regarded as being the best strategy for long-term virus control. This approach is hampered, however, by the limitation of suitable sources of resistance. In the past, the introgression of genetic sources for plant resistance has been successfully applied to develop a limited number of virus-resistant cultivars. Although plant breeding for virus resistance still has great potential, there are limitations to this conventional approach. An appropriate source of resistance may not be available, the resistance may be tightly linked to undesirable traits, or it may be multigenic and as such difficult to use in breeding programs.

Plant genetic engineering is an alternative to conventional breeding for resistance. One approach to genetically engineering virus resistance is pathogen-derived resistance involving expression of transgenes that contain virus-derived sequences. This has proven effective against many different types of plant viruses. The protection is expressed as prevention of infection, a delay in the onset of virus accumulation, or symptom development in systemically infected leaves.

There are, however, concerns about the biosafety of this approach to virus resistance. In addition, pathogen-derived resistance may break down under high inoculum pressure or could promote evolution of resistance-breaking viral isolates. Therefore, we are attempting to develop a molecular breeding approach to virus resistance in potato that does not provoke these concerns and that does not have the limitations of conventional plant breeding. "Molecular breeding" is the transfer of individual genes between plants using transformation rather than intercrossing. It has been demonstrated recently that molecular breeding could be applied to virus resistance. The *N* gene and its phenotype of resistance against tobacco mosaic virus was successfully transferred by transformation from tobacco to tomato.

Although the technology to isolate disease resistance genes was developed only recently, it has now been refined to the level that it can be applied even in crop plants such as potato. The most important components of this technology (Figure 1) include the development of genetic maps in which there is a high density of molecular markers. Using the markers that are closely linked to and flank the resistance gene of interest, it is possible to identify deoxyribonucleic acid (DNA) clones that span the interval between the

1 CIP, Lima, Peru.
2 Sainsbury Laboratory, Norwich, U.K.

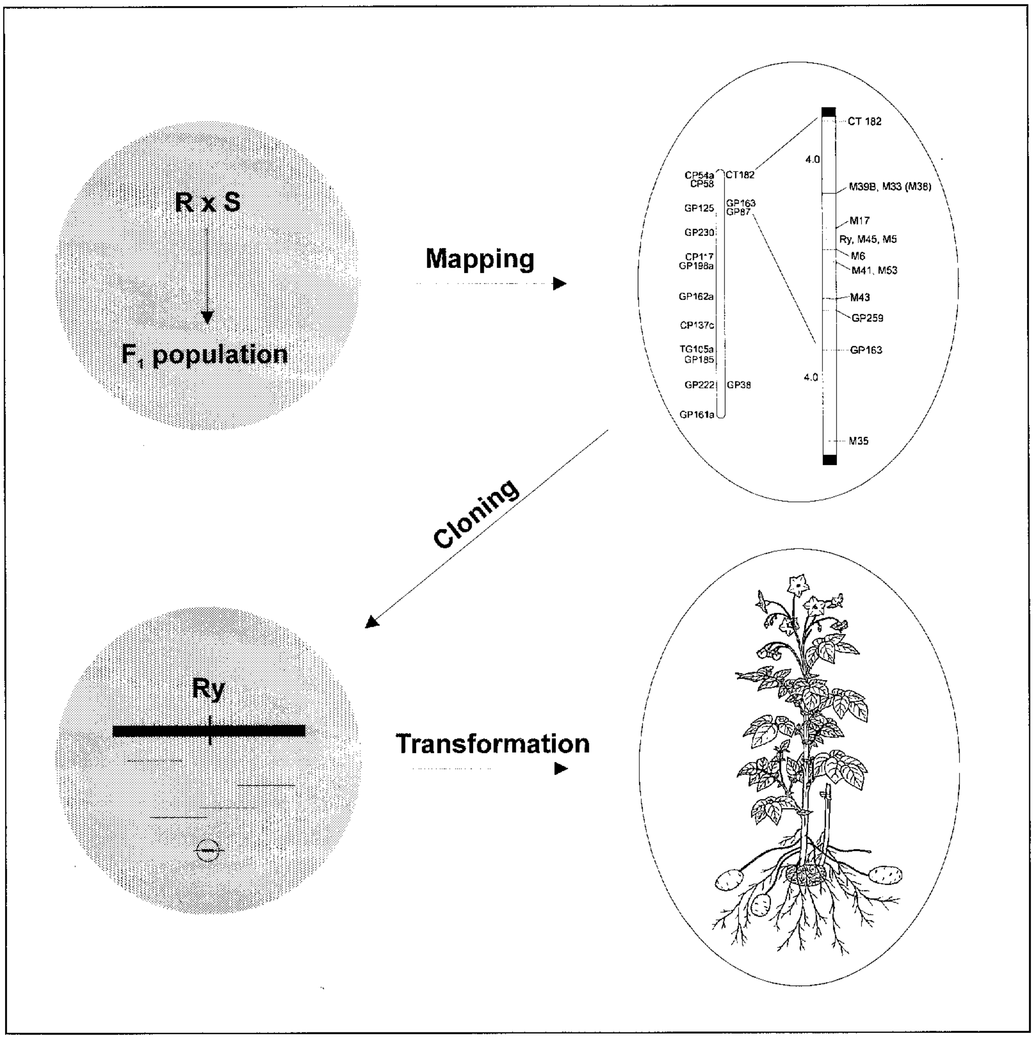


Figure 1. Schematic representation of the steps involved in the transfer of individual genes between plants using transformation.

markers, and therefore include the resistance gene of interest.

This high-resolution genetic mapping is useful not only for molecular breeding but also for marker-assisted transfer of desirable genes among varieties from related wild species. It will make it possible to analyze and transfer complex polygenic characters as well.

Materials and Methods

Virus diseases in potato

In potato, PVX, PVY, and potato leafroll virus (PLRV) are the three most important viral pathogens. PVY, the type member of the potyvirus group, is an aphid-transmitted virus and probably the most difficult to control in potato fields. Genes triggering hypersensitive response and field immunity against PVY are present in several potato species. There are also *Ry* genes conferring extreme resistance to PVY in *S. tuberosum* subsp. *andigena* (Ry_{adg}) and *S. stoloniferum* (Ry_{sto}). Already these loci have been introduced into several commercial cultivars by conventional breeding.

PVX is the most common virus infecting potato worldwide. Strains of PVX have been classified into four groups on the basis of their interactions with the dominant resistance genes *Nx* and *Nb*, which control a hypersensitive response, and the extreme resistance gene *Rx*. The *Rx* resistance is effective against all known isolates of PVX, with the exception of PVX^{HB}, which can overcome all known resistance genes. PVX^{HB} is found in Bolivia and a limited number of sites in the Andean region. Several *Solanum* spp. carry *Rx* genes for extreme resistance. Those from *S. tuberosum* subsp. *andigena* and *S. acaule* are the most commonly used in breeding programs.

The potato has a good regeneration and transformation ability and, in general, provides a good background for the application of recent developments in molecular biology. To exploit this potential, the molecular virology unit of CIP is collaborating with the Sainsbury Laboratory, U.K., on the characterization, isolation, introduction, and expression of plant-derived resistance genes in transgenic potato plants. The immediate targets of this program are the *Rx* and *Ry* genes of potato, for the reasons described below.

First, resistant plants challenged with either virus do not develop visible symptoms, and virus accumulation cannot be detected by either enzyme-linked immunosorbent assay (ELISA) or ribonucleic acid (RNA) hybridization. There is no evidence that these resistance traits can be overcome by high inoculum pressure.

A second consideration was the durability of the resistance conferred by *Rx* and *Ry*. In the case of *Ry*, the resistance is effective against all known isolates of PVY, whereas *Rx* is overcome by a resistance-breaking isolate (HB), although it has not become a problem in most potato-growing areas.

The potential to carry out molecular breeding with both genes simultaneously would have agronomic benefits, because these viruses interact to produce severe crop losses. In addition, studies have shown that PVX or PVY reduce the durability and the degree of resistance to PLRV, for which no immunity genes have been found so far. The establishment of stable virus resistance is of high priority, and the development of cultivars resistant to the three viruses has always been a great challenge for breeders. Molecular breeding of resistance to PVX and PVY would be an important and significant step in that direction.

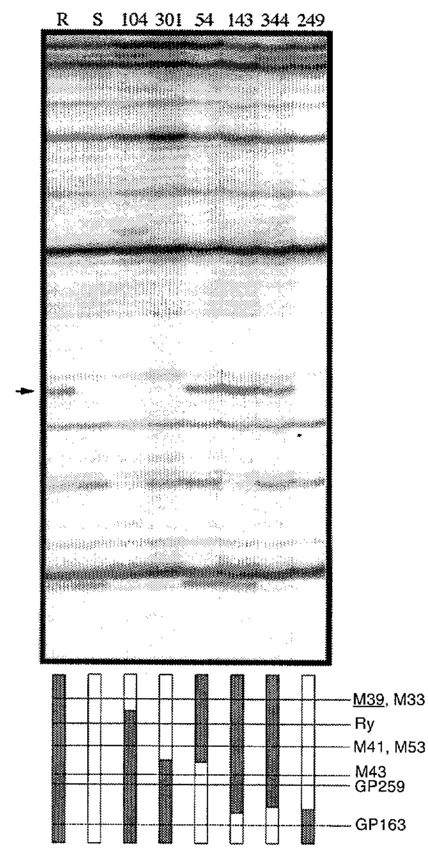


Figure 2. Detail of an AFLP-gel autoradiograph showing resistant (R) and susceptible (S) bulk DNA samples (each consisting of DNA from 10 individuals) and six individuals from the F_1 population (top), and schematic representations of the corresponding chromosomes (bottom). The segregation of marker M39 is indicated on the autoradiograph. The location of additional markers and recombination events in the F_1 lines is indicated in the bottom panel.

Mapping *Ry*

A chromosomal assignment of Ry_{sto} was the first step toward the molecular cloning of Ry_{sto} from potato by a map-based approach. Molecular linkage maps of potato and tomato genomes were readily available, so we used amplified fragment length polymorphism (AFLP) technology as a source of molecular markers linked to Ry_{sto} (Figure 2). *Ry* from *S. stoloniferum* has been mapped at the Sainsbury Laboratory on the top arm of the potato chromosome XI.

A second step involved constructing a high-resolution genetic map around the *Ry* locus. That was obtained using an F_1 segregating population of 360 plants. Several AFLP primer combinations were tried on DNA pools of resistant and susceptible plants. Two AFLP markers (M17 and M6) at either side of the gene (separated by a single recombination event) and two more markers (M45 and M5) cosegregating with *Ry* were found. DNA markers linked to the resistance gene have been used to screen 22 CIP crosses that carry Ry_{sto} and segregate for the resistance.

To increase the map resolution of the markers relative to the resistance gene, an additional 3,079 F_1 segregating progeny (1,779 progeny from the 1st year and 1,300 from the 2nd year) have been screened. The resistant parent (I-1039) of this new cross was the same as the one originally used at the Sainsbury Laboratory for chromosomal assignment of Ry_{sto} and construction of the first genetic map.

Results

The screening has been carried out in several stages. First, polymerase chain reaction (PCR) markers were used so that plants with recombination events close to the resistance gene could be identified (i.e., plants with recombination between the markers). The flanking PCR markers used in the screening of the new cross were M39b and GP163. A few hundred recombinants were found in this interval. Using the GP259 PCR marker, the number of recombinants was reduced. From these data it was also possible to confirm the order of the PCR markers in the genome relative to each other and, following resistance testing of the recombinant plants, relative to Ry_{sto}.

The recombinants identified were analyzed by AFLP using the primer combinations for the closest markers: M17, M5, M45, and M6. The new map obtained with this second mapping population was compared with the previous map. The order of the markers is conserved although the genetic distances have increased slightly. We have been able to separate M39b from M33, but M17 is now cosegregating with M5 and M45 (Figure 3).

To obtain an estimate of the physical distances around the *Ry* locus, we began screening bacterial artificial chromosome (BAC) and cosmid libraries. We identified a single BAC clone (cBAC-15) of 110 kb containing three of our markers (M17, M5, and M45) although it is from a chromosome that carries the *ry* (rather than the *Ry*) allele. We are now attempting to map the ends of cBAC-15 to obtain new markers in the vicinity of *Ry*.

If the currently available libraries do not yield *Ry*, we will prepare new libraries from dihaploid plants that have been generated from the tetraploid parent I-1039 (which carries *Ry* in the simplex condition). When clones that span the *Ry* locus have been produced, we will identify the precise location of the gene by complementation. Different fragments of DNA from the *Ry* interval will be transformed into susceptible plants and the transgenic lines will be tested for resistance to PVY.

Discussion

For several years CIP has invested a great deal of effort in searching for sources of resistance to several viruses in the wide range of potato genotypes in the germplasm collection held at CIP. Breeding for virus resistance was focused on the three major viruses, PVX, PVY, and PLRV. The main goal was the development of advanced materials with combined resistance to PVX, PVY, and PLRV to allow farmers to keep their own seeds season after season, in this way reducing their cost of potato production.

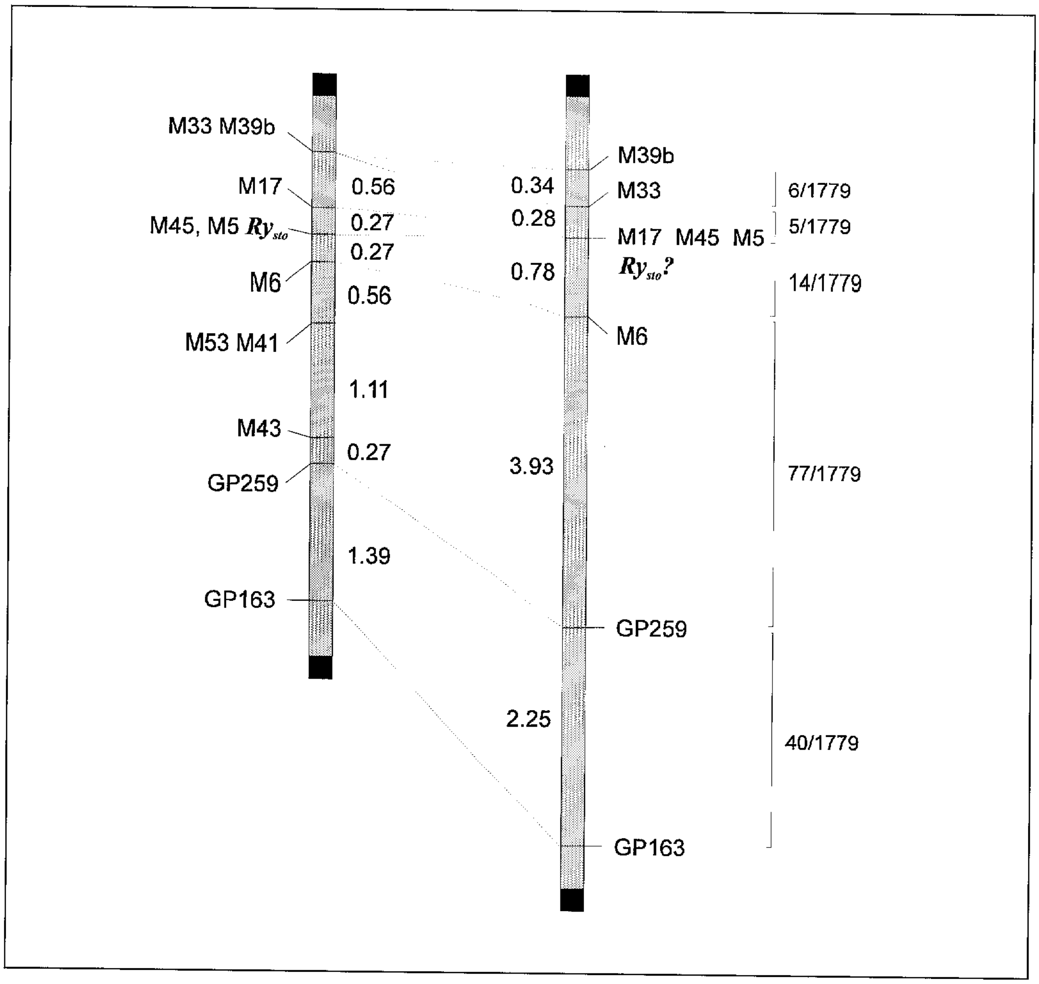


Figure 3. High-resolution map of the Ry_{sto} region on the top arm of potato chromosome XI. The genetic distances between markers were inferred from an F_1 population of 360 plants (chromosome on left) and for a population of 1,779 plants (chromosome on right). The number of recombinant progeny obtained for different intervals is indicated on the right. In the larger population, markers M39b and M33 were separated. An additional 1,300 plants are being analyzed to refine the relative positions of markers M17, M45, and M5.

The strategy followed was to first introduce PVX and PVY extreme resistance genes from *Solanum tuberosum* subsp. *andigena* into advanced breeding populations, then to combine PVX and PVY extreme resistance with resistance to PLRV and possibly other pathogens. Genes controlling resistance often originate from wild species; undesirable traits may be closely linked to the resistance gene and may be difficult to eliminate.

In our transformation approach, we will transfer only isolated and characterized genes (not a large piece of the whole genome) so that the recipient genotype remains largely intact. Transformation with natural resistance genes is potentially the shortest and most precise procedure for introgressing resistance genes into a crop species.

The ultimate aim of this work is to support increased potato production in developing countries. But we also expect the project to generate knowledge of the mechanisms involved in virus resistance as well. We perceive a practical application of this new approach over the medium term and long term. In the medium term, practical applications will be achieved through the identification and isolation of natural genes that confer extreme resistance to PVX, PVY, and PLRV, and their insertion into available susceptible but agronomically important potato cultivars.

Over the long term, we plan to integrate this nonconventional approach to optimize advances on resistance to other pests and pathogens already achieved through conventional breeding. Of particular interest will be the combination of conventional and nonconventional breeding methods to increase levels of PLRV resistance. In addition, molecular breeding methods can be used to add resistance to viruses (*Rx* and *Ry* genes) to advanced materials with resistance to other pathogens.

The concept of plant-derived transgenic resistance provides an attractive strategy to produce a novel but genetic form of virus control by transforming crop plants with nucleotide sequences derived from the plant genome itself. Natural resistance genes for plant protection would eliminate most of the biosafety concerns associated with the use of virus-derived sequences in transgenic plants.

Selected Reading

Bendahmane, A., K. Kanyuka, and D.C. Baulcombe. n.d. High resolution genetical and physical mapping of the *Rx* gene for extreme resistance to potato virus X in tetraploid potato. Theor. Appl. Genet. (In press.)

Brigneti, G., J. García-Mas, and D.C. Baulcombe. 1997. Molecular mapping of the potato virus Y resistance. Theor. Appl. Genet. 94:198-203.

Encapsidation of PSTVd in PLRV Particles and Its Transmission by Aphids

M. Querci[1], R.A. Owens[2], and L.F. Salazar[1]

Like all known viroids, potato spindle tuber viroid (PSTVd) is an independently replicating agent, which completes its infection cycle without generating either a capsid or other viroid-specific proteins. Its genome is a small (359 nt), single-stranded, covalently closed circular ribonucleic acid (RNA) molecule whose extensive regions of intramolecular complementarity are responsible for its unusual stability *in vivo.*

The natural spread of PSTVd in potato was known to occur only by foliar contact or botanical seed.

In contrast to PSTVd, potato leafroll virus (PLRV), a member of the genus *Luteovirus,* is readily transmitted by aphids, with *Myzus persicae* being the most efficient natural vector. Like all luteoviruses, PLRV is restricted to the phloem tissue of infected plants, and aphid transmission is both persistent and nonpropagative. PLRV has a narrow host range, and the virus is commonly found wherever potatoes are grown.

Earlier we confirmed that *M. persicae* could transmit PSTVd to potato and other test plants only when the source plant was doubly infected with PLRV and PSTVd. In some experiments, PSTVd transmission reached 100%; but no transmission was observed from source plants infected with the viroid alone.

Transmission by Aphids

Occasional PSTVd contamination of PLRV isolates maintained at CIP provided the first indication that PLRV might facilitate aphid transmission of PSTVd. Additional epidemiological evidence for an association between PSTVd and PLRV in field-grown potatoes was subsequently obtained by testing plants growing at several sites in China for the presence of PSTVd and PLRV. A total of 880 plants from three sites were tested by nucleic acid spot hybridization (NASH) in 1994, and Table 1 summarizes the results from these analyses.

Rates of infection for both PLRV and PSTVd varied considerably, ranging from 3.6% to 86% and 0.9% to 27.2%, respectively. Vector pressure was highest at the Bashang Institute (Hebei Province).

As expected, the incidence of PLRV at that site appeared to be somewhat greater than at the others. Most (but not all) PSTVd-infected plants at all three sites were also infected with PLRV. No effect on either host genotype or site was identified for aphid transmission of either PLRV or PSTVd, and the pooled data were analyzed to test the independence of PSTVd and PLRV distribution. The x^2 value (29.68) was highly significant, strongly suggesting that PLRV facilitates the spread of PSTVd under field conditions.

Additional aphid transmission experiments were carried out to more precisely characterize the mode of PSTVd transmission by *M. persicae.*

Materials and Methods

Potato clone DTO-33 (CIP No. 800174), a *Solanum tuberosum* x *S. andigena* hybrid susceptible to PLRV and PSTVd, was used as both inoculum source and test plant. Plants doubly infected with PLRV and PSTVd were obtained by initially inoculating them with PLRV

1 CIP, Lima, Peru.
2 Beltsville Agricultural Research Center, Beltsville, Maryland, USA.

Table 1. Incidence of PLRV and PSTVd at three potato-growing sites in China, 1994.[a]

Potato variety	Site	Samples	Infection rate (%)		Coinfection rate (%)
			PLRV	PSTVd	
Tiger Head	Bashang Inst. Hebei Province	132	66.7 (88)	2.3 (3)	2.3 (3)
88-1-19	Bashang Inst. Hebei Province	114	86.0 (98)	2.6 (3)	1.8 (2)
Bashu No. 10	Bashang Inst. Hebei Province	106	63.2 (67)	0.9 (1)	0 (0)
Purple Flower White	Wachuan County Inner Mongolia	241	17.8 (43)	1.7 (4)	0 (0)
Desiree	Wachuan County Inner Mongolia	56	3.6 (2)	0 (0)	0 (0)
Tiger Head	Inner Mongolia University	103	68.9 (71)	27.2 (28)	25.2 (26)
Purple Flower White	Inner Mongolia University	128	36.7 (47)	18.8 (24)	18.8 (24)

a. Field surveys were conducted in 1994. Samples from the Bashang Institute and Wachuan County were obtained from farmers' fields. All samples were randomly selected, and the presence or absence of PLRV and PSTVd was determined by NASH. Numbers of singly and doubly infected plants are shown in parentheses. Analysis of all data (including a Yates correction) yielded a x^2 value of 29.68. Assuming no effect of host variety or site on aphid transmission, a x^2 value of 6.64 indicates significance at the 1% level.

by means of its vector, *M. persicae*, and then manually inoculating them with sap from PSTVd-infected tomato (*Lycopersicon esculentum* cv. Rutgers). After inoculation, plants were maintained in a growth chamber and periodically tested for PSTVd and PLRV infection.

Apterous aphids from a nonviruliferous colony of *M. persicae* were raised on Chinese cabbage (*Brassica pekinensis* (Lour.) Rupr.). One month after PLRV or PSTVd inoculation, apterous aphids were allowed a 3-day acquisition access period on either singly or doubly infected source plants. Aphids (5 aphids/plant) were then transferred to young uninfected potato plants by placing the insects on filter paper squares using a sterile brush and then allowing them to walk onto a plant leaf.

A final 2-day passage on healthy Chinese cabbage was included in one experiment. After a 3-day transmission access period (TAP), aphids were killed by spraying plants with a contact insecticide.

Nature of PSTVd and PLRV Association

Fifteen and 45 days after the TAP, inoculated plants were tested for the presence of PSTVd and PLRV using a combination of the NASH test and enzyme-linked immunosorbent assay (ELISA). *M. persicae* was able to transmit PLRV under all conditions tested (Table 2). PSTVd transmission, in contrast, was observed only when the aphids were allowed to acquire the viroid from doubly infected source plants. Comparison of data presented in rows 3 and 4 shows that aphids allowed to feed sequentially on plants singly infected with PLRV or PSTVd were unable to transmit PSTVd.

Feeding on healthy cabbage before transfer to the test plants reduced, but did not eliminate, the ability of aphids to transmit PSTVd from doubly infected source plants. Thus, PLRV-mediated transmission of PSTVd by *M. persicae* appears to be of the persistent type.

To further characterize the nature of the association between PSTVd and PLRV, a se-

Table 2. Aphid transmission of PLRV and PSTVd to potato variety DTO-33.

Inoculum source(s)	Passage	Successful transmission [a]	
		PLRV	PSTVd
PLRV	None	Yes (4/5)	No (0/5)
PLRV	Chinese cabbage	Yes (2/5)	No (0/5)
PLRV → PSTVd [b]	None	Yes (2/3)	No (0/3)
PLRV → PSTVd [b]	Chinese cabbage	Yes (1/5)	No (0/5)
PLRV + PSTVd	None	Yes (4/5)	Yes (3/5)
PLRV + PSTVd	Chinese cabbage	Yes (1/5)	Yes (1/5)

a. Data presented as no. of infected plants/no. of inoculated plants.

b. Aphids were allowed two acquisition feedings, on PLRV-infected plants followed by the second on PSTVd-infected source plants.

ries of virus purifications were carried out using leaf tissue collected from singly and doubly infected potato plants. The first experiment compared the amounts of PSTVd RNA associated with virions purified from doubly infected plants with those associated with particles isolated from a pooled sample of leaves collected from singly infected plants. PLRV was purified, and encapsidated RNAs were recovered by phenol/chloroform extraction and ethanol precipitation. RNA pellets were resuspended in sterile nuclease-free water and reverse-transcribed using a random hexanucleotides mixture (pdN6).

PSTVd- and PLRV-specific cDNAs were then amplified separately by polymerase chain reaction (PCR) using the appropriate pairs of oligonucleotide primers.

Amplifications (40 cycles) were carried out using a 94°C (1 min), 55°C (2 min), 72°C (1 min) profile followed by a 5-min final extension at 72°C; PCR products were visualized by electrophoresis on 5% acrylamide gels. Predicted sizes for the PSTVd- and PLRV-specific PCR products were 226 and 534 bp, respectively.

As shown in Figure 1A, large amounts of a PLRV-specific product of the appropriate size were present in PCR reactions containing RNA derived from either singly (lane 3) or doubly infected (lane 2) plants. The corresponding PSTVd-specific product was present only in reactions containing RNA derived from doubly infected tissue (lane 5). When virions were isolated from a mixture of leaves collected from singly infected plants, no PSTVd-specific PCR product was produced (compare lanes 5 and 6).

To determine whether transencapsidation of PSTVd by PLRV was responsible for its observed aphid transmissibility, two types of samples were treated with micrococcal nuclease: PLRV virions isolated from doubly infected leaf tissue, and mixtures of virions isolated from singly infected plants plus sufficient PSTVd RNA to produce a comparable ratio of PSTVd/PLRV.

Trial experiments showed that 15-min incubation at 30°C with 1×10^{-3} units/μl micrococcal nuclease completely destroyed concentrations of PSTVd similar to those found in PLRV virions isolated from doubly infected tissue (results not shown).

Parallel incubations were carried out, each containing the same amount of virus but only

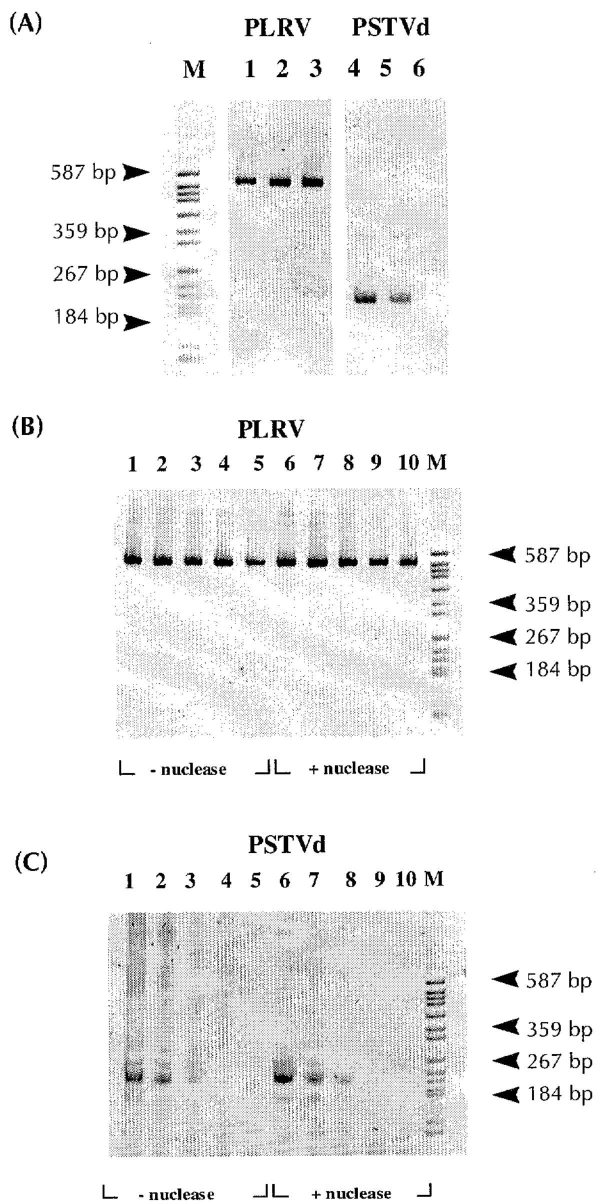


Figure 1. PAGE (polyacrylamide gel electrophoresis) analysis of RT-PCR products. (A) Association of PSTVd with PLRV virions purified from different sample types: PSTVd RNA plus PLRV virions purified from singly infected plants (lanes 1 and 4); PLRV virions purified from doubly infected plants (lanes 2 and 5); PLRV virions purified from leaves from singly infected plants combined before PLRV purification (lanes 3 and 6). (B-C) Relative sensitivity of PLRV and PSTVd RNAs to digestion by micrococcal nuclease. RT-PCR analyses were carried out using pairs of (B) PLRV- or (C) PSTVd-specific primers. Virions purified from doubly infected potato plants were incubated for 15 min at 30°C in either the absence (– nuclease) or presence (+nuclease) of micrococcal nuclease before extraction of RNA. Lanes 1-5 and 6-10 contain serial threefold dilutions of the mixture of randomly primed PLRV and PSTVd cDNAs. M=DNA size markers.

one containing micrococcal nuclease. After incubation, the undigested RNAs were isolated by phenol-chloroform extraction, reverse transcribed, and analyzed by reverse transcription polymerase chain reaction (RT-PCR). Results from these analyses are presented in Figures 1B and 1C.

Each set of five amplifications (lanes 1-5 and 6-10) contained a series of threefold dilutions of the initial preparation of randomly primed PLRV and PSTVd cDNAs.

Samples in lanes 1-5 were derived from untreated virions, whereas those in lanes 6-10 were treated with micrococcal nuclease before RNA extraction. In Figure 1B, comparison of lanes 1-5 with 6-10 shows that, as expected, the viral genomic RNA was resistant to micrococcal nuclease digestion. The corresponding PSTVd-specific analyses are shown in Figure 1C. Because the virions contain relatively low levels of viroid RNA, the amount of PSTVd-specific PCR product decreased as the amount of randomly primed cDNA template was reduced. Micrococcal nuclease digestion, however, had no effect on the amount of PSTVd-specific PCR product synthesized.

This experiment was repeated several times with different virus preparations, and though the relative amount of PSTVd in the different PLRV preparations varied, the results obtained were consistent and comparable. The explanation for our results is that the PSTVd associated with virions isolated from doubly infected plants is, like the PLRV genomic RNA, located within the virus particle. Unencapsidated PSTVd RNA would have been degraded by the micrococcal nuclease digestion. Expressed on a molar basis, the amount of PSTVd from doubly infected plants is approximately one molecule of PSTVd for every 3,000-5,000 molecules of PLRV RNA.

Discussion

In nature, plant viruses and other subviral pathogens (satellite/defective interfering RNAs or viroids) have many opportunities for interaction. Multiple virus infections commonly occur in crop and weed hosts. That may result in virus particles in which (1) individual particles contain structural proteins derived from more than one virus or (2) the genome of one virus is encapsidated in the structural proteins of another. This phenomenon, variously known as *transencapsidation, genomic masking*, or *phenotypic mixing*, has been observed many times for members of the luteovirus and potyvirus groups. Several sobemoviruses are known to support the replication of small viroid-like satellite RNAs, as in the case of velvet tobacco mottle virus (VTMoV), which has been shown to encapsidate PSTVd. Even more recently, a small, ribozyme-containing satellite RNA has been reported in association with certain isolates of barley yellow dwarf virus-RPV serotype. The size of PSTVd is similar to that of barley yellow dwarf virus satellite RNA (i.e., 359 vs. 322 nt). Our data show that it too can be encapsidated by a luteovirus, PLRV.

Transencapsidation of PSTVd by an assistor virus and the resulting acquisition of aphid transmissibility have important epidemiological implications. Although viroids are generally thought to be mechanically transmitted, some workers see a different possibility. In that view, a viroid originating in a plant species in which it is symptomless could be encapsidated by a virus and vectored to another plant species. Even though that plant might not be a host for the virus itself, it could be one in which the viroid becomes pathogenic. Our survey data from China indicate that, even where the overall level of PLRV infection was relatively moderate, all or almost all plants found infected with PSTVd were also infected with PLRV. VTMoV greatly suppresses PSTVd replication in *Nicotiana clevelandi*. Nevertheless, tomato plants, which are immune to VTMoV, became infected with PSTVd when inoculated with viroid-containing VTMoV preparations. Additional data will be required to determine whether PLRV has a similar effect on PSTVd replication in potato, but transmission by aphids or other insect vectors provides a plausible explanation for the presence of PSTVd in such atypical hosts as avocado, a phenomenon occurring in Peruvian avocados.

Aphid transmission of PSTVd may be most important in long-distance dissemination of the viroid, thus facilitating its spread and greatly reducing the possibility of its control.

Conclusions

An important step in breeding for virus resistance is the identification of specific factors that tend to break down or overcome that resistance. In the case of PLRV, no genes conferring immunity have been described, and the various resistance genes known appear to act by different mechanisms. Compared to the levels of genetic resistance to potato virus X (PVX) or potato virus Y (PVY), the level of PLRV resistance conferred by individual genes is rather low.

In previous studies we found that the presence of PSTVd can lead to a decrease in the level of resistance to PLRV. Infection rates of 100% were observed for *S. acaule* accessions OCH 13823 and OCH 13824, following aphid-mediated transmission of virus from doubly infected source plants. In the absence of PSTVd, infection rates were fourfold or fivefold lower. These two genotypes had been shown to be resistant to both PLRV infection and multiplication.

A similar decrease in PLRV resistance is observed when resistant genotypes such as cv. Mariva are infected by either PVX or PVY. Knowledge of how other pathogens such as PSTVd might interfere with the expression of genes conferring PLRV resistance would help in selecting the type of resistance to be incorporated and predicting its expected durability. We are working to identify the different components of resistance to PLRV as well as to elucidate the role of PSTVd in decreasing such resistance.

Selected Reading

Querci, M., R.A. Owens, I. Bartolini, V. Lazarte, and L.F. Salazar. 1997. Evidence for heterologous encapsidation of potato spindle tuber viroid in particles of potato leafroll virus. J. Gen. Virol. 78:1207-1211.

Progress in Identifying Viruses Infecting Andean Root and Tuber Crops

C. Lizárraga, M. Santa Cruz, and L.F. Salazar[1]

The first step in the control of any disease is the isolation and study of the pathogen. Because virus diseases can reduce yields in many crops and are easily transmitted in vegetative propagation, identifying viruses that infect Andean root and tuber crops (ARTC) is a major priority in the effort to produce planting materials of high quality, and to facilitate the international exchange of valuable virus-free germplasm.

The Andean tuber crops include ulluco (*Ullucus tuberosus* Caldas), oca (*Oxalis tuberosa* Mol.), and mashua (*Tropaeolum tuberosum* R. & P.). Two root crops are arracacha (*Arracacia xanthorrhiza* Bancroft) and mauka (*Mirabilis expansa* R. & P.). Viruses in these crops have not been well studied.

Previously, only four viruses were reported infecting ulluco: ullucus mosaic virus (UMV), ullucus virus C (UVC), papaya mosaic virus (PapMV-U), and tobacco mosaic virus (TMV-U); three infecting oca: potato black ringspot virus (PBRV), arracacha B, and PapMV-O; and three infecting arracacha: arracacha A (AVA), arracacha B (AVB), and arracacha potyvirus 1 (AP-1). Their effect on ARTC has not been determined.

Materials and Methods

Virus identification

Standard virological techniques applied to studies of potato viruses were used. Viruses were isolated by mechanical inoculation or graft inoculation, or were insect-transmitted to indicator plants and identified by serology using antisera available for known viruses. Purified preparations of the isolated viruses were injected into rabbits to produce antisera for detection and for determining serological relationships to well-known plant viruses.

Virus effect on yield

Two ulluco accessions, MH-290 and MH-296, from the germplasm collection maintained at CIP and freed of virus infection by thermotherapy and meristem culture were provided by C. Arbizu (CIP). The in vitro plants were multiplied by cuttings in the screenhouse in CIP-Huancayo (3,200 m above sea level) and the tubers were collected.

To study the effect of primary infection, the tubers were planted in October 1994 in CIP-Huancayo. The young ulluco plants were mechanically inoculated in December 1994 with UMV, UVC, and PapMV-U individually, and with the three viruses simultaneously. Control plants were mock-inoculated with distilled water. The tubers were harvested in June 1995 and stored until October 1995, when the MH-290 tubers were planted in the same field to study secondary infection. Tubers from MH-290 were harvested in June 1996.

Results

Table 1 shows the viruses isolated and the ones now known to infect five ARTC.

No significant differences ($P \leq 0.05$) were found for the yield of ulluco plants with primary viral infection and the healthy control. Table 2 shows the effect of three different viruses on the yield of ulluco plants (MH-290) with secondary viral infection in CIP-Huancayo. As expected, the combined infection by the three viruses caused a higher yield decrease.

1 CIP, Lima, Peru.

Table 1. Viruses known to infect ulluco, oca, mashua, arracacha, and mauka, CIP, 1996.

Crop	Viruses identified previously	Viruses identified in this study	Viruses in process of identification
Ulluco	UMV	PLRV	—
	UVC	APLV	
	PapMV-U	AVA	
	TMV		
Oca	PBRV	PVT	O-2
	AVB		
	PapMV-O		
Mashua	—	SoMV	M-1, M-3, M-4, M-5
Arracacha	AVA	PBRV-A	AV-3
	AVB		
	AP-1		
Mauka	—	—	Mir-1

Table 2. Average yields (kg) of ulluco plants MH-290 with secondary infection of three viruses, CIP-Huancayo, 1996.

Treatment	Total yield[a]	First category tubers	Yield reduction[b] (%)
UMV	19.1 bc	10.5 b	29
UVC	19.7 bc	10.7 b	27
PapMV	24.2 ab	14.5 ab	10
UMV + UVC + PapMV	16.7 c	10.5 b	38
Healthy control	26.9 a	16.0 a	—

a. Inner rows of 66 plants. Means within columns followed by the same letters are not significantly different at the $P \leq 0.05$ level.

b. Compared with healthy control total yield.

The reported incidence of viruses in ulluco, oca, and arracacha in the Andean region (Table 3) indicates the possible relative importance of the different viruses that infect ARTC.

Discussion

In the Andes, ulluco, oca, and potato are often intercropped and the presence of potato viruses in ulluco and oca supports the premise that plant viruses can adapt to new hosts subsequent to long-term associations. Although the importance of these viruses in ulluco and oca is unknown, PLRV is the most important virus in potato. PLRV-infected ulluco plants grown near potato seed stocks could have serious epidemiological implications, particularly because PLRV has a reported incidence of 37% in ulluco.

Table 3. Reported incidence of viruses in ulluco, oca, and arracacha in the Andean region.

Crop	Virus	Reported incidence (%)
Ulluco	UMV	57
Ulluco	UVC	87
Ulluco	PapMV-U	85
Ulluco	TMV	34
Ulluco	PLRV	37
Ulluco	APLV	44
Ulluco	AVA	3
Oca	PBRV	0.2
Oca	AVB	0.2
Oca	PapMV-O	22
Arracacha	AVA	6
Arracacha	AVB	25
Arracacha	AP-1	51
Arracacha	PBRV-A	7
Arracacha	AV-3	52

The practical impact of ARTC virus identification studies is the production of virus-free planting materials that will allow farmers to obtain higher yields and reduce degeneration of cultivars. The results of field experiments in Huancayo have shown that clean ulluco planting materials can have higher yields than plants secondarily infected with viruses. UMV and UVC have reported incidences of 75% and 87%, respectively, and apparently are the most important viruses in ulluco since they cause yield reductions above 27%.

The antisera produced in these studies can be used in the sensitive serological technique called enzyme-linked immunosorbent assay (ELISA) to provide reliable virus detection for institutions involved in cleaning up ARTC and producing healthy planting materials.

Conclusions

Although these results indicate that virus-free ulluco can have higher yields, further work must be done in farmers' fields to confirm this and to determine the rate of reinfection to justify using resources in the production of virus-free materials. The same studies should be done for all ARTC, beginning with the most economically important ones.

Many viruses infect ARTC; determining which ones cause major yield reductions must be a high priority in the continuation of this work. Information on viral incidence and distribution has a collateral role in ascertaining the importance of viruses.

Selected Reading

Lizárraga, C., M. Santa Cruz, and U. Jayasinghe. 1996a. Detection of an isolate of Andean potato latent virus in ulluco (*Ullucus tuberosus* Caldas). Plant Dis. 80:344.

Lizárraga, C., M. Santa Cruz, and L.F. Salazar. 1996b. First report of potato leafroll virus in ulluco (*Ullucustuberosus* Caldas). Plant Dis. 80:344.

Salazar, L.F. 1996. Potato viruses and their control. CIP, Lima, Peru. 226 p.

PROGRAM REPORT

Program 4

Integrated Pest Management

Fausto Cisneros[1]

Six premises guide the work of CIP's Integrated Pest Management (IPM) Program within the overall ecological context of IPM for crop protection without affecting human health and the environment. First, small- and medium-size farmers with limited resources are defined as the clientele. Second, IPM research and implementation are considered a continuum that culminates in farmers' fields. Third, IPM components are offered to farmers not as a technological package but as a menu of options appropriate to their situations. Fourth, IPM is implemented in the broader context of integrated crop management in collaboration with farmers' organizations, NARS[2], and NGOs. Fifth, IPM programs are sustainable only insofar as they are simple to implement and maintain. Finally, training activities and training materials are oriented toward improving farmers' capacity to understand and better select the IPM options.

To develop our work along these premises, we follow a strategy that has five developmental phases: (1) pest assessment, (2) development of IPM components, (3) integration of these components, (4) establishment of IPM pilot units in farmers' fields, and (5) large-scale IPM implementation.

In addition, the FAO's farmer field school model, developed for implementing IPM on rice, is being adopted by CIP's regional office in Southeast Asia to manage sweetpotato pests. The objective is to improve analytical and decision-making skills of farmers. This experience is in the initial stage.

1 Program Leader, CIP, Lima, Peru.
2 Acronyms cited in this section can be found written out in the section *Acronyms*, p. 320.

Target Pests

Selected key pests of potato were the complex of potato tuber moths (PTM) that included the common PTM (*Phthorimaea operculella*), widely distributed in the warmer potato-producing areas; the spotted or Andean PTM (*Symmetrischema tangolias*), present at mid-elevations in the Andean countries; the Central American PTM (*Tecia solanivora*), which is rapidly spreading to South America; and the Andean weevil complex (APW), which includes *Premnotrypes* spp. and other related genera, in the high mountains (> 2,800 m) of the Andean region. These pests can cause damages above 50% in the field (APW) or in stores (PTM). Another selected key pest is the leafminer fly, *Liriomyza huidobrensis*, and related species. They are widespread and responsible for the heavy use of insecticides in potato and other vegetable crops.

Weevils were the selected key pests for sweetpotato. The Asian species (*Cylas formicarius*) is the most serious pest of sweetpotato in the Caribbean and South Asia. The African species (*C. brunneus* and *C. puncticollis*) that occur in sub-Saharan Africa are equally injurious.

Research Achievements

Progress in IPM for key pests under study is reported here in the IPM phases at which most of the work was done during the report period, 1995-96. The economic importance of each pest was assessed before biological research started.

Development of IPM components

IPM components in the developmental phase are those for control of the African species of sweetpotato weevil in sub-Saharan Africa, leafminer fly in Latin America and the Caribbean, and PTM in Morocco and Yemen.

Research on the African weevils was conducted in Uganda and included the study of the life cycles and seasonal history of the two species, the effects of cultural practices on weevil damage, and the identification and synthesis of sex pheromones for both. Pheromones may become a key IPM component for managing the weevils. These components are beginning to be tested in pilot units.

Research on leafminer flies included the study of the life cycle, the seasonal history, plant-insect interactions (with special attention to the egg-extrusion phenomenon), development of resistant potato clones, the occurrence and effectiveness of the complex of natural enemies, the selective effect of larvicides, and the effects of cultural practices.

In Morocco and Yemen, the development of IPM components for PTM concentrates on biological control. In addition to using granulosis virus (GV) and *Bacillus thuringiensis* (Bt), four parasitoids are being reared for release in Yemen and Tunisia: *Copidosoma koehleri*, *Diadegma molliplum*, *Chelonus phthorimaea*, and *Orgilus lepidus*.

Integration of IPM components into pilot units

After several years of investigation, the components for the management of South American PTM and APW, and the common PTM in northern Africa, have been integrated into pilot units. In some areas, implementation is already extending beyond the pilot unit boundaries.

Latin America and the Caribbean. In Peru, pilot units have been established in six farm communities: two in the south (Cusco) with the participation of ARARIWA (an NGO) and INIA, three in the central mountains (Junín) with the participation of TALPUY (an NGO) and INIA, and two in the north (Cajamarca) with the participation of INIA.

Weevil damage in the north was reduced from an initial level of 60% to a current level of 10%, and from 44% to 7-10% in the south. The areas of influence of these pilot units are increasing steadily as farmers of neighboring communities participate in field days when farmers in the pilot units explain their experiences.

The NGO CARE-Peru created an IPM program for the management of APW and PTM with the financial support of USAID (1994-96) and the technical support of CIP. The program, called MIPANDES, proved very successful and benefited 3,200 peasant families in the high mountains.

Similar pilot units have been established in Bolivia (at Mizque for PTM and at Kollana for APW) with direct participation of PROINPA and IBTA. In Ecuador, pilot units are situated in Chimborazo and Cotopaxi with the participation of INIAP. In Colombia, pilot units at Ventaquemada and Motavita have the collaboration of CORPOICA, the local UMATAs, the Secretaría de Agricultura, and SENA. These pilot units in the Andean countries are supported financially by the Inter-American Development Bank.

Finally, in the Dominican Republic we established pilot units for PTM in Constanza with the collaboration of MIP/JAD. Sprayings for PTM control have been reduced from six per cropping season to only one.

Middle East and North Africa. Pilot units for managing PTM in stores were established at 13 sites in Egypt to introduce the use of GV and Bt as alternatives to the toxic insecticide fenitrothion, which has been officially banned for use on ware potatoes. Five sites are producing GV and two are producing Bt. More than 250,000 pheromone traps are used to monitor PTM populations in the field to determine when to begin control measures and to reduce pesticide use. Three government agencies are involved in the program: PPRI, AGERI, and ARC.

Pilot units have been established in three major potato areas in Tunisia: Jendouba, Cap Bon, and Bizerte. They are demonstrating the efficiency of GV for PTM control as an alternative to deltamethrin and malathion, which are commonly used.

Large-Scale Implementation

A case of extraordinary growth of IPM with CIP's technical support is the management of the sweetpotato weevil in Cuba. Damage to the Cuban sweetpotato crop had been held to about 10%, with 10-12 sprayings a season, when Cuba was obtaining insecticides from the Soviet Union. But damage ballooned to about 50% when the insecticides were no longer available, beginning in 1991-92.

In just three years (1993-96), the first two pilot units covering 230 ha in two provinces (Cienfuegos and Villa Clara) expanded to about 10,000 ha in all 13 provinces of the island. The Cuban organization INIVIT simultaneously developed an active research program and an implementation campaign. Pheromone traps, predatory ants, the parasitic fungus *Beauveria bassiana,* and strict cultural practices were the main components of the program. As a result, weevil damage is back down to 5-10%, without any use of insecticides.

Integrated Management for the Potato Tuber Moth in Pilot Units in the Andean Region and the Dominican Republic

M. Palacios and F. Cisneros[1]

The potato tuber moth complex is the most damaging pest of potato (*Solanum tuberosum*) under the warm and dry environments of fields and stores. It is formed by three main species: the common moth (*Phthorimaea operculella*), distributed worldwide; the Andean species (*Symmetrischema tangolias*), in the Andean valleys of Bolivia, Colombia, and Peru; and the Central American moth (*Tecia solanivora*), which has spread from Central America to Colombia, Ecuador, and Venezuela in recent years. Damage caused by these pests is around 30% in the field and above 50% in stores when not controlled.

Farmers commonly use highly toxic chemicals to control tuber moths. As a result, production costs increase, farmer health is compromised, moths develop resistance to most treatments, and in some places whiteflies (Aleyrodidae) appear as induced pests. Surveys show that farmers do not distinguish different moth species or moth behavior in fields or in stores, nor do they understand the seasonal history of the pest. That lack of knowledge results in inadequate control methods.

CIP has developed a series of control methods considered as integrated pest management (IPM) components. They are part of a menu of options being offered to farmers in pilot units distributed in the Andean countries and the Dominican Republic.

Rationale of IPM Components

The life cycle and control measures of the common potato moth (*P. operculella*) are well known. But little is known of *S. tangolias*. Our studies have shown important differences between these species in terms of duration of life cycles (Table 1), seasonal history, behavior in fields and in stores, favorable ecological conditions, and control methods. In most Andean valleys, *P. operculella* and *S. tangolias* have three or four generations a year. *S. tangolias* is not a pest at low altitudes, whereas *P. operculella* develops 6 to 10 generations a year. *T. solanivora* may have up to six generations a year at medium to high altitudes.

Sources of infestation are potato stores and potato fields, especially those fields where potato residue is allowed to remain after harvest. Moths commonly move in both directions. Field-infested tubers, or tubers infested at harvest, carry initial infestations to stores. The various IPM components are designed to reduce pest movement between fields and stores and to lower larval and adult moth densities. Pheromone traps to capture adult males and the use of a *Baculovirus* to protect stored seed tubers are key IPM components. These measures have impressed farmers and prompted them to adopt other IPM measures as well.

Field control measures during crop growth

Measures to protect the potato crop from planting to harvest are primarily cultural control methods.

Good soil preparation. Adequate soil preparation not only ensures vigorous plant growth but also helps to destroy the remaining stages, mostly pupae, of the tuber moth before planting.

1 CIP, Lima, Peru.

Table 1. Life cycle in days for the three species of the potato tuber moth complex under conditions of pilot units in Peru, Colombia, and the Dominican Republic, 1996.

Species	*Phthorimaea operculella*			*Symmetrischema tangolias*	*Tecia solanivora*	
Country	Dominican Republic		Peru	Peru	Colombia	
Department/ Province	Constanza		Cajamarca	Cajamarca	Antioquia	Boyacá
Av temp (°C)	20.6	15.7	13.0	13.0	16.0	13.0
Stage:						
Egg	5	12	21	17	10	14
Larva	19	21	71	57	20	30
Pupa	8	24	36	31	20	23
Total	32	57	128	105	50	67
Longevity	12	23	32	33	22	22
Oviposition period	7	8	24	25	13	13
Eggs/female	150	150	138	185	101	290

Timely planting. Based on seasonal occurrence studies, optimum planting dates were determined to coincide with lower temperatures and the onset of rains. Farmers who plant in the dry period face high moth infestations.

Deep planting. Covering tuber seed to a depth of 5-10 cm prevents female moths from ovipositing in seed tubers and keeps larvae from migrating to tubers from infested aboveground sprouts. Neonate larvae of *S. tangolias* can burrow to a depth of 5 cm; those of *P. operculella* as much as 10 cm to the seed tubers.

High hilling. High hilling of growing plants protects the developing tubers from ovipositing females and reduces the possibility of larvae reaching the bulking tubers. High hilling can reduce damage by 30%.

Frequent irrigation. Adequate watering and cultivation prevent cracks from forming in the soil. Soil cracks allow female moths to reach the potato tubers for oviposition, and provide shelter for adult moths. Sprinkling irrigation alone reduces damage by 30%.

Pheromone traps. Commercial pheromones are available for *P. operculella* and *T. solanivora*. Mass trapping of male moths reduces the probabilities of moth mating, thus causing a drop in egg fertility. Pheromone traps can reduce infestation by 50%.

Control measures at harvest

The two most important control measures at harvest are protecting harvested tubers from ovipositing females and removing crop residues from the field.

Timely harvesting. During the last phases of the crop (tuber filling and plant senescence), the infestation rate accelerates. Delaying harvest by 1 or 2 mo can increase damage by as much as 70%.

Storing healthy tubers. Only healthy tubers should be stored. Infested tubers should be buried under at least 10 cm of soil.

Covering tubers. Female moths become active in the evening and most eggs are laid at that time. Harvested tubers should not remain exposed to ovipositing females overnight. If they cannot be stored immediately, tubers should at least be covered; otherwise the infestation level could reach 60% within a few days.

Destroying harvest residues. *P. operculella* and, to a larger extent, *S. tangolias* pupate in tubers and dry stems left in the field. Moths from these pupae infest the crop the following season (Table 2). Also, tubers left in the field become volunteer plants in the rotation crop. For these reasons, all harvest residues must be destroyed.

Measures to avoid damage in stores

Protecting tubers in stores can reduce moth damage by 70% to 95%.

Cleaning stores. Cleaning floors, walls, and ceilings of rustic stores before storing healthy tubers destroys pupae and other life stages of the moth.

Storing healthy tubers. Tubers should be sorted and infested ones discarded before storing. Tubers exposed to moth oviposition should not be stored, as eggs are commonly overlooked during sorting. Storing infested tubers or those that have been exposed to moth oviposition along with healthy tubers may result in infestation of the entire store in as little as 4 mo.

Using *Baculovirus*. A dust formulation of *Baculovirus phthorimaea*, containing 20 diseased larvae/kg at a dose of 5 kg/t tubers, is the most effective insecticide against *P. operculella*. Protection is somewhat lower in the case of the other two moth species. Tubers should be treated before larval infestation begins.

Repellent plants. The foliage of some plants, rich in essential oils, such as *Eucalyptus* spp., *Lantana camara*, and the native species *Schinus molle* and *Minthostachys* spp., repels potato moths. The leaves are dried under shade, crushed, and then used to cover the stored tubers. On the average, protected tubers are 80% less damaged than nontreated tubers.

Pheromone traps. Commercial pheromones disrupt mating of *P. operculella* and *T. solanivora* during storage. Tubers stored with pheromone traps are about 95% less infested than the control stores.

Diffused-light stores. Potatoes stored in diffused light are generally about 70% less infested than those stored in the dark. Illumination results in greening of the tubers (with glycoalkaloid formation), which is unfavorable for the moth. In addition, the arrangement of tubers in diffused-light stores facilitates the periodic elimination of damaged tubers.

Table 2. Number of moths emerged per hectare[a] from harvest residues (tubers and stems) and volunteer plants. Pilot units, Peru and Colombia, 1996.

Species	Moth larvae (no./ha)		
	Tubers	Stems	Volunteer plants
S. tangolias (Peru)	49,000	118,000	481,000
P. operculella (Peru)	43,000	—	—
T. solanivora (Colombia)	32,000	—	—

a. Sampling in pilot units (25 samples of 1 m^2 each)

Selection of Pilot Units

IPM components are tested in the field for final adjustments and evaluation of farmers' acceptance. That is done in pilot units of participating farmers who perceive the importance of the pest and are interested in trying new methods for its control. The participation of governmental agencies and nongovernmental organizations (NGOs) is crucial, because the pilot unit is considered as a demonstration area for IPM implementation at the national level.

The following activities take place in the pilot unit: evaluation of the problem, training of farmers and local counterparts, implementation of IPM components, adaptive adjustments of components, and identification of new research opportunities.

Training and field days are essential in the pilot units. They are designed to motivate all local stakeholders (including farmers), technicians, rural schoolteachers, university students, and community authorities to ensure the stability of the program. CIP provides technical support, participates in training, and provides basic instructional materials.

CIP set up IPM pilot units at two sites in Peru and Colombia in 1995 and one site in the Dominican Republic in 1993. The IPM components adopted by farmers in the pilot units and the results they obtained are reported here.

Pilot units in Peru

Two pilot units have been established in Peru: one in the southern community of Urquillos, Cusco; and one in central Peru at Carhuapaccha, Huancayo. In those areas, two species of moths occur: *P. operculella* in the warmer valleys, and at higher altitudes *S. tangolias*, which is rapidly increasing in importance. No commercial sex pheromone is available for the control of *S. tangolias*. The most important biological control agent is a *Baculovirus*.

Urquillos. Potato is grown year-round in Urquillos. During the rainy season, potatoes are grown at elevations of 3,600-3,800 m. In the dry season, they are grown under irrigation at lower elevations (2,800 m) where the crop is stored under constant pest pressure. The dominant species is *S. tangolias*, although *P. operculella* is also present (Figure 1). The pest problem is most serious in stores. Prac-

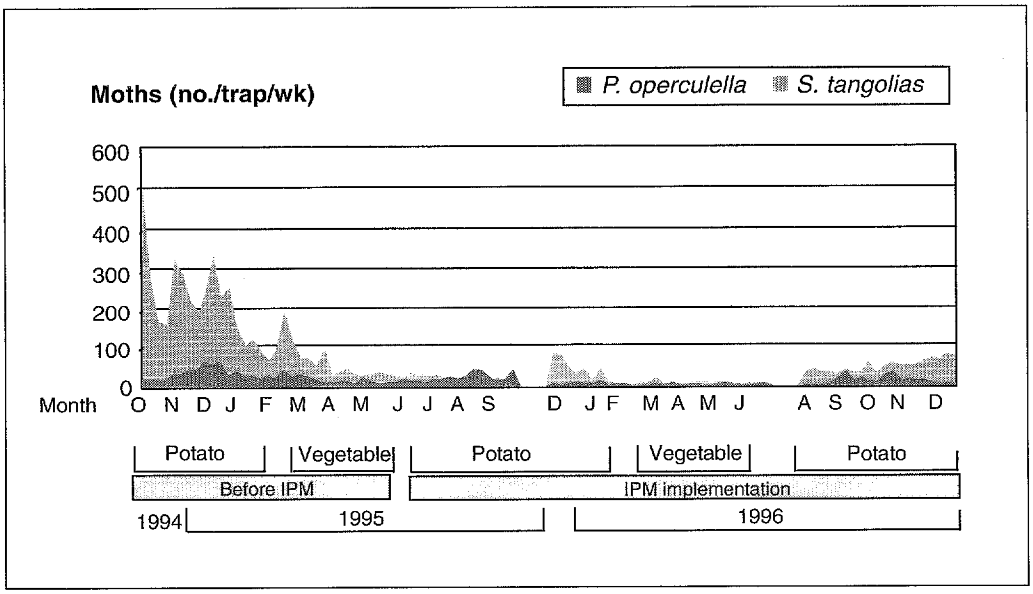


Figure 1. Potato tuber moth field populations in two consecutive years showing the effect of IPM implementation in Urquillos, Cusco, Peru.

tices adopted by farmers (largely by women of the community) are cleaning of stores and use of repellent plants and pheromone traps against *P. operculella*. Cleaning alone reduced infestation in rustic stores to only 10% of that experienced previously. Field practices adopted are deep planting, high hilling, irrigation, and timely harvest.

Before the IPM program began in 1994, average damage in stores was 65% despite the use of highly toxic insecticides such as parathion. In 1996, average damage for farmers participating in the IPM program was 3.4% (0-12%), whereas other farmers experienced 40-80% damage.

Farmers in Urquillos have formed an IPM committee to expand the use of IPM in the area, and the Farmers Federation of Cusco now promotes IPM.

Carhuapaccha. Potato production in Carhuapaccha is commercially oriented and insecticide use is intensive. Potato is produced at the higher elevations of the community (3,160-3,800 m). Irrigation is available at lower elevations and farmers produce other vegetables. Storage is limited to seed tubers and tubers for self-consumption. The bulk of production is sold in the local market.

Practices adopted in stores to control *S. tangolias* were cleaning stores, sorting, use of *Baculovirus* to protect tuber seed, and repellent plants to protect potatoes for home use.

About 50% of the tubers were infested in stores before the program started in 1995; damage in 1996 was reduced to 10%, whereas damage on neighboring farms ranged from 65% to 85%.

Pilot units in Colombia

The most damaging pests of potato in Colombia are the Andean potato weevil (*Premnotrypes* spp.) and *T. solanivora*, which was introduced from Venezuela to Colombia in 1985. At first it was restricted to the Norte de Santander Department, but by 1996 it had spread to the south of Colombia (Nariño Department) close to Ecuador. The aggressiveness of this pest, which infests tubers but not aboveground plant parts, created panic among farmers, who then started heavy spraying of fields and stores.

CIP's assistance in dealing with the pest was requested in 1994. A work program oriented toward implementing IPM began in two pilot units, one in El Santuario, Antioquia, and the other in Ventaquemada, Boyacá.

El Santuario. The Corporación del Instituto Colombiano Agropecuario (CORPOICA) was CIP's counterpart, leading in the implementation of CIP recommendations for the area. The first step was an intensive campaign to teach farmers and technicians how to recognize this new pest and its life cycle, behavior, and movements. The effectiveness of sex pheromone trapping was demonstrated, the effectiveness of *Baculovirus* was tested, and training materials were produced.

Farmers adopted the following practices: pheromone traps in fields and stores, use of *Bacillus thuringiensis* (Bt) and *Baculovirus* in stores as alternatives to toxic insecticides, use of healthy seed, high hilling, timely harvest, and cleaning stores.

In 1994, 50% of the area planted to potato was infested with *T. solanivora*. Thirty percent of tubers were infested at harvest. In stores, 100% tuber infestation was common. In 1996, the average number of infested tubers at harvest for the whole Antioquia Department, including the pilot units and different levels of IPM influence, dropped to 4.4% (0-43%), and average damage in stores was 11.4% (0-37%). During the last season, about 23,300 pheromone traps were used.

Ventaquemada. Until 1993, the only potato tuber moth species reported damaging potato was *P. operculella*. Average infested tubers at harvest was low, 3.5%, because of the intensive use of insecticides (12 sprays per season). In 1994, the presence of *T. solanivora* was confirmed in Boyacá and heavy losses were reported—56% infested tubers at harvest. The most affected municipality was Ventaquemada. A program developed included research on seasonal occurrence, studies on the effectiveness of *Baculovirus* and sex pheromone trapping, and the implementation of sanitary measures. An intense training program was developed for farmers and technicians.

In fields, farmers adopted destruction of crop residues, sex pheromone trapping, high hilling, and timely harvest. In stores, they adopted cleaning, use of *Baculovirus* to protect tuber seed, pheromone traps, and, to a limited extent, diffused-light stores.

Farmers that adopted IPM measures had only 1% infested tubers at harvest, whereas other farmers had 40% damage despite the use of insecticides (Figure 2). The selling price of IPM potato was 35% higher than that of insecticide-treated potato. A total of 14,800 pheromone traps were used in 1995 over an area of 925 ha.

The Secretaría de Agricultura de Boyacá has started producing *Baculovirus* to cope with the increasing demand.

Pilot unit in the Dominican Republic

In the Dominican Republic, the main potato-producing area (85% of national production) is the high Constanza plateau, where other vegetables are also cultivated. Intensive spraying is a characteristic of the area. Six to eight sprays per season (at 6-8-day intervals) to control *P. operculella* are common. Under heavier infestations, potato fields are sprayed at 3-4-day intervals.

The local semiprivate organization Programa Nacional de Manejo Integrado de Plagas (MIP) started a program to reduce the excessive use of insecticides in 1991. In 1993, CIP coordinated a program with MIP to implement IPM on potato.

Farmers adopted planting healthy tubers, deep planting, sex pheromone trapping, frequent irrigation, timely harvest, and the use of Bt. Action thresholds were established for determining the timing of Bt applications.

Field populations of the moth have been reduced from an initial catch of 136 moths/trap/week to 19. In 1996, infested tubers at harvest in IPM fields were 0.1% without the

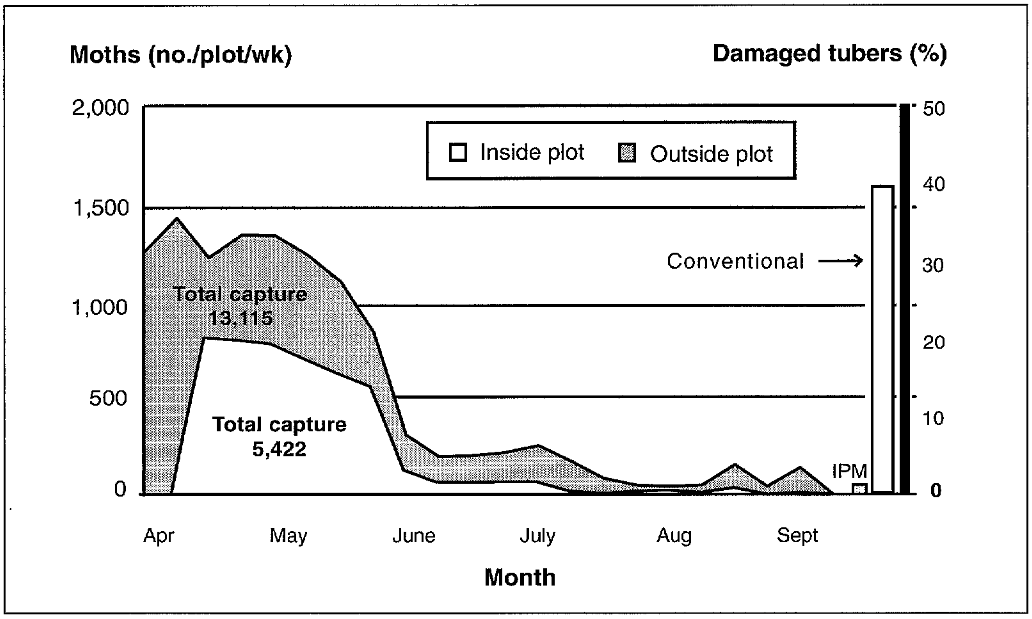


Figure 2. Population variation of *Tecia solanivora* in IPM plots and percentage of damaged tubers at harvest. Ventaquemada, Boyacá, Colombia, 1996.

use of insecticides. Fields with conventional control programs had 15% infested tubers. Average yield in MIP fields was 13.8 t/ha compared with 8.9 t/ha in fields where conventional control practices prevailed.

Conclusions

The implementation of IPM for the management of the potato tuber moth in pilot units in Peru, Colombia, and the Dominican Republic has demonstrated that CIP's approach is viable, well accepted by farmers, and catalytic for the participation of local institutions, both governmental and NGO. Net benefits were evident: pest damage decreased significantly and the use of insecticides dropped to a minimum.

The acceptance of IPM by farmers was due not only to the effective components developed by CIP's program but also to the adequate training programs for farmers, technicians, and other stakeholders, and the participation of local institutions. In this case, a total of 9,728 persons received some kind of training in 1,207 activities, most of them carried out by local institutions.

Technologies such as mass trapping with sex pheromones and the use of *Baculovirus* have stimulated the interest of various private and official organizations in commercially producing these biological control products to make them widely available to farmers.

In Peru, the participation of CARE-Peru, an NGO, expanded the influence of the IPM pilot units to 3,500 families in the poorest areas of the mountains. This successful program is now being extended to 10,000 families by a collaborative effort of CARE and the Programa Nacional de Manejo de Cuencas Hidrográficas y Conservación de Suelos (PRONAMACHCS), a government-related organization.

Integrated Management for Andean Potato Weevils in Pilot Units

J. Alcázar and F. Cisneros [1]

Potato (*Solanum* spp.) that is cultivated in the high Andean mountains (2,500-4,750 m) of Bolivia, Peru, Ecuador, Colombia, and Venezuela is severely damaged by the Andean potato weevil or white grub. This is a complex of species, most of them belonging to the genus *Premnotrypes* (Curculionidae). The dominant species are *P. latithorax* (Pierce) in Bolivia and southern Peru, *P. suturicallus* Kuschel in central Peru, and *P. vorax* (Hustache) in northern Peru, Ecuador, Colombia, and Venezuela (Figure 1). Species of other genera, *Rhigopsidius tucumanus* Heller and *Phyrdenus muriceus* Germar, are largely restricted to Bolivia.

1 CIP, Lima, Peru.

Most inhabitants of the high Andes are poor peasants, with an extremely low level of literacy, who receive little, if any, technical assistance. They accept the damage caused by weevils (commonly above 50%) as inevitable and occasionally abandon fields because of high infestations. The division of land into small units has rendered impractical the old system of large communal land rotations that was once used to efficiently control weevils and other pests and diseases.

Farmers close to cities are more commercially oriented and use toxic insecticides (carbofuran, parathion, aldicarb, and methamidophos) to control weevils. Despite

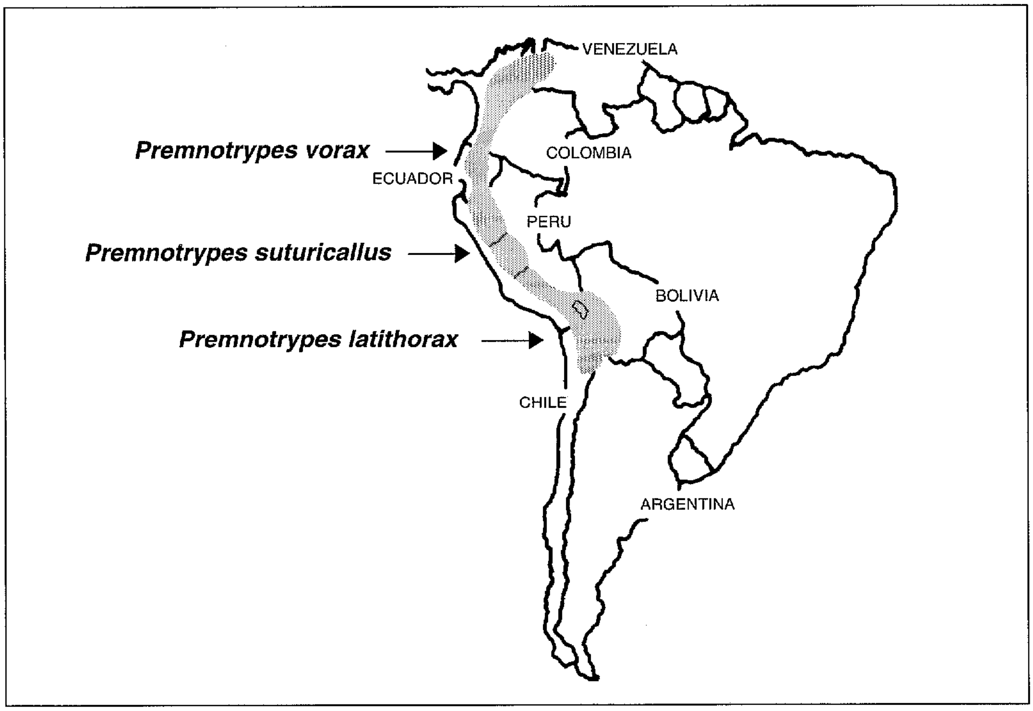


Figure 1. Distribution of the main species of Andean potato weevil.

the use of insecticides, 20-30% tuber infestation is common. Although all farmers are familiar with the larvae that bore into tubers, they know little else about the insect, including its life cycle and seasonal history, which would help them improve their pest control practices.

Rationale of IPM Components

The three common species of weevils have similar life cycles (Table 1) (one generation a year, except for *P. vorax,* which presents two generations in some parts of Ecuador and Colombia), behavior, and seasonal history (Figure 2).

Research conducted on these characters led to the development of a series of control measures, most of which could be included as components in integrated pest management (IPM).

The absence of parasitoids, limited predators, and only a single pathogen (*Beauveria brongniartii* (Saccardo) Petch) made it clear that cultural practices would be major control components. Even the pathogen had a scattered distribution in the field. Other important considerations were: all potato cultivars are susceptible to weevil attack; the weevil invades potato fields by crawling from overwintering places because it is unable to fly.

Sources of infestation are abandoned potato fields, fields harvested the previous year, places where potatoes were piled up during harvest and sorting, rustic stores, and volunteer plants in rotation crops. Most control measures aim at destroying the overwintering population, interrupting migration of the weevil to new fields, and reducing the weevil population in infested fields.

Reducing weevil infestation in the field

There are several ways of reducing in-field populations of potato weevil. They include early planting and use of early-maturing varieties, timely harvest, use of healthy tubers, handpicking adult weevils from the crop, and destroying volunteer potato plants in rotation fields.

Early planting. Emergence of overwintering adults lasts 8-14 wk and coincides with

Table 1. Life cycles of the three most injurious species of Andean potato weevils in Cajamarca (*Premnotrypes vorax*), Huancayo (*P. suturicallus*), and Urubamba (*P. latithorax*), Peru.

Stage	Life cycle (days)		
	P. vorax	*P. suturicallus*	*P. latithorax*
Egg	43	33	48
Larva I	16	11	9
Larva II	14	9	8
Larva III	17	12	8
Larva IV	18	57	35
Larva V	58	—	—
Pupa	50	54	29
Wintering adult	66	115	110
Longevity	181	143	179
Total cycle	463	438	424
Ovipositing period	119	106	101
Eggs/female	374	631	162

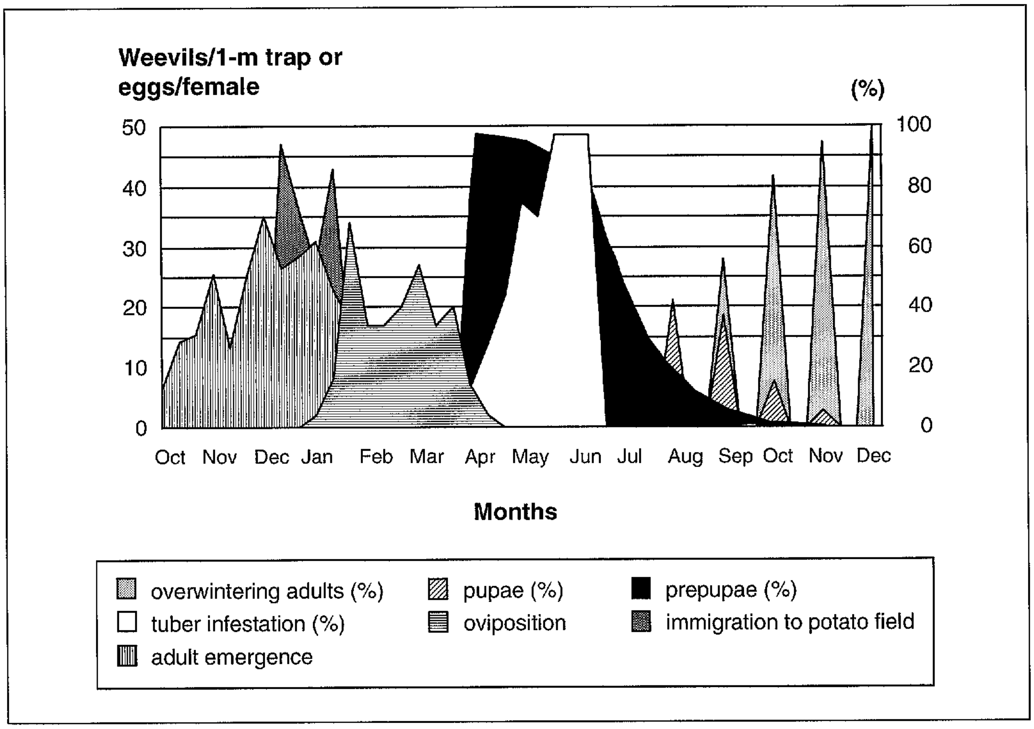


Figure 2. Seasonal history of the Andean potato weevil (*Premnotrypes latithorax*) in Urubamba, Peru. Average of two years (1994-96).

the rainy season. Females lay eggs for 12-14 wk. As more adults emerge, there is a continuous increase in the number of females that find later plantings as ovipositing places. Early-planted fields are 4-5 times less infested than those planted late. This measure reduced weevil infestation and damage by 82.2% (Table 2). Early-maturing varieties are less exposed to weevil infestation than late varieties and accomplish the same result as early planting.

Timely harvest. Delayed harvest extends exposure of tubers to weevil infestation, although farmers sometimes delay harvest in the hope of getting higher prices. Occasionally, early harvesting is recommended. A delay of 10 d in harvest resulted in an increase in tuber damage from 6.8% to 29.5% in one field check.

Healthy planting material. In general, healthy tuber seed favors vigorous growth of potato plants. In particular, seed tubers damaged by Andean potato weevils rot readily, which results in poor stand establishment. Planting seed that had been bored by the Andean weevil reduced yield by 31% compared with planting noninfested seed (Table 2).

Handpicking weevils. Adult weevils in the potato field become active in the evening; they climb the foliage for feeding and mating. They can easily be captured by shaking the foliage over any container. Farmers have readily accepted this practice. Collecting weevils six times in a growing season reduced damage by 34% (Table 2).

Destroying volunteer plants. Volunteer potato plants in rotation fields are important sources of weevil infestation and should be destroyed as early as possible. Initially, some farmers were reluctant to accept this practice because they could harvest some early potatoes from volunteer plants. But more than 30,000 weevils infested 6,500 volunteer plants/ha in a rotation field in Huancayo.

Table 2. Experimental results showing the benefits of measures recommended to reduce weevil infestation and damage[a] (experiments conducted in Cusco and Huancayo, Peru), 1993-96.

Measure	Check	Tuber damage (%) or yield (MT/ha)	Decrease in damage (%)
Early planting (October)		3.2%	82.2
	Late planting (December)	18.0%	
Timely harvest (10 April)		6.8%	77.0
	Delayed harvest (20 April)	29.5%	
Healthy tuber seed		9.6 MT/ha	31.3
	Infested tuber seed	6.6 MT/ha	
Handpicking weevils (6 times)		23.8%	34.1
	Handpicking weeevils (none)	36.1%	

a. Expressed as percentage of infested tubers at harvest.

Interrupting adult migration and larval movement

Because adult weevils cannot fly, physical barriers effectively halt their migration from field to field as do peripheral trenches, which allow migrating weevils to be captured. Larval movement from tuber to soil can be prevented by using plastic sheets at harvest and sorting or storing tubers in diffused-light stores. Weevil larvae and pupae are often fed to chickens.

Barriers. Migratory weevils can be intercepted by digging field peripheral trenches and capturing or killing them with insecticides, or by simply spraying a 3-m-wide band of insecticide around the perimeter of the field. Bordering fields with nonhost plants also disrupts the migratory process, and is preferable to chemical control where it can be practiced. Table 3 shows the reduction in tuber damage resulting from these practices.

Shelter traps. Straw bundles, pieces of sisal, or plastic sheets and other materials provide shelter to weevils during the day when they can be captured. An alternative is to put insecticides in the shelter. Better effects are obtained with insecticide-treated potato foliage placed in new potato fields. This practice has been studied and well accepted in Ecuador.

Ground sheeting. At harvest, many full-grown larvae abandon the tubers and dig into the soil to pupate. Larvae can be intercepted on their way to the soil by barriers of plastic sheets or other materials.

Diffused-light stores. Seed tubers kept in diffused-light stores maintain better quality. Because the tubers are not in contact with the soil, the larvae abandoning the tubers can be destroyed or fed to chickens.

Reducing overwintering populations

Measures to reduce overwintering weevil populations can be carried out in the field or in stores (Table 4). Harvested fields are winter-plowed to destroy larvae that move from tuber to soil. Breaking the soil where potatoes were piled at harvest or for sorting also destroys underground larvae and pupae. Plowing abandoned fields is effective in destroying overwintering insect stages.

Winter plowing. Many larvae reach maturity before harvest and leave the tubers to overwinter underground as pupae. Most of these pupae are destroyed by plowing the field 2 or 3 mo after harvest. At least 50% of the larvae and pupae in the soil are destroyed when plowing is done with oxen. Chickens help destroy exposed larvae and pupae.

Table 3. Experimental results showing the benefits of measures recommended to intercept migration of adult weevils and movement of larvae from tubers to the soil (average of experiments conducted in Urubamba and Huancayo, Peru), 1993-96.

Measure	Intercepted population/damage at harvest	Reduction in damage (%)
Trenches in store	23,430 weevils (stores: 70 m^2)	—
Trenches in field (insecticide treated)	134 weevils/m of trench	68.9
Nonhost plant barrier and picking weevil	12.7% vs. 35.0% (check)	63.7
Sprayed border	6.7% vs. 19.9% (check)	66.3
Sheets at harvest	1,515 larvae/100 kg potato (24 hours)	—
Sheets at pre-store sorting	23,450 larvae/100 kg/90 days	—

Table 4. Preferred adoption (>50% of target population) of IPM components by communities integrating IPM pilot units in Peru.

Province	Urubamba	Tayacaja	Huancayo		Cajamarca
Community	Huatata	Aymara	Casabamba	Chuamba	Chilimpampa
Harvest on time	X	X	X	X	X
Handpicking weevil	X	X	X	X	X
Volunteer plants	X	X		X	X
Trenches					
Plant barriers					X
Border sprays		X	X	X	
Shelter traps					X
Sheeting at harvest	X	X	X		X
Diffused-light stores			X	X	
Winter plowing	X	X	X		X
Breaking soil	X				X
Chickens	X	X	X	X	X
Parasitic fungus	X				

Abandoned fields are another major source of weevil reproduction and migration. During winter, abandoned fields should be plowed at least twice.

Breaking the soil. When recently harvested potatoes are not piled on sheets, large numbers of larvae dig into the soil to pupate. The soil should be broken up in winter to destroy underground larvae and pupae. More than 90% of overwintering larvae are destroyed by this practice.

The parasitic fungus *Beauveria brongniartii* can be used to control larvae digging into the floor of rustic stores. Mortality surpasses 80%.

Selecting Sites as IPM Pilot Units

Selecting the pilot unit is a crucial step in the implementation of IPM. Here, the scientific development of IPM components meets the real world of farmers—their risks, interests, economics, culture, cropping practices, and other factors that can determine the success or failure of the program. This precedes the large-scale implementation of IPM. In addition to farmers, other key players are members of national agricultural research systems (NARS), nongovernmental organizations (NGOs), and other groups that will eventually assume responsibility for expanding the program.

Two conditions had to be met for a community to qualify as a pilot unit. The first was that farmers had to recognize the Andean potato weevil as the most serious pest problem. Second, there had to be a nucleus of farmers willing to try new methods to reduce tuber damage and insecticide use.

Selected sites in Peru were Huatata, Urubamba Province; Chuamba and Casabamba, Huancayo Province; Aymara, Tayacaja Province; and Chilimpampa, Cajamarca Province. Four other sites were chosen outside Peru: La Paz Department in Bolivia, Cotopaxi and Chimborazo provinces in Ecuador, and Boyacá Department in Colombia.

Description of Main Pilot Units

With pilot units, CIP's IPM staff works closely with farmers to evaluate the effectiveness of practices and the reaction of farmers to the IPM program. Farmers from neighboring communities, directly or by influence of local organizations, commonly adopt practices they have seen demonstrated in the pilot units. These ancillary "areas of influence" provide some assistance in diffusing IPM concepts.

Farmers in the pilot units were trained on the basics of the program to make them fully aware of the options presented as IPM components. We organized short courses, field days, and workshops and produced training materials such as bulletins, posters, samples, slide sets, flip charts, and videos. Training was extended to selected collaborators from several institutions who would take over field work in the large-scale implementation phase. In a four-year period (1992-96), 3,984 farmers took part in field days in Junín, 2,058 heard talks in Cajamarca, 1,627 participated in weevil-picking contests in Cusco, and 1,835 received short courses in Cajamarca.

Pilot units in Peru

Pilot units in Peru were selected to optimize the evaluation of the IPM components under different conditions.

- In the south (Urubamba), with the weevil species *P. latithorax* and traditionally oriented potato production.
- In central Peru, with *P. suturicallus*, in more commercially oriented Huancayo and in more traditionally oriented Tayacaja.
- In the north (Cajamarca), with *P. vorax* and less traditional varieties.

Huatata. Practices that have more than 50% acceptance are timely harvest, use of chickens as predators, breaking the soil or using sheeting, handpicking weevils, destroying volunteer plants, and using *B. brongniartii* in rustic stores. Although some farmers have stopped using insecticides, many others still use one spray of a "safe IPM compatible" product, as it is described by insecticide dealers.

Before the program began in 1990 and despite heavy use of insecticides, damage (% of infested tubers at harvest) was 44%. In 1996, damage varied from 8% to 12%.

Chilimpampa. Most farmers have adopted handpicking weevils, timely harvest, use of tarwi or barley as nonhost field edge barriers, use of sheeting at harvest and sorting, winter plowing, use of chickens as predators, breaking of soil, and shade traps. Farmers have adopted anywhere from three to five practices.

When the program began in 1993, farmers had an average damage of 61% of infested tubers at havest. During the 1996 harvest, damage dropped to 13%. Farmers in the community have a fairly good knowledge of the biology and seasonal history of the pest and its control.

Aymara. Most farmers adopted the use of sheeting at harvest, eliminating volunteer plants, timely harvest, use of chickens as predators, winter plowing, and border spraying. Some practices such as destroying volunteer plants and handpicking weevils are organized and conducted by the whole community. Damage in 1993 was 39% of tubers at harvest despite the use of insecticides. During 1996, damaged ranged from 15% to 20%.

Casabamba and Chuamba. Most farmers adopted handpicking of weevils, use of sheeting at harvest, timely harvest, high hilling, use of diffused-light stores, use of chickens as predators, destroying volunteer plants, winter plowing, and border spraying. Damage in Casabamba decreased from 45% in 1994 to 19% in 1996. In Chuamba, the program was adopted only in 1996. Damage in demonstration fields was 13%, whereas damage in the rest of the area was 41%.

Pilot units in Bolivia, Colombia, and Ecuador

The Peruvian experience was extended to Bolivia, Colombia, and Ecuador following similar criteria in the selection of the pilot units. In this respect, PROINPA-IBTA, CORPOICA, and FORTIPAPA-INIAP played key roles.

Bolivia. Farmers adopted field border trenches, winter soil breaking, use of chickens as predators, timely harvest, use of sheeting at harvest, border spraying, and destroying volunteer plants. Infected tubers at harvest in the 1994-95 cropping season reached 44%. This was reduced to 30% in 1996, the first year of the program.

Ecuador. Most farmers have adopted the use of shelter-treated traps, treated potato plant-baits, crop rotation, destruction of volunteer plants, breaking the soil in sorting and storing places, and selective chemicals (Orthene instead of carbofuran). Damage at harvest in IPM fields in 1996 varied from 6% to 22%; in nonparticipating fields, damage varied from 33% to 97%.

Colombia. Farmers in 1995-96 concentrated on reducing spraying, which is common in the area. Instead of broadcast treatments, spraying was limited to edge bands with similar results. Complementary practices include destroying crop residues and monitoring the weevil population near field edges. More recently, diffused-light stores are being adopted to reduce damage from the weevil and the potato tuber moth *Tecia solanivora*.

At the beginning of the program, damaged tubers at harvest varied from 20% to 60%, depending on the intensity of chemical use. During 1996, fields within the program had 2-12% damage, whereas fields with traditional (mostly chemical) protection sustained 8.5% to 60% damage.

Conclusions

Working with farmers in the high Andes requires more resources than CIP has available. At the same time, there are governmental organizations and NGOs in the area working to improve farmers' productivity and general welfare. These institutions benefit by taking advantage of existing technologies such as those developed by CIP for the management of the Andean potato weevil. CIP in turn gains valuable research partners. Figure 3 shows CIP cooperators in the Andean region IPM program.

Most of the research needed to develop IPM components for the *Premnotrypes* Andean potato weevils has been completed. There still remains the task of improving the use of the parasitic fungus *B. brongniartii* and developing measures for the control of *Phyrdenus* and *Rhigopsidius* weevils whose behavior differs from that of the other species.

Two or three more years of implementation in the pilot units will give a clearer picture of the year-to-year variations in climate and pest incidence. This time will also allow us to consolidate the training of personnel from collaborating institutions that will be involved in the large-scale implementation of IPM in areas where the Andean weevil is the key pest.

Future research should focus on the management of the fleabeetle *Epitrix* spp., which is the second most important pest for potato in the high Andes.

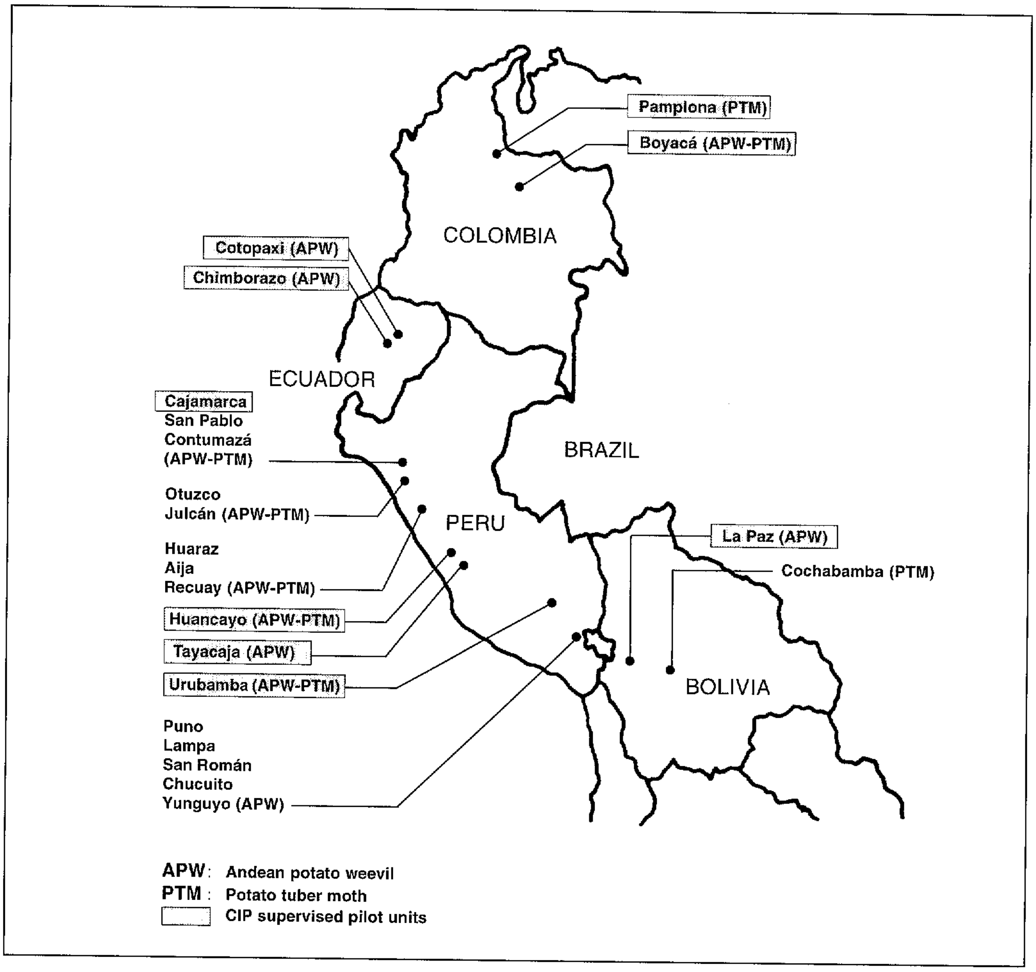


Figure 3. Integrated management of potato pests in the Andean region; location (provinces) of pilot units. Collaborating institutions are Corporación Colombiana de Investigación Agropecuaria (CORPOICA), Colombia; Instituto Nacional Autónomo de Investigaciones Agropecuarias (INIAP), Fortalecimiento de la Investigación y Producción de Semilla de Papa en el Ecuador (FORTIPAPA), Ecuador; Instituto Boliviano de Tecnología Agropecuaria (IBTA), Programa de Investigación de la Papa (PROINPA), Bolivia; Instituto Nacional de Investigación Agraria (INIA), Grupo de Investigación y de Desarrollo de la Ciencia Andina (TALPUY), CARE-Perú, and Asociación ARARIWA, Peru.

Developing IPM Components for Leafminer Fly in the Cañete Valley of Peru

N. Mujica and F. Cisneros[1]

The leafminer fly *Liriomyza huidobrensis* Blanchard is a serious pest of potato in many places where potato is intensively cultivated. It is the most damaging pest in the coastal valleys of Peru. Farmers in the Cañete valley try to control the pest by spraying 8-13 times per season on a calendar basis. Insecticides are the highest input cost (an average of US$600/ha) followed by fertilizer, fungicides, and manure. Noncontrolled infestations commonly reduce yields by 50% or more.

In most places, leafminer flies have developed significant levels of resistance to most carbamate, organophosphate, and pyrethroid insecticides commonly used to kill adult flies. Rapid development of resistance and naturally occurring pest tolerance of many chemicals seem to be a generalized characteristic of *L. huidobrensis*. For these reasons, this species is commonly regarded as the most difficult-to-kill leafminer fly worldwide.

Frequent spraying in the coast of Peru has created additional problems such as severe infestations of the white mite, *Polyphagotarsonemus latus* (Banks), and the budmidge, *Prodiplosis longifila* (Gagne).

Although native to the neotropics (infestations are reported from Peru, Chile, Argentina, Brazil, Central America, and Mexico), *L. huidobrensis* is rapidly spreading to other areas where it readily becomes a serious pest. It has recently been reported in Europe, several countries in Africa, and in Indonesia, Malaysia, and Israel.

1 CIP, Lima, Peru.

Life Cycle, Behavior, and Seasonal Abundance

The life cycle of the leafminer fly has been studied in the laboratory and the greenhouse in Lima and Cañete, using potato and bean as host plants. We have determined the duration of each developmental stage, oviposition capacity, sex ratio, and adult longevity. Table 1 summarizes this information.

The adult female punctures the upper or lower surfaces of tender leaves with her ovipositor, or egg-laying structure. Males and females feed on the exudates produced by the lesions. Similar punctures are used by the female to encrust the egg in the leaf tissue.

Neonate larvae start tunneling through the chloroplast-containing spongy mesophyll leaf layer. Tunnels increase in diameter as the larva grows. Although any part of the leaf blade can be tunneled, full-grown larvae tend to stay close to the midrib. Full-grown larvae pupate inside barrel-shaped puparia on the leaf surface. Puparia fall to the ground and remain there until the emergence of the adult flies. Mating occurs 2-3 days after emergence.

There is a clear seasonal variation of fly population densities in the Cañete valley where early potato plantings take place in March (end of summer) and harvest of late plantings occurs in December (end of spring). Higher population densities occur during the winter months—June, July, August, and September. Fly populations are low during the warm months (November-March).

Within a given field, the fly population is associated with the phenology of the potato

Table 1. Life cycle (days) of the leafminer fly *Liriomyza huidobrensis* under screenhouse ambient conditions, Cañete, Peru, 1996.

Stage	August (winter)			October (spring)		
	min	max	av	min	max	av
Egg	3	4	3.6	3	4	3.3
Larva						
I	3	3	3.0	3	4	3.1
II	3	3	3.0	2	3	2.5
III	4	4	4.0	3	3	3.0
Pupa	14	18	16.3	12	17	14.0
Total immature stages	27	32	29.9	23	31	25.9
Longevity						
Female	4	30	15.7	3	28	25.9
Male	3	6	4.7	2	4	3.0
Total life cycle						
Female	31	62	45.6	26	59	39.9
Male	30	38	34.6	25	35	17.0
Eggs/female	40	285	116.6	11	704	161.4

plant. For example, there is a relatively slow increase during the vegetative growth and a rapid and sustainable increase during flowering, followed by a decline as plants enter into senescence. This trend is more notorious in the case of the larval population.

Host-Plant Range

The leafminer fly is a polyphagous insect that infests a large number of crop and ornamental plants. The long list includes potato, beans, peas, alfalfa, and most vegetables (tomato, celery, lettuce, peppers, spinach, cucurbits, and others) grown in Cañete and other valleys of the Peruvian coast. This has implications when crop rotation is being considered. In addition, leafminer flies infest many weed species.

In a study to determine the role of weeds as sources of leafminer fly infestations and as refuges of parasitoids, 24 weed species were identified corresponding to 13 families. Significant levels of fly larval parasitism (40-70%) were found in *Trianthema portulacastrum* (Aizoaceae), *Stachys arvensis* (Lamiaceae), *Chenopodium murale* and *C. album* (Chenopodiaceae), *Datura stramonium* (Solanaceae), *Bidens pilosa* and *Galinsoga parviflora* (Asteraceae), *Diplotaxis muralis* (Brasicaceae), *Malva parviflora* (Malvaceae), *Ricinus communis* (Euphorbiaceae), and *Stellaria media* (Caryophylaceae). The identification of the leafminer flies and their parasitoids at the species level is under way.

Insect-Potato Plant Interactions

It is common to see adult flies in potato fields from when potato plants emerge until they become senescent. Feeding punctures can often be seen all over a growing plant, giving the impression that a generalized outbreak of larval infestation is in process. But the development of the larval damage follows a rather fixed pattern, somewhat different from that of the adult fly population. First, the initial larval infestation and the corresponding damage occur in the lower third of the plant. As infestation increases, the medium part of the plant is affected and, finally, the top of the plant becomes infested (Figure 1). At this time, practically the whole aboveground part of the plant becomes necrotic and dies. The rate and level of infestation of plants are affected by varietal differences, age, and the physiological state of the plant.

Although potato plants can be infested by leafminer flies once they emerge from the soil surface, larval damage is consistently less severe during the vegetative phase of the plant. At this time, the first leaves to show larval damage are those of the lower part of the plant.

In contrast, when the plant is fully grown, from the flowering phase onward, foliar infestation develops at a much faster rate all over the plant, giving the impression of a sudden outbreak. The occurrence of egg extrusion might explain this phenomenon.

When the leaf is mature, most of the egg remains encrusted in the leaf tissue until hatching. Then, the neonate larva immediately starts tunneling the foliar pallisade tissue. Larval survival is close to 100%. But soon after the egg is laid, on a still-growing leaf, a

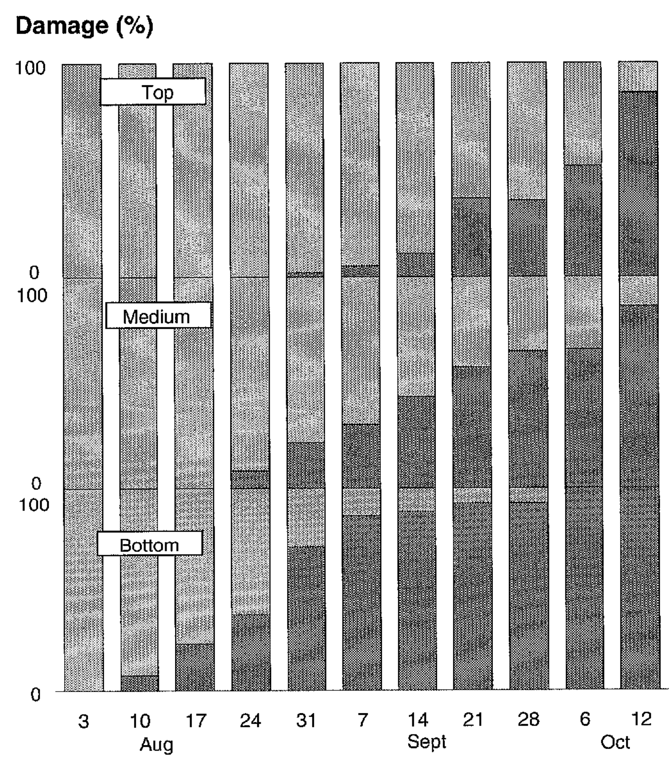


Figure 1. Occurrence of mining (■) in potato foliage caused by leafminer fly larvae, in the bottom, medium, and top parts of the potato plant (cv. Revolución), Cañete, Peru, 1995.

proliferation of cells occurs in the tissue surrounding the egg. That results in the extrusion of the egg to the leaf surface. There, the egg remains exposed to the action of adverse physical factors (mainly dehydration) and predators.

The neonate larvae that are able to hatch are also exposed to dehydration and predation before starting to tunnel into the leaf tissue. More than 90% of the eggs were extruded and around 60% of the eggs and neonate larvae died by dehydration under laboratory conditions. Under these conditions, lower larval infestation during the vegetative growth of the potato plant would be expected, despite a high adult fly population. The probability of successful larval development from an egg in mature foliage is much higher than in a growing leaf.

Developing Management Components

Farmers' only measure to control leafminer flies is the heavy use of chemicals against adult flies and larvae, usually with mediocre results. The alternative methods investigated included the evaluation of susceptibility/tolerance of commercial cultivars, the development of tolerant potato clones, the role of natural enemies, effects of cultural practices, trapping devices, and the selective use of larvicides. These techniques, along with methods for monitoring the fly population, are the basis for structuring the integrated management of this pest.

Differences in susceptibility

Experiments to test the degree of susceptibility among the most common varieties cultivated in Cañete showed differences in the area of foliage mined, the necrosing rate of the mines, and yield reduction. Effects of fly infestations on yield reduction were determined by comparing plots with and without control measures (Figure 2).

Developing resistant/tolerant clones

Breeding work at CIP resulted in genotypes with reasonable levels of tolerance of

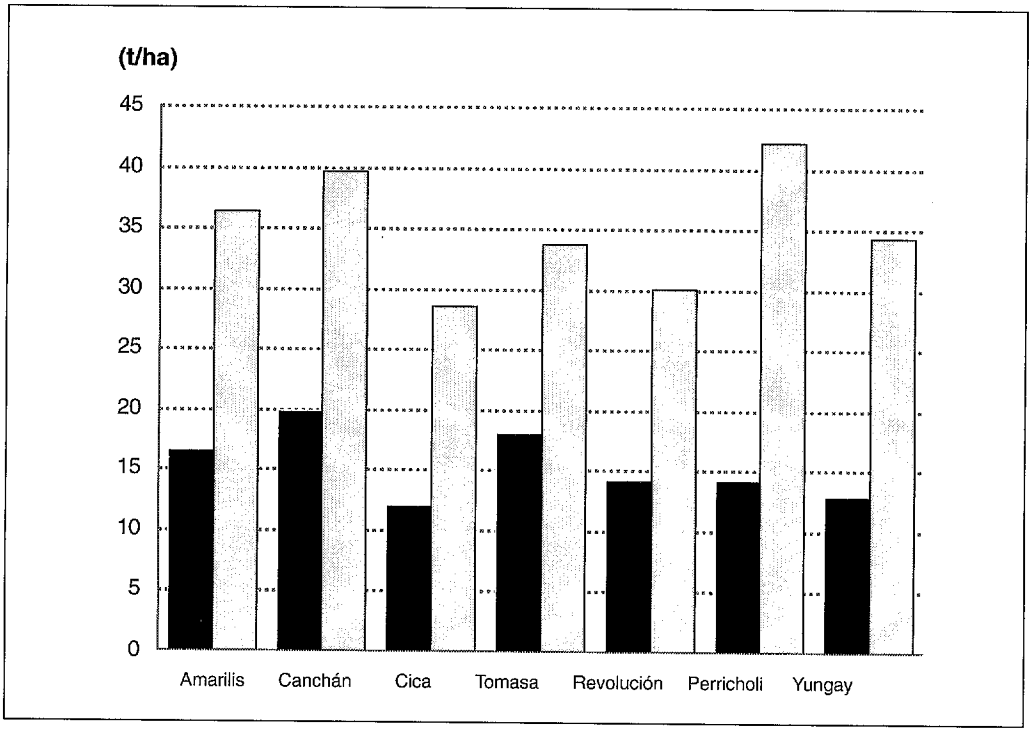


Figure 2. Yields of treated (□) and nontreated (■) plots to control leafminer fly infestation in the most common potato cultivars in Cañete, Peru (average of two years: 1994-95).

leafminer fly infestations, high yields, and good quality characteristics. Farmers of the Tambo valley participated in the final selection of a group of these materials. Farmers selected clone CIP-282 after evaluating its growing period, harvest, yield, cooking qualities, processing qualities, and marketability. Yields of marketable tubers were double those of the leading local variety Canchán at medium elevation in the Cañete valley, 30.4 t/ha vs. 15.2 t/ha. At high elevation, CIP-282 yielded 51.6 t/ha compared with 33.5 t/ha for Canchán. The clone has been released as María Tambeña by the Instituto Nacional de Investigación Agraria (INIA). The good qualities of this new variety are in great demand by farmers.

Biological control: occurrence and role of natural enemies

An important complex of natural enemies attacks leafminer fly larvae in the Cañete valley. Intensive sampling of infested leaves of potato and bean plants rendered 10 species of parasitoids whose seasonal occurrence and relative effectiveness against leafminer fly have been determined. Endoparasitoids and ectoparasitoids were recorded. The occurrence of high parasitism (close to 100%) during the warmer months of the year seems to be the factor responsible for the extremely low populations of the fly during this period.

Ectoparasitoids recorded are *Diglyphus websteri* (Craw.), *D. begini* (Ash.), *Diglyphus* sp., *Closterocerus cinctipennis* Ash., and *Zagrammosoma multilineatum* (Ash.). The female ectoparasitoid first paralyzes the fly larva in the leaf mine and then lays its eggs in the vicinity of the larva. The parasitoid larva feeds externally on the fly larval body and pupates inside the leaf. In the case of the endoparasitoids, the female lays an egg inside the body of the fly larva where the larva of the parasitoid develops.

Pupation of the parasitoid occurs inside the fly puparium, which is formed outside the leaf tunnel. Endoparasitoids recorded are *Halticoptera* sp., *H. arduine* (Walker), *Chrysocharis* sp., *C. phytomizae* (Bre.), and *Ganaspidium* sp.

Ectoparasitoids were abundant in bean plants. *D. websteri* showed the highest percentages of parasitism followed by *C. cinctipennis*. Endoparasitoids were more abundant in potato plants. *H. arduine* was the most common parasitoid in potato followed by *D. websteri*. The value of weeds as sources of parasitoids cannot be disregarded as we have recovered from weeds a rich fauna of parasites that attack leafminer flies. Average parasitism in 18 weed species was 44%, with a maximum of 71%. Not all parasitoids have been identified.

Predatory flies of the families Dolichopodidae and Empididae were found capturing and killing leafminer fly adults. Although these voracious predators have been observed occasionally in large numbers, their importance has been difficult to assess quantitatively due to the lack of adequate sampling methods.

Cultural practices

Healthy, vigorous-growing potato plants are able to counteract the effect of leafminer infestation, particularly during the vegetative phase. The fast-growing foliage enhances the egg extrusion reaction of the foliar tissue. Plants deficient in irrigation water and fertilizer, or coming from low-quality seed (e.g., virus-infested seed), show damage earlier and their tunneled leaves dry more rapidly. Under these circumstances, low yields due to inadequate agronomic conditions or low-quality seed are further reduced by the synergistic effects of leafminer fly infestations.

Trapping devices

The attractive effect of yellow surfaces on leafminer flies was reported in the early 1980s. Yellow surfaces covered with a sticky substance were used for trapping adult flies to monitor their populations. Years later CIP entomologists verified the trapping effects of yellow sticky traps and expanded their use for mass trapping leafminer flies in control programs. By using 60 fixed traps/ha, the number of insecticide treatments was reduced from 4-6 sprays to 1-2 sprays in the Tambo valley, Peru, where fly infestations are moderate.

Leafminer fly infestations in the Cañete valley are much more severe than those of the Tambo valley. Yellow traps became saturated and needed to be changed before the end of the cropping season despite the use of 80-100 traps/ha. Close to 5 million flies/ha/season were captured in evaluated plots. Half that amount was enough to saturate 100 traps. The increase in the number of traps required and the need to change them in the middle of the season made their use too expensive. The original traps were manufactured with expensive, imported sticky materials (cost of the yellow plastic plus the sticky material was about $1 per trap) that made them uneconomical under severe sustained fly infestations. Therefore, new, cheap, locally available materials were tested. The most cost-effective alternative was automotive motor oil 50SAE, which reduced the cost from $234/ha to $66/ha. A further development was the use of mobile traps—yellow plastic sheets that are passed over the plant canopy covering four or more rows at a time. Farmers adopted them readily and modified them according to their ingenuity. Figure 3 shows the effect of trapping on the fly population compared with a check field. Trapping can replace the use of insecticides against adult flies.

Experiments were also conducted to improve trapping efficiency. Aspects studied were the effective attractive distance of the traps, the number of traps required per hectare, orientation of the traps in relation to wind direction, spatial distribution of the traps, optimum timing for the installation of traps with respect to crop growth, trapping efficiency and in relation to the field fly popula-

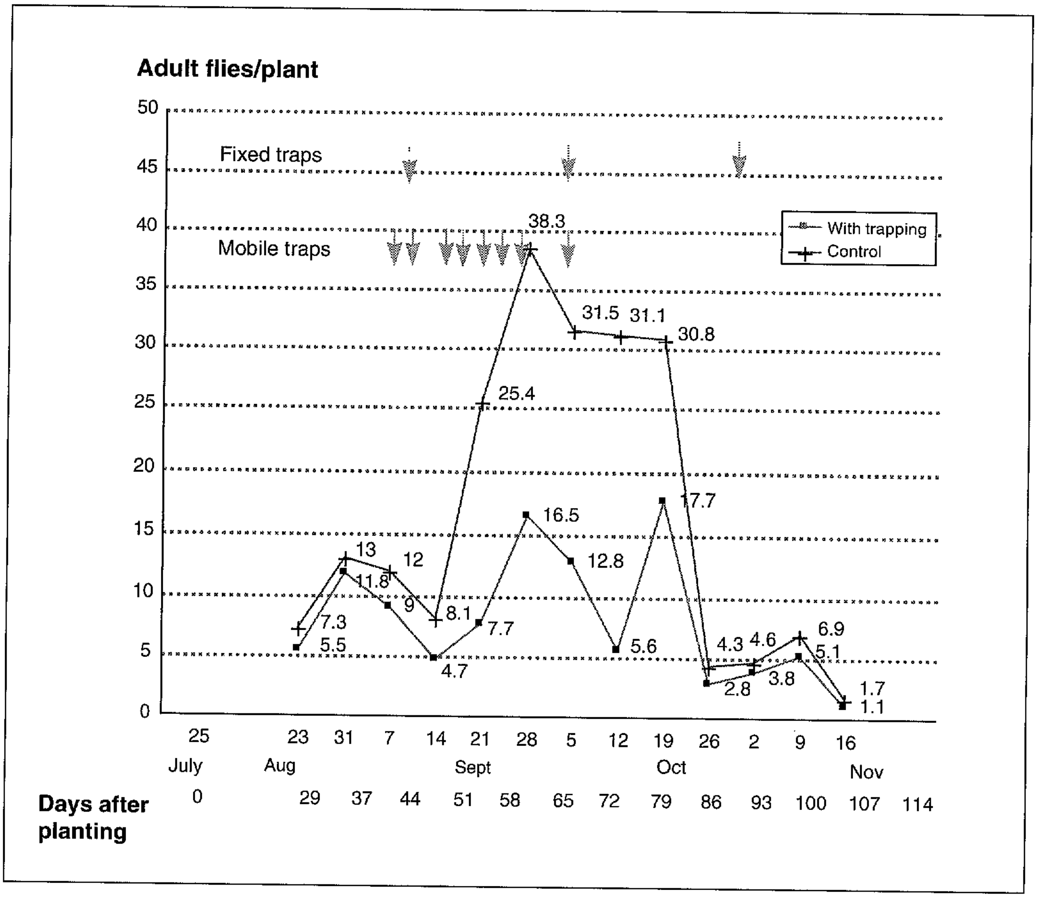


Figure 3. Effect of trapping on leafminer fly field population, comparison of fields with and without trapping, Cañete, Peru, 1996.

tion, and comparisons of efficiency of fixed traps vs. mobile traps.

Selective use of larvicides

A critical aspect of leafminer fly management is the reduction in the use of insecticides. Farmers tend to spray wide-spectrum insecticides as soon as they see the first adult flies on the foliage. Nothing is more inappropriate than this. Flies are not only tolerant of many compounds, but readily develop resistance to them. Even if affected by a spray, the treated population recovers rapidly because of immigration. Worse, early sprays against adults destroy natural enemies of leafminer flies and other pests early in the season. As a result, resurgence of the fly occurs and new pests are encouraged, as in the cases of the white mite and budmidge in Cañete.

The combined effects of egg extrusion by the growing foliage, which can be further stimulated with good cultural management practices, and the yellow sticky traps can effectively counteract the apparent need to use insecticides against adult flies.

Nevertheless, potato plants, after vegetative growth stops, might need protection for their foliage against the mining larvae if the level of control by natural enemies is not enough to avoid yield reductions. When these sprays are required, they should be as selective as possible. Cyromazine is effective against fly larvae and is largely compatible with natural enemies.

Monitoring Methods for Fly Damage and Population Levels

Monitoring pest populations and damage has two purposes: to study the population dynamics of the pest and to make decisions about control measures.

Monitoring adult fly populations by counting the number of flies per plant or the number of flies captured by sticky traps is useful for population dynamics studies. Both methods have been used in our studies and we have found a fairly good correlation between them.

For many years, monitoring fly infestation for deciding spray treatments was based on adult fly counts. But we have demonstrated the inconsistent relation between adult and larval populations. In most cases, adult counts lead to unnecessary sprays. The alternative is to count the number of larvae or fresh tunnels per leaflet by sampling the bottom, middle, and top parts of the plant. This has proved to be an efficient method for deciding when to use larvicide sprays.

Unfortunately, direct observation of larvae in the field does not provide information about the incidence of natural enemies. To get this information, infested leaflets must be taken to the laboratory and kept for 21 days. By that time we know the number of adult flies that developed from healthy larvae, the number of larvae killed by insecticides, and the level of parasitism based on the number of parasitoids recovered (Figure 4). But a 21-day delay in obtaining this information is too long for deciding the timing of a spray. In several of our experiments, we found that a second larvicide spray could be avoided if we had the information on parasitism at the time of sampling. More research is needed to solve this problem.

Conclusions

The amount of research conducted so far on the development of IPM components for leafminer flies allows us to offer a preliminary menu of options to farmers. Some preliminary trials envisage the possibility of reducing the number of sprays currently used (8-13) against leafminer flies to one or two sprays per season. The integration and implementation of IPM programs in farmers' fields will be completed with economic evaluations of the practices adopted.

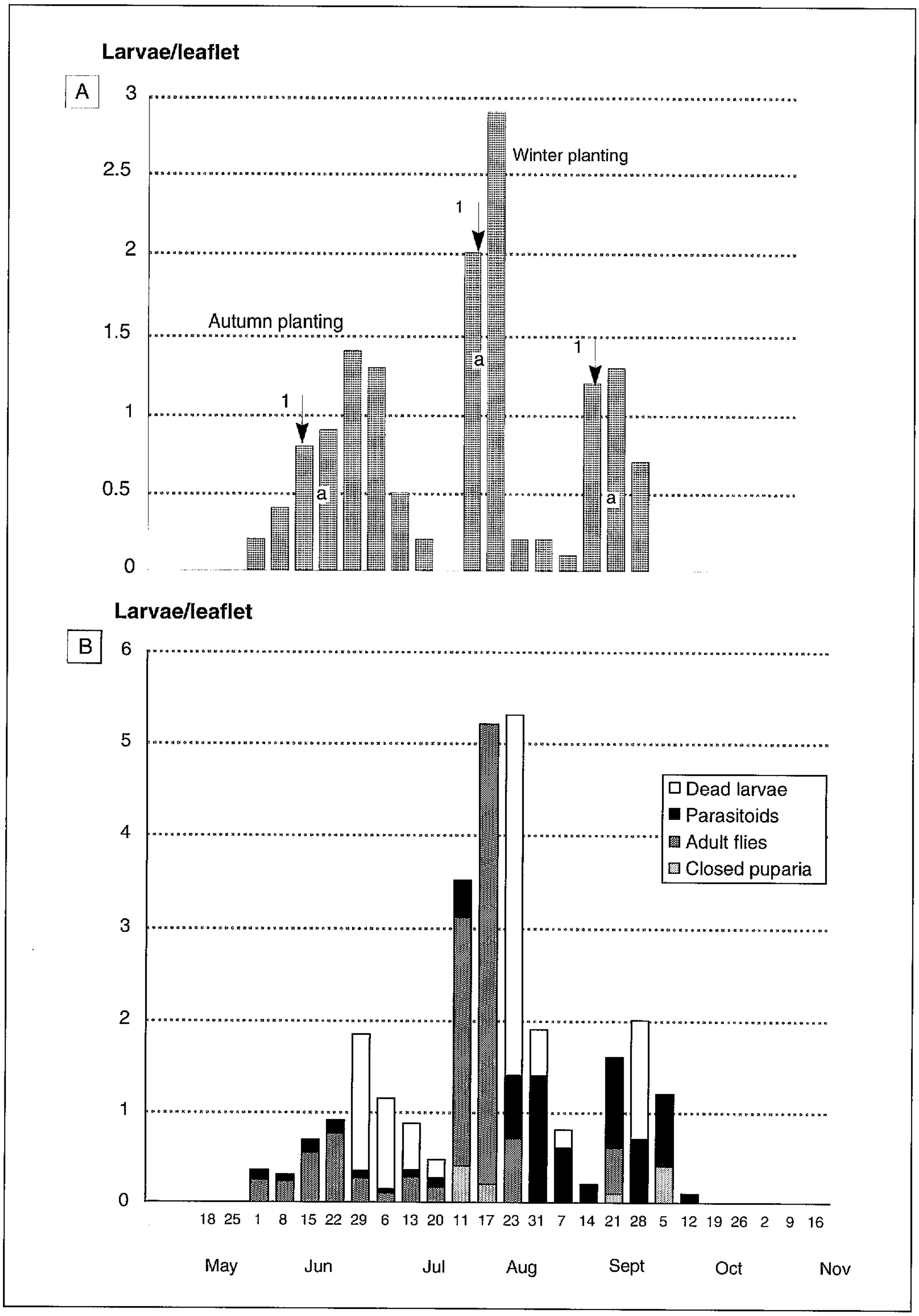


Figure 4. Monitoring of leafminer fly population. Comparison between (A) direct sampling observation in the field and (B) field sampling and laboratory analysis, 21 days after sampling. Note that in the laboratory analysis healthy larvae and larvae affected by parasitoids and insecticides can be detected. (1 = cyromazine treatment, a = sampled 1 day after treatment.)

Large-Scale Implementation of IPM for Sweetpotato Weevil in Cuba: A Collaborative Effort

J. Alcázar[1], F. Cisneros[1], and A. Morales[2]

CIP started investigating the sweetpotato weevil, *Cylas formicarius* (Fabricius), the most injurious pest of sweetpotato in the Caribbean area, in 1990. Activities were concentrated in the Dominican Republic on the use of sex pheromone traps. In 1993, studies were expanded with financial support from the Organization of Petroleum Exporting Countries Fund for International Development, and Cuba was included. Cuban scientists participating in an IPM workshop in Santo Domingo, Dominican Republic, expressed their interest in collaborating with CIP in managing this pest in their country, where 60,000 ha are planted to sweetpotato each year.

Scope of the Problem

The Asian sweetpotato weevil is the most important sweetpotato pest in the Caribbean, and practically the only one in Cuba. Damage is so severe that when insecticides from the Soviet Union were no longer available in Cuba (1991-92), damage amounted to 40-50% of production. Previously, Cuban farmers had sprayed their sweetpotato fields 10-12 times per season, with damage amounting to around 10% of production.

The pest is present in all provinces of the country. Historically, reported yields of traditional cultivars were low (6 t/ha), but in areas where new varieties developed by the Instituto Nacional de Investigación de Viandas Tropicales (INIVIT) were planted, yields reached 20-30 t/ha.

It is difficult to express yield losses in economic terms, because of the special characteristics of the Cuban economy. But if no control measures are taken, weevil damage to sweetpotato is equivalent to a total loss of 24,000-30,000 ha annually, about half the area planted to the crop.

Sweetpotato is one of the staple foods in Cuba. The other crops include banana, cassava, yam, and cocoyam.

Rationale of IPM Components and Their Integration

The urgency created by the sudden lack of insecticides and the resultant rapid increase in weevil damage obviated the need for assessment and characterization of the pest, which normally constitutes the first phase of CIP's strategy. The need to produce enough food with limited resources during what Cubans call the "special period" of the Cuban economy made sweetpotato production even more important. First, efforts concentrated on developing IPM components and filling some knowledge gaps in the biology and seasonal occurrence of the weevil.

Maximum efforts were initially dedicated to compiling and verifying information about research and experiences for controlling the weevil worldwide. Later, knowledge gaps were identified during coordination meetings when new results were discussed and new research activities were scheduled.

A significant amount of new information was generated through research conducted within Cuba. The only new key component foreign to the Cuban experiences was the use of pheromone traps, which CIP had been test-

1 CIP, Lima, Peru.
2 Head, IPM team, INIVIT, Cuba.

ing and improving in the Dominican Republic for several years.

Research led to the identification of a series of practices to reduce the weevil population or its damage, and a basic IPM program was designed (Figure 1). These practices were offered to farmers and agrarian-cooperative technicians as menu options. The initial demonstration fields were located near INIVIT's station in Santa Clara. The main practices recommended were biological and cultural.

Cultural Control Components

Healthy planting material

Planting infested sweetpotato stem cuttings is a primary way to distribute sweetpotato weevil. More than 95% of the eggs are deposited in the first 35 cm of stem. By discarding the basal stem portion, the apical portion of the stem makes a healthy cutting.

INIVIT established a system to produce large quantities of healthy seed cuttings in cooperatives. A 1-ha plot produces enough healthy cuttings to plant 20 ha in 4 mo.

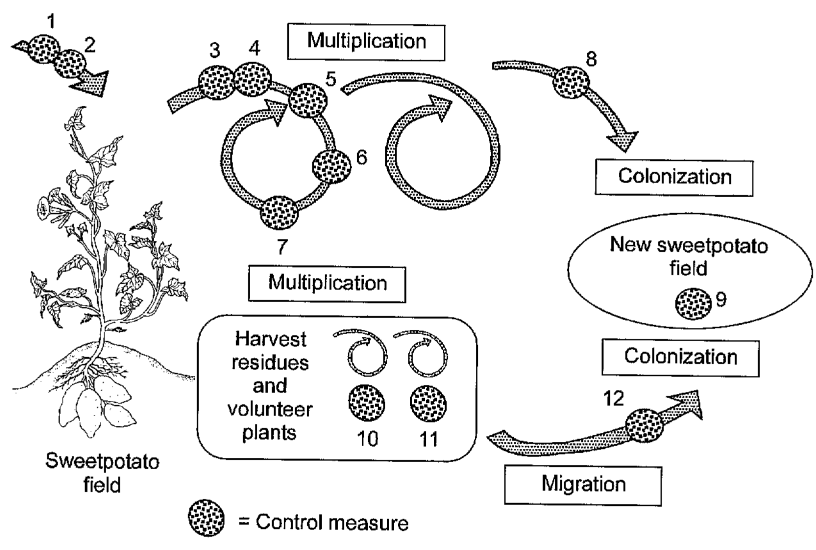
Crop rotation

About 20% of the area planted with sweetpotato is rotated with potato. Insecticides and the relatively large amount of water used in potato fields destroy all remains of the weevil population in one season. With no crop rotation, the number of weevils captured by pheromone traps in a 60-d period exceeded 8,000.

That was reduced to 418 weevils after a 1-yr rotation with crops other than potato, 40 weevils after 17 mo, and only 2 weevils after 2 yr. Rotation is even more effective as more successive crops are planted within the same rotation period.

Neighboring fields

In highly infested areas, INIVIT recommended separating new sweetpotato plantings from older fields by at least 1,000 m. Infesta-



1. Early tolerant or resistant cultivars
2. Healthy or disinfested cuttings (chemically or *Beauveria bassiana*-treated)
3. Sex pheromone
4. *Beauveria bassiana*
5. Colonization or predatory ants
6. High hilling
7. Irrigation management (avoid soil cracking)
8. Early harvest
9. Crop rotation
10. Destroy crop residues
11. Destroy volunteer plants
12. Avoid neighboring, old sweetpotato fields

Figure 1. Sweetpotato weevil: population dynamics and management in Cuba.

tion risk increases with proximity to older sweetpotato fields.

Timely harvest

Farmers may delay harvest after physiological maturity to increase yields or to get higher prices at a later date. But in Cuba, postponing harvest 30 days means a fourfold increase in damage. INIVIT recommended harvesting mature crops before the level of infestation reached 3%.

Destroying crop residues

Field sampling from various parts of Cuba showed that crop residues left on fields average 0.7 t/ha. That is enough material to harbor as many as one million weevils. Eliminating harvest residues increases the effectiveness of the other IPM measures.

Water management

In Cuba, 70% of the sweetpotato crop (42,000 ha) is planted in the rainy season and the rest during the dry season. Soil moisture is essential for plant growth and it has a clear effect on weevil infestation levels.

Cracking of the soil because of drought or deficient irrigation water facilitates female weevils reaching the sweetpotato fleshy roots to deposit their eggs. Well-irrigated fields are commonly 4-5 times less infested than those suffering from moisture deficit (Table 1).

Varietal selection

Early maturity and deep storage roots help sweetpotato escape weevil damage. Shallow-rooting varieties are four times more infested than varieties that root 8 cm below the soil surface. Early-maturing varieties (90-120 d) are three or four times less infested than late varieties (180 d or more). The recommended varieties in Cuba are INIVIT B-88, CEMSA 85-48, Cautillo, and CEMSA 78-354.

Biological Control Components

Disinfestation

Under heavy weevil infestations, healthy cuttings (without eggs and larvae) may still harbor adults that are attracted by the cut stem. Cubans disinfest cuttings by dipping them in a dilution of the parasitic fungus

Table 1. Effects of some selected IPM components for sweetpotato weevil in Cuba expressed as damage (% infested storage roots) and yields in spring-planted experimental fields, INIVIT, Villa Clara, Cuba, 1994.

IPM component	Irrigated		Nonirrigated	
	Damage (%)	Yield (MT/ha)	Damage (%)	Yield[a] (MT/ha)
Pheromone	2.3 c	37.3 abc	21.4 bc	12.5 b
Beauveria bassiana	5.8 b	29.9 bc	27.0 ab	9.0 c
Pheromone + *B. bassiana*	0.6 de	34.9 a	18.4 c	12.9 ab
Pheidole megacephala	2.7 c	31.8 abc	25.9 ab	10.2 c
Tetramorium guineense	4.4 b	31.5 abc	25.8 ab	9.9 c
Pheromon. + *Pheidole*	1.6 cd	34.0 a	18.9 c	11.9 b
Beauveria + *Pheidole*	2.0 c	33.5 ab	21.8 bc	10.2 c
Pher. + *Beau.* + *Pheid.*	0.1 de	35.4 a	17.8 c	12.7 b
Insecticides	0.4 c	28.7 c	17.4 c	14.5 a
Check	8.2 a	22.3 d	29.4 a	7.1 d

a. Plot size: 1,250 m^2 (partial influence of neighboring plots not discarded). Duncan's multiple range test was used. Insufficient water affected yields in addition to weevil damage.

Beauveria bassiana, which kills infected weevils within 2 or 3 d after treatment.

Fields planted with disinfested cuttings showed 3-4 times lower weevil populations than those with nondisinfested cuttings.

Predators

Two species of predatory ants, *Pheidole megacephala* and *Tetramorium guineense,* are common inhabitants of banana plantations. INIVIT has devised a simple system using rolled banana leaves as artificial intermediary nests to transport the ants from their natural reservoir to the sweetpotato fields where they prey upon weevils and other insects. Colonizing fields 30 d after planting with 60-110 nests/ha can keep weevil infestation at low levels (3-5%).

Pheromone trapping

Mass trapping of male weevils using sex pheromone traps efficiently controls the sweetpotato weevil. Farmers consider pheromone traps as an essential IPM component (Figure 2).

With 16 traps/ha, the weevil population is significantly reduced. Captured weevils are killed by insecticides or by spraying the parasitic fungus *Beauveria bassiana.*

The Collaborative Approach: The Role of INIVIT

Successful implementation of IPM requires collaborative commitments from institutions devoted to helping farmers in their crop production. In the Cuban case, an ideal situation was presented with the interest of INIVIT in collaborating with CIP to develop a program for management of the sweetpotato weevil. INIVIT is the Cuban research institution in charge of tropical staple food crops in that country.

INIVIT's activities to improve sweetpotato production include developing new, more productive, short-season varieties, improving agronomic and plant protection practices, and training farmers on management of the sweetpotato crop during the rainy and dry seasons.

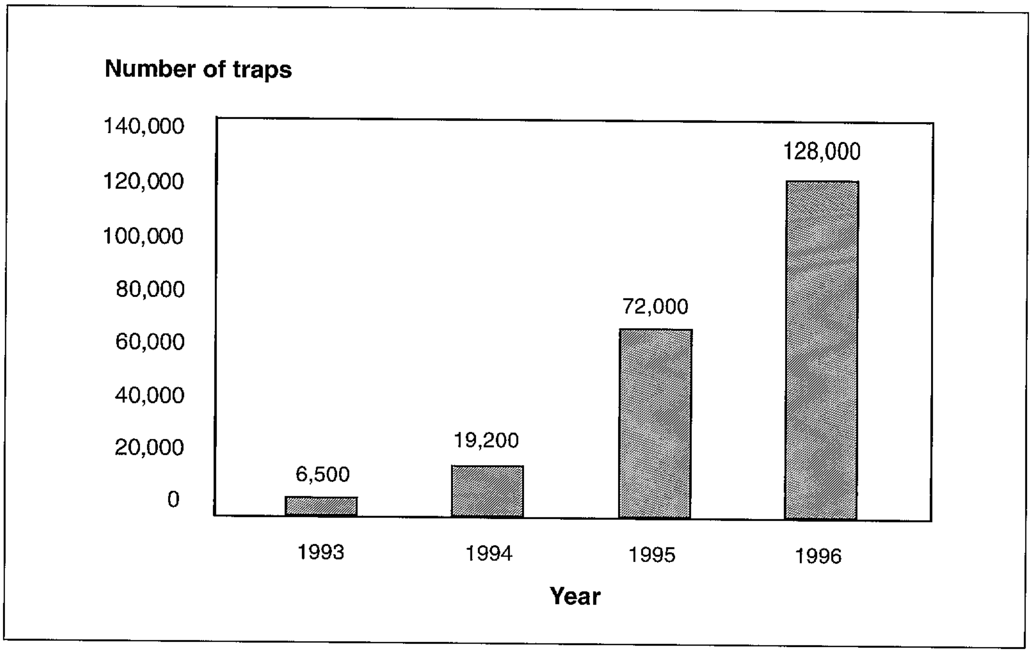


Figure 2. Number of sex pheromone traps used in Cuba to manage the sweetpotato weevil, *Cylas formicarius,* INIVIT-CIP, 1996.

The strategy for implementing IPM for the sweetpotato weevil in Cuba was based on CIP's experience in managing potato pests such as the Andean potato weevil *Premnotrypes* spp. and the potato tuber moths *Phthorimaea operculella* and *Symmetrischema tangolias* in the Andean region. Some INIVIT researchers visited CIP's headquarters to become aware of CIP's work on IPM. Other INIVIT staff participated in training courses organized by CIP in the Dominican Republic and Cuba.

INIVIT took the responsibility for all the work on research and implementation in Cuba. CIP's staff participated during the planning phases of the research and reviews of the program, and supported the diffusion activities.

One or two visits to Cuba a year to jointly analyze progress and suggest adjustments to the program completed the collaboration. After 3 years, Cuba's experience was used as the background for a 1995 workshop on management of the sweetpotato weevil, with the participation of specialists from Cuba and the Dominican Republic.

The Pilot Units

The first pilot unit, where most of the IPM components were integrated, was established in Arimao, Cienfuegos Province, with governmental enterprises, cooperatives, and private farmers with small landholdings. The pilot area increased from 250 ha in 1993 to 908 ha in 1995.

A second pilot unit was established in Santa Clara, Villa Clara Province, with 120 ha in 1993 and 620 ha in 1995. Other pilot units were in La Habana and Santiago de Cuba, with a total of 400 ha in 1993 and 781 ha in 1995.

Training

Training received a high priority for developing the large-scale phase of sweetpotato IPM in Cuba.

In 1995, INIVIT trained 4,965 people through 4 courses, 78 talks, 23 field days, and numerous field and monitoring visits. Follow-up training was conducted in 1996 and an IPM International Workshop was held with participants from the Dominican Republic, Peru, Venezuela, and all the provinces of Cuba.

Large-Scale Implementation

The Cuban experience of successfully managing sweetpotato weevil in a fairly large area (10,000 ha in 1996) created a demand for large-scale implementation in the rest of the country. Figure 3 presents the distribution of the implemented areas.

As a result of the IPM program, weevil damage decreased from an initial level of 40-50% to 4-8%, after 3 yr. The number of insecticide sprays was reduced from 10-12 per season in 1991-92 to zero in 1996, the only exception being limited sprays surrounding pheromone traps (16 traps/ha). The area sprayed is around 480 m^2 compared with 10,000 m^2 conventionally sprayed over an entire hectare. The fungus *B. bassiana* has since replaced the use of insecticides. Finally, yields have increased from the reported 6 t/ha to 15-30 t/ha.

The INIVIT IPM team, our counterpart, received the Cuban Government 1996 Relevant Award for the Cuban IPM project.

All the components of the IPM program are available locally except for the sex pheromones. That limitation is the only foreseeable constraint to reaching national coverage of 60,000 ha in the near term.

Selected Reading

Cisneros, F., J. Alcázar, M. Palacios, and O. Ortiz. 1995. A strategy for developing and implementing integrated pest management. CIP Circular 21(3):2-7.

Cisneros, F. and P. Gregory. 1994. Potato pest management. Aspects Appl. Biol. 39:113-124.

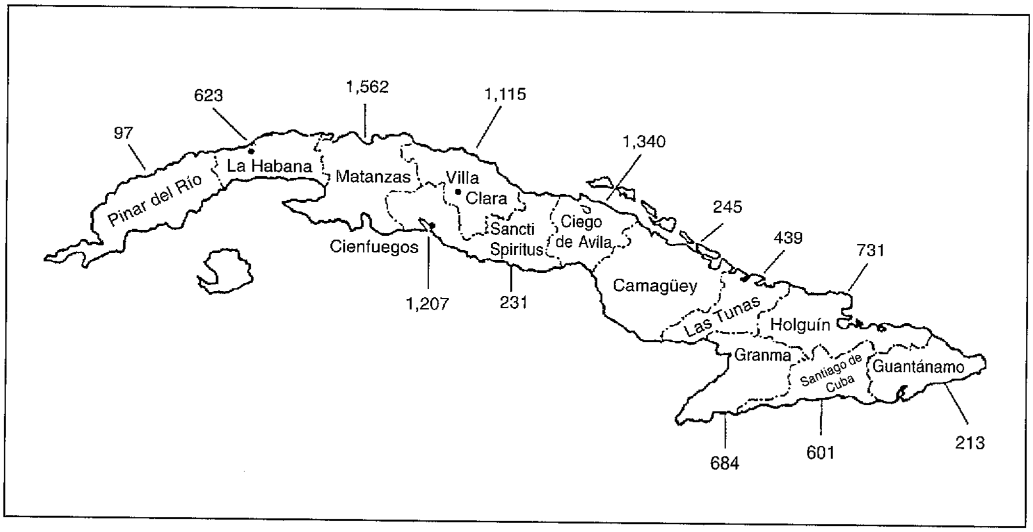


Figure 3. Management of the sweetpotato weevil in Cuba: area (ha) under IPM implementation in 1996, INIVIT-CIP.

Integrated Pest Management for Sweetpotato in East Africa

N. Smit[1] and B. Odongo[2]

In East Africa, sweetpotato is mostly grown as a subsistence crop by resource-poor female farmers, who do not use inputs. Often, a few roots are dug up and sold to generate cash for household necessities. Production plots are small, rarely larger than 0.5 ha, although some larger-scale production exists. The crop is grown in two types of food systems. One is cereal-based, where sweetpotato is a food-security crop, as in Kenya. The other is nongrain, starchy staple-based. In this system, sweetpotato is one of several staple foods, and plays an important role in Uganda, Rwanda, Burundi, and adjacent parts of Zaire and Tanzania. Uganda alone produces 2.0 million t annually, making it the world's fourth-largest sweetpotato producer.

Agroecological conditions under which sweetpotato is grown range from semiarid to high-altitude, temperate climates. There is almost no fresh storage of roots. Farmers practice in-ground storage and piecemeal harvesting. This means that crops are left in the ground for 7 mo to more than a year, and roots are removed as necessary for family meals. This practice guarantees that fresh roots are available for consumption during a large part of the year. But it also means that sweetpotato crops are in the field throughout the year in many areas where they are susceptible to pest infestation.

Since 1990, CIP researchers have collaborated with the national root crops programs of Kenya, Uganda, and Tanzania; the Crop Science Department of Makerere University; the Natural Resources Institute (NRI), United Kingdom; and the International Institute of Biological Control (IIBC) to develop integrated pest management (IPM) for sweetpotato in East Africa. The major pest in the region is the sweetpotato weevil *Cylas* spp.

IPM development can be divided into five distinct and consecutive phases, some of which may overlap. They are (1) pest problem assessment and characterization, (2) development of management components, (3) integration of key components, (4) implementation of IPM in pilot units, and (5) implementation of IPM on a large scale.

This CIP strategy has proven to be very successful in managing potato pests in the Andean region and North Africa, and managing sweetpotato weevil *Cylas formicarius* (Fabricius) in the Caribbean. However, these successes were obtained with commercial crops grown by relatively resource-rich farmers who commonly use insecticides to protect their crops. The situation of sweetpotato production in East Africa is very different and requires adjustments in strategy and expectations.

Pest Problem Assessment

Socioeconomic research into sweetpotato production and use pointed toward some important considerations relating to pest control.

First is farmers' perceptions of pest problems. It makes little sense to help farmers solve problems that they do not consider important. During surveys throughout East Africa, farmers in areas with long dry seasons indicated that root-damaging sweetpotato weevils (*Cylas* spp.) were a major constraint to their sweetpotato production. An insect pest of

1 CIP-Uganda.
2 National Agricultural Research Organization (NARO), Uganda.

regional importance is the sweetpotato butterfly *Acraea acerata* in the high-altitude regions of Uganda, Rwanda, and Burundi. Throughout these regions, most sweetpotato roots are destined for home consumption. Consequently, quality demand is low and what entomologists consider high pest levels are tolerated.

Biological research is one part of pest problem assessment. The sweetpotato weevil species found in East Africa, *Cylas puncticollis* (Boheman) and *C. brunneus* (Fabricius), are unique to the continent. Their counterpart *C. formicarius* (Fabricius) is a pest on sweetpotato in Asia, the United States, and the Caribbean. It has been widely studied, but little or no published information is available on the biology and ecology of the African sweetpotato weevil species or on the sweetpotato butterfly. Basic studies revealed differences in the biology of the two weevil species (Table 1) and the presence of species-specific pheromones for the weevils.

Knowledge of sweetpotato weevil ecology, biology, and behavior may indicate how to manage the pest. For instance, weevils cannot dig down through soil; the only roots females can lay their eggs in are those they locate through soil cracks or those exposed aboveground. Soil cracks are more common during the dry season, thus exposing roots for attack. Possibilities for control are the use of varieties that escape weevil damage by producing roots deep in the soil, covering exposed roots with soil and filling soil cracks to protect roots from weevil attack, and adjusting planting and harvesting times so that roots are not present in the dry season.

Development of Management Components

The technological options for an IPM program include host-plant resistance; biological control; cultural control; chemical control; and behavior-influencing techniques such as pheromones, sticky traps, and repellents. Methods described in the literature for controlling *C. formicarius* were validated under ambient conditions for the local species. Practices that farmers traditionally use to control pests were considered as a good basis for research and verification trials.

Host-plant resistance

So far, research has not identified germplasm immune to *C. formicarius.* But some studies suggest that sweetpotato clones differ in their levels of resistance. These levels are low and do not stand up under high weevil pressure. CIP and its collaborators have conducted several field and laboratory experiments with varieties from local germplasm collections to detect resistance to the African sweetpotato weevil species.

Although some varieties were clearly less susceptible than others, no reliable source of resistance has been identified. Conventional breeding techniques appear to have limited potential to incorporate weevil resistance into sweetpotato. An alternative approach under study is the development of transgenic sweetpotato with proteinase inhibitors for *Cylas* spp.

Table 1. Life cycle data on two *Cylas* species taken in Kenya at 27±1°C and 45±5% relative humidity, 1992.

Cylas species	Developmental period (d)	Longevity[a] (d)	Number of eggs per female	Number of eggs per female per day
puncticollis	20–28	140±10 a	103±16 a	1.10±0.04 b
brunneus	32–41	92±12 b	100±18 a	1.53±0.06 a

a. Means within a column followed by different letters are significantly different by the t-test ($P < 0.05$).

Some varieties are less susceptible to weevil damage than others due to an escape mechanism known as pseudoresistance. Short-season varieties can be harvested early before the weevil population builds up. Deep-rooted varieties escape weevil damage because their roots are less accessible for females to lay eggs.

Biological control

Because several life stages of sweetpotato weevils are completed underground within the roots, it is difficult for parasites to locate them. Entomopathogenic fungi, bacteria, nematodes, and ground-dwelling insect predators appear to have greater potential as biological control agents of *Cylas* spp.

Of all known fungal pathogens reported to attack *Cylas* spp., *Beauveria bassiana* is the predominant species. In East Africa, scientists from IIBC isolated several strains from field-infested *C. puncticollis* and *C. brunneus* specimens. CIP collaborated in experiments to field-test strains that had proved to be the most pathogenic in the laboratory. Results were inconclusive.

Further field experimentation is planned in swampy areas, where farmers maintain their sweetpotato planting material during the dry season. Here environmental conditions might be more suitable for establishment of the fungus.

Cultural control

Recommended cultural practices that may help reduce *C. formicarius* damage include crop rotation, field sanitation, use of clean planting material, planting away from weevil-infested fields, hilling up to reduce soil cracking, adjusting planting time, and timely harvesting.

The ecology and biology of *C. puncticollis* and *C. brunneus* are similar to those of *C. formicarius* considering flight activity, host range, and mode of entry into the plant. In principle, the cultural practices advocated for reducing damage by *C. formicarius* also apply to the African sweetpotato weevil species.

Collaborative field experiments at research stations in Uganda and Kenya on some of the cultural practices confirmed this. However, the production systems of sweetpotato in Africa are very different from those of the United States and Asia, where the recommendations were developed. Suitable cultural control practices are site-specific and depend on agroecological and socioeconomic conditions. Some practices such as hilling up and rotation have become so common among farmers for agronomic reasons that they are not recognized as control techniques.

Two practices that are expected to have the most noticeable effect on weevil control—good field sanitation and planting away from weevil-infested fields—might require a community effort in densely populated areas. Practices that would require more labor from farm families might be a constraint, especially during peak periods of farm activity. An example is extra hilling of mounds and filling soil cracks.

The traditional practice of in-ground storage combined with piecemeal harvesting is contrary to the recommendation of prompt harvesting. On-station research, however, demonstrated that accumulated yield and yield loss under piecemeal harvesting compared favorably with once-over harvesting at the optimum harvesting time (Figure 1).

Knowledge of the biology and behavior of weevils will give farmers insight into the rationale behind recommended cultural practices. Site-specific, farmer-participatory research on cultural practices is presently needed, to verify which practices fit the farmers' uses and customs.

Sex pheromones

The sex pheromone of *C. formicarius*, identified in 1985, proved to be an important component of an IPM program for this insect in its host range. *C. puncticollis* and *C. brunneus* appear to have their own species-specific, female-produced pheromones. In 1995, a holdback project funded by the Overseas Development Administration (ODA) began devel-

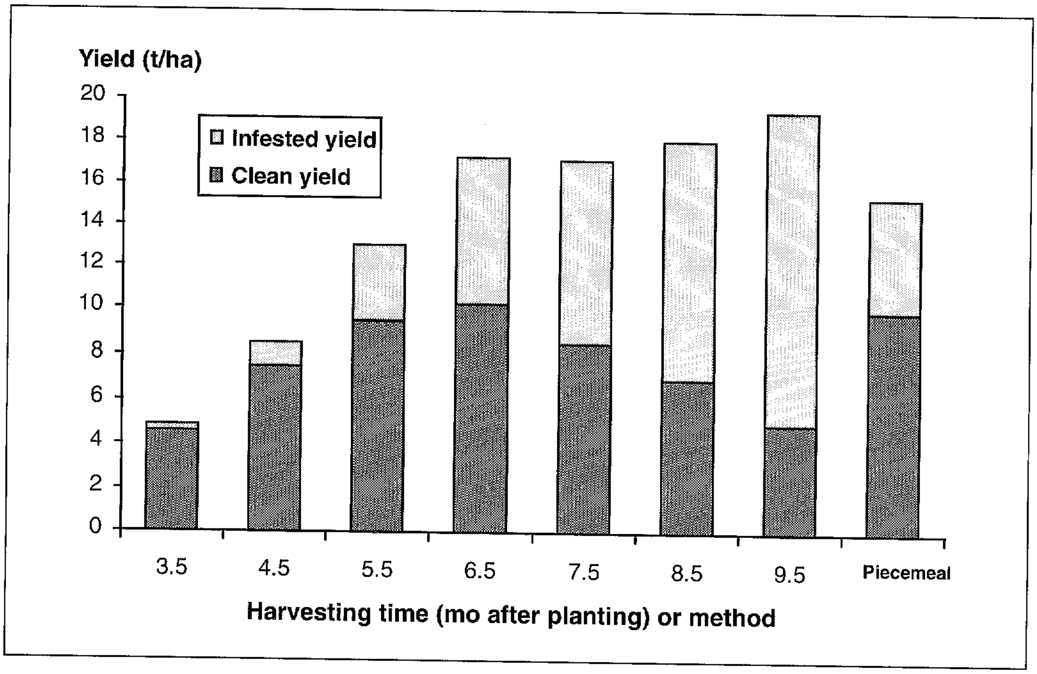


Figure 1. Comparison of yield and yield loss due to sweetpotato weevil damage between once-over harvested plots and a piecemeal harvested plot, Namulonge, Uganda, 1995.

oping pheromones for monitoring and controlling the African *Cylas* spp. This is a collaborative project of the National Agricultural Research Organization (NARO) of Uganda, NRI, and CIP. NRI identified pheromone compounds that proved effective in catching male weevils under field conditions in Uganda. Exciting research results have been obtained on the most effective trap type (Figure 2), pheromone dose, lure and composition, male weevil diurnal activity (Figure 3), etc. A 5-L jerry can, filled with soapy water and tied to a pole so that it hangs slightly higher than the canopy of the crop, is presently the most effective and robust trapping system.

We are conducting on-station field experiments on the use of pheromone traps for mass trapping of males for weevil control. With participating farmers, mass trapping experiments have begun in small planting material nurseries, which are kept during the dry season. During this time of the year, the sweetpotato area is smaller and mass trapping might be more feasible. Sex pheromone traps might show potential as a component of IPM.

Chemical control

Most sweetpotato weevil life stages take place underground within plants. Therefore, postplant application of insecticide requires frequent applications to kill newly emerged adults. This is not cost-effective for subsistence farmers. Preplanting insecticide applications by dipping cuttings in systemic insecticide kill weevils within the vine and can protect it for at least 1 mo after planting. But the chemicals involved are highly toxic, and expensive. For these reasons, little attention is paid to chemical control of weevils.

Farmer Participatory Research in Pilot Area

The most promising IPM components at the moment—cultural control practices and sex pheromones—both require adaptation by farmers. The input of farmers at an early stage would alert researchers to any major unforeseen constraints to the eventual adoption of these management components. Research on other components, such as host-plant resistance and biological control, for which readily available technologies do not yet exist, can continue at the research stations.

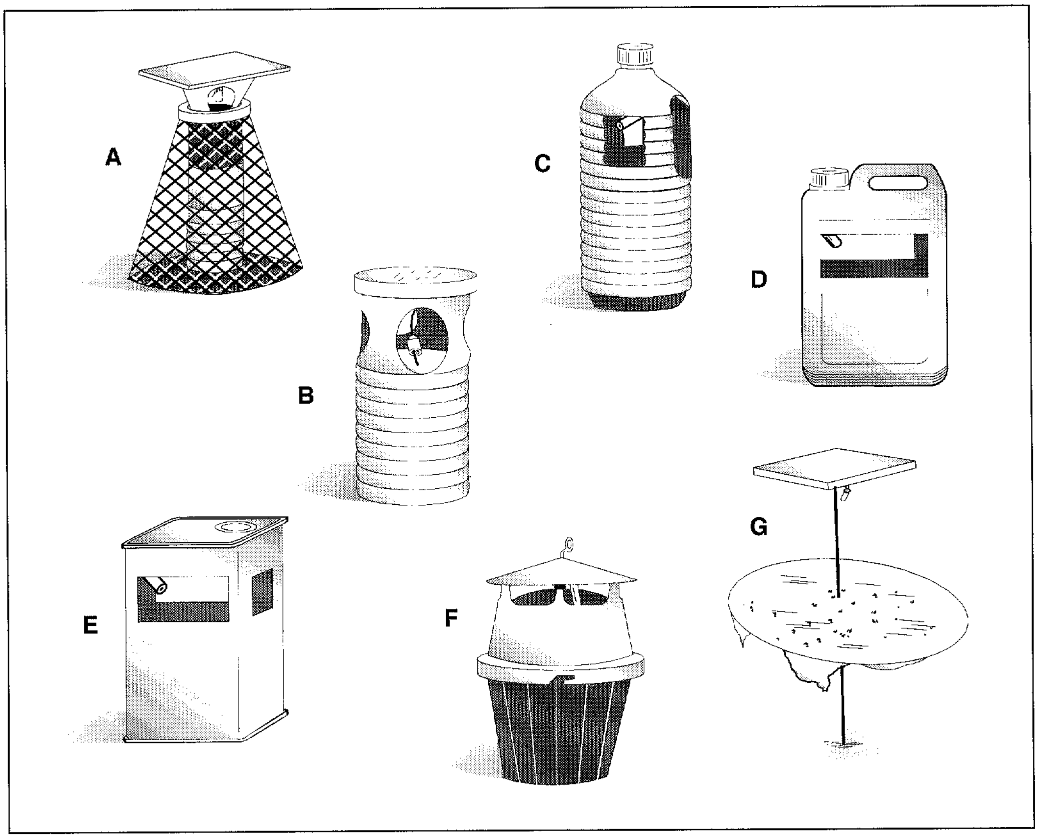


Figure 2. Seven pheromone trap types tested in Uganda: (A) plastic funnel trap, (B) 1-L bottle/funnel trap, (C) 2-L plastic jerry can trap, (D) 5-L plastic jerry can trap, (E) 4-L metal oil can trap, (F) Uni-trap, (G) sticky disc trap.

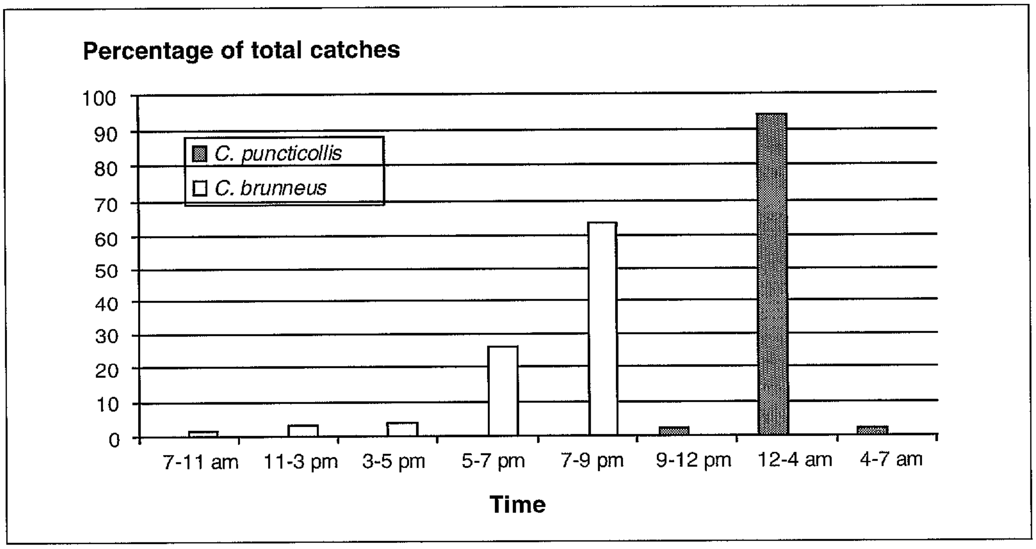


Figure 3. Diurnal timing of male weevil catches in their respective sex pheromone traps, Namulonge, Uganda, 1996.

IPM in complex, diverse, and risk-prone agriculture in sub-Saharan Africa has had few successes. Those reported were based on classical biological control or highly resistant varieties, or involved cash crops on which there was an overuse of insecticide. None of these conditions relate to IPM for sweetpotato, so a careful approach has to be taken. To increase the likelihood of practical success of the program, some modification of the CIP IPM model is required.

Selection of pilot area

Pests are often but one of many risks and sweetpotato but one of many crops. Farmers in East Africa often tolerate high yield losses. It is important to select a pilot area where pest management of sweetpotato might be a high priority for farmers.

A combination of specific socioeconomic and agroecological factors controls the selection of an IPM pilot site in East Africa. At the site, sweetpotato should be a basic staple food or a major cash crop, rainfall should be low or poorly spread seasonally with one or two long dry seasons, and sweetpotato production should have become increasingly important and intensive.

Part of northeastern Uganda forms a region within East Africa that fulfills all three conditions and is suitable as a pilot area for sweetpotato IPM. A suitable pilot area was found in Gweri subcounty in Soroti District.

Sweetpotato is the predominant staple crop, providing the majority of dietary starch throughout the year. And it is an important cash crop for the Kampala market during the major harvest months. Urban consumers prefer one variety, Tanzania, which is early maturing and highly susceptible to weevil attack due to its rooting characteristics. Farmers also like this variety for its taste and high yield.

The preferred staple and important cash crop cassava had virtually disappeared from the area due to African cassava mosaic virus disease (ACMVD) since 1986, but is slowly reappearing in the form of resistant varieties. Sweetpotato has taken over most of cassava's role as a cash crop and for food security.

For similar reasons, the site was suitable for testing storage technology of fresh roots, which offered the opportunity to extend the period of availability of the crop. Before the onslaught of ACMVD, fresh cassava roots were available more or less throughout the year, as these can be stored in-ground on the plants. Sweetpotato plots, however, have to be dug up at the beginning or toward the middle of the dry season, because sweetpotato weevil damage increases rapidly to unacceptable levels.

At that time of the year, sweetpotato is dried and stored, to provide food during the long dry season. However, the product cannot be stored very long because of common storage pests. Sweetpotato therefore cannot completely replace cassava, and a period of insufficient food availability occurs nearly every year just before the earliest harvest of cereal crops in the rainy season. If final harvesting of sweetpotato could be delayed 1 mo, by reducing the incidence of sweetpotato weevil, this would be a large benefit for the farmers. IPM for sweetpotato weevils and storage of fresh roots are complementary in extending the period of availability of the fresh produce.

Integrated crop management (ICM) approach in pilot area

The pilot program began in July 1996. Enthusiastic extension staff and an NARO/CIP-sponsored local staff oversee the daily activities in the program. Basic information on impact of sweetpotato pests, farmers' knowledge of pests, and current crop and pest management practices is obtained through participatory rural appraisal (PRA) methods, formal questionnaires, and year-long recordkeeping in farmers' fields.

The research phase began in December 1996. During the PRA exercises, farmers expressed an interest in and need for management of sweetpotato weevils. In three target villages, farmer-experimenters, selected from and appointed by the farmers involved in the pest problem assessment, are trained on the biology and behavior of the insect pests, the ecological basis for pest outbreaks, and the rationale for the control measures to be tested. Mass trapping with pheromone traps, in combination with good field sanitation and planting away from infested fields, is being tested in the dry-season planting material nurseries in swampy areas.

Besides IPM components, farmers also expressed an interest in testing other technologies. In partnership with researchers from other disciplines, testing of new varieties, methods for storing fresh sweetpotato, and the use of sweetpotato in pig keeping takes place. Based on the needs and interests of the farmers, this integrated crop management approach was taken, as it became clear that yield loss due to sweetpotato weevil damage was but one of several related constraints that farmers face in sweetpotato production.

The pilot project will run for two years. If farmers are convinced of the practical value of an ICM program and take up crop protection practices, more pilot units will be considered, including extension of the program to neighboring countries. We cannot expect quick results from the development of an ICM program for the subsistence crop sweetpotato, but the present holistic approach with farmer participation holds promise to improve their living conditions.

Selected Reading

Smit, N.E.J.M. n.d. The effect of the indigenous practices of in-ground storage and piecemeal harvesting of sweetpotato on yield and quality losses caused by sweetpotato weevil in Uganda. Agric. Ecosyst. Environ. (In press.)

Smit, N.E.J.M. 1995. Farmers' cultural practices and their effects on pest control in sweetpotato in South Nyanza, Kenya. Int. J. Pest Manage. 41:2-7.

Smit, N.E.J.M., M.C.A. Downham, B. Odongo, D.R. Hall, and P.O. Laboke. n.d. Development of pheromone traps for control and monitoring of sweetpotato weevils, *Cylas puncticollis* and *C. brunneus*, in Uganda. Entomol. Exp. Applic. (In press.)

Farmer Field Schools for Sweetpotato in Indonesia

A.R. Braun[1], E. Priatna[1], R. Asmunati[2], Wiyanto[2], Y. Widodo[3], and E. van de Fliert[4]

In 1986 Indonesia adopted integrated pest management (IPM) as a national policy and began implementing IPM for rice through farmer field schools (FFS), based on a model developed by the FAO Intercountry Rice IPM Program. That experience provided a foundation for expanding the program to horticultural and secondary crops. Indonesian farmers can now learn to become IPM practitioners through FFS for chile, cabbage, tomato, potato, shallot, and soybean. As of 1994, FFS for maize, cassava, and sweetpotato, the other main secondary crops, had not been developed.

Sweetpotato (*Ipomoea batatas*) is a common rotation crop in Java's irrigated rice-growing areas and is the main cash crop in some rainfed areas of East and Central Java. In 1994 the Research Institute for Legumes and Tubers (RILET) and CIP analyzed farmers' IPM needs in the main sweetpotato-growing areas of Java. Farmers rated rats, root rot, leaf-feeding insects, stemborers, and the sweetpotato weevil as the most important pests.

But improving pest management was much less important to them than solving marketing problems. Farmers' main concerns are fluctuating prices and their weak bargaining position with the traders who buy the standing crop in the field and monopolize the marketing system. Under this system, farmers are not paid according to what they produce. Several days or weeks before harvest, the trader makes the farmer an offer for the output of the field. The farmer is at a disadvantage because he or she does not know how to estimate the yield, and usually accepts the trader's offer with little, if any, bargaining. On harvest day, the trader returns with his laborers to dig up the roots and transport them to market. If the output is higher than the trader expected, the farmer receives no additional benefit. If there is pest damage or the yield is lower than expected, traders often pay farmers less than the agreed-upon price.

Developing a Field School for Sweetpotato

Analyzing the sweetpotato enterprise

Mitra Tani, a nongovernmental organization (NGO); RILET; Duta Wacana Christian University (UKDW); eight farmers from four villages in East and Central Java; and CIP joined forces in 1994 to develop an FFS for sweetpotato. The four villages were Bendunganjati, Turi, Ngargoyoso, and Kradenan.

The first job for the project team was to analyze sweetpotato cultivation as a farming enterprise. The data gathering was managed by two farmers from each village who were trained as *field researchers*. Each was responsible for supervising a network of five to eight farmers in keeping a daily calendar of all activities, inputs, and costs related to sweetpotato production; for evaluating losses from pests and diseases; and for recording yield and income from the sale of the crop.

The key results from several seasons of recordkeeping are as follows:

- There is tremendous variability in input use and yields (Figure 1), even within a single village.

1 CIP-ESEAP Regional Office, Bogor, Indonesia.
2 Mitra Tani, Yogyakarta, Indonesia.
3 Research Institute for Legumes and Tubers, Malang, Indonesia.
4 Duta Wacana Christian University, Yogyakarta, Indonesia.

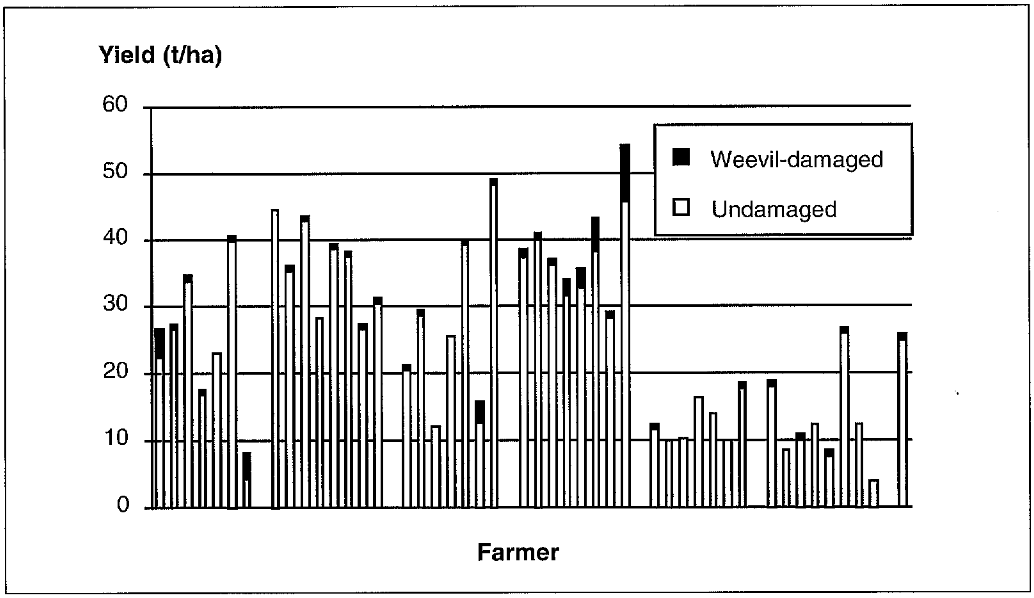


Figure 1. Sweetpotato yields of 45 farmers at six sites in East and Central Java, Indonesia. Each bar represents a farmer; each group of bars represents a site. The last bar on the right represents the global average. Turi, Ngargoyoso, Bendunganjati, Indonesia, 1995 dry season.

- Losses from sweetpotato weevil (*Cylas* spp.), the most serious insect pest, are relatively minor, even during the dry season.
- Yield is related to the age of the crop at harvest. With knowledge of the weekly yield increase, farmers can use current market prices and projected prices to make better-informed decisions on when to sell to traders (Figure 2).
- There is tremendous variability in profitability of the sweetpotato crop, even within a single village. Sharecroppers frequently lose money.
- Higher yields are not related to greater labor inputs.
- The expenditure for fertilizers and pesticides is the smallest portion of money spent for inputs.
- Farmers producing higher yields tend to earn more than those producing lower yields, indicating that traders are paying a higher price per ton to farmers who produce more (Figure 3).
- The most promising way to increase income from the sweetpotato enterprise, at least in the short term, is by improving crop management and using inputs more efficiently.

Field researchers also received training in methods for monitoring pests, natural enemies, and diseases. They made weekly evaluations in the fields of the farmers who were participating in the daily recordkeeping. The objective of this activity was to develop their expertise in routine field monitoring and to build knowledge of how insect populations behave. This knowledge is the basis for learning to judge whether and when a given insect is a pest.

Farmers' field research agenda

The field researchers developed an agenda of issues they wanted to investigate. The project team from RILET, Mitra Tani, UKDW, and CIP helped them design, conduct, and evaluate their experiments. These included agronomic, varietal, and pest management trials. Many of the trials were designed to follow up issues raised by the recordkeeping experience, particularly those relating to increasing input use efficiency.

Farmers keeping daily calendars applied between100 and 400 kg/ha of nitrogen, but no clear relation between the rate of N application and yield emerged. All four villages par-

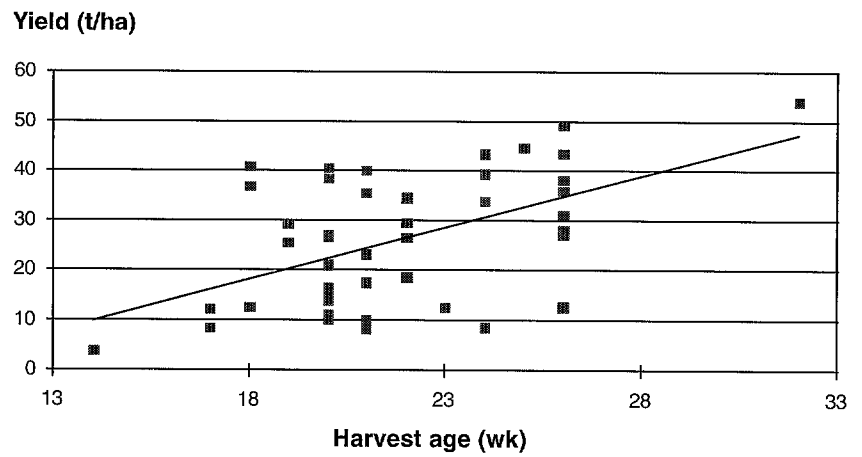


Figure 2. Relation between sweetpotato age at harvest and yield. Each point represents a farmer. Turi, Ngargoyoso, Bendunganjati, East and Central Java, Indonesia, 1995 dry season.

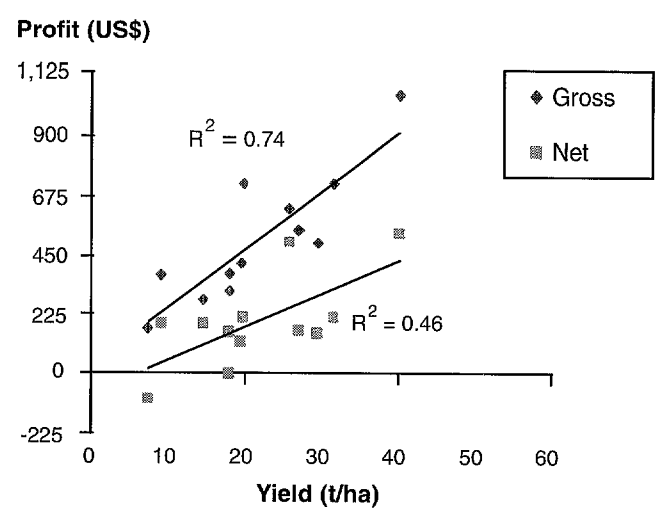


Figure 3. Profit vs. yield of sweetpotato. Each point represents a farmer. Turi, Ngargoyoso, Bendunganjati, East and Central Java, Indonesia, 1996 dry season. The 1996 exchange rate was Rp. 2,230 = US$1.00.

ticipated in a trial designed to investigate the effect on sweetpotato yield of urea application rates between 100 and 250 kg/ha. The field researchers and their network of farmer collaborators concluded that the crop was not responding to urea applications in this range (Figure 4). Farmer researchers are currently investigating the effect of N application rates of <100 kg/ha.

Farmers from the participating villages are eager to test new varieties. During the first season of collaboration, the field researchers decided to exchange elite varieties from each village.

The conclusions from the first varietal trial conducted by farmer field researchers follow:

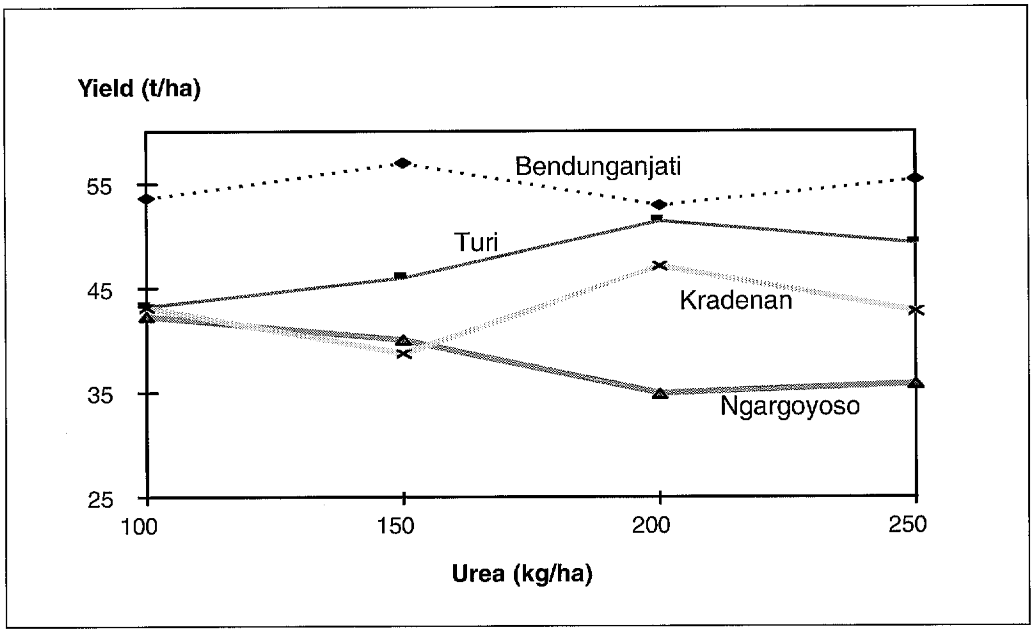


Figure 4. Effect of urea application on yield of sweetpotato in four Javanese villages, Ngargoyoso, Turi, Bendunganjati, and Kradenan, East and Central Java, Indonesia, 1995 dry season.

- Varieties tend to perform best in their village of origin. An exception was Jegos Super, which outyielded the best local variety Bestak in Bendunganjati village by more than 20 t/ha.
- Turi and Bendunganjati tended to have higher losses from sweetpotato weevil than the other villages. The field researchers attributed that to the heavier soils in those villages, and to the practice of planting two consecutive crops of sweetpotato each year.
- Some pests tend to be more of a problem in certain varieties (e.g., white grubs in varieties Kankung and Menthik).
- Some problems seem related to both site and variety (e.g., root cracking in Jegos Super in Ngargoyoso and Kradenan villages).

The field researchers are now testing germplasm provided by RILET.

Curriculum development

Field schools are based on adult education principles that stress the importance of learning through hands-on activities, with the field itself the learning laboratory. Rather than an instructor or lecturer, a facilitator acts as guide and mentor to steer participating farmers through the FFS learning process. The facilitator is either a trained farmer or an extension worker.

The project team developed an experimental curriculum and a guide for FFS facilitators. Course content was drawn from the results of five seasons of farmer experiments; complementary experiments conducted by Indonesian institutions, CIP, and the University of Queensland, Australia; and the literature on sweetpotato agronomy, pathology, and entomology.

The first pilot field school was conducted during the 1995 dry season in Turi, with an experienced rice IPM farmer-trainer as facilitator. Feedback from the participants was used to improve the curriculum, the activities, and the training materials. A second pilot school was run in Turi during the 1996 dry season. This field school served as an arena for training the field researchers who were to become the first group of sweetpotato FFS facilitators.

The second field school applied integrated crop management (ICM) principles and practices on an experimental plot. Marketable yield in the FFS plot was 15 t/ha higher than that in neighboring fields managed by farmers who were not participating in the field school.

The key ICM practices included field sanitation to eliminate sources of insects and diseases, selection of healthy planting material, use of tip cuttings, application of organic fertilizer and KCl, reduced N application, and hilling-up to minimize soil cracking. Pest management practices were based on weekly field observations.

Profile of a Farmer Field School

Sweetpotato field schools cover the entire cropping cycle, beginning with the selection of planting material. During the crop establishment phase and when harvest time is approaching, they meet weekly. Meetings are held every 2 wk during the intervening time.

Each FFS has a field of approximately 1,000 m^2 where participants conduct field observations and collect data. The field is managed based on agroecosystem analysis following ICM principles. Participants make weekly observations throughout the growing season to learn about the agroecosystem, insect population dynamics, and many other topics. At harvest, yields and damage levels from direct pests (weevils, root rot, rats, white grubs) are compared. The economic return from the experimental plot is analyzed and compared with neighboring fields under traditional management.

Agroecosystem observation, analysis, and presentation of results is the core activity of the FFS. Working in small groups, farmers make observations of the experimental plot. Participants collect data from ten 1-m^2 quadrats per plot, focusing on factors that work for and against crop health. They observe plant vigor, numbers of pests and natural enemies, disease damage symptoms, and other field details. Following the observations, the farmers meet to draw what they have just observed on large pieces of newsprint, and to examine specimens brought from the field. The drawings indicate the size and stage of the sweetpotato plant, the pests and natural enemies observed, and other salient details. While drawing, farmers discuss the data they have collected and decide on the management practices to be carried out in the field. A summary of these is added to the drawing. One member of each group presents these findings and decisions to the larger group. After each presentation, the floor is opened for questions and discussion. Management of the experimental field is based on the consensus reached in the discussion.

Special topics (Table 1) support agroecosystem analysis by delving more deeply into specific issues relating to the sweetpotato agroecosystem, IPM principles, and crop health, and they provide an opportunity for farmers to practice basic experimental methods. After the trainer introduces the topic and explains the steps in the process, participants assume active management of the experiment or activity. Data collection and analysis are emphasized.

An example of a special topic in sweetpotato field schools is the use of flooding to eliminate sources of weevil infestation. In this exercise, farmers simulate flooding by placing infested roots under water for different periods and then cutting them open to look for surviving weevils. In another exercise, farmers defoliate small sweetpotato plots at different points in the crop development cycle. The objective is to analyze whether defoliating insects such as leaf folders and tortoiseshell beetles, which often provoke pesticide applications, decrease yield.

Scaling-up

The field researchers who were trained in the pilot school suggested that the FFS would have greater credibility among farmers if it were part of the national IPM program. We held a workshop in October 1996 to describe the experiences and outcome of the project to representatives of the national IPM program, universities and national agricultural research institu-

Table 1. Special topics in farmer field schools for sweetpotato (Indonesia,1996).

Field school session	Wk after planting	Topic
1	-2	· Introduction to the farmer field school · Healthy soil
2	-1	· Healthy planting meterial · Setting up an experiment
3	0	· Planting sweetpotato
4	1	· Agroecosystem analysis · Crop health
5	2	· Natural enemies
6	3	· Pests · Defoliation experiment
7	4	· Diseases · Weeds: friends or foes?
8	5	· Aphids, mites, etc. · Pesticides: medicine or poison?
9	6	· Chemical fertilizers
10	8	· Organic fertilizers
11	10	· Vine lifting · Estimating field size
12	12	· Stemborers
13	14	· Sweetpotato weevil
14	16	· Planting systems
15	18	· Choosing varieties
16	20	· Estimating yield · Harvesting and marketing sweetpotato
17	21	· Field sanitation

tions, and NGOs that conduct field school activities. Participants were asked to analyze three options for the future of the project:

1. The project should concentrate on refining the model before considering scaling-up.
2. A limited scaling-up process should be designed around existing NGOs and farmer networks.
3. The sweetpotato FFS should become part of the national IPM program's activities.

The workshop recommended the third option. Since then the national IPM program has decided to conduct sweetpotato FFS as a follow-up to rice IPM field schools. Farmers who have already received rice IPM training can extend their experience by delving more deeply into crop, pest, or disease management problems in rice, or by attending a field school for another crop. During 1997, the sweetpotato field researchers and members of the project team will train 50 rice IPM farmer-trainers to facilitate sweetpotato ICM field schools, and the first field schools will be initiated.

Rice IPM field schools are concentrated in irrigated rice-growing areas. Therefore, follow-up field schools for sweetpotato conducted by the national IPM program will not reach farmers in rainfed areas who depend on sweetpotato as a main source of income. To reach those farmers, the project team is analyzing prospects for collaborating with NGOs that are working to improve dryland agriculture.

In December 1996, this project won an award for excellence in methodological innovation for farmer participatory research from the Users' Perspectives With Agricultural Research and Development (UPWARD). This project is supported by UPWARD, the Government of Japan, and CIP's Integrated Pest Management Program.

Selected Readings

Braun, A.R. and Dan Edy Priatna. 1994. Suatu tinjauan penelitian tentang hama dan penyakit ubi jalar. Cakara Tani. Edisi Khusus. Desember 1994. Fakultas Pertanian Universitas Sebelas Maret. Surakarta, Indonesia. p. 18-24.

Braun, A.R., E. Van de Fliert, C. Wheatley, G. Prain, and Y. Widodo. 1995. Improving profits from sweetpotato by linking IPM with diversification of markets. CIP Circular 21(3):8-15.

Braun, A.R., and E. Van de Fliert. n.d. The farmer field school approach to IPM in Indonesia: User participation. In: Proc. Fifth Annual Conference. Users' Perspectives With Agricultural Research and Development, 9-12 Dec. 1996, Subic Bay, Philippines. UPWARD, Los Baños, Philippines.

Van de Fliert, E., R. Asmunati, Wiyanto, Y. Widodo, and A.R. Braun. 1996. From basic approach to tailored curriculum: Participatory development of a farmer field school model for sweetpotato. In: Into action research: Partnership in Asian rootcrop research and development. UPWARD, Los Baños, Laguna, Philippines.

Developing Weevil Resistance in Sweetpotato with Genetic Transformation

D.P. Zhang[1], A. Golmirzaie[1], G. Cipriani[1], A. Panta[1], M. Ghislain[1], N. Smit[1], I. Rety[2], and D. Michaud[2]

Crop loss of sweetpotato (*Ipomoea batatas* (L.) Lam.) caused by insect damage is the most important problem in the field. Although the importance of pest species varies regionally, sweetpotato weevil (*Cylas* spp.) is the most important threat worldwide. The weevils *C. formicarius* (Fabricius) and *C. puncticollis* (Boheman) are the most destructive. Larvae of this pest tunnel through storage roots, resulting in major damage and economic yield loss. Production losses often surpass 60% and can reach 100%.

Weevil damage imparts a characteristic turpentine odor to the roots, which renders even slightly damaged roots unfit for human consumption. Larvae also feed inside the vines.

The cryptic feeding habit of the sweetpotato weevil larvae and the nocturnal activity of the adults make it difficult to detect sweetpotato weevil infestations. Approximately 80-90% of the weevil population within vines and roots is distributed below the soil surface. These factors limit the effectiveness of chemical insecticides applied for weevil management.

Host resistance is an important component in successful integrated pest management (IPM). CIP's experience in Caribbean countries demonstrated that use of less susceptible cultivars significantly contributed to the effect of IPM. The search for weevil resistance started 50 years ago, but the level of resistance found in sweetpotato and its wild relatives is rather low. A large genotype by environment interaction and low heritability generally preclude the use of conventional breeding techniques.

Genetic transformation with genes that encode protease inhibitors (PI) is a novel approach to creating weevil resistance in sweetpotato. Foreign genes that encode protease inhibitors have been introduced into tobacco, tomato, strawberry, potato, and many other crops to control a range of insect pests. These proteins bind to proteases in the midgut of the insect, thus affecting the insect's metabolism.

In this article, we summarize research at CIP and its collaborating institutions to develop a transgenic sweetpotato with protease inhibitor genes. This work is divided into three parts:

1. Developing a regeneration and transformation system protocol for sweetpotato,
2. Identifying appropriate protease inhibitors for sweetpotato weevil, and
3. Producing transgenic plants that carry foreign protease inhibitors.

Regeneration and Transformation System

Sweetpotato plant regeneration

We have developed an efficient regeneration protocol and *Agrobacterium*-mediated transformation system. Using this system, we have been able to regenerate and transform most of the sweetpotato cultivars tested.

The bottleneck in developing transgenic sweetpotato has been the lack of a reliable regeneration system, because regeneration is strongly genotype dependent. Cultivars vary

1 CIP, Lima, Peru.
2 Horticultural Research Center, Laval University, Quebec, Canada.

significantly in their regeneration successes. Therefore, we conducted a series of experiments at CIP to modify the regeneration media and to standardize protocol to improve regeneration efficiency.

Two pathways for sweetpotato regeneration—somatic embryogenesis and organogenesis—have been explored. So far, our regeneration is achieved mainly by shoot organogenesis from leaves, roots, and stem internodes. We have regenerated most cultivars tested. Table 1 lists the ones that have been successfully regenerated at CIP, even though the regeneration rate remains genotype dependent. Meanwhile, we are actively exploring use of somatic embryogenic suspension cultures, which will eventually improve the efficiency of regeneration.

All tested cultivars were obtained from the in vitro gene bank maintained at CIP. Plants were propagated in vitro at 25 ± 2°C under fluorescent light (45 $uEm^{-2}s^{-1}$) with 16 h photoperiod. Using explants of stem segments and complete leaves, we achieved direct regeneration through shoot organogenesis using a two-stage regeneration protocol. In general, we found that the protocol using complete leaves gave the best regeneration rate.

Transformation through *A. tumefaciens*

Plasmid description. We tested the transformation system using two plasmids. One was pBI121 plasmid containing GUS (β-glucuronidase), cecropin (encoding cecropin proteins that have activity against bacteria), and NPTII (neomycin phosphotransferase) genes. The other was pCIP5 plasmid containing NPTII and WCI-3 genes. WCI-3 encodes chymotrypsin inhibitor from winged bean (*Psophocarpus tetragonolobus*). Plasmids were transferred to *A. tumefaciens* by electroporation.

Culture of bacteria. *Agrobacterium tumefaciens* was subcultured and incubated at 28°C for 48 h. Isolated colonies were transferred to a yeast-mannitol liquid medium and incubated at 28°C for another 48 h. Bacteria concentration in the liquid medium was determined by spectrophotometry. Bacteria were then inoculated in Erlenmeyer flasks containing 25 ml of liquid potato propagation medium.

Transformation. Explants were excised from the top of young in vitro plants and inoculated in the liquid potato propagation medium at 25°C. Inoculated explants were transferred to batata propagation media and co-cultured at 25°C for 2-3 d. After co-culture, explants were transferred to different regeneration media depending on the type of explants.

Using this transformation system, we have obtained 70 putative transgenic lines with the cecropin gene from cultivars Huachano, Regal, and Jewel. The GUS assay and Southern blot have confirmed the insertion of the GUS gene into the genome of sweetpotato (Figures 1 and 2). About 300 putative transgenic lines

Table 1. Regeneration rate of sweetpotato cultivars from complete leaf using CIP-developed protocol.

Cultivar	Regeneration rate (%)
Jewel	70.0
Chugoku	43.5
PI 318846-3	28.6
Rusenya	10.0
Mabrouka	10.0
Tanzania	7.8
Huarmeyano	5.0

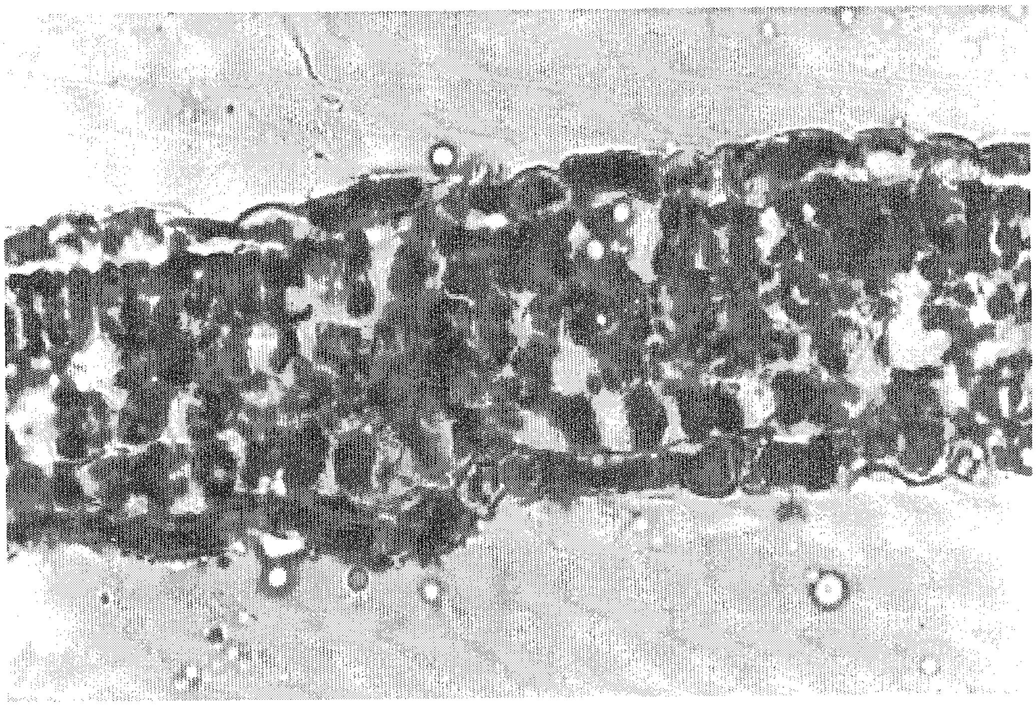


Figure 1. Expression of GUS (β-glucuronidase) gene in the leaf of transgenic sweetpotato Chugoku.

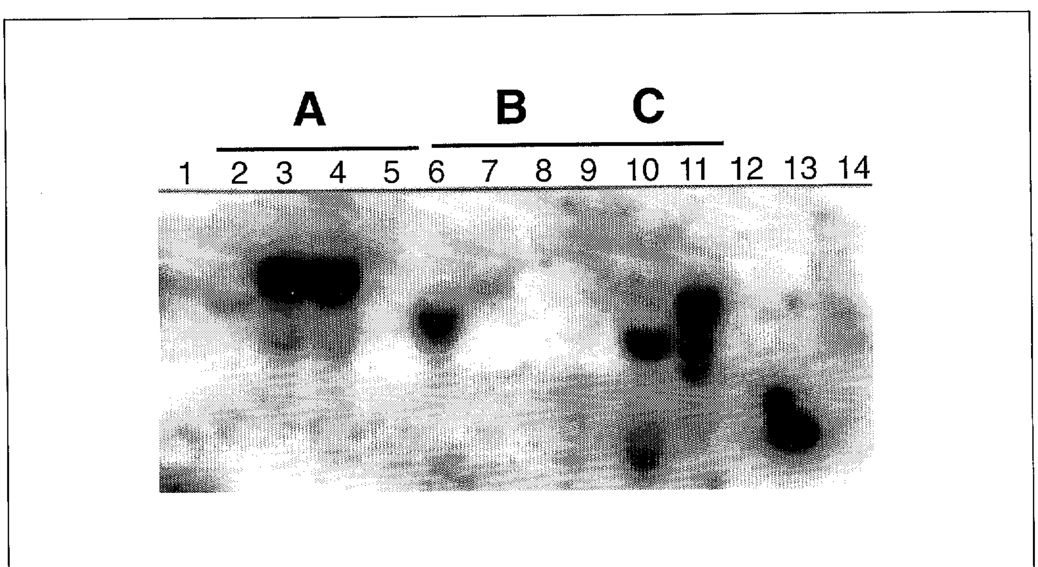


Figure 2. Southern blot analysis of DNA isolated from sweetpotato cultivars. The DNA was digested with Hind III. Lane 13 is 50 pg of plasmid containing GUS gene. (A) Huachano plants transformed (via *A. tumefaciens*) with Ca2Att gene construct (lane 2 = control plant, lanes 3-5 show bands containing the GUS gene). (B) Jewel plants transformed (via *A. tumefaciens*) with pBI121 containing the GUS gene (lane 8 = control plant, lanes 7-8 show bands containing the GUS gene). (C) Chugoku plants transformed (via *A. rhizogenes*) with pBIG121 containing intron-GUS gene (lane 9 = control plant, lanes 10-11 show bands containing the intron-GUS gene).

with WCI-3 genes were obtained from cultivars Chugoku, Huachano, Huarmeyano, PI-318846-3, Jewel, Mabrouka, Morada Inta, and Tanzania.

These results show that the *A. tumefaciens*-mediated transformation system works efficiently on sweetpotato. We now have the technical ability to transform and regenerate most sweetpotato cultivars, including the ones most widely grown in Asia and Africa.

Identification of Appropriate Protease Inhibitors

To select efficient protease inhibitors for sweetpotato weevil control, we need to know which proteolytic enzymes are used by these weevil species for the hydrolysis of dietary proteins. As a first step, midgut proteases were analyzed in larvae and adults of three *Cylas* species, *C. formicarius, C. brunneus,* and *C. puncticollis. C. formicarius* was collected in southern China and Indonesia, whereas *C. brunneus* and *C. puncticollis* were sampled in Uganda. Characterization of the weevil digestive proteases was conducted at the Horticultural Research Center (CRH), Laval University, Quebec, Canada. The study was done using standard quantitative assays and electrophoretic techniques developed at CRH for the analysis of protease-protease inhibitor interactions.

Digestive protease activity in all three species was partly accounted for by sets of stage-specific protease species. Larvae and adults of all three species were shown to use a mixture of exopeptidases and endopeptidases active primarily in the alkaline pH range.

High caseinase activity was detected in the insect samples at pH 10-11, whereas barely detectable activity was measured in mildly acidic conditions (pH from 5 to 7), even in the presence of reducing agents such as l-cysteine or di-thiothreitol. This observation, which suggests the predominance of serine-type proteases in the midgut of all three species, was confirmed by inhibition assays.

Whereas inhibitors such as cystatins (cysteine-type inhibitors) and pepstatin (aspartyl-like inhibitor) showed no effect, a significant fraction of the caseinase activity measured at pH 10.5 was inhibited in reducing conditions by the serine-type protease inhibitors phenylmethylsulfonyl fluoride (PMSF) and soybean (*Phaseolus angularis*) trypsin inhibitor (SBTI). Interestingly, the inhibitory spectrum of SBTI against the midgut proteases was apparently larger than that of endogenous inhibitors in sweetpotato (Figure 3), suggesting the potential usefulness of this inhibitor in weevil control.

At this point, we are not clear whether all the serine endopeptidase activity in weevil was blocked by SBTI, because the insect may have certain proteases that are insensitive to the plant trypsin inhibitors. A partial inhibition, however, is enough to cause developmental alterations as demonstrated in many other Coleopteran insects. Foreign (nonhost) inhibitors such as recombinant SBTI and cowpea (*Vigna unguiculata*) trypsin inhibitor (CpTI) are promising candidates for the development of transgenic sweetpotato with resistance to *Cylas* weevils. Therefore, SBTI and CpTI genes were selected and are being used to develop weevil-resistant transgenic sweetpotatoes.

Production of Transgenic Plants

The first transgenic sweetpotato with the cowpea trypsin inhibitor was developed by Axis Genetics Ltd., U.K. Since the gene construct CpTI encodes a Bowman-Birk trypsin inhibitor, our objective is to determine whether the transgenic lines with CpTI will demonstrate enhanced resistance to *C. formicarius.*

Ten transgenic lines of cv. Jewel were obtained through a collaborative project between Axis Genetics Ltd. and CIP, and seven of them had the cowpea trypsin inhibitor. The other three lines had both the CpTI gene and PCG gene, which encodes snowdrop lectin.

We have propagated these transgenic plants in an isolated screenhouse following Peruvian biosafety guidelines. These transgenic lines will be evaluated in Cuba and China using a screenhouse and field bioassay.

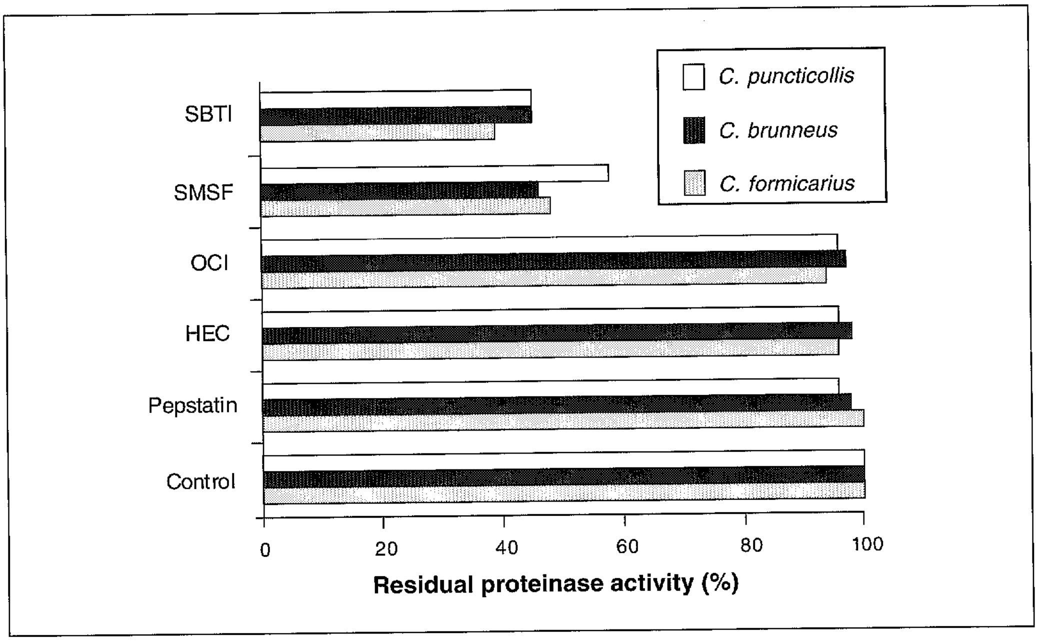


Figure 3. Response of *Cylas* spp. midgut proteinases to the action of class-specific proteinase inhibitors. Protease activity was measured with larval extracts at pH 10.5, using casein as a substrate. Data represent relative residual activity (%) ± SE, compared with a control for which no inhibitor was added (100% activity). HEC = hen egg cystatin; OCI = oryzacystatin I; PMSF = phenylmethylsulfonyl fluoride; SBTI = soybean trypsin inhibitor (Kunitz-type).

Meanwhile, we are incorporating a new plasmid, pAD1289, into *A. tumefaciens* LBA4404. It enhances transformation efficiency as reported in tobacco, cotton, and other crops. We are using three PI genes for sweetpotato transformation: OCI, which encodes a cystatin of rice; CpTI, which encodes a Bowman-Birk trypsin PI of cowpea; and SBTI, which encodes a Kunitz-type trypsin PI from soybean. The spectrum of these inhibitors covers the major digestive proteases of sweetpotato weevils (CpTI and SBTI), and of other pests of sweetpotato (OCI).

Biochemical analyses provided evidence that sweetpotato weevil larvae, which feed mainly on storage roots, and adults, which feed mainly on foliage, both use similar digestive proteolytic systems. The use of root-specific promoters appears unnecessary and a constitutive expression of the recombinant inhibitors is preferred. Therefore, CIP is using the cauliflower mosaic virus 35S promoter (CaMV35S) for all gene constructions. The expression of this promoter should lead to a constitutive expression of the PI transgenes in all tissues of the plant.

Conclusions

Serine protease inhibitors such as SBTI from soybean and CpTI from cowpea were identified as candidate inhibitors for transformation. Transgenic cv. Jewel sweetpotato expressing CpTI is being propagated for field evaluation for weevil resistance. Co-transformation with several serine PI and cystatin PI genes will be applied to construct a combined defense mechanism against sweetpotato pests.

Genetic transformation plays an important role in enhancing sweetpotato germplasm. Recent progress in developing a transformation system and identifying candidate protease inhibitors has established an essential base for creating host resistance for sweetpotato weevil. The combination of several serine PI in sweetpotato through transformation would most likely produce a durable defense mechanism against sweetpotato weevil.

Selected Reading

Chalfant, R.B, R.K. Jansson, D.R. Seal, and J.M. Schalk. 1990. Ecology and management of sweetpotato insects. Annu. Rev. Entomol. 35:157-180.

Michaud, D., N. Bernier-Vadnais, S. Overney, and S. Yelle. 1995. Constitutive expression of digestive cysteine proteinase forms during development of the Colorado potato beetle, *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae). Insect Biochem. Mol. Biol. 25:1041-1048.

Newell, C.A., J.M. Lowe, A. Merryweather, L.M. Rooke, and W.D.O. Hamilton. 1995. Transformation of sweetpotato (*Ipomoea batatas* (L.) Lam.) with *Agrobacterium tumefaciens* and regeneration of plants expressing cowpea trypsin inhibitor and snowdrop lectin. Plant Sci. 107:215-227.

Propagation and Crop Management

Mahesh D. Upadhya[1]

Research and development activities in 1995-96 in Program 5 continued to focus on three major areas: (1) management and distribution of pathogen-tested germplasm, (2) multiplication and distribution of clean planting material, and (3) breeding for and evaluation of hybrid TPS families. In addition, notable progress has been achieved in breeding and selecting for frost and drought tolerance. PROINPA/CIP collaboration made it possible to select four new frost-tolerant potato clones that are also wart resistant, and three drought-tolerant clones from germplasm supplied to this project. Selection for drought tolerance in sweetpotato germplasm indicated that cv. Tanzania was the highest producer of foliage and roots under severe water stress, whereas clone CIP-440034 had twice the foliage yield of Tanzania.

Management and Distribution of Pathogen-tested Germplasm

The collection of pathogen-tested germplasm increased to 14,000 with the addition of 198 new clones. In addition, 96 new clones are in the process of being cleaned up by CIP-contracted institutions in Australia, Austria, and Luxembourg.

Eighteen new cultivars released in seven countries consisted of 13 clones developed by CIP under different projects and 5 clones from germplasm being maintained and distributed by CIP.

1 Program Leader, CIP, Lima, Peru.

Information on the worldwide distribution of germplasm since 1990 has been included in a database that is now accessible to all CIP scientists in Lima. This database will be made accessible to all regional scientists in 1997.

Multiplication and Distribution of Clean Planting Material

Alternate methods for the distribution of clean seed of selected cultivars (native and improved ones) to farmers were developed through the diffusion of rustic nurseries by PROINPA. More than 300 of these nurseries were established in different ecoregions of Bolivia.

Rapid multiplication techniques were verified with the Mariano Marcos State University, Ilocos Norte, Philippines. Seed tubers derived from apical stem and sprout cuttings can be produced on-station and sold to farmers through the informal seed system.

A major potato seed multiplication activity was carried out at the CIP/KARI seed unit for Rwanda in 1995 as part of the "Seeds of Hope" intercenter project. The seed unit produced and supplied to Rwanda 560 kg (approximately 6,400 tuberlets) of its three major cultivars: Sangema, Cruza, and Mabondo. This unit also supplied 45,000 minitubers and in vitro plantlets to target NARS in Kenya, Uganda, and Ethiopia.

Breeding for and Evaluation of Hybrid TPS Families

Major achievements in this area involved successful evaluations of hybrid TPS families produced by CIP under final trials in Egypt, India, Bangladesh, and Vietnam. The results of 144 demonstration trials carried out in 1995-96 in Munshiganj, Jassore, and Bogra districts of Bangladesh showed that hybrid TPS families HPS-II/67 and HPS-7/67 had the best performance. About 16 kg of TPS was produced at the Debiganj Seed Station of TCRC, Bangladesh.

There has been a progressive increase in area planted from TPS-derived planting material in Bangladesh, India, and Vietnam. State departments of agriculture/horticulture and a number of NGOs are now involved in disseminating technology of TPS utilization for potato production to farmers.

The project "Field-Testing of True Potato Seed in Lowland Tropics," funded by the Asian Development Bank, has achieved its objectives in all the participating countries in the first phase. In the rice-based cropping system of the Red River Delta (RRD) in Vietnam, all original plans and projections were carried out to a large degree, and the TPS technology may now be considered as a permanent feature of the RRD cropping system. This unexpectedly rapid success has been possible because the TPS technology met a specific need of an entire region by offering an alternative to a discredited system that relied on degenerated tuber seed of questionable origin.

From the beginning, the project had the support of the research community and scientists from the Vietnam Agricultural Science Institute (VASI) and political leaders of several provinces in the RRD. The presence of CIP scientists from Lima and from the regional office in Indonesia at crucial moments in the decision-making process was one of several important factors in the success of this project. Two of the hybrid TPS families (HPS-II/67 and HPS-7/67) selected under the project in the RRD have been released as Hong ha-2 and Hong ha-7 (RRD-2 and RRD-7). Technical support and parental lines have been provided to VASI to begin hybrid TPS production in the RRD and Dalat.

Evaluations of new hybrid TPS families were carried out under four contrasting thermo-photoperiodic conditions. Promising families showing stability for yield across the four conditions have been identified. One set with early bulking (75 days after transplanting) is for subtropical regions and the second set is for Latin American countries where high yields can be obtained at 90 days after transplanting.

TPS quality tests developed at CIP-Lima have consistently predicted relative field establishment and performance. The dormancy release procedure developed at CIP-Lima has helped to improve the emergence and field performance of hybrid TPS.

Studies were carried out on the reproductive biology of potato in clones from 320 *andigena* accessions in the germplasm collection held at CIP. Characters studied included style/stigma morphology, pollen quality and quantity, seed/berry after selfing, and 100-seed weight as well as the proportion of different seed types with respect to embryo morphology. Data are being processed and will be entered into CIP's database.

Simultaneous Selection for Yield and Stability in Hybrid True Potato Seed Families

M. Upadhya and R. Cabello[1]

For crop performance trials across diverse environments, where genotype x environment (GE) interactions occur, a selection criterion that takes GE interaction into consideration does not exist. Kang and Magari (in 1995), however, came out with a BASIC program for calculating stability and yield stability for use in selecting high-yielding stable genotypes, especially in short-term trials that allow the use of GE interactions.

Although hybrid true potato seed (TPS) families do not exactly fit the definition of a genotype as a unit among genotypes subjected to evaluation, efforts have been made to use Kang and Magari´s program for the selection of high-yielding and stable TPS families. Two sets of TPS families were grown as transplants for two seasons at two altitudes and the data were analyzed using the STABLE program. The results are presented in this article with a view to bringing out the value of this program in helping to select high-yielding stable TPS families in short-term trials. However, the final test will be to send these selected families to collaborating NARS in different agroecologies for trials to confirm selection results from trials in Peru. If the results of international trials confirm the primary selection using the STABLE program, then short-term trials within Peru will help us reduce the number of TPS families to be sent to NARS for their evaluation, thus saving valuable resources.

This STABLE program could also serve as a tool to evaluate parental lines for their contribution to high-yielding stable hybrid families. In this study, we tried to use common selected male parents with a number of selected female clones to generate hybrid TPS families. These hybrid TPS families were then evaluated during two seasons at two different altitudes under contrasting thermo-photoperiod conditions. Analysis of the data using the STABLE program has not only allowed us to select high-yielding stable TPS families, but has also helped in comparing the contribution of female parents of the hybrid TPS families to yield and stability. This article presents and discusses the results.

Materials and Methods

Seedlings from hybrid TPS families were raised in plastic trays containing substrate chemically sterilized with methyl bromide. The substrate is a mixture of two parts peat moss and one part sand. A fertilizer supplement for NPK was added to 100 kg of substrate at the rate of 60 g of ammonium nitrate, 250 g of single superphosphate, and 50 g of potassium sulfate.

In each tray (33 x 23 x 5.5 cm), 100 seeds were sown at 0.5-cm depth, covered with fine powder of the substrate, and watered with a spray can. Seedlings were raised in nethouses for the first 3 wk after seed sowing and then hardened under field conditions for 1 wk before being transplanted bare-rooted in the field. One foliar application of 3% ammonium nitrate was given to the seedlings 20 d after seed sowing.

Two sets of hybrid TPS families were used for the trials. One set of families was selected for distribution to countries where harvesting

1 CIP, Lima, Peru.

was to be done 90 d after transplanting and where segregation for tuber skin color is not important. The TPS families in this set were segregating for skin and eye color; otherwise, all of them had uniform tuber shape and flesh color.

The second set of TPS families was meant for distribution to countries where the crop was to be harvested 75 d after transplanting and where uniformity of skin color was necessary. These TPS families were uniform for tuber skin, flesh color, and tuber shape.

Two trials for each of the sets of TPS families were conducted in CIP fields at La Molina (247 m) and two trials at Huancayo (3,225 m). Trials at La Molina were conducted during winter and spring and at Huancayo during spring and summer of 1995-96. Each trial had three replications with four rows of 20 plants each. There were 30 cm between plants and 90 cm between rows.

The crop was harvested after 15-20 d of haulm cutting and data were recorded on tuber yield/plot, which was then converted into t/ha.

In the field, NPK was applied as 200 kg N, 185 kg P, and 120 kg K. Half the dose of nitrogen as ammonium sulfate and full doses of P and K as single superphosphate and potassium sulfate were applied before transplanting. The remaining half dose of nitrogen was split again and 50 kg was given as urea at the time of first earthing at 35 d after transplanting and the remaining dose of 50 kg as urea was applied at the second earthing at 50 d after transplanting.

The data were subjected to statistical analysis using the STABLE program for calculating stability and yield stability for the comparative performances of two sets of hybrid TPS families as well as for simultaneous selection for yield and stability in performance trials.

Results and Discussions

Table 1 presents the average yield data for the first set of hybrid TPS families meant for Latin American countries, with the simultaneous selection for yield and stability analysis given in Table 2. Out of a total of 22 TPS families evaluated, 11 were selected by the program for their yield and stability. These 11 TPS families are ranked from 1 to 11 based on their average yields.

Similarly, Table 3 presents the average yield data for the second set of hybrid TPS families meant for global distribution, with the analysis for the simultaneous selection for yield and stability given in Table 4. A total of 35 TPS families were compared, keeping cultivar Desirée as the check grown from certified tuber seed of 30-50 g. Out of 35 families evaluated, 19 were selected by the program based on the YS(i) statistic.

The TPS families in the first set had four male clones that were crossed with 15 female clones to generate 22 hybrids. Out of the 11 families selected by STABLE, seven had the male clone 104.12 LB in common, whereas three had R-128.6 and only one had 4.1DI as the male parent. Atzimba as the female parent combined well with R-128.6 and 104.12 LB, but not with 7XY.1, to give high-yielding stable families.

The clone LT-8 was a good general combiner because it produced selected families with all three male parents. Meanwhile, I-1035 proved to be a good combiner with R-128.6 but not with 104.12 LB. Whereas Chiquita did not prove to be a good combiner, clones CFK-69.1, MF-II, and Serrana produced stable-yielding families with the clone 104.12 LB, a good general combiner.

Among the TS clones crossed with the common male 104.12 LB, only TS-6 and TS-14 have produced stable-yielding families.

The results also indicate that to evaluate the performance of new male parents, clones like Atzimba and LT-8 as common female parents could provide effective selection of the best pollinator clones, whereas the male clones R-128.6 and 104.12 LB could be used to select good-performing female clones in a breeding program.

Table 1. Performance (yield in t/ha) of the first set of hybrid TPS families as transplants for Latin America in trials at La Molina and Huancayo (1995 and 1996).

Family	La Molina		Huancayo	
	Spring	Winter	Spring	Summer
1. Atzimba x R128.6	8.9	9.8	29.6	33.1
2. Atzimba x 7XY.1	19.0	12.3	12.6	27.3
3. Atzimba x 104.12 LB	16.6	13.3	17.7	38.3
4. CEW-69.1 x 104.12 LB	11.5	12.8	17.5	17.0
5. CFK-69.1 x 104.12 LB	20.2	12.9	19.8	35.3
6. Chiquita x 104.12 LB	15.8	12.0	12.2	34.1
7. Chiquita x R128.6	9.2	12.5	15.2	33.2
8. I-1035 x R128.6	12.5	9.5	18.6	29.0
9. I-1035 x 104.12 LB	16.2	9.2	13.7	29.2
10. LT-8 x 104.12 LB	18.0	17.8	19.5	34.9
11. LT-8 x 4.1 DI	14.8	9.3	16.1	34.9
12. LT-8 x R128.6	13.3	12.0	17.5	31.3
13. MF-II x 104.12 LB	11.8	13.3	21.9	32.2
14. Serrana x 104.12 LB	15.7	14.5	17.2	36.2
15. TPS-2 x 104.12 LB	10.7	9.5	12.7	23.1
16. TPS-7 x 104.12 LB	10.0	10.9	16.1	28.5
17. TS-5 x 104.12 LB	10.6	8.6	18.3	25.2
18. TS-6 x 104.12 LB	15.1	11.8	21.6	38.5
19. TS-9 x 104.12 LB	15.1	8.8	13.6	26.6
20. TS-11 x 104.12 LB	15.6	4.2	16.0	24.5
21. TS-13 x 104.12 LB	14.8	5.6	11.4	22.3
22. TS-14 x 104.12 LB	19.9	8.9	19.4	34.3
Mean	14.3	10.9	17.2	31.3

DMS 0.05 = 3.94, CV % = 13.25.

Similarly, Table 4 also provides results for the effective selection of parental clones for the production of stable-yielding hybrid TPS families. The first six families had already been evaluated under different agroclimates of Asia and had proved their value as high-yielding stable TPS families. The two pollinator clones, TPS-13 and TPS-67, were excellent general combiners in studies made in India by the CIP team.

The clone TPS-113 was the original *andigena* clone selected for its excellent general combining ability. But the hybrid families produced using this clone as the male parent showed some segregation for tuber skin color under certain cool climates. Therefore, after selfing it and growing the progeny from seed >1/16" and with A type embryo, TPS-13 was selected as a new pollinator clone, which proved to be as good a general combiner as the parental clone TPS-113, with-

Table 2. Simultaneous selection for yield (t/ha) and stability in the first set of hybrid TPS famillies in performance trials.

	Family	Yield	Yield rank	Adjustment to rank	Adjusted	Stability variance	Stability rating	YS(i)
1.	Atzimba x R128.6	20.3	16	2	18	178.4	- 8	10+
2.	Atzimba x 7XY.1	17.8	11	- 1	10	56.7	- 8	2
3.	Atzimba x 104.12 LB	21.3	19	2	21	31.3	- 8	13+
4.	CEW-69.1 x 104.12 LB	14.7	3	- 3	0	154.3	- 8	- 8
5.	CFK-69.1 x 104.12 LB	22.0	21	3	24	9.1	0	24+
6.	Chiquita x 104.12 LB	18.5	12	1	13	43.9	- 8	5
7.	Chiquita x R128.6	17.5	10	- 1	9	41.1	- 8	1
8.	I-1035 x R128.6	17.4	9	- 1	8	5.7	0	8+
9.	I-1035 x 104.12 LB	17.1	8	- 1	7	14.1	- 2	5
10.	LT-8 x 104.12 LB	22.5	22	3	25	10.4	0	25+
11.	LT-8 x 4.1 DI	18.8	14	1	15	22.6	- 4	11+
12.	LT-8 x R128.6	18.5	13	1	14	0.9	0	14+
13.	MF-II x 104.12 LB	19.8	15.	1	16	28.7	- 8	8+
14.	Serrana x 104.12 LB	20.9	18	2	20	19.5	- 4	16+
15.	TPS-2 x 104.12 LB	14.0	2	- 3	- 1	17.9	- 4	- 5
16.	TPS-7 x 104.12 LB	16.4	7	- 2	5	9.6	0	5
17.	TS-5 x 104.12 LB	15.7	5	- 2	3	22.8	- 8	- 5
18.	TS-6 x 104.12 LB	21.8	20	3	23	38.5	- 8	15+
19.	TS-9 x 104.12 LB	16.0	6	- 2	4	12.8	0	4
20.	TS-11 x 104.12 LB	15.1	4	- 2	2	46.4	- 8	- 6
21.	TS-13 x 104.12 LB	13.5	1	- 3	- 2	42.0	- 8	- 10
22.	TS-14 x 104.12 LB	20.6	17	2	19	32.4	- 8	11+
	Mean	18.2						6.5
	LSD (P=0.05)	1.6						

a. + = selected families.

out showing segregation for tuber skin color. TPS-13 also produces a higher amount of pollen and has pollen fertility above 80%.

In the second set, the TPS family Chiquita with TPS-113 was selected, whereas in the first set Chiquita as a female with two of the male parents was not selected.

Similarly, in the first set, I-1035 as a female with R-128.6 got selected. In the second set, however, in combination with either of the two pollinators, TPS-13 and TPS-67, the TPS families were not selected.

The clone LT-8 with both the male clones produced hybrid families that were selected,

Table 3. Performance (yield in t/ha) of the second set of hybrid TPS families as transplants for global distribution in trials at La Molina and Huancayo (1995 and 1996).

Family	La Molina		Huancayo	
	Spring	Winter	Spring	Summer
1. HPS-7/67	8.4	9.5	6.4	24.3
2. HPS-7/13	7.7	9.3	5.7	25.0
3. HPS-25/13	5.9	11.1	4.9	28.6
4. HPS-I/67	7.0	15.7	4.1	24.5
5. HPS-I/13	4.7	13.2	5.9	29.5
6. HPS-II/13	9.3	12.6	4.7	24.8
7. Aracy x TPS-113	8.7	10.4	7.1	24.1
8. CEW-69.1 x TPS-113	5.3	10.5	4.5	26.9
9. Chiquita x TPS-113	7.1	12.1	6.8	24.0
10. C320LM86B x TPS-67	10.7	10.1	3.1	18.9
11. C320LM86B x TPS-13	9.0	8.0	2.9	18.2
12. C914LM86B x TPS-13	14.3	9.7	4.8	24.3
13. C914LM86B x TPS-67	12.6	11.1	7.9	26.3
14. I-1035 x TPS-67	9.8	8.3	4.1	18.7
15. I-1035 x TS-13	5.7	3.7	0.9	11.0
16. Katahdin x TPS-13	9.2	6.5	3.9	19.7
17. Katahdin x TS-67	11.3	9.4	4.2	18.8
18. LT-8 x TPS-13	9.6	12.4	5.9	23.8
19. LT-8 x TPS-67	9.0	10.3	8.2	28.3
20. Serrana x TPS-13	12.3	11.7	7.1	28.0
21. Serrana x TPS-67	9.8	12.4	5.8	23.3
22. TS-5 x TPS-67	7.8	10.2	7.4	24.1
23. TS-6 x TPS-13	4.3	12.2	10.0	28.3
24. TS-8 x TPS-113	6.1	10.7	3.5	19.6
25. TS-9 x TPS-113	9.4	13.1	4.9	29.7
26. TS-9 x TPS-67	13.9	13.0	8.8	24.3
27. TS-10 x TPS-13	6.1	10.4	5.8	25.1
28. TS-10 x TPS-67	6.1	9.9	8.6	24.3
29. TS-12 x TPS-113	9.1	10.3	3.6	19.3
30. TS-13 x TPS-67	8.7	10.3	2.6	18.0
31. TS-13 x TPS-13	8.7	10.3	3.1	25.5
32. TS-14 x TPS-67	11.1	5.3	3.3	27.4
33. TS-14 x TPS-13	10.2	10.0	2.0	15.4
34. Atzimba x TPS-13	6.1	11.0	10.3	26.9
35. Atzimba x TPS-67	6.3	10.5	8.6	24.5
36. Desirée (check)	23.7	20.7	26.8	17.5

DMS 0.05 = 3.66, CV % = 18.5.

Table 4. Simultaneous selection for yield and stability in first set of hybrid TPS families in performance trials.

Family	Yield	Yield rank	Adjustment to rank	Adjusted	Stability variance	Stability rating	YS(i)[a]
1. HPS-7/67	12.1	17	-1	16	2.1	0	16+
2. HPS-7/13	11.9	16	-1	15	5.6	0	15+
3. HPS-25/13	12.6	22	1	23	39.6	-8	15+
4. HPS-I/67	12.8	23	1	24	32.9	-8	16+
5. HPS-I/13	13.3	28	1	29	60.5	-8	21+
6. HPS-II/13	12.8	25	1	26	5.5	0	26+
7. Aracy x TPS-113	12.6	21	1	22	0.8	0	22+
8. CEW-69.1 x TPS-113	11.8	12	-1	11	28.2	-8	3
9. Chiquita x TPS-113	12.5	20	1	21	5.9	0	21+
10. C320LM86B x TPS-67	10.7	9	-2	7	21.8	-8	-1
11. C320LM86B x TPS-13	9.5	3	-2	1	12.9	0	1
12. C914LM86B x TPS-13	13.3	27	1	28	27.9	-8	20+
13. C914LM86B x TPS-67	14.5	33	2	35	5.3	0	35+
14. I-1035 x TPS-67	10.2	7	-2	5	15.0	-4	1
15. I-1035 x TS-13	5.3	1	-3	-2	47.6	-8	-10
16. Katahdin x TPS-13	9.8	4	-2	2	11.4	0	2
17. Katahdin x TS-67	11.0	10	-1	9	24.0	-8	1
18. LT-8 x TPS-13	12.9	26	1	27	0.8	0	27+
19. LT-8 x TPS-67	14.0	31	2	33	18.3	-4	29+
20. Serrana x TPS-13	14.8	34	2	36	8.8	0	36+
21. Serrana x TPS-67	12.8	24	1	25	1.3	0	25+
22. TS-5 x TPS-67	12.4	19	1	20	3.6	0	20+
23. TS-6 x TPS-13	13.7	30	1	31	60.0	-8	23+
24. TS-8 x TPS-113	10.0	6	-2	4	7.5	0	4
25. TS-9 x TPS-113	14.3	32	2	34	32.4	-8	26+
26. TS-9 x TPS-67	15.0	35	2	37	7.5	0	37+
27. TS-10 x TPS-13	11.8	14	-1	13	11.0	0	13
28. TS-10 x TPS-67	12.8	18	-1	17	17.0	-4	13
29. TS-12 x TPS-113	10.6	8	-2	6	10.6	0	6
30. TS-13 x TPS-67	9.9	5	-2	3	17.5	-4	-1
31. TS-13 x TPS-13	11.9	15	-1	14	12.4	0	14
32. TS-14 x TPS-67	11.8	13	-1	12	58.7	-8	4
33. TS-14 x TPS-13	9.4	2	-2	0	50.5	-8	-8
34. Atzimba x TPS-13	13.6	29	1	30	34.1	-8	22+
35. Atzimba x TPS-67	11.8	11	-1	10	7.3	0	10
36. Desirée (check)	22.2	36	3	39	411.7	-8	31+
Mean	12.3						14.9
LSD (P=0.05)	1.5						

a. + = selected families.

as was the case in the first set, thus further proving the value of this clone. Serrana as a female clone was also a good combiner with the two male clones in the second set (Table 4), as it was in the first set (Table 2).

Although Atzimba with TPS-13 was selected, the family with TPS-67 as the male did not perform well.

Among the TS clones, TS-6 with TPS-13 was also selected, as it was in the first set with 104.12 LB as the male parent. However, TS-14 in combination with TPS-13 and TPS-67 did not produce stable-yielding families, whereas in the first set it was selected with 104.12 LB as the pollinator clone. The clone TS-9 in combination with TPS-113 and TPS-67 produced hybrid families that were selected, but as in the first set, the family TS-9 x 104.12 LB was not selected. Likewise, the hybrid families with Katahdin as the female parent did not perform well. The clone CEW-69.1 did not perform well in either of the sets.

Conclusions

These results will allow us to send fewer hybrid TPS families to our collaborators in different countries who are experimenting with TPS technology. In addition, the performance values of female and male clones used as parents will be used to further improve the parental clones, and the selected clones will be used as testers for the newly selected genotypes.

Use of the STABLE program to evaluate the performance of hybrid TPS families has proved its worth both as a tool to determine the parental values of the clones used as parents for the hybrid TPS families and for the selection of high-yielding stable families based on short-term performance trials. Comparison by NARS of the data from trials under different agroecologies will provide the final proof of the usefulness of the STABLE program as a tool for the selection of TPS families in short-term trials.

Selected Reading

Kang, M.S. 1993. Simultaneous selection for yield and stability in crop performance trials: Consequences for growers. Agron. J. 85:754-757.

Kang, M.S. and R. Magari. 1995. STABLE: A basic program for calculating stability and yield-stability statistics. Agron. J. 87:276-277.

Temperature and Moisture Affect Dormancy and Deterioration of True Potato Seed During Storage

N. Pallais and R. Falcón[1]

True potato seed (TPS) lots with 90% germination or better, when tested in the laboratory, often fail to emerge in the field. The problem is that newly harvested TPS are dormant, and the nature and environmental control of TPS dormancy is not well understood.

TPS dormancy ceased to be a problem in clonal breeding after 1961 when it was found that gibberellic acid (GA) could easily be applied to promote germination. But in spite of treatment with GA, emergence of dormant seeds decreases considerably as the temperature approaches 25°C. Moreover, seedlings of dormant seeds that are induced to germinate with GA produce significantly less foliage dry matter (DM) than seedlings produced by dormant seeds.

Before the discovery of GA as a "solution" for TPS dormancy, it had long been known that new TPS did not germinate as well as older seeds. This study examines the relationship between storage conditions and dormancy of TPS with respect to its sowing value.

Our work showed that dormant TPS of variety Serrana (*Solanum tuberosum*) germinated readily at 20°C or below, whereas non-dormant seeds germinated readily at 27°C or above. High storage temperature coupled with low seed moisture content (SMC) reduced the period of storage required for losing TPS dormancy from 18 to 4 mo.

Research to determine the applicability of these results to open-pollinated TPS of the ancient Peruvian potato cultivar Ccompis (*S. tuberosum* subsp. *andigena*) was deemed necessary because of the increasing demand for its use by small farmers in the Andes of Peru. The objective of the present study was to determine the effects of increasing temperature, SMC, and time in storage of freshly harvested TPS on germination and emergence from soil under different temperatures.

Materials and Methods

Experiments were conducted at CIP with open-pollinated seeds provided by Semilla e Investigacion en Papa (SEINPA). The TPS were produced according to the recommended practice for high-quality seed, in a large plot of cultivar Ccompis grown for basic seed tuber production in Cusco (3,600 m above sea level), Peru.

After harvesting the mature berries, the TPS were washed and dried in the shade until reaching 7.3% SMC (dry weight basis). About 12.5 kg of TPS were separated into large (51%) and small (49%) lots using a round-hole screen at 1.46 mm over a seed shaker for 4 min. Large TPS were separated with a seed blower into high- (63%) and low-density sublots. Only high-density TPS were sampled at random for this study.

The treatments were prepared by drying TPS sealed with fresh silica gel at 22°C and monitoring SMC until the desired moisture levels were achieved. TPS were immediately hermetically sealed in aluminum packages at 3.4, 4.2, 5.1, 6.1, and 7.3% SMC and stored at 15, 30, and 45°C. Each treatment was composed of five random samples of 1 g each and packaged separately for opening during each evaluation period.

1 CIP, Lima, Peru.

Evaluations were based on monthly laboratory germination and seedling emergence (greenhouse) tests conducted in tandem during 6 mo of storage. Before testing, TPS were moistened to a uniform SMC of 13% by placing them in a sealed environment above water at 22°C for 24 h. Germination tests consisted of four replications of 100 seeds each placed evenly over dry filter paper in 9-cm Petri dishes. TPS were hydrated with 5 ml of deionized water before placing the dishes in an incubator. Temperature in the germination environment was held constant at 27°C, until the 8th day when it was lowered to a constant of 17°C. Water was added as needed. The germinating TPS received laboratory light and higher temperature (22°C) only for about 20 min during evaluations. Germination was checked daily for 16 d after sowing (DAS) and germinated seeds were removed at first sight of radicle emergence. Percentages of germination at 8 and 16 d are presented to summarize the results (Tables 1 and 2).

Table 1. Effects of increasing storage temperature, seed moisture content (SMC), and time in storage on percentage of germination at 27°C.

Temp	SMC	Storage (mo.)							
(°C)	(%)	1	2	3	4	5	6	L[a]	Q
	3.4	1	2	0	1	0	1	ns	ns
	4.2	0	2	1	2	0	1	ns	ns
15	5.1	2	4	4	5	6	20	***	ns
	6.1	1	6	8	13	19	46	***	ns
	7.3	3	3	7	13	17	52	***	ns
	L	**	ns	***	***	***	***		
	Q	*	*	***	***	***			
	3.4	2	3	5	6	12	38	***	ns
	4.2	2	8	24	37	44	65	***	ns
30	5.1	4	21	55	63	72	81	***	ns
	6.1	7	30	48	63	67	78	***	ns
	7.3	9	21	50	59	67	87	***	ns
	L	***	***	***	***	***	***		
	Q	***	***	***	***	***	***		
	3.4	2	45	74	79	78	92	***	ns
	4.2	5	75	81	75	79	86	***	ns
45	5.1	14	69	61	63	34	50	ns	ns
	6.1	21	21	0	0	0	0	***	***
	7.3	22	15	0	0	0	0	***	***
	L	***	***	***	***	***	**		
	Q	***	***	***	***	***	***		

a. Linear (L) and quadratic (Q) regression; *, **, ***, and ns denote $P < 0.5$, < 0.01, < 0.001, and > 0.05, respectively.

Table 2. Effects of increasing storage temperature, seed moisture content (SMC), and time in storage on percentage of germination at 17°C.

Temp (°C)	SMC (%)	Storage (mo.) 1	2	3	4	5	6	L[a]	Q
	3.4	79	93	56	58	87	60	ns	ns
	4.2	87	96	53	70	87	80	ns	ns
15	5.1	89	91	83	84	96	95	***	*
	6.1	95	94	93	91	97	84	***	ns
	7.3	97	95	93	95	99	89	***	ns
	L	**	ns	***	***	***	***		
	Q	**	*	***	***	***	***		
	3.4	94	94	83	75	98	99	***	ns
	4.2	94	95	100	78	100	95	***	ns
30	5.1	96	96	100	89	100	98	***	ns
	6.1	85	99	100	92	92	95	***	ns
	7.3	87	88	99	94	94	97	***	ns
	L	ns	ns	**	***	ns	ns		
	Q	ns	ns	***	***	ns			
	3.4	96	91	99	99	99	99	***	ns
	4.2	98	99	99	93	97	93	***	ns
45	5.1	97	89	99	93	93	95	**	ns
	6.1	99	85	0	0	0	0	***	***
	7.3	83	77	0	0	0	0	***	***
	L	ns	**	***	***	**	***		
	Q	ns	**	***	***	***	***		

a. Linear (L) and quadratic (Q) regression; *, **, ***, and ns denote $P < 0.5$, < 0.01, < 0.001, and > 0.05, respectively.

Seedling tests consisted of 5 replications of 20 seeds each sown in a steam-sterilized soil mixture of equal parts moss and sand. Emergence was checked daily and counted at first sight of the hypocotyl hook during the first 17 DAS, but only the percentage of emergence at 10 d is presented for simplicity of data interpretation (Table 3). Temperature in the greenhouse was monitored with a hygrothermograph and average maximum and minimum daily temperatures were recorded (Table 3).

The experimental design was a complete randomized factorial arrangement. Data were subjected to linear and quadratic regression analysis with SMC as the independent variable for each evaluation, and with time in storage for each SMC. General correlation coefficients of germination and seedling emergence were also analyzed (Table 4).

Results and Discussion

This study showed that TPS lots that germinate only at 17°C are dormant and should not

Table 3. Effects of increasing storage temperature, seed moisture content (SMC), and time in storage on percentage of emergence under variable temperature conditions[a].

Temp	SMC	Storage (mo.)							
(°C)	(%)	1	2	3	4	5	6	L[b]	Q
	3.4	4	19	0	0	0	2	*	ns
	4.2	2	14	0	0	4	3	ns	ns
15	5.1	3	33	4	3	15	37	*	*
	6.1	17	49	8	4	25	40	ns	ns
	7.3	9	42	7	1	23	54	*	*
	L	*	***	***	ns	***	***		
	Q	ns	***	ns	***	***	***		
	3.4	4	38	3	1	17	50	*	**
	4.2	10	64	21	9	63	78	***	**
30	5.1	14	85	52	33	74	84	**	**
	6.1	19	86	47	34	67	78	*	ns
	7.3	11	86	58	35	76	78	*	*
	L	ns	***	***	***	***	*		
	Q	ns	***	***	***	***	**		
	3.4	7	91	59	32	73	91	**	*
	4.2	6	98	61	49	87	94	**	**
45	5.1	40	93	55	39	74	68	ns	ns
	6.1	41	50	0	0	0	0	***	***
	7.3	45	11	0	0	0	0	***	***
	L	***	***	***	***	***	**		
	Q	***	***	***	***	***	***		

a. Maximum/minimum temperatures in the greenhouse at each evaluation were 32/20°C, 34/21°C, 36/24°C, 38/25°C, 41/25°C, and 37/23°C for tests after 1, 2, 3, 4, 5, and 6 months, respectively.

b. Linear (L) and quadratic (Q) regression, *, **, ***, and ns denote $P < 0.5, < 0.01, < 0.001$, and > 0.05, respectively.

be used for sowing a crop of potatoes under field conditions (Tables 1, 2, and 3). The results also demonstrated that a high temperature level close to the maximum allowable for germination can be used as a measure of degree of dormancy. Germination at 27°C accurately predicted relative seedling emergence of TPS from soil under various temperature conditions. The combination of germination results at 27 and 17°C might be used as a practical criterion for estimating present and future sowing value of TPS. The low percentage of germination at 27°C followed by high germination at 17°C can be explained as evidence of dormancy. Seed deterioration can be assumed when seeds do not germinate at either temperature.

Table 4. General correlations for each evaluation among the various germination and seedling criteria tested.

Laboratory germination (%)	Screenhouse emergence (%) (mo. in storage)					
	1	2	3	4	5	6
At 27°C	0.73[a] ***	0.72 ***	0.94 ***	0.88 ***	0.91 ***	0.92 ***
At 17°C	0.07 ns	0.21 ns	0.59 ***	0.48 ***	0.50 ***	0.72 ***

a. Correlation coefficients (r); *** and ns denote $P < 0.001$ and > 0.05, respectively.

TPS dormancy was effectively released with progressive increases in storage temperature, SMC, and time in storage. TPS dormancy was more strongly preserved at 3.4% SMC at all temperatures. At $\geq$ 5.1% SMC germination was suboptimal or decreased within the first month of storage at 45°C. The results indicated that the critical moisture point (CMP) above which seed deterioration in storage proceeds at a logarithmic rate is about 5% SMC for TPS. This limit varies within orthodox species (i.e., seeds resistant to desiccation) from 2% in *Arachis hypogaea* to 6.2% in *Pisum sativum.* It is safe to recommend that TPS should always be stored below 5% SMC.

Drying much beyond the CMP is believed to serve no additional purpose for preserving seed quality in storage. Overdrying TPS, however, should be avoided because germination and seedling emergence were increasingly inhibited as SMC decreased below the proposed 5% CMP lower limit. Since this inhibition was also more evident as storage temperature decreased, it might be a consequence of enhanced TPS dormancy, which is best preserved under low temperature and low moisture.

The nature of TPS dormancy was shown to be similar to that of many other species in which the true seeds have not been domesticated for sexual propagation, such as seeds of noncultivated grasses and fruit trees in the family *Rosaceae*, and buds and bulbs of underground perennials. These "wild" seeds are characterized by a gradual widening of the allowable temperature for germination during dormancy loss in storage.

Storing freshly harvested TPS at high temperature and low moisture until sufficient seeds have lost dormancy, as determined by germination at 27°C, however, should only be considered a compromise solution for overcoming TPS dormancy. For example, the results of this study suggest that the safest and most effective treatment for rapidly decreasing TPS dormancy could be 2 mo storage at 45°C and 4.2% SMC, even though only 75% of the progeny was apparently nondormant at this time, according to germination at 27°C (Table 1). Protein and lipid alterations result from heat injury to biological organisms; therefore, further storage at 45°C would be detrimental to seed quality. Dormant seeds are protected from heat injury, but high temperature will unavoidably damage less dormant seeds of a given TPS progeny while the more dormant seeds are still losing their dormancy.

Consequently, we prefer to after-ripen freshly harvested TPS at 30°C and 4.5% SMC, even if longer periods of storage are required; 40°C is used only when dormant TPS are urgently needed for planting. Germination tests at 27°C are regularly conducted and when germination after 8 d at 27°C has increased to >50%, then seeds are stored at lower temperatures (10-20°C). If partially dormant TPS need to be used immediately, sowing rates must be increased accordingly. Otherwise, continued storage at 10-20°C is recommended until most seeds become nondormant.

Conclusions

This study showed that TPS that germinate only at 17°C should be considered dormant and inappropriate for sowing a potato crop. The percentage of germination after 8 d at 27°C, on the other hand, was shown to be an accurate criterion for estimating potential sowing value of TPS. When this measure is used in conjunction with germination at 17°C, relative dormancy levels can also be estimated.

The evidence presented also suggests that TPS should always be stored at below 5% SMC to preserve seed viability, regardless of storage temperature. Much lower SMC values inhibited germination, and higher values increased the rate of seed deterioration.

This work also clearly demonstrated that a period of dry after-ripening in storage at high temperature might be used to accelerate the rate of TPS dormancy loss. This strategy, however, should be used with caution because seeds will begin to deteriorate after losing dormancy under high storage temperature. Therefore, breeders should seek a genetic solution to the dormancy problem so that TPS can realize its full potential as an alternative method for propagating potatoes.

Selected Reading

Karssen, C.M. 1982. Seasonal patterns of dormancy in weeds. In: The physiology and biochemistry of seed development and fermentation. A.A. Khan (ed.). Elsevier Biomedical Press, New York. p. 243-298.

Pallais, N. 1995. High temperature and low moisture reduce the storage requirement of freshly harvested true potato seeds. J. Am. Soc. Hort. Sci. 120:699-702.

Pallais, N., N. Fong, R. García, and J. Santos-Rojas. 1990. Factors affecting seedling vigor in potatoes. II. Genotype, after-ripening and pre-sowing treatments. Am. Potato J. 67:109-119.

Roos, E.E. 1980. Physiological, biochemical, and genetic changes in seed quality during storage. HortScience 15:19-22.

Frost-Tolerant Potato Varieties for the Andean Highlands

E. Carrasco[1], A. Devaux[2], W. García[1], and R. Esprella[1]

Sensitivity to cold stress is one of the major constraints to potato production in the Andes. It is estimated that around 400,000 ha, representing 70% of the area under potato cultivation in the Andean highlands of South America, are affected by frost. In Bolivia, most of the 140,000 ha planted to potato are above 3,000 m, where frost is one of the major constraints to production.

Frost affects production in three ways: (1) frost itself reduces production from 10% to 70% for nontolerant varieties; (2) the threat of frost results in extensive, low-input management practices because farmers do not want to invest in risky operations; (3) farmers in the most affected areas reduce frost risk by using frost-tolerant bitter potatoes selected over centuries from natural hybrids between wild and cultivated species. Because of their high glycoalkaloid levels, the tubers of these bitter varieties need to be processed before they can be used for consumption.

Nonbitter potato varieties currently grown by farmers are susceptible to frost or, in the case of some native ones, tolerant to 0 to -1°C. It is estimated that if the level of frost tolerance of selected nonbitter potatoes could be maintained at -3 to -4°C for as little as 2 h, yields could be increased by as much as 20% to 30%.

PROINPA, the Bolivian National Potato Research Program, was established under an agreement between the Bolivian Ministry of Agriculture, CIP, and Swiss Development Cooperation (SDC). One of the main objectives of PROINPA's research program is to make potato production systems in the highlands more sustainable by developing and adapting technologies that respond to farmers' main constraints. As part of this work, PROINPA began developing frost-tolerant potatoes, building on breeding and selection work.

Materials and Methods

New cultivars were obtained using two strategies: (1) the introduction of genetic material from CIP and the Colombian Agricultural Institute (ICA) for evaluation and selection, and (2) the generation of new clones by crosses between native Bolivian cultivars, introduced cultivars, and wild potato species. The clonal evaluation of the material was also carried out on-farm, thus involving farmers' families in the selection of the best-performing clones.

Introduction, evaluation, and selection of genetic material

Since 1989, about 500 clones introduced from CIP and ICA were tested in areas where frosts are frequent during the growing season. These areas are located at around 3,500 m, where the average temperature is around 9°C (the average minimum 1°C, and maximum 15°C) and the yearly precipitation is 500 mm. Evaluations of the following factors were carried out during seven successive growing seasons:

- Percentage of foliage damage caused by frost, and capacity of recuperation after frost damage.
- Agronomic characteristics of plant and tubers.
- Tuber yield and culinary quality.

1 Bolivian National Potato Research Program (PROINPA).
2 CIP and the Bolivian National Potato Research Program (PROINPA), Cochabamba, Bolivia.

- Resistance to other stresses such as nematodes (*Nacobbus aberrans*) and wart (*Synchytrium endobioticum*).

The material was tested in comparison with cultivated varieties, including a susceptible one (*Solanum tuberosum*), a tolerant one (*S. andigena*), and a resistant bitter variety (*S. juzepczukii*).

Generation of new clones

We initiated crosses between cultivated and wild species in 1990. Table 1 presents the material used in this breeding program.

The F_1 hybrid population obtained from these crosses was exposed to frost; the most vigorous and frost-tolerant clones were selected. Many F_1 lines generally show resistance, but their yield is low and their cooking quality is poor. However, one or more backcrosses to cultivated varieties were made to improve yield and tuber organoleptic quality. The material obtained from these backcrosses was evaluated in the growth chamber to eliminate the susceptible clones. Selected clones were field-tested following the same clonal evaluation process.

Frost data

In the Andean highlands, frosts occur only at night, always after sunny days with temperatures of 15 to 20°C. The critical point usually occurs between 0400 and 0630 h, when the temperature falls below 0°C.

For evaluations in the growth chamber, a temperature curve of a frosty night was simulated with minimum temperatures of -5°C. In the field, plants were exposed to natural frosts. Temperatures were recorded with a thermohygrograph or with a maximum-minimum thermometer located in the field at plant level.

Participatory evaluation with farmers

Frost tolerance alone will not ensure the acceptance of new varieties. Other characteristics such as tuber shape and color, and culinary properties, must also be acceptable to farmers, market intermediaries, and consumers.

During the last three cropping seasons (1993-96), farmers have evaluated the most advanced material in on-farm trials. One of the techniques used was matrix scoring. After harvest the new cultivars were placed in piles at the end of each row where they had been grown. A group of farmers carefully examined the new cultivars. They identified the most important criteria they looked for in adopting new varieties (yield, size of tubers, and level of insect infestation). Taking one

Table 1. Some potato species used by PROINPA for frost tolerance.

Species	Classification	Ploidy	Chromosomes (no.)
S. tuberosum	Cultivated	Tetraploid	48
S. andigena	Cultivated	Tetraploid	48
S. juzepczukii	Cultivated	Triploid	36
S. curtilobum	Cultivated	Pentaploid	60
S. phureja	Cultivated	Diploid	24
S. ajanhuiri	Wild	Diploid	24
S. acaule	Wild	Tetraploid	48
S. commersonii	Wild	Diploid	24
S. toralapanum	Wild	Diploid	24
S. megistacrolobum	Wild	Diploid	24
S. sancta-rosae	Wild	Diploid	24

criterion at a time, farmers placed a number of grains of maize by each pile of potatoes to indicate how they had scored each one. The potatoes were then boiled and farmers evaluated culinary characteristics using the same method.

Nutritional and culinary evaluation

Nutritional analysis of the selected material was carried out in collaboration with the Food and Natural Products Laboratory of San Simón University in Cochabamba, Bolivia. Fresh tubers stored for a month were used for these analyses. To determine culinary characteristics, the potatoes were evaluated as fried and boiled. In both cases, a tasting panel of six people assessed the clones. The criteria used for fried potatoes were internal and external color, internal and external texture, taste, and general appearance. The maximum score of these criteria was 100. For boiled potatoes, the criteria were consistency, flouriness, moistness, color, taste, and flesh discoloration, with an evaluation score of very good, good, average, and bad.

Results

Four potential varieties were selected from the material evaluated during the last seven years. One came from CIP (389349.1), the others from PROINPA. Figures 1 and 2 present the difference in yields and frost damage between potential varieties and control cultivars for field evaluations from 1993 to 1996. These data show a high phenotype stability of the clones compared with control varieties. There is some variability between years, however, due to genotype-environment interaction considering frequency and severity of frost, development stage of the crop when affected by frost, irregular precipitation, and the effects of hail and drought.

During the 1993-94 growing season, three frosts occurred with temperatures from -2 to -5°C for 2 h. During the 1994-95 growing season, only one frost (-3°C for 2 h) and a hailstorm were registered. During the 1995-96 growing season, two frosts of -2°C for 2 h, a 2-mo drought at the start of the growing season, and one hailstorm during the midgrowth period occurred.

The yield and frost tolerance of the four selected clones were stable during the 5 yr of evaluation and were consistently better than those of the control (Figure 3). From field observations, it appears that the four clones can tolerate frost of -3°C for 2 h and of -4°C

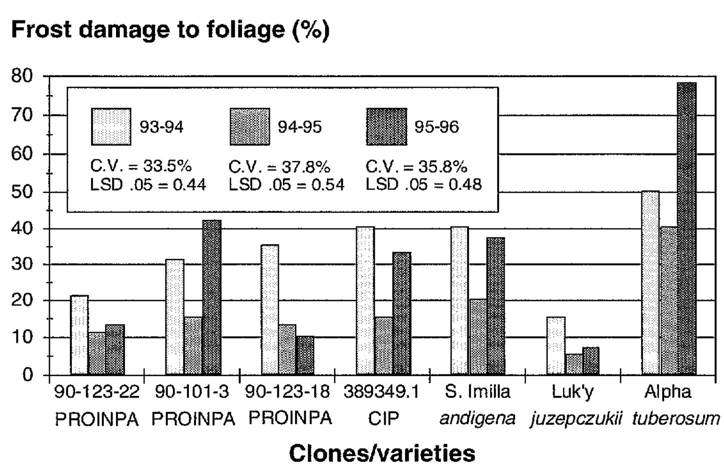


Figure 1. Foliage damage caused by frost in selected clones and control varieties in three growing seasons, from 1993 to 1996.

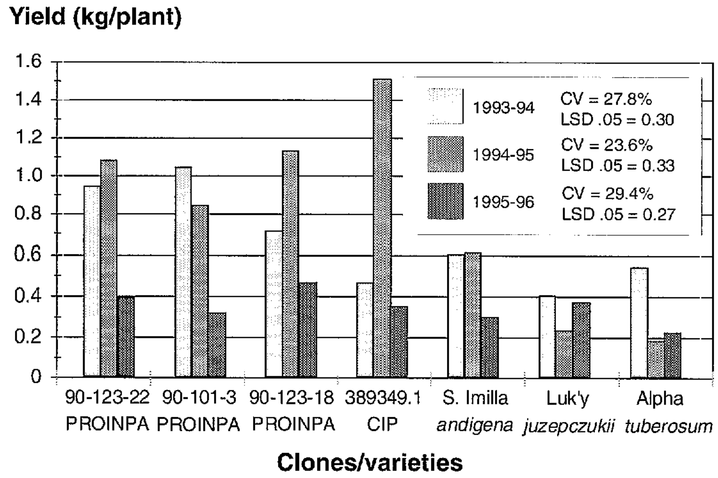


Figure 2. Yield of frost-tolerant selected clones and control varieties in three growing seasons from 1993 to 1996.

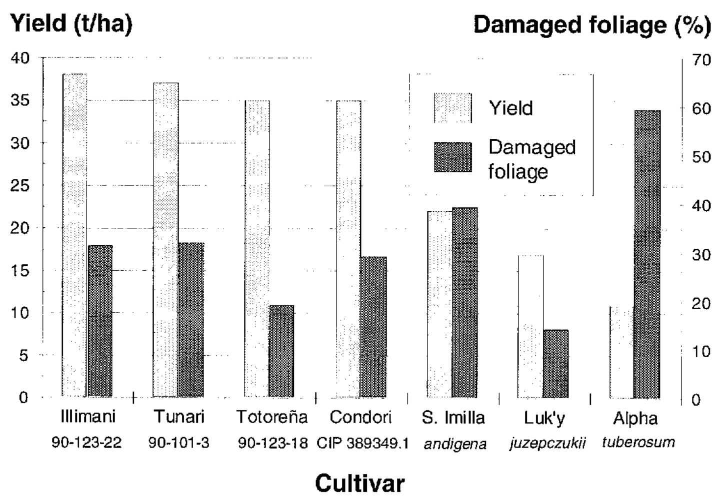


Figure 3. Yield and frost damage to foliage in potential and control varities. Average of five growing seasons, from 1993 to 1996.

somewhat less. Moreover, they have also shown a good capacity for recuperation and regrowth after frost.

Some of the frost-tolerant clones, such as 389349.1 and 90-123-22, scored as high as or higher than control varieties in agronomic and culinary qualities.

There is still a need to test the selected clones on a larger scale in different production areas to confirm their market acceptance. For that reason, these clones have already been named (Figure 3) and have been included in PROINPA's seed production program to initiate the process of clean seed production. Prebasic seed of these varieties should be available in 1998.

Table 2 shows reactions of the selected varieties to biotic and abiotic stresses, and the earliness evaluation.

Besides the quality evaluation at the farmer's level, the four potential varieties were also tested for nutritional and culinary characteristics in comparison with one of the most popular varieties in Bolivia, Waych'a (Table 3).

Conclusions

PROINPA's experience in Andean conditions indicates that the use of wild species with cultivated potatoes in a breeding program is not as complex as is often argued. In many cases, only one or two backcrosses to cultivated species are required to obtain potatoes with acceptable agronomic characteristics.

It appears that ecological and climatic conditions, genetic variability, and pollen fertility of the species and cultivars in the Andes,

Table 2. Earliness and reactions[a] of selected clones to some biotic and abiotic stresses, CIP-PROINPA, 1994-1996.

Clone	Earliness	Wart	Nematode	Hail	Drought
90-123-22	Late (130-160 days)	MR	T	T	T
90-101-3	Late (130-160 days)	R	T	T	T
90-123-18	Late (130-160 days)	MR	T	T	T
389349.1	Late (130-160 days)	MR	T	T	T
Sani Imilla (*S. andigena*)	Late (130-160 days)	S	S	T	S
Luk'y (*S. juzepczukii*)	Very late (160-180 days)	S	S	T	R
Alpha (*S. tuberosum*)	Early (120 days)	S	S	S	S

a. R = resistant, MR = moderately resistant, S = susceptible, T = tolerant.

Table 3. Nutritional analysis and culinary tests of potential frost-tolerant varieties, CIP-PROINPA, 1996.

Name of cultivar	Clone number	Nutritional analysis (%)			Culinary quality[a]	
		Dry matter	Starch	Protein	CQFP	CQCP
Illimani	90-123-22	24.0	18.6	4.1	69.0	VG
Totoreña	90-123-18	26.0	19.0	3.1	58.5	VG
Tunari	90-101-3	19.8	20.0	3.8	54.0	G
Condori[b]	389149.1	21.0	20.3	0.8	60.0	G
Waycha (control)	(*S. andigena*)	22.3	16.0	1.9	60.0	VG

a. CQFP = Culinary quality in fried potatoes (scale:100), CQCP = culinary quality in cooked potatoes, VG = very good, G = good.

b. CIP selection.

especially in Bolivia, give these potatoes more flexibility for genetic manipulation than potatoes in other regions, since potato fertility and reproduction are very sensitive to environmental changes.

The yield capacity of the material tested was not directly related to percentage of foliage damaged by frost. Some varieties show good frost tolerance in their foliage but do not yield well, for example, the bitter variety used as a control. The capacity of the plant to recuperate after a frost is an important factor in frost tolerance and is an important selection criterion. There is, however, a need to better understand the relationship between different levels of frost intensity and yield to estimate the potential impact of frost-tolerant varieties under different frost conditions of Bolivian highlands. Research on modeling the response of potato to frost intensity will be carried out in collaboration with CIP and CONDESAN.

Although these potential varieties have been selected through participatory research with farmers, there is still the important test of market acceptance. The strategy will be to have the varieties evaluated in different areas of the country with farmers' communities, development projects, and seed production institutions involving local traders. In the future, we plan to involve, earlier in the selection process, these other potential users of new varieties.

The two strategies followed by PROINPA's breeding program have led to the selection of potential frost-tolerant varieties with a high potential impact in the Bolivian highlands where frost is a major constraint to production. Some of these varieties could also be of interest in other countries where frost is a problem. The regional networks and the catalytic role played by CIP in the interaction between national agricultural research systems of different countries should contribute to and ensure the exchange of varieties and technologies of common interest.

Selected Reading

Estrada, N. 1982. Breeding wild and primitive potato species to obtain frost-resistant cultivated varieties. In: Plant cold hardiness and freezing stress. P.H. Li and A. Sakai (eds.). Academic Press Inc. p. 615-633.

Estrada, N., W. García, J. Gabriel, and E. Carrasco. 1993. Breeding potatoes for tolerance to frost and resistance to late blight. Am. Potato J. 70:809. (Abstr.)

Sweetpotato Seed Units for the Dissemination of Planting Materials of Improved Varieties

E.E. Carey[1], S.T. Gichuki[1], O. Hidalgo[2], and D.P. Zhang[2]

Relatively little attention has been given to sweetpotato improvement in many developing countries where the crop is important. In these countries, research programs usually have not selected improved varieties, and, even if they have, formal systems for the dissemination of planting materials rarely exist. Instead, sweetpotato farmers in many developing countries grow large numbers of varieties, many of which are low yielding or late maturing. These varieties are disseminated through informal systems based on farmer-to-farmer exchange.

The lack of early maturing, high-yielding varieties acceptable to farmers and the lack of timely availability of planting materials are two important constraints to increased sweetpotato production in most places where sweetpotato has received little attention from researchers. The problems of timely availability of planting materials are particularly severe in drier upland areas, where resource-poor farmers usually do not have access to irrigation and may have to wait for remnants of previous crops to resprout at the beginning of the rains, or for small multiplication plots to produce adequate quantities of materials for planting. By the time planting materials are available, the rains may be tapering off, thus limiting sweetpotato yields. When planting materials are scarce at the beginning of the season, farmers may accept any available ones, thus contributing to varietal mixtures, but not necessarily increasing the frequency of preferred varieties.

1 CIP, Nairobi, Kenya.
2 CIP, Lima, Peru.

Research Objectives

The basic objective of the CIP sweetpotato seed unit is to conduct research and development activities to assist with the dissemination of superior varieties, and to improve the effectiveness of sweetpotato seed systems, so that farmers in developing countries will have a better availability of high-quality planting materials of superior varieties. To date, seed unit activities have primarily concentrated on Peru and Kenya. In Peru, efforts have been made to multiply and distribute substantial quantities of high-quality planting materials of recently released or promising varieties, and to identify varieties with a high capacity to produce cuttings from sprouted storage roots. In Kenya, efforts have concentrated on the international distribution of promising varieties for national testing and dissemination. Results of these efforts are reported here. This report also discusses areas of possible future emphasis for the seed unit.

Multiplication of Planting Materials

In Peru, pathogen-tested in vitro cultures were used as the starting material for multiplication of planting materials of selected superior varieties for distribution to various sites in 1995 and 1996. Multiplications were carried out using 2-node cuttings in beds, at a density of 100 plants per square meter. Table 1 shows the quantities of planting materials produced by variety. Apical cuttings of selected varieties harvested from the multiplication beds were distributed to various locations to serve as nuclear stocks for subsequent multiplication and distribution to farmers. Varying numbers of varieties were distributed

Table 1. Quantities of planting materials of selected sweetpotato varieties multiplied and distributed to Peruvian production zones by the seed unit in Peru.

Name (CIP number)	1995 second season	1996 first season
Nacional (187003.1)	4,930	14,750
Costanero (187016.2)	11,430	3,550
Salyboro (187017.1)	5,430	10,250
Yarada (187018.1)	3,230	4,050
Tacna (187019.1)	3,430	2,050
Atacama (187020.1)	1,430	2,050
Canetano-INIA (188006.1)	20,630	13,650
Jonathan (420014)	19,300	11,050
Helena (420068)	14,430	11,250
Jewel (440031)	14,000	16,750
YM89.232 (189008.5)	—	5,250
YM89.052 (189013.2)	—	11,250
Limeño Morado (420096)	—	7,050
Trujillano (420097)	—	7,050
Tanzania (440166)	—	4,750
No. 29 (440168)	—	4,750
DLP 3548	—	10,750
CC 89.213	—	9,250
Total	**98,240**	**149,500**

to each location, depending on local adaptation and demand for varieties under multiplication. During the first season, planting materials were distributed to 14 sweetpotato-producing zones in Peru, and during the second season, planting materials were distributed to 15 locations.

Sprouting Ability

A study was undertaken to examine differences in sprouting ability among CIP-bred clones. Fourteen clones from a high dry matter breeding population were used. Storage roots were placed 15 cm apart in beds on Nov. 22, 1995, and the number of roots sprouted per clone was monitored weekly starting 26 days after planting and continuing until 29 days after planting, at which time the number of sprouts per plot was counted. Nine roots of each clone were planted per plot, and the trial was laid out as a randomized complete block design with three replications. Data analysis was done using the Proc Anova procedure of SAS, and mean separation was done using the Waller grouping method. Table 2 presents results of the trial. Significant cultivar variation was found for sprouting ability. In addition, those clones that produced the highest number of sprouts sprouted the earliest. The two clones with the best sprouting ability were selected for inclusion in crossing blocks as parental clones.

Seed Unit Activities

In Kenya, seed unit activities are mainly conducted under the auspices of the KARI Plant

Table 2. Variation among sweetpotato clones for ability to produce sprouts.

Clone	Sprouts (no.)	Waller grouping
YM89.118	149.3	a
SR92.130	120.3	ab
CC89.212	100.0	bc
YM89.133	86.7	bcd
USSC.500	71.3	cde
ST87.070	49.0	def
SR90.307	48.7	def
LM89.128	46.0	defg
YM89.215	43.7	defg
SR89.519	43.0	defg
YM89.162	38.3	efg
SR90.411	31.0	efg
SR90.323	19.0	fg
YM89.099	0.0	g

Quarantine Station (PQS) at Muguga. This work involves the regional distribution of relatively small quantities of planting materials of promising varieties to be tested and disseminated by various partners in the region. This activity is distinct from the regional breeding activities that involve the distribution and testing of much larger numbers of genotypes at selected regional testing sites to identify limited numbers of promising genotypes for wide distribution. Table 3 lists the names, CIP numbers, and origins of six varieties that are currently being widely disseminated by the seed unit in response to requests

Table 3. Promising sweetpotato varieties distributed widely by the seed unit in Nairobi.

Name (CIP number)	Origin	Exceptional characteristics
Cemsa 74-228 (400004)	Cuba	Early, high yielding, good taste, good foliage vigor
Zapallo (420027)	Peru	Early, high yielding, drought tolerant, orange fleshed, low dry matter content
Helena (420068)	Peru	High foliage yield
Yan Shu 1 (440024)	China	Early, high yielding, fair taste, proven acceptability for refugee relief food in Zaire
Naveto (440131)	Papua New Guinea	Early, high yielding, good taste, broad adaptation, good foliage vigor
Tanzania (440166)	Uganda	Early, high yielding, broad adaptation, excellent taste, probably most widely grown variety in sub-Saharan Africa

for improved varieties by national programs and NGOs.

The international distribution of planting materials of sweetpotato, a vegetatively propagated crop, requires strict adherence to phytosanitary regulations accepted by national plant quarantine services. This has usually been considered to require the in vitro shipment of pathogen-tested planting materials. In vitro multiplication and distribution are problematic, however, as in vitro plantlets are quite perishable, and clones are frequently lost during the process of shipment and subsequent transfer of plantlets to soil.

To overcome these problems, we have begun to distribute clones internationally as cuttings taken from pathogen-tested mother plants maintained in the quarantine screenhouse at PQS. These mother plants originate from pathogen-tested in vitro plants obtained from CIP headquarters. At PQS they are transferred to pots and retested for sweetpotato viruses using serology and grafting to indicator plants. Periodic re-testing ensures that pathogen-free planting materials are distributed. At the time of distribution, small, 2- to 3-node cuttings are taken from the mother plants, their leaves are removed, and they receive a fungicide treatment prior to packaging and shipping, usually by a courier service.

By expanding the production of mother plants in the screenhouse, large numbers of pathogen-tested cuttings can be produced per clone. However, given the rapidity with which sweetpotato can be multiplied under field conditions, there is usually little need for shipping anything more than nuclear stocks (such as 20 to 40 cuttings per clone) of planting materials from PQS.

With the implementation of germplasm shipments as pathogen-tested cuttings, losses during shipping and establishment have dropped markedly in comparison with in vitro shipments. Furthermore, improvements have been made in packaging of cuttings, which should lead to still further reductions in losses. Initial shipments of cuttings were wrapped in moist paper towels packed in paper bags. Although few losses of shipments were reported, some problems arose with desiccation. We have subsequently found that this can be greatly reduced by packing cuttings in plastic bags. Table 4 presents a comparison of weights of 10 2- to 3-node cuttings either wrapped in moist paper toweling or packed in plastic bags, following 10-d storage in the dark at PQS. At the end of the storage period, cuttings wrapped in moist paper towels weighed roughly one-fourth as much as cuttings packed in plastic bags.

Table 4. Weights of 2-node sweetpotato cuttings wrapped in moist paper towels or in plastic bags after 1 wk of storage.

Treatment	Mean weight of cuttings (g)
Moist paper towel	2.2
Plastic bag	8.5

Future Considerations and Challenges

There is considerable potential for further expansion of sweetpotato seed unit activities, particularly with respect to finding ways of improving seed systems to ensure the timely availability of planting materials of improved varieties in developing countries. Particularly noteworthy is the general lack of information on the potential benefits of foundation seed programs in developing countries. Sweetpotato is a crop that is well known for the tendency of varieties to degenerate (i.e., to lose yield potential and varietal characteristics over subsequent vegetative generations). This degeneration has been attributed to the accumulation of deleterious mutations and pathogens. In the United States, several states operate foundation seed programs that provide farmers with seed stocks of varieties maintained true to type through positive hill selection for high yield and through the elimination of off-types. Recommendations have also been developed to enable farmers to maintain their own high-quality seed stocks.

These programs have clearly demonstrated the benefits of positive hill selection for yield and trueness to type.

Sweetpotato foundation seed programs do not exist in most developing countries, nor do recommendations for farmers to maintain their planting stocks. In traditional systems where farmers grow a number of varieties, there is a turnover of varieties with time, with yields of older varieties often declining, and with the introduction of new, better performing varieties obtained from various sources. Farmers also usually pay close attention to the selection of disease-free planting material, particularly in areas where virus diseases can severely affect yields. One thing that is rarely practiced in the tropics, however, even by many researchers, is the selection of planting material on the basis of per-plant performance (hill selection). This is because planting materials in the tropics are usually taken as vine cuttings from existing plants; storage roots are not used as a source of seed.

Recent studies reported by ASPRAD researchers in Sri Lanka and Thailand have shown the rapid benefits that hill selection can have in improving yields of sweetpotato in those countries. There is a need for further verification and broad dissemination of the findings from these programs in other developing countries. Demonstration of the benefits of hill selection could lead to the widespread practice of hill selection by both researchers and farmers, and might lead to increases in sweetpotato yields while halting the commonly observed phenomena of varietal decline and turnover.

Another challenging area for research by the seed unit is the search for solutions to the problem of timely availability of planting materials for farmers in drier areas. Although technological innovations may help solve the problem, approaches developed in a community-based, participatory fashion will likely be more successful. In this area, NGO partners may be sought, or work aimed at stimulating viable community-based seed systems may be conducted as part of multidisciplinary efforts to boost sweetpotato production by diversifying forms of utilization.

Selected Reading

Dangler, J.M. (ed.). 1994. Sweetpotato foundation programs. HortTechnology 4:223-238.

De Silva, K.P.U., and H.D. Jayawickrema. 1996. Selection of true-to-type variety Waryipola-red. In: E.T. Rasco and V.dR. Amante (eds.). Selected Research Papers, July 1995-June 1996. Volume 2: Sweetpotato. ASPRAD, Manila. p. 1-3.

De Silva, K.P.U., and A. Premathilake. 1996. Effect of variety and number of generations of vegetative propagation on vegetative and yield traits of sweetpotato. In: E.T. Rascc and V.dR. Amante (eds.). Selected Research Papers, July 1995-June 1996. Volume 2: Sweetpotato. ASPRAD, Manila. p. 4-9.

PROGRAM REPORT

Program 6

Postharvest Management, Marketing

Gregory J. Scott[1]

Postharvest issues are being pushed to the top of the research agenda in many countries that produce potatoes, sweetpotatoes, and Andean root and tuber crops (ARTC). The driving force to overcome postharvest constraints and capitalize on market opportunities is the growing commercialization of agriculture combined with urbanization, population growth, rising incomes, and increasing employment of women. During 1995-96, CIP's postharvest program collaborated with industrialized- and developing-country institutions to develop technologies, provide training, and supply information to make postharvest research on roots and tubers contribute to reducing poverty, improving nutrition, and providing opportunities for women in Asia, Africa, and Latin America.

Potato

Noteworthy results were achieved in

- global projections of production, use, and trade;
- storage; and
- marketing and processing.

Projections. In anticipation of the World Food Summit in Rome in November 1996, CIP's Postharvest Management, Marketing Program collaborated with the Basic Foodstuffs Service of FAO[2] on a study of the world potato economy. We found (1) a tremendous shift under way in the relocation of potato production from developed to developing countries, and (2) an emerging importance of processing and trade in potatoes and potato

1 Program Leader, CIP, Lima, Peru.
2 Acronyms cited in this section can be found written out in the section *Acronyms*, p. 320.

products, which could lead to a 50% increase in potato production in developing countries by 2000. These findings portend a greater recognition of the importance of potatoes generally, and the needs of developing countries specifically, in the global research agenda.

Storage. Seasonal potato production patterns in India generate large fluctuations in prices paid to farmers for their crop. With improved rustic stores, small farmers would have another option besides selling their crop at harvest when prices are usually the lowest or putting it in cold storage. CIP worked with the Central Potato Research Institute of India to document traditional storage practices, analyze the experience of small farmers with cold storage, and develop low-cost rustic stores. The rustic storage improvements were a technical success, but more costly. And the demand for such stores was lower than previously calculated. A ware storage manual synthesizing the collaborative research in India and experiences elsewhere is being developed because storage remains high on the list of major production constraints in Asia.

Marketing and processing. Baseline case studies in collaboration with the CAAS in China, CORPOICA in Colombia, and COSUDE in Bolivia show that potato farmers are increasingly market-oriented. Policies aimed at improved commercialization, such as facilitating local processing and exploiting export opportunities, merit greater attention.

Processing is a growth sector in China and Colombia in particular. Rapid market appraisals of the processing sector in Kenya with KARI, in Mexico and Central America in collaboration with PRECODEPA, in Indonesia with UPWARD, and thesis research in Peru, with support from the University of Nymegen in the Netherlands, all point to a rapidly expanding market for processed products.

Imports of such products, while currently limited, could balloon if local supply does not expand to meet local demand. This tendency has already emerged in parts of Latin America, where tariffs continue to fall so countries can adhere to GATT. Field trials in Peru to select processing materials from advanced clones with desired agronomic traits continue to generate a small number of promising cultivars. All indications are that the demand for such materials is likely to increase.

Sweetpotato

Advances in sweetpotato postharvest research have consisted of

- macrostudies of processing potential;
- microanalysis of starch, flour, and feed;
- development of the commodity database and projections; and
- completion of methods materials.

Macrolevel studies. Studies of national and provincial statistics in China, in collaboration with CAAS, document the spread of sweetpotato processing primarily for feed and starch. Processing has income- and employment-generating potential for small farmers in the poorer parts of the country. The potential for the expanded use of sweetpotato as a substitute for imported maize in pig feed is a heretofore overlooked way for China to avoid massive feed imports predicted by some observers.

Regional surveys conducted in Vietnam indicate an upswing in the use of sweetpotato for animal feed and sweetpotato starch for making noodles, with prospects for even more expansion. The surveys and analysis were done by the National Institute of Agricultural Sciences, the Post Harvest Technology Institute, and the Animal Husbandry Research Institute, with assistance from CIP, UPWARD, and CIAT staff.

Similar research conducted by economists at the University of the Philippines at Los Baños shows negligible current use of, but considerable potential for, sweetpotato to substitute for imported feed and flour. Analysis of secondary data in Indonesia found that current processing accounts for some 25% of total production—far more than previously believed. But, as in the Philippines, lower raw material costs in the form of higher yields and higher conversion rates are needed for processing to reach its full potential.

These macrostudies document the importance of and potential for sweetpotato processing, lay out a set of collaboratively forged research priorities and policies, and provide a common framework for the various institutions engaged in sweetpotato postharvest research.

Microanalysis. Detailed evaluations of existing technology focused on starch, flour, and feed in China, Kenya, Peru, and Uganda. Work with SAAS on small-scale starch production in Sichuan Province, China, was the most promising of all. It identified several areas for immediate improvement. Operational analysis in Peru quantified the raw material costs and conversion rates needed to achieve profitability at an existing starch plant. The necessary higher yields with more extractable starch seem well within reach. Sweetpotato flour appears more problematic in Peru for a variety of reasons. However, in Uganda—and to a lesser extent in Kenya—prospects are brighter for flour. Markets are emerging in the wake of declining supplies of cassava flour. Economic analysis of farm-level use of roots for pig feed in China is extremely encouraging. Modest changes can improve the prospects for even more widespread use.

In Peru, dual-purpose varieties with balanced production of vines for fodder and roots for human consumption show considerable potential to improve the lot of small-scale dairy farmers.

Databases and projections. The pocket-sized compendium of sweetpotato statistics for 33 major sweetpotato-producing countries, issued in 1996, aims at broadening public awareness about the potential for sweetpotato in developing countries.

Methods materials. In addition to research results and policy recommendations, a major effort has been made to improve local research capacity by preparing postharvest methodologies appropriate to conditions in Africa, Asia, and Latin America. *Adding value to root and tuber crops*, the manual on product development, co-published with CIAT and IITA, provides operational guidelines and a common framework for sweetpotato postharvest researchers worldwide. *Prices, products, and people*, a compendium of methods for analyzing agricultural marketing in developing countries, prepared with several IARC social scientists, is intended to serve a similar purpose.

Andean Root and Tuber Crops

In our work on ARTC, considerable progress was made in each of three special projects: (1) biodiversity, (2) commodity systems, and (3) starch processing. Work in the COSUDE biodiversity project has emphasized evaluating traditional postharvest practices for crops such as ulluco, oca, and native potatoes with a view to their eventual improvement. IDRC commodity systems research has focused on developing commercial products such as protein-enriched snacks or new uses for traditional flours. BMZ-supported postharvest work involves documenting processing techniques and consumption patterns for starches derived from ARTC, for example, from achira, and investigating the biochemical properties of the products.

As the consortium of CONDESAN partners consolidates, progress has been made in forging a common conceptual framework and research agenda to follow up on findings to date. Closer links with PRODAR, the Latin American network for small-scale agroenterprise, and CIAT's rural agroenterprise initiative have also been established.

Making Sense of Agricultural Marketing in Asia, Africa, and Latin America

G.J. Scott[1]

Recent trends in domestic, as opposed to foreign, agricultural marketing are the focus of a 1995 book, *Prices, products, and people: Analyzing agricultural markets in developing countries.* This collection of papers by social scientists at various international agricultural research centers and their collaborators in national research systems covers both data collection and data analysis methods.

Marketing and Economic Development

Agriculture has become more market-oriented in virtually all developing countries over the past 30 years. Subsistence production has declined in relative importance in part because technological improvements mean that producers have more output to sell. Mushrooming urban areas—particularly in sub-Saharan Africa—mean that more and more consumers depend on agricultural marketing for their daily food requirements. Even environmentalists have shown a growing interest in the benefits and costs associated with agricultural marketing.

1 CIP, Lima, Peru.

Most important, increased production, population growth, and improvements in infrastructure have meant that the sheer volume of agricultural goods traded in domestic markets has expanded enormously (Table 1). Hence, the potential rewards to society and individuals from improvements in domestic agricultural marketing have multiplied in corresponding fashion.

Limitations of Previous Research

Much of the literature on agricultural marketing in developing countries can be categorized into one of three types: (1) compilations of basic principles or concepts, (2) reviews, syntheses, or concept papers, and (3) case studies of particular marketing systems or agricultural marketing enterprises.

In publications such as these, the end results of the application of economic analysis to the study of agricultural marketing often abound. But often lacking are step-by-step explanations of the procedures by which such location-, time-, and product-specific research might be extrapolated to another place

Table 1. Trends in food production and foreign trade in developing countries, 1961-91.

Country	Commodity	Production (000 t)		Trade (%)[a]	
		1961	1991	1961	1991
Philippines	Rice	3,910	9,673	4.8	0.1
India	Wheat	10,997	55,134	28.1	1.2
Kenya	Maize	940	2,340	11.2	0.8
Colombia	Potato	551	2,225	0.1	1.4

a. Exports plus imports divided by production.

Source: FAO, PC-Agrostat, unpublished, 1993.

or another commodity. It is this gap between the conceptual and case study literature on domestic agricultural marketing in developing countries that *Prices, products, and people* attempts to breach.

Because of the frequent need for prompt attention to particular policy-related marketing issues, this publication emphasizes practical and rapid research procedures. Also included are simplified substitutes for more complicated approaches. In setting out a collection of methods to help practitioners address the types of marketing questions that analysts are most frequently confronted with in developing countries, the volume also aims at providing researchers with a cross section of techniques most appropriate for the task at hand.

Many contributions have appendices that spell out guidelines on survey procedures or analytical techniques in greater detail. Nearly all chapters provide examples of the application of these techniques to specific commodities based on research in different developing countries. The intent here is to enrich the general exposition of a series of methods with an array of commodity-specific experiences involving their use.

Selected Reading

Fleming, E.M. 1990. Proposal for a marketing systems research approach in agricultural development planning. Agric. Systems 32:97-111.

Kinsey, J. 1988. Marketing in developing countries. Macmillan Education Limited, London.

Scott, G. (ed.). 1995. Prices, products, and people: Analyzing agricultural markets in developing countries. Lynne Rienner Publishers, Boulder, Colorado, USA.

Sellen, D., W. Howard, and E. Goddard. 1993. Production to consumption systems research: A review of methods and approaches. Report prepared for the International Development Research Centre, Department of Agricultural Economics and Business, University of Guelph, Guelph, Canada.

Perceptions Versus Projections for Potatoes: New Estimates Point to a Changing Global Research Agenda

G.J. Scott[1] and A. Coccia[2]

In preparation for the World Food Summit in Rome in late 1996, FAO carried out a series of studies to provide an overview of past trends and future outlook for the world's major agricultural commodities. CIP and FAO staff jointly prepared the study (begun in 1994 and written up in 1995) on potatoes—the first of its kind for FAO for this commodity. This paper summarizes the principal findings from that collaborative effort, including the analysis of past trends in production, area planted, and yields; the evolution of marketing and use patterns; and projections to the year 2000—what those trends predicted and how they compare with actual output in recent years.

These findings served as the catalyst for initiating a collaborative effort with economists from the International Food Policy Research Institute (IFPRI) to generate projections for potatoes, sweetpotatoes, and cassava in the year 2020. Preliminary results from that work are also included here to lend greater weight to the data presented.

Materials and Methods

We analyzed historical growth rates in production, area, and yield by region and by country for the period 1961-93. Point-in-time comparisons for consumption, use, and trade for 1961-63 vs. 1991-92 were similarly analyzed.

The statistics are all from FAO databases with the exception of use data for the United States from the U.S. Department of Agriculture. The latest FAO figures on these variables are cited selectively to substantiate the analysis when necessary.

The FAO/CIP projections are for a single commodity and for individual countries in major economic and geographical regions such as Europe, the area of the former USSR, Africa, Asia, and Latin America and the Caribbean. The base period is 1987-89 and the projections go to the year 2000. On the demand side, the model is basically driven by changes in population and per capita incomes inasmuch as relative prices are assumed to remain constant throughout the period (1987-89 to 2000). The results cover two iterations: (1) the base period to 2000, and (2) incorporating the effects of the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) for the same time frame.

Preliminary results from the IFPRI/CIP collaboration are only for potatoes. But those projections for the year 2020 are made using a model that simultaneously estimates supply, demand, and trade for all the major food commodities. The model also explicitly allows for changes in relative prices and generates results for selected countries, subregions (e.g., East Africa), and regions.

Results and Discussion

Misperception 1. As developing countries grow economically, potato production and consumption will follow the pattern of sharp decline in Europe.

Recent reports on potatoes in Europe are replete with statistics on declines in area planted and production. Data on use also show sharp drops in per capita consumption

1 CIP, Lima, Peru.
2 FAO, Rome, Italy.

of fresh potatoes and in the use of potatoes for animal feed. Based on these figures, European observers often assume that, as the economies of other regions of the world mature, similar patterns must already exist or will certainly prevail in the not-too-distant future. But empirical evidence indicates just the opposite.

Potato production in developing countries rose from 29 to 85 million t between 1961-63 and 1994-96, more than offsetting the drop in production in industrialized countries. Hence, world potato output rose slightly, from 265 to 275 million t, even though output in Europe dropped by more than 50 million t during the same period. China is now the world's largest potato producer since the breakup of the USSR; India ranks sixth. In fact, area planted to potatoes grew faster in developing countries than for any other major food crop over the 30-yr period studied (Figure 1).

Production increases were second only to those of wheat (Figure 2). Production increases have been particularly strong in Asia. The annual growth rate in production averaged 4.0% over the past 30 yr as area planted expanded 2.6% yearly and yields increased by 1.4% annually.

From a base period figure of 75.6 million t in 1987-89, the FAO/CIP projections developed in 1994 called for potato output in developing countries to reach 105.4 million t in 2000. By 1994-96, FAO production figures showed output at nearly 100 million t, well on target to reach the projected total. Furthermore, preliminary estimates from the IFPRI/CIP projections indicate that potato production in developing countries will continue to expand at an average annual rate of 2.0% over the next 25 yr.

Misperception 2. The bulkiness and perishability of potatoes severely limit international trade.

In economists' jargon, potatoes are the archetypical "nontradable," that is, the good that is classified as one for which only an internal (or domestic) market exists. Reasons for this classification abound. Potatoes indeed are bulky and perishable, and therefore difficult to transport over considerable distances. Their low unit value-to-weight ratio and corresponding transport costs also discourage trade. Local (consumer) preferences for skin color, flesh color, and tuber size, as well as for packaging and grading, constitute additional constraints to international commerce.

Nevertheless, trade in table potatoes and seed rose from 3 million t in 1961-63 to 7.5 million t in 1991-93. If trade in processed potato products is added, recent estimates put

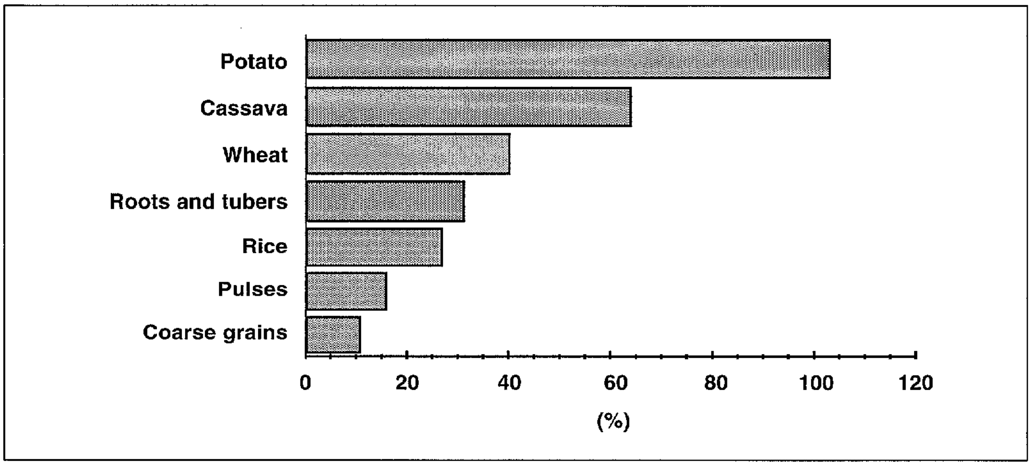


Figure 1. Percentage increase in area of selected food crops in developing countries: 1961-63 and 1994-96 averages.

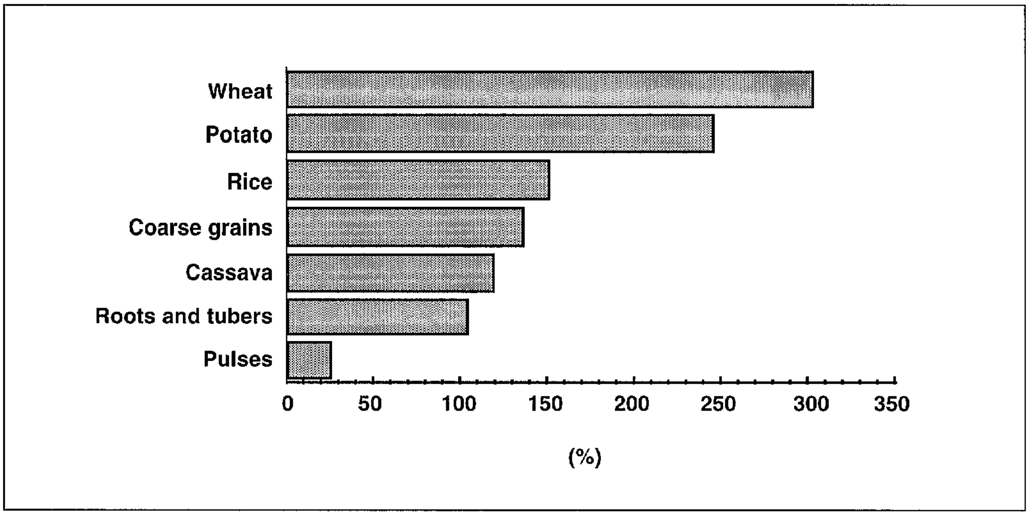


Figure 2. Percentage increase in production of selected food crops in developing countries: 1961-63 and 1994-96 averages.

world potato trade at 10 million t yearly, or about 4% of annual global production. By way of comparison, world trade in rice is roughly 3% of annual output.

Trade patterns for potatoes have also diversified over the past 30 yr. Exports of potatoes by developing countries have risen from 400,000 t to nearly 1.3 million t in this period. Shipments of seed and processed potato products from industrialized to developing countries have also expanded sharply. By the late 1980s, for example, more than one quarter of all Dutch seed exports were to developing countries in North Africa. A world market for potatoes is clearly emerging, with countries tending to specialize in different types of potatoes as well as developing regional trading partners.

Part of the misperception about trade is the result of inadequate statistics. FAO includes in its trade data only trade in fresh potatoes and seed. Until governments supply better figures, data available to FAO will continue to underestimate international trade in potatoes and potato products. More important, many developing and developed countries have only recently begun to appreciate the implications for their potato sectors of liberalized trade policies and regional trade agreements. In a number of Latin American countries, imports have risen sharply even though tariffs are still comparatively high. As these tariffs fall in the years ahead to comply with GATT, the pressure to improve competitiveness or be forced out of production will be considerable. The window of opportunity to effectively address such developments is closing rapidly, given that tariffs for many countries are due to reach the agreed-upon minimums in 6 or 7 yr. That is roughly the minimum lead time required to fully promote development and diffusion of improved germplasm.

Misperception 3. Potatoes produced in developing countries are cultivated mainly by subsistence farmers for on-farm consumption.

Potatoes are produced in nearly 100 countries in Asia, Africa, and Latin America, typically by small-scale farmers with holdings usually less than 5 ha. A "big" potato farmer in Bangladesh, for example, might have 2 ha planted to the crop. These growers usually depend on family as well as hired labor to plant and harvest. Potatoes are nearly always consumed by those farm households that produce the crop. In fact, potatoes in developing countries are often harvested when the basic staples of rice, wheat, or maize are in seasonal short supply. Hence, potatoes are often referred to as a subsistence crop.

The bulk of potatoes produced in Asia, Latin America, and North Africa—even on small farms—is sold. Potato sales are an important source of cash income, even in those parts of sub-Saharan Africa and in more isolated pockets in Latin America where on-farm consumption prevails. Commercial potato production dominates in developing countries because yields—particularly in Asia—are high enough for farm families to be able to eat some of what they harvest and still sell most of the crop. Returns for potato, a crop with a vegetative period of 100-130 days in many parts of the tropics and subtropics, are extremely lucrative because of strong off-farm demand and relatively high prices.

Misperception 4. As per capita incomes rise in developing countries, per capita potato consumption will fall.

Per capita consumption of potatoes in Western Europe fell by 22% between 1961-63 and 1991-93; even more in Eastern Europe and the former Soviet Union. As incomes generally increased during the past 30 yr, European consumers have preferred to eat fine grains, fruits, and other vegetables over potatoes. Hence, per capita consumption shrank in Western Europe from 102.3 to 79.3 kg/yr, in Eastern Europe from 117.4 to 80.3 kg/yr, and in the former Soviet Union from 131.8 to 78.0 kg. As incomes increase elsewhere—it is often inferred—per capita potato consumption will fall accordingly.

Per capita potato consumption in developing countries rose by 43% during the past 30 yr. It is much lower in Asia (11.7 kg), Africa (8.0 kg), and Latin America (20.6) than in Europe (78-80 kg). Incomes are also lower. Potato is typically a complementary vegetable or seasonal staple in developing countries rather than a principal source of carbohydrates. As income goes up, consumers often prefer to eat more potatoes to diversify their cereal-based diets.

Detailed information on consumer expenditures by commodity by income group in a given developing country is often hard to find. Such data are typically for "all roots and tubers," or "all vegetables," and for "all income groups." Where such disaggregated statistics are available, the results typically show that consumption increases with income, even among low-income consumers. In addition, potatoes play an important role in developing-country diets as a source of vitamin C and essential amino acids like lysine that are limiting in rice.

Misperception 5. As the area planted to cereal staples increases in Asia, the area planted to less important crops like potato must decrease.

Increased food production in developing countries—particularly in Asia—over the past 30 yr is most commonly associated with the adoption of new, high-yielding varieties of wheat and rice. This trend is particularly true in South Asia, where dwarf wheat and high-yielding rice varieties were gradually taken up by large, medium, and even small farmers. Thousands of ha are now under cultivation with these varieties, which in large part explains the increases in area planted and production (Figures 1 and 2). The spread of the improved wheat and rice varieties greatly facilitated the expansion of area planted to potatoes in several respects.

The new, high-yielding cereals have a much shorter duration than the traditional varieties. Hence, the time required to grow a rice crop in Bangladesh was shortened from five or more months to four or less. This left a period during the agricultural calendar when an additional crop could be grown. Furthermore, to take full advantage of the improved varieties, farmers need irrigation. But with the much higher yields of the improved varieties, investments in irrigation were now fully justified and spread rapidly in the cereal-growing areas. Although there is not enough irrigation water in the off-season(s) to grow rice, there is sufficient water to grow a potato crop. As higher yields from improved cereals meant higher incomes for small farmers in many areas, the increased purchasing power often translated into more demand for potatoes. That meant additional increases in potato production and, consequently, further growth in area planted.

The most recent (1991-95) national statistics for area planted to potato in China show continued expansion in the area under potato cultivation. Similar trends are evident elsewhere in Asia. Furthermore, preliminary estimates from the IFPRI/CIP projections to the year 2020 also indicate continued expansion in area planted in the decades ahead, albeit at a more modest rate than before.

Conclusions

Recent analyses of past trends and future projections for potato clearly indicate the crop's increasing importance as a world food crop. Statements that would suggest otherwise are frequently based on misperceptions about the performance and potential of the crop in developing countries. As such, potatoes merit closer attention by policymakers and researchers concerned with global food problems in both developing and industrialized countries in the years ahead.

The concentration of potato production is shifting from Europe to Asia and other parts of the developing world at an astounding pace. In 1961, potatoes produced in developing countries accounted for about 11% of global output. Potato production reached some 30% in the early 1990s and is projected to be around 40% in 2020. No other major food crop has experienced such a shift in the location of production over this period (1961-93).

In addition, developing countries are increasingly the target of industrialized countries' potato exports and, to a lesser extent, vice versa. Therefore, the needs of producers and consumers in Asia, Africa, and Latin America increasingly will be the focus of potato researchers worldwide. Postharvest issues such as trade and processing are entering a critical phase in this regard inasmuch as tariff barriers are set to come down and the demand for processed products is certain to increase for many reasons.

Processing and trade are the two fastest growing sectors in the global potato economy. The international database for processing and trade—particularly for developing countries—needs to be improved. Otherwise, forecasters will simply continue to underestimate their growing importance. Building on past successes in the collaborative work on projections, this might well be an area for future joint initiatives between CIP and FAO.

Selected Reading

Crosnier, J.C. 1994. L'evolution de la culture de la pomme de terre en Europe et en France. In: Proceedings of the 12th Triennial Conference of the European Association for Potato Research. Held in Paris, France, 18-23 July 1994. Institut de Recherche Agricole (INRA), Paris, France.

FAO/CIP (Food and Agriculture Organization of the United Nations/ International Potato Center). 1995. Potatoes in the 1990s: Situation and prospects of the world potato economy. Rome, Italy. 39 p.

Rosegrant, M., M. Agcaoili-Sombilla, and N. Pérez. 1995. Global food projections to 2020: Implications for investment. Food, Agriculture, and the Environment Discussion Paper 5. IFPRI, Washington, D.C., USA.

Scott, G. 1994. The emerging world market for potatoes and potato products. Economie et Gestion Agro-alimentaire (France) 30:19-27.

Sustainability of Potato Consumption in Developing Countries: The Case of Bangladesh

G.J. Scott[1] and H.E. Bouis[2]

Since the early 1960s, a number of horticultural crops have experienced very rapid increases in production in developing countries. Typically, they are high-value, short-duration, labor-intensive crops grown primarily for sale rather than for on-farm consumption. As a result, several countries, particularly in Asia, look increasingly to horticultural crops as a source of increased output, consumption, and income.

Potato (*Solanum tuberosum*) is particularly important, partly because production growth has been so noteworthy. The percentage increase in production for potatoes in developing countries from 1961 to 1996 was greater than that for any other major food crop except wheat. For example, potato production in India increased by 525% during the period to nearly 17 million t. In Pakistan, potato production increased from 28,400 t in 1947-48 to over 1 million t by 1994-96. Turkey, Iran, North Korea, and Bangladesh have also had substantial increases in potato output. The domestic market has absorbed virtually all of this increased production.

These trends have raised a series of questions about the potential for expanded potato consumption and production.

- Has the observed increase in consumption been due to changes in relative prices or changes in income?
- To what extent would even lower prices, through increased production, stimulate even higher demand?

We attempt to answer these questions by examining historical demand elasticity estimates for potatoes in the case of Bangladesh and then comparing them with observed trends in use.

Materials and Methods

Results presented in this paper draw upon three different methods and sets of data. Because of space limitations, only the results themselves and their interpretation are included here. The first method involves estimating the demand parameters for a number of key food groups based on household expenditure data and a simplified analytical technique designed especially to estimate a demand matrix for a highly disaggregated group of foods.

The second method consists of a more traditional procedure used to estimate the same parameters, but with household expenditure data collected some 15 yr later.

The third method includes the results of a rapid market appraisal and descriptive analysis of the latest secondary data on production and consumption gathered in field work and statistical monitoring since 1982. The cross-checking of results is intended to test the predictability of the estimated parameters as well as the reliability of such estimates for predicting longer-term trends in consumer behavior.

Results and Discussion

Baseline historical data for Bangladesh are taken from the Household Expenditure Sur-

1 CIP, Lima, Peru.
2 International Food Policy Research Institute, Washington, D.C., USA.

vey for 1973-74, conducted by the Bureau of Statistics. Selected food consumption patterns using these data are shown for urban and rural, high- and low-income consumers (Table 1). Relative price data per 1,000 calories are expressed as a ratio of the price paid for the least expensive grain (in this case, for wheat) by the low-income, urban quartile. For example, in 1973-74, the lowest income urban consumer in Bangladesh paid 1.63 times the price of wheat for 1 kg of potatoes (Table 1). However, since potatoes contain roughly one-fifth the calories of wheat on a price per calorie basis, potatoes were 7.39 times more expensive than wheat, due partly to their higher price, but more importantly to the lower quantity of calories (Table 1).

Rice and wheat are the two main staple foods consumed in Bangladesh. In calorie equivalents, rice was more than twice as expensive as wheat in urban areas at the time of the 1973-74 survey. Based on these historical data, apparently both urban and rural populations would buy higher quality wheat and rice as incomes rose, although the tendency is more marked for rice. Wheat was more expensive in rural areas than in urban areas; the price of rice was about the same between urban and rural areas.

Per capita annual potato consumption in Bangladesh in 1973-74 was higher in urban areas than in rural areas (Table 1). More than 85% of the total population resided in rural areas at the time. Still, in urban areas, potatoes were more than seven times as expensive a source of calories as wheat for low-income groups and nearly nine times as expensive for high-income groups, which purchased higher quality potatoes. Also in urban areas, potatoes were more than three times as expensive a source of calories as rice. The price differential between wheat and potatoes and between rice and potatoes was not nearly so great in rural areas.

Historical information about food imports and real wages helps to put these figures in perspective. In 1973-74, Bangladesh had just recently achieved nationhood after a war of independence. The devastation of the war was aggravated by the famine of 1974. Hence, in 1973-74 Bangladesh was heavily dependent on food aid and commercial cereal imports.

Table 1. Consumption per annum and calorie prices for potato, wheat, and rice in Bangladesh, 1973-74.

Income[a] group		Per capita consumption (kg)			Calorie price[b] (per 1,000 calories)			Market price (US$)		
		Potato	Wheat	Rice	Potato	Wheat	Rice	Potato	Wheat	Rice
Urban	1	3.6	68.6	83.2	7.39	1.00	2.18	1.63	1.00	2.24
	2	5.2	64.0	98.8	7.98	1.01	2.39	1.76	1.01	2.46
	3	7.3	58.2	111.8	8.03	1.04	2.49	1.77	1.04	2.56
	4	8.8	54.1	125.3	8.98	1.06	2.67	1.98	1.06	2.75
All		6.8								
Rural	1	1.0	41.1	75.4	6.62	1.43	2.28	1.46	1.43	2.34
	2	2.6	41.1	103.0	6.39	1.50	2.36	1.41	1.50	2.43
	3	3.1	34.8	130.5	7.44	1.46	2.41	1.64	1.46	2.48
	4	4.7	26.0	162.8	7.94	1.64	2.66	1.75	1.64	2.74
All		3.5								

a. Income groups refer to total expenditure quartiles with 1 designating the lowest expenditure quartile.

b. Relative to price of cheapest grain calorie source.

Total wheat supply was in the neighborhood of 1.7 million t. According to FAO, nearly 95% was imported. Domestic wheat production at the time was slightly over 100,000 t. Domestic potato supply consisted of some 725,000 t, virtually all of which was produced locally. Local wheat prices were depressed by aid, imports, and food subsidies, particularly in urban areas. Hence, the large differences in relative prices per calorie for potatoes vs. wheat that prevailed at the time the household survey was carried out were at least partly due to these unusual circumstances.

Real wages in Bangladesh were also at a relatively low point in 1973-74. Reasons cited for this include the political unrest leading up to independence, destruction caused by the war for independence, and the famine of 1974.

The 1973-74 survey data reveal large percentage increases in per capita consumption of potatoes across income quartiles in both urban and rural areas (Table 1). Consumption was low, however, even for high-income groups when compared with industrialized countries.

Simulated demand changes

Using historical demand characteristics for potatoes in Bangladesh, we ran four sets of simulations to examine the effect changes in the prices of particular foods and income might have on potato demand. We applied the consumption level in 1973-74 to the food demand elasticities given in Table 2 to yield the simulations presented in Table 3.

The first set of simulations assumed a 25% increase in income for each income quartile. Not unexpectedly, consumption increases are large given the low initial levels of potato consumption and the high income elasticities.

The second set of simulations assumed a 25% increase in the prices of all foods. That is somewhat equivalent to a decrease in income (except that nonfood expenditures become relatively more attractive). Under this assumption, consumption decreases precipitously.

Table 2. Summary of selected income, own price, and cross-price elasticity estimates for potatoes by income quartile and urban and rural populations for Bangladesh, 1973-74.

Urban-rural/income quartile	Income elasticity	Own-price elasticity	Cross-price elasticity in demand for potatoes	
			Food # 1 (Rice)	Food # 2 (Wheat)
Urban				
1 (low income)	1.17	-1.02	-0.20	-0.20
2	1.09	-1.02	-0.19	-0.15
3	1.02	-1.02	-0.18	-0.11
4	0.87	-1.04	-0.11	-0.05
Rural				
1 (low income)	1.67	-1.01	-0.58	-0.37
2	1.44	-1.02	-0.50	-0.22
3	1.32	-1.01	-0.43	-0.12
4	1.02	-0.99	-0.27	-0.04

Table 3. Simulated changes in demand for potatoes by income quartile and urban and rural populations for Bangladesh, 1973-74.

Urban-rural/income quartile	Initial per capita consumption per year	Change in per capita consumption per year (kg/year)			
		25% increase in per capita income	25% increase in price of all foods	25% decrease in price of primary staple foods	25% decrease in price of potatoes
Urban					
1 (low-income)	3.6	1.06	-1.10	0.18	0.93
2	5.2	1.41	-1.51	0.25	1.32
3	7.3	1.86	-2.04	0.33	1.86
4	8.8	1.93	-2.30	0.25	2.22
Rural					
1 (low-income)	1.0	0.43	-0.42	0.15	0.26
2	2.6	0.93	-0.93	0.32	0.66
3	3.1	1.03	-1.06	0.33	0.78
4	4.7	1.19	-1.36	0.31	1.16

A third set of simulations assumed a 25% decrease in the price of rice, which effectively increases income. Even though rice becomes an even cheaper source of calories than potatoes, potato consumption increases because of the increased income.

The fourth simulation assumed a 25% decline in the price of potatoes. The increase in per capita consumption of potatoes based on that assumption is on the order of 25%.

Actual demand changes

Given the rise in per capita consumption of potato and its growing importance in the lean season in Bangladesh since 1973-74, potato has evolved from a minor vegetable to the most important vegetable in the diet and an occasional partial substitute for rice. That is consistent with the historical demand parameter estimates reported in the previous section, and with an observed increase in the price of rice relative to potatoes. The price ratio rose 45% from 1973 to 1983 in Dhaka. The decrease in the relative cost of potatoes greatly contributed to the increase in rural consumption from around 5 kg per capita in 1973-74 to around 16 kg per capita in 1981-82.

More recent consumption patterns

Patterns in 1988-89. Several factors led to changes in potato consumption patterns in Bangladesh during the remainder of the 1980s. First, potato production increased markedly due to increases in yield and area planted. Yield increased an average 2.7% annually from 1961 to 1993, whereas area planted increased at an annual rate of 1.8%. By 1993, annual potato production was 1.3 million t.

Second, wheat production increases were also impressive during the period, although they have tended to level off in recent years. Wheat production was 1.08 million t in 1991-93, only slightly higher than the 1.03 million t produced in 1981-82. Area planted to wheat grew by about 7% in the 1980s, from 563,000 to 604,000 ha. Not only did local production of wheat increase, but imports in 1988-89 were higher in absolute terms than in 1973-

74. However, population growth in Bangladesh virtually eliminated any increases in per capita availability of wheat.

Third, total rice supplies increased by more than 40%, from 12.9 to 18.8 million tons. The spread of high-yielding varieties was a principal factor. Rice import increases were minor compared with increases in domestic production.

Fourth, real income increased sharply during the 1980s (Figure 1). Among the possible reasons are the spread of improved rice varieties capable of high yields in the dry season.

Fifth, results from the Bangladesh household expenditure survey for 1988-89 show that per capita potato consumption rose sharply (Table 4). That appears consistent with the shift in relative prices for potatoes vs. wheat—particularly in urban areas where relative prices fell by 50%.

The relative price for potatoes vs. rice, however, remained virtually unchanged in urban areas and actually rose in the countryside (Table 4). As rice consumption increased, particularly among low-income consumers, this added sense of wealth engendered increased potato consumption as well. Increased potato consumption is consistent with the rise in real wages.

Potatoes are more than just an alternative source of calories, or a tasty alternative to a strictly cereal-based diet. In Bangladesh, potatoes are an important source of vitamin C and also provide essential amino acids that are low in rice.

Patterns in 1995-96. Potato production in Bangladesh rose by nearly 250,000 t between 1988-89 and 1995-96 to 1.45 million t. Detailed consumption figures by place of residence and income quartile are harder to come by. But FAO Food Balance Sheet data indicate that average per capita consumption in 1992-94 was 9.8 kg/yr, more than double the 4.8 kg/yr reported for 1961-63. The International Food Policy Research Institute and CIP estimate continued increases in potato

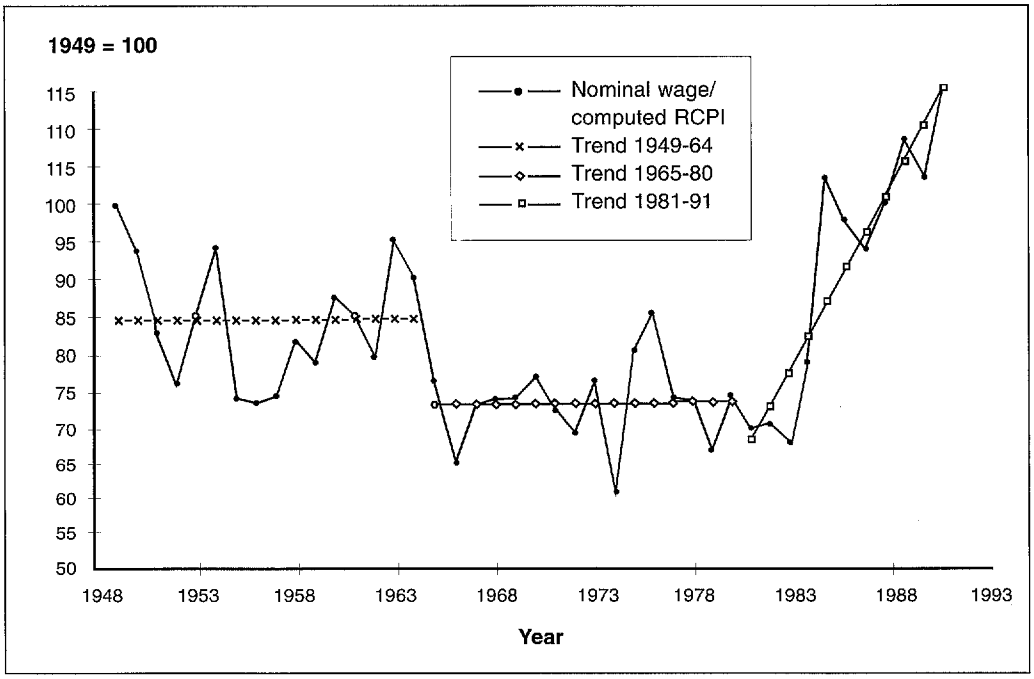


Figure 1. Real wages of agricultural laborers, Bangladesh, 1949-93.

Table 4. Consumption of rice, wheat, and potatoes, and computed relative prices per 1,000 calories in Bangladesh, 1973-74 vs. 1988-89.

	1973-74 quartiles		1988-89 quartiles	
	High	Low	High	Low
Consumption (kg/cap/year)				
Urban				
Rice	125.3	83.2	149.8	135.3
Wheat	54.1	68.6	19.7	20.1
Potato	8.8	3.6	29.7	14.4
Rural				
Rice	162.8	75.4	196.3	132.3
Wheat	26.0	41.1	17.0	25.1
Potato	4.7	1.0	23.7	8.5
Relative prices (per 1,000 calories)				
Urban				
Potato vs. wheat	8.47	7.39	4.18	3.93
Potato vs. rice	3.36	3.39	3.16	3.19
Rural				
Potato vs. wheat	4.84	4.63	4.14	3.84
Potato vs. rice	2.98	2.90	3.28	3.18

production and consumption well into the next century.

Conclusions

Potatoes are of increasing interest to policymakers and planners in developing countries because of their proven potential to raise farm incomes, rural employment, and food consumption. This last consideration is particularly important in South Asia where large segments of the rural population are low-income consumers.

To better understand past increases in potato consumption and to more accurately estimate the potential for further growth, basic information is required on the demand characteristics of the commodity. In North America and Europe, potatoes are regarded as a starchy staple. But in Asia they are valued for their dietary variety, taste, and the essential vitamins and amino acids they provide. Potatoes are still an expensive source of calories relative to wheat and rice. But as we have shown in Bangladesh, the relative price vs. wheat has fallen substantially. Estimates for Bangladesh indicate that the prospects for increased potato consumption are favorable, yet modest in per capita terms, if incomes increase and potato prices continue to decline relative to staples.

Government policy can greatly influence the future demand for potatoes. Various measures might be adopted to help further lower production costs and the retail price. Among them are lowering the cost and improving the availability of planting material and storage facilities, and cutting subsidies on imported wheat. Given the estimated demand parameters, increased potato supplies could be readily consumed in the local market.

Selected Reading

Bouis, H.E. and G.J. Scott. 1996. Demand for high-value secondary crops in developing countries: The case of potatoes in Bangladesh and Pakistan. Food Consumption and Nutrition Division Discussion Paper No. 14. International Food Policy Research Institute (IFPRI), Washington, D.C. 42 p.

Goletti, F. 1993. Analysis of demand for potatoes in Bangladesh. IFPRI, Washington, D.C. 35 p. (In mimeograph.)

Scott, G. 1988. Marketing Bangladesh's potatoes: Present patterns and future prospects. International Potato Center (CIP)/Australian Development Assistance Bureau (ADAB), Dhaka, Bangladesh. 107 p.

Improved Rustic Storage in South Asia

S.G. Ilangantileke[1], V.S. Khatana[1], J.P.Singh[2], and D. Kumar[2]

India ranks second only to China among the Asian countries in potato production. The country produced 20.3 million t of potatoes from 1.26 million ha area during 1994-95. If the trend of the 1990s continues, total production could reach 28 million t by the year 2000. Thus the country should be ready to handle an additional 8 million t of potatoes within 5 yr. This may be a difficult task, particularly when postharvest facilities to handle existing potato production are limited.

Potato production is mainly concentrated in the northern plains comprising the states of Uttar Pradesh, Bihar, and West Bengal. About 81% of the total potatoes produced in the country are harvested from January to April and are available for market, but only 28% of those potatoes are demanded as ware potatoes during the period. This creates a surplus of 53% of ware potatoes, which have to be used or stored over the next 6 months from May to November. In addition, about 10% of the total potato produce harvested in the same season needs to be stored as seed to be used for the next production year.

A major portion of the harvested potatoes are stored in cold stores for long-term storage. Potato prices are lowest at the peak harvest season, generally from early February to early March when the major crop of potatoes is harvested in Uttar Pradesh. The usual trend in price variation results in about a 50% increase in prices within 2-3 mo of the peak harvesting period.

The available cold-storage capacity in many of the potato-producing states in India falls short due to the high demand experienced during the harvest. The installed capacity of cold stores is 8.7 t. Estimates indicate that 92.5% of total cold-store space is used to store potatoes.

Assuming that the entire existing installed cold-storage capacity for potato operated at full efficiency, only 40% of the potatoes produced in the country could be cold-stored. Because of the shortfall of cold-storage capacity and low prices experienced at harvest, about 4 million t of harvested potatoes are still traditionally stored, since this is the only choice left with farmers.

Traditional storage practices vary by districts within a state. The end use of the harvested potato governs the storage practice. It could vary from domestic storage in households, mainly for family consumption, to commercial storage in traditional structures, heaps or clumps under trees in orchards, and underground pit-storage structures found in the state of Madhya Pradesh. The main force behind pit storage, where potatoes are kept for over 2 mo under ambient conditions, is the demand for potatoes for processing. In humid West Bengal, potatoes are stored in ordinary rooms, generally on raised bamboo platforms. Storage in Uttar Pradesh begins in late winter and the temperature increases rapidly from late February onward. The increasing temperatures result in heavy storage losses.

Considering FAO estimates of 17% postharvest potato losses in India, then the monetary losses for a season could be approximately US$55 million. Farmers who are unable to avail themselves of cold-storage space will benefit from improved traditional storage methods that decrease losses and increase their income.

Earlier studies indicated that rustic stores with evaporative cooling to lower tempera-

1 CIP, South and West Asia Regional Office, New Delhi, India.
2 Central Potato Research Station, Modipuram, India.

tures and increase humidity provide a better storage atmosphere than the traditional storage systems. But research is limited and the effectiveness of the storage system on-farm has not been studied. We therefore undertook rustic-storage trials in Uttar Pradesh to test such storage systems in farmers' fields for ware potato storage. We also conducted storage surveys to determine the status of traditional and cold stores in potato-growing districts.

Materials and Methods

Over the past three years, CIP constructed and evaluated evaporative cooled rustic stores (EVS) in farmers' fields. The storage experiments were done in collaboration with the Indian Council for Agricultural Research (ICAR) in the Central Potato Research Institute (CPRI).

The actual experimentation was done in collaboration with scientists from the Central Potato Research Station (CPRS), in Meerut District, and in farmers' fields in Meerut, Muzaffarnagar, and Farrukhabad districts of Uttar Pradesh. Storage surveys were conducted in collaboration with scientists from the CPRI. Eighteen improved EVS were constructed in different farmers' fields using locally available material such as brick, mud, wood, and thatched roofs (Figure 1). Cement and bricks were used to build the evaporative chamber at the bottom of each store. Cement troughs were constructed with an arrangement of brick channels, to increase the movement of air under the store. Sand used as the evaporating surface was placed in the troughs to a depth of 6 cm between the brick channels and was kept wet during potato storage. The water level was kept at about 0.5 cm

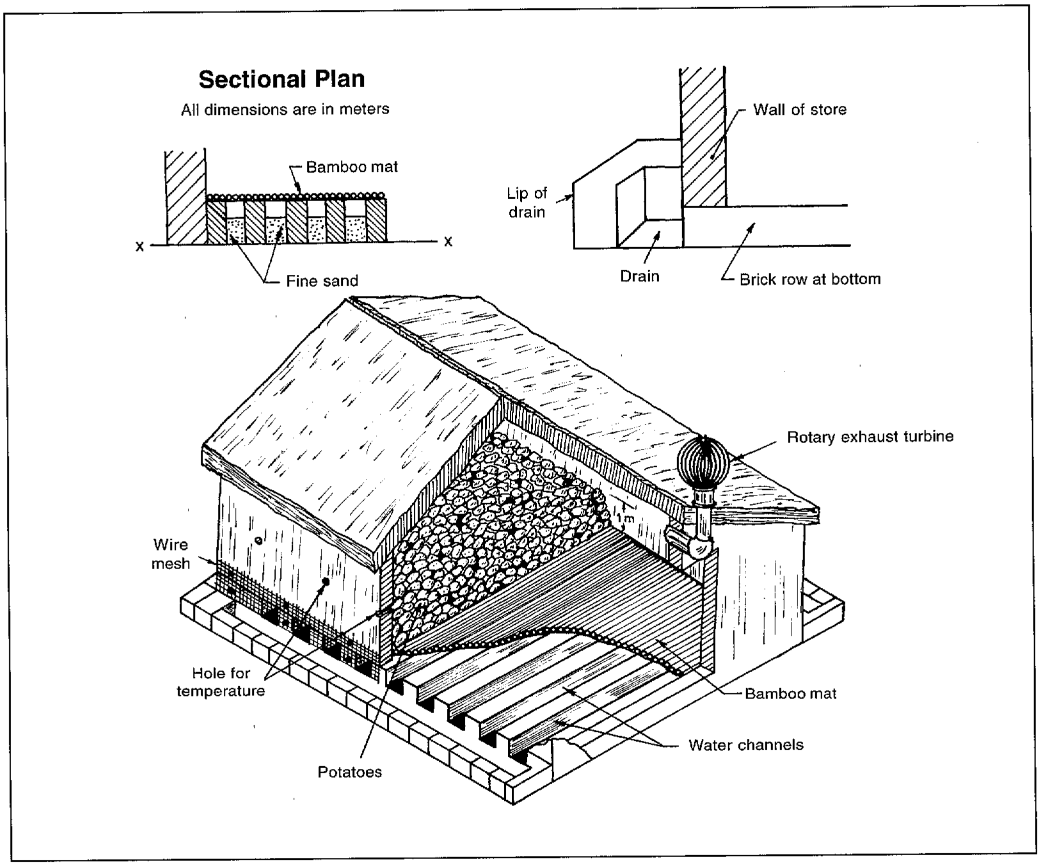


Figure 1. Drawing of an evaporative cool store.

above the sand to ensure adequate moisture for evaporation.

A locally constructed wind turbine was fitted to the roof of each store. The suction of the turbine was set to minimize desiccation of the stored potatoes. Westerly winds prevailed during most of the storage season, so the stores were constructed facing the north-south direction. The easterly lip of the water trough was higher than the westerly lip to restrict the hot, dry air moving through the trough to the outside. This enabled a longer residence time for the hot, dry air inside the water trough, thus providing better evaporation.

The potatoes were stored on bamboo mats placed on the brick channels inside the store. Walls were plastered with about 3 cm of mud and straw mixture to give better insulation. Holes (2 cm diam) were made on the side walls of the eastern and western side of each store at a height of 1.5 m to measure temperature inside the store using a long-stemmed thermometer. The holes were sealed with mud between temperature readings.

Initial temperature and relative humidity (RH) data were collected at the time of filling stores and regularly thereafter. At the CPRS store, dial thermometers were permanently installed with the probes in direct contact with the stored potatoes to give temperature of potatoes during storage. A Stevenson's screen was fixed for ambient temperature and RH measurements. Continuous monitoring of store temperature and RH at the CPRS store was done using a continuous-recording Thermohydrograph installed at a height of 1.6 m. Observations on potato quality were taken at 2-wk intervals by opening the stores early in the morning when the difference between the inside and outside temperature was a minimum. Similar observations were made in farmers' fields during regular visits to monitor the progress of the experiment.

Potatoes for storage were sorted and weighed; damaged tubers were discarded. Stores were filled in March. The varieties stored were Kufri Bahar, Kufri Badshah, Kufri Chandramukhi, JI-5857, and TPS families. Potatoes were piled to a maximum height of 1.5 m. The effective storage capacity of the stores was 10 t, although in some instances the capacities were increased at farmers' requests and at their cost. The quantity stored ranged from 2.5 t to as much as 14.6 t. After the stores were loaded, their doors were sealed with mud to give better insulation. Moisture or weight loss of potato in the improved rustic stores as well as in the heap/ordinary room was evaluated by placing 5-9 10-kg bags of potatoes in different places (bottom, middle, and above the stored potatoes).

Potatoes were stored under these conditions until farmers decided to sell, based on the prevailing market price. Observations taken on the day of selling the stored potatoes were (1) number of sprouted tubers, (2) number and weight of rotted tubers, and (3) the final weight of good tubers. The prevailing price of potato in markets in close proximity to the stores under study was noted at the time of both storage and sale.

Results and Discussion

Cooling efficiency

Daily and weekly temperature data taken from the beginning of storage in March to 1 June (the time of selling) indicated that there was a uniform reduction in temperatures between ambient and the inside of the store. The morning (0800 h) ambient temperatures were not significantly different from the temperature inside the store (Figure 2). The outside temperatures in the morning began to rise significantly from March to the end of May. The difference between the temperature from 0800 h to 1400 h averaged around 16°C.

Temperatures increased from about 35°C in March to more than 40° C at the end of May for readings taken at 1400 h; inside the EVS the temperature recorded at 1400 h was 12-19°C lower than the ambient. The turbine influenced uniform upward movement of evaporating moist, cool air through the potato pile and reduced fluctuations in tempera-

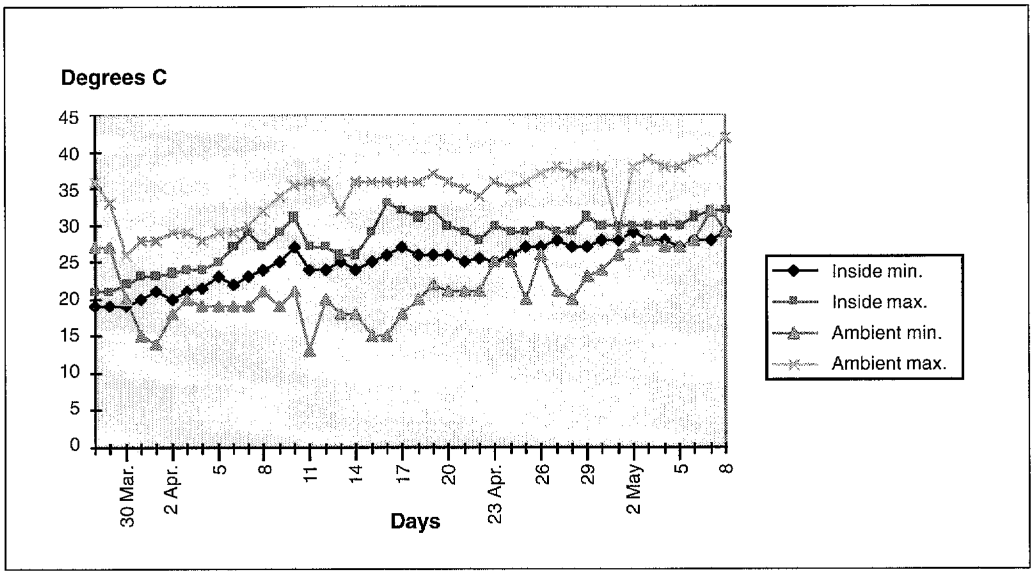


Figure 2. Comparison of minimum and maximum inside and outside air temperatures in EVS, March to April 1996.

ture inside the store. The temperatures inside the store observed at 0800 h and 1400 h were not significantly different. Therefore, early morning hours are the best times to inspect the stores.

The airflow provided by the turbine reduced the desiccation of potatoes in storage, and maintained a uniform temperature inside the store depending on outside temperature and humidity.

Reduction in losses

In 1995, average total losses were 11.3% in Muzaffarnagar and Meerut, and 20.4% in Farrukhabad. The losses were substantially less (10%) at the research station, which may be because of better maintenance and management of the store at the research farm. The minimum losses of 3.5% were observed at a farm in Bopada village in Muzaffarnagar. This farmer was very progressive and worked on the construction of the EVS, and took a keen interest in monitoring temperature and water levels in the trough.

During 1996, farmers of Farrukhabad suffered losses of 2.8-10.4%, over a storage period of 24-61 d. The losses in potatoes stored for 61 d in the ordinary room were 13.9% compared with 10.4% in EVS during the same period (Figure 3). The reason for short-duration storage in some stores was the sale of potatoes by farmers when the prices were comparatively higher than at harvest.

In 1996, losses of the EVS in Meerut varied from 6% to 11% over a storage period of 43-53 d. The farmers who stored in March, when temperatures were still low, had only 8% losses in an 85-d storage period. Rotted tubers varied from 0.7% to 3% and sprouted tubers varied from 5.5% to 98.7%. Maximum sprouting was noticed in the case of the farmer who stored the longest (85 d).

Farmers in the study area without storage facilities heaped their produce. The losses in heaps were 4.3% and 7.5% in storage periods of 33 and 35 d, respectively. The 7.5% losses in heaps during 35 d was higher than a 6.9% loss in EVS during 47-d storage. Farmers who stored their potatoes in heaps were paid lower prices because of the low quality.

There was a significant reduction in temperature and increase in humidity inside the EVS during the hot, arid months from April to June, thus maintaining a higher quality of stored potatoes. Weight losses in potato were

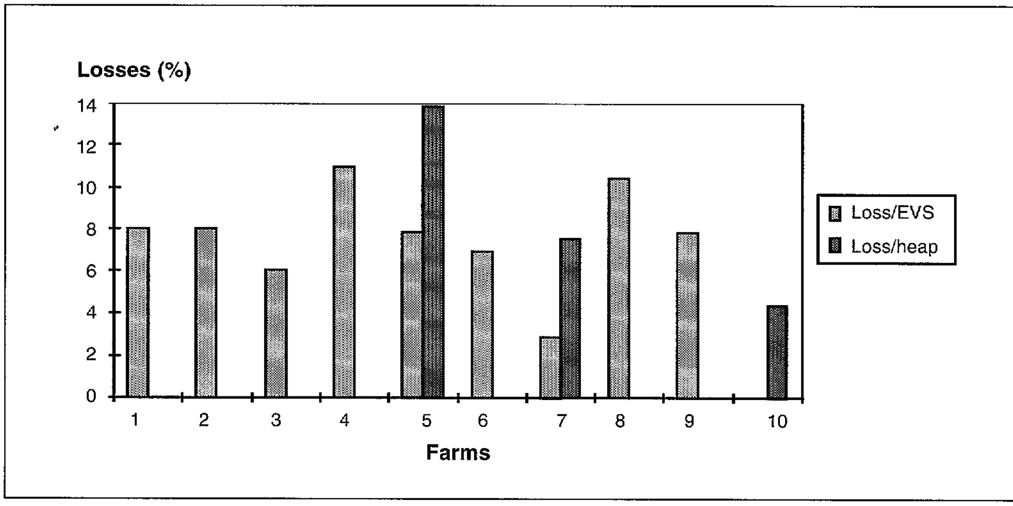


Figure 3. Comparison of storage losses for potatoes stored in EVS and those stored in heaps after 61 d, 1996.

influenced by variety, preharvest and postharvest management practices, store construction, and store management.

This study was the first major attempt to take the technology of rustic storage to farmers' fields. The results indicate that potatoes stored in EVS had lower weight loss and higher quality at sale time. An added advantage is that the EVS provided a convenient means of keeping potatoes in bad weather, whereas those stored in heaps were exposed to rain and desiccation.

Losses in the Farrukhabad stores were higher than those in Meerut and Muzaffarnagar. There was no climatic difference in these districts and the losses may be attributed mainly to leakages and poor management of water in the troughs. Although stores were located in close proximity to tube wells, the nonavailability of an assured source of power and the lethargy of farmers to keep the sand surface moist resulted in lower cooling efficiencies.

Lower losses in 1996 at all sites compared with 1995 strengthens the line of thinking that store management plays a key role in potato storage. Farmers were more knowledgeable about potato storage during the second year of the trial and thus reduced their storage losses.

Profitability

Profitability of an improved technology is the main factor that influences adoption. The EVS technology was more profitable than the farmers' practice of storing potatoes in houses and in heaps. In Farrukhabad, the price of potato was Rs 2.1/kg ($0.06/kg) when stores were filled. It had increased to approximately Rs 3.75/kg ($0.11/kg) after a period of 24-61d. The gross return was 11% higher per kg of potato stored in EVS than in ordinary rooms and in heaps.

In Meerut, overall weight loss in potatoes stored in EVS varied from 6% to 11% over a storage period of 43-85 d. The gross returns in heaps ranged from Rs 189/t ($5.30/t) to Rs 494/t ($14/t) compared with Rs 269/t ($7.62/t) to Rs 1,030/t ($29/t) for potatoes in the EVS. The highest gross return was earned by a farmer who stored for the longest period (85 d) in the EVS, because he received the highest sale price in June. But when net profits are considered, heaping of potatoes is more profitable because of the high cost of constructing EVS. Storage in heaps, however, has a risk of high rottage due to rain. Neither can potatoes be stored as long in heaps as in EVS.

More than 20% of the potatoes grown in the Uttar Pradesh plains are used for seed and stored in cold stores after harvest. Uttar

Pradesh is traditionally a seed supplier to the rest of the potato-growing areas and therefore depends heavily on cold stores. This has resulted in a concentration of cold stores in Uttar Pradesh. Any new technology must have significant advantages over cold stores, traditional heaps, and other structures. The cost of EVS is still higher than that of the heaps or other structures, and not significantly lower than the cost of cold storage per kg of potato.

The EVS has a definite advantage for farmers wanting to dispose of their potatoes in the early months of storage, for those who do not want to be at the mercy of cold-store owners, and for those unable to avail themselves of cold-store space at harvest. If the storage cost of the EVS could be significantly reduced to below the cost of cold storage, then EVS could be justified for short-term storage. If not, Uttar Pradesh farmers will continue to use cold stores, which guarantee better produce quality even though their availability fluctuates. Table 1 compares costs and returns for the EVS, heaps, and pits with the cost of cold storage.

Table 1. Comparison of storage cost of EVS, heaps, and pits with the cost of cold storage[a].

	Value	EVS Rs	US$	Value	Heap Rs	US$	Value	Pits	US$
Fixed cost									
Cost of constructing store storage:		20,100	574		1,000	29		3,000	86
Salvage cost		804	23		40	1		150	4
Life span	10		—			—	10		—
Depreciation		1,930	55		240	7		285	8
Interest on investment (%)	14	2,814			140	4	14	420	12
Total fixed cost		4,744	136		380	11		705	20
Variable costs of storage									
Labor for loading and unloading and water use/yr		360	10		500	14		600	17
Repairs/yr		480	14		100	3		200	6
Weight of potato in storage (kg)	10,000			10,000			10,000		
Price of potato at storage/kg	2.50			2.50			2.50		
Cost of potato in storage		25,000	714		25,000	714		25,000	714
Total variable cost (including potatoes)		25,840	738		25,600	731		25,800	737
Total cost (including potatoes)		30,584	874		25,980	742		26,505	757
Total cost (without potato)/kg/yr		0.56	0.016		0.10	0.003		0.15	0.004
Cold-storage costs/kg		0.60	0.02		0.60	0.02		0.60	0.02
Returns from storage									
Losses in storage (%)	6.9			7.5			7.5		
Price at time of sale (Rs/kg)		4.47	0.13		4.13	0.12		5.00	0.14
Risk loss in kg				75					
Weight at sale (kg)	9,310			9,175			9,250		
Gross returns from sale		41,615	1,189		37,893	1,083		46,250	1,321
Net profit		11,032	315		11,913	340		19,745	564
Net profit/ton		1.10	0.03		1.19	0.03		1.97	0.03

a. This calculation is made for traditional heaps in the field for a similar duration as the EVS of 75 days for the same farmer.

Adoption domains

The cooling efficiency of the EVS during the hot, arid months from April to June gave a higher-quality potato to the market. But farmers have yet to understand the need for overall management of both produce and stores during the storage period, if the technology is to be successful.

The Uttar Pradesh plains are semiarid. Temperature rises to about 44 °C in summer and drops to about 3-4 °C during winter. The states of Madhya Pradesh and Gujarat have temperatures similar to Uttar Pradesh, but the humidity is even lower. The scope for EVS adoption is higher in these three states than in all the other potato-growing areas in India.

Increasing interest and demand for processed potato, mainly for chips, is creating a significantly increased demand for indigenously stored potatoes. Large processing companies pay premium prices for good-quality potatoes that have not been in cold storage in Madhya Pradesh. These potatoes have lower sugar contents and optimum processing quality.

In Madhya Pradesh, Gujarat, and Karnataka, cold-store space falls much short of the optimum level of 55% of the total produce (Table 2). Cold-store charges in these states are much higher than in Uttar Pradesh. Farmers in these states may find the EVS technology quite profitable for ware and for processing. These states cater to the needs of potato processors by storing potatoes in indigenous structures, built with high investments. The investment in EVS is significantly lower than the investment in traditional stores, which do not have the cooling and lower weight loss advantage of the EVS.

Conclusions

Rapidly increasing potato production in India is placing a strong demand on the currently available, limited postharvest facilities, especially those to store ware potatoes. By the year 2000, the country needs to be ready to handle an additional 8 million t of potatoes, although cold-store space is limited.

Store losses in the different districts varied from 4% to 11%. Loss depended mainly on the initial condition of potatoes going into storage and the duration of storage. Other factors such as store management and water control in the EVS troughs also contributed to losses. Losses in heaps were lower than expected, but still higher than losses in EVS for a similar duration.

Table 2. Potato production and cold-storage capacity in major potato-producing states of India, 1992-93.

State	Production (000 t)	Cold-storage capacity (000 t)	Cold-store space being used for other purposes (%)	Cold-storage capacity as percentage of potato production
Uttar Pradesh	5907.6	3585.3	0	60.7
Gujarat	444.3	203.9	30	32.1
Madhya Pradesh	367.5	158.3	20	34.5
Karnataka	452.4	19.1	55	1.9
Maharashtra	64.5	129.1	73	54.0

Source: Compiled from the information given by National Horticultural Board, Jan. 1995.

Profits (based on prevailing prices) of farmers were significantly higher for those who stored their produce efficiently for 2 mo or more.

Postharvest management of potatoes before storage and the management of stores after filling affect EVS efficiency. Proper management of the total storage system provides a better quality of stored produce.

Recent Advances in CIP's Strategy for Collaborative Postharvest Research on Sweetpotato

G.J. Scott and C. Wheatley[1]

Postharvest issues are particularly relevant to the development of root and tuber crops. Unlike the cereals, these crops are perishable. And given their seasonal production patterns, their effective use, either as planting material or for consumption, depends on proper preservation through storage or processing. In fresh form, root and tuber crops are bulky and low value in relation to transport costs. They are often produced in rural areas at considerable distances from urban consumption centers—a problem particularly acute in sub-Saharan Africa.

Greater availability of sweetpotato in the market and at reduced cost to consumers is contingent upon improved processing or marketing or both.

Roots and tubers often contain either toxic (glycoalkaloids) or unattractive (flesh color) traits that can be eliminated in processing. Postharvest activities enable roots and tubers to achieve their full potential as sources of food in other than fresh form (flour, meal, starch), as raw materials for secondary processed products (modified starch, noodles, glucose, candy), or in the form of feed (foliage, roots, by-products). In the case of roots and tubers, the combination of traditional knowledge and modern science offers particularly good promise for impact.

This paper presents a synthesis of the strategy and recent advances from CIP's collaborative postharvest research program for sweetpotato. The section on materials and methods summarizes the objectives and gives an overview of the four phases (Table 1) of CIP's postharvest research strategy. The paper then examines the results of the first two phases. Emphasis is on phase 2 activities during 1995-96.

Materials and Methods

Postharvest research at CIP has as its overall objectives those of the Center itself, namely, to increase production and use of sweetpotato. Postharvest research concentrates on varietal traits, raw material characteristics, processing techniques, and socioeconomic issues. The goal is to make processed products made from sweetpotato more affordable and nutritional and their production more profitable. As such, postharvest research aims not only to increase small farmers' and processors' incomes from existing production, but to provide the incentive for the adoption of yield-increasing, cost-reducing technologies provided by other areas of research at CIP.

As the planning of postharvest research on sweetpotato at CIP evolved in the 1990s, a global strategy with guiding principles gradually emerged (Table 1). The strategy has four phases, each with a specified but flexible timeframe, set of activities, and expected outputs. These phases are:

- Phase 1. Identification of problems and opportunities (1989-92).
- Phase 2. Evaluation of existing technologies and ex ante assessment (1993-96).
- Phase 3. Collaborative technology development, market research, and training (1997-2000).
- Phase 4. Enterprise development and ex post assessment (2000-2003).

---

1 CIP, Lima, Peru, and CIP, Bogor, Indonesia, respectively.

Table 1. Elements of CIP collaborative sweetpotato research strategy.

Objectives
- Increase and diversify crop use
- Increase incomes/welfare
- Increase nutrition levels

Means
- Make better products at more affordable prices
- Make processing more efficient and profitable
- Make sweetpotato more nutritious

Target beneficiaries
- Small farmers (producers/consumers)
- Small-scale processors
- Undernourished consumers

Phases
- Phase 1. Identification of problems and opportunities (1989-92)
- Phase 2. Evaluation of existing technologies and ex ante assessment (1993-96)
- Phase 3. Collaborative technology development, market research, and training (1997-2000)
- Phase 4. Enterprise development and ex post assessment (2000-2003)

Guiding principles
- Build on rural small-enterprise innovations
- Selective and prioritized locations and issues
- Participatory diagnostic and action research
- Flexibility

The phases in CIP's strategy for sweetpotato postharvest research closely reflect at a global, or macro, level, the steps involved in postharvest technology and marketing for root and tuber crops at the local, or micro, level. Microlevel steps are: (1) problem and opportunity identification, (2) research on products and processes, (3) pilot project, and (4) commercial-scale expansion. Phase 3 involves interdisciplinary and institutional collaboration, and direct involvement of users' groups (processors, consumers, and animal producers) as active research partners. To ensure widespread effect, phase 4 brings the postharvest research results together with other aspects of enterprise development. In the following section we describe the outcomes in phase 1 to provide the context for the more detailed review of recent results in phase 2.

Results and Discussion

Phase 1

Phase 1 ended with the consolidation of a global agenda for sweetpotato postharvest research that had been developed in collaboration with developing- and developed-country partners. That agenda was now to focus on 7 of some 100 sweetpotato-producing countries with the greatest processing potential, at particular sites within those countries, and on three types of priority products (Table 2). The products were starch, flour, and feed (i.e., roots and vines for pigs in Asia and vines for cattle in Africa and Latin America).

Phase 2

Phase 2 of CIP's sweetpotato postharvest strategy calls for a dichotomous approach. Macrolevel or regional studies look at the more long-term outlook for sweetpotato processing by examining existing or potential practices in light of production and use trends, prices, and trade patterns. This ex ante research seeks not only to assess the economics of existing processing but also to set targets for competitiveness and evaluate the prospects for achieving them. In keeping with the guiding principle of building on local rural momentum (Table 1), phase 2 also calls for evaluating existing technologies to complement the macrostudies. Key factors here are drying and extraction rates, costs, and identification of the postharvest attributes of potential processing cultivars.

Asia

China. China produces about 85% of the developing world's sweetpotatoes. Since the early 1960s, the percentage of production used for feed or processed products has risen steadily to over 50% of annual output. Relatively little information was available for projecting future sweetpotato uses. A more detailed assessment of the potential for sweetpotato processing in China involved four research activities: (1) a macroreview of Chinese secondary data and associated literature on production and use trends, (2) case studies in a select number of provinces to analyze county data on production and use, (3) a microlevel analysis of sweetpotato feed use in Sichuan Province, and (4) the evaluation and improvement of small-scale processing of sweetpotato roots into starch.

The macroreview and provincial case studies detected a recent reversal in the downward trend in area planted to sweetpotato in south, southwest, and central China (Figure 1). Sichuan Province in the southwest, which had become the largest pig-producing province in China, was suffering from a chronic shortage of feed maize. Farmers substituted sweetpotato for maize in their hog rations as a result.

Small-scale processing of roots into starch for noodles also had expanded tremendously, especially in Shandong and Sichuan Provinces. In Anyue County, Sichuan, for example, sweetpotato noodle production increased from 3,000 to 26,000 t between 1990 and 1996. Anyue noodles are marketed from the far west of China to coastal cities. Urbanization and income increases in China appear

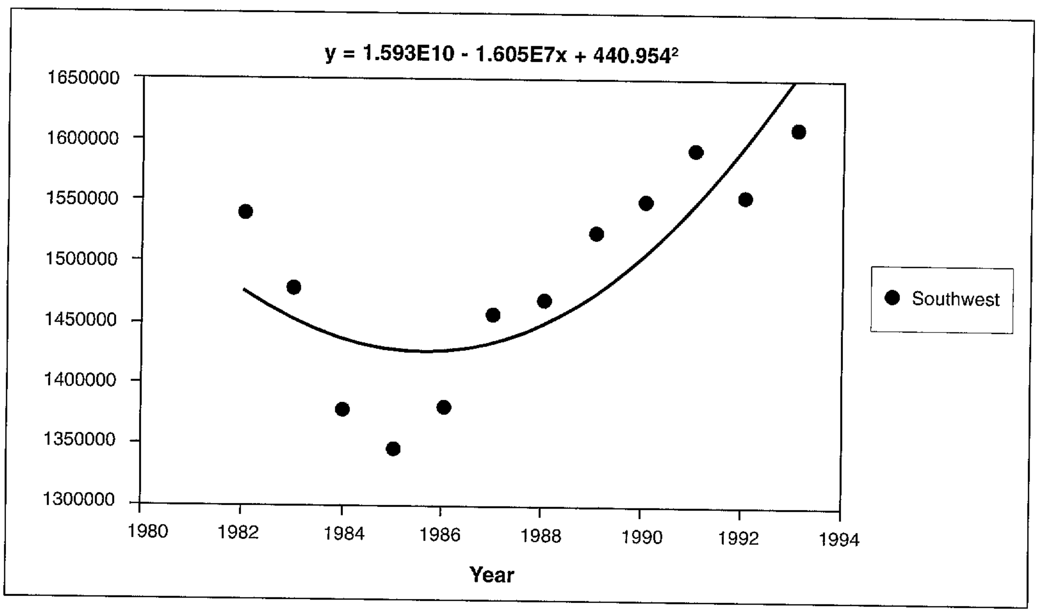


Figure 1. Sweetpotato sown area (ha) trends in southwest China, 1982-93.

to be driving demand for better-quality starch noodles, thus offering opportunities for small-scale processors to produce goods with high added value. Collaborative research with the Sichuan Academy of Agricultural Sciences (SAAS) focuses on quality improvement for both starch and noodles, and involves links with food scientists at Hong Kong University and processing enterprises themselves.

Feed and processing together account for well over 50% of use in most of the provinces studied and are clearly on the increase. Processing includes dried chips for feed, as well as starch. Research in China carried out by the Australian Center for International Agricultural Research (ACIAR) estimated that the expected benefits from sweetpotato were higher than for any other crops except rice and wheat. Ninety-five percent of the pigs produced in China are raised on small farms. The initial Center for Integrated Agricultural Development (CIAD)-SAAS farm-level analysis of pig production in Sichuan Province showed that the traditional sweetpotato feed system used by small farmers is inefficient due to nutrient-poor rations, which lead to low pig growth rates and prolonged production times. Adding appropriate feed supplements to sweetpotato offers the potential to increase efficiency and profitability on a small scale.

The composite picture of sweetpotato processing emerging from these studies is one of a great deal of local innovation with tremendous potential for growth to the benefit of the poorest households in rural China. Priority research topics include efforts to improve technical efficiency in feed operations, and commercialization studies to target the most dynamic markets for starch and related products.

Philippines. Ex ante impact assessment in the Philippines focused on the potential for sweetpotato use as animal feed and flour. The study notes that the limited demand for fresh roots offers little incentive for sweetpotato producers to increase production.

Instead, the report identified a site in Central Luzon as the most promising site for sweetpotato processing enterprises. Success will depend on government policies to (1) facilitate the adoption of high-yielding varieties with high dry matter content, and (2) improve processing efficiency. Since the study was completed, the private sector has established medium-scale sweetpotato starch plants in Central Luzon, targeting high-value export markets for noodle production in Korea. The performance of these enterprises, especially in relation to the supply of fresh roots, will be relevant for assessing the feasibility of producing starch or other products for domestic markets.

Latin America

Recent research on sweetpotato postharvest issues in Peru resulted from the collapse in prices paid producers in early 1990 and the ever-increasing imports of wheat flour. The private sector responded by partially substituting raw, grated sweetpotato for wheat flour in a new type of sweetpotato bread. Subsequently, exploratory research projects all provided positive indicators of the potential for sweetpotato bread and other products. Beginning in 1995, CIP coordinated a Dutch Ministry of Foreign Affairs (DGIS)-funded project on sweetpotato product development for flour, starch, and foliage.

Results from the work on sweetpotato as a wheat flour substitute have been mixed. The raw, grated method turned out to be hard to sustain on other than a novelty basis because of seasonal and year-to-year price fluctuations, and the logistics of securing and grating regular supplies of fresh roots. Trade liberalization and the lifting of subsidies drove the price of wheat flour down, not up as expected. That made the substitution of sweetpotato flour even more problematic.

On the other hand, CIP-supported research found the use of sweetpotato in flour-like form in a children's weaning food highly attractive. This product is intended for mass distribution in the government-sponsored campaign to help eradicate malnutrition in the most vulnerable segments of Peru's population. The weaning food formula has attracted interest by large-scale food processors. The cost of sweetpotato flour has resurfaced as a key issue, especially as the price of imported wheat flour has experienced some sharp price hikes in recent months. The government-sponsored weaning food program also calls for some 70-80% of the ingredients to be produced domestically.

Sub-Saharan Africa

Sweetpotato postharvest research in eastern Africa focused initially on poor, female farmers and women's groups engaged in sweetpotato processing in the dry, western part of Kenya. Earlier consumer surveys and product testing had shown there was an interest in sweetpotato as a flour substitute. A CIP multidisciplinary team and scientists from the Kenyan Agricultural Research Institute (KARI) at the outset faced the challenge of doing postharvest research with a crop that people were remarkably unfamiliar with when it came to uses other than simply boiling it for direct human consumption. The collaboration had two principal thrusts.

One involved using sweetpotato to make a variety of locally popular baked goods (chapatis, mandazis). Different ways were tried, but all were within the capabilities of the intended, limited-resource beneficiaries. These new uses for sweetpotato and the associated simple processing techniques proved quite attractive. Some procedures were tried for a while and dropped; others were quickly adopted as income-generating activities, sometimes in modified form.

Another thrust was to improve nutrition levels through a package of related initiatives. Among them was encouraging women sweetpotato farmers to plant varieties shown to do well under local growing conditions and to contain high amounts of beta carotene. This would help overcome vitamin A deficiency, which is high in western Kenya.

Proposed work includes (1) improving quality control, (2) incorporating the high beta carotene-containing varieties into processed products, (3) increasing the widespread diffusion of improved varieties and simple processing practices, and (4) conducting an ex post appraisal of the effect of these initiatives. In addition, the technical and economic feasibility of using sweetpotato as an ingredient in composite flours needs to be assessed if growers in western Kenya are to penetrate rapidly growing urban markets in that part of the country and elsewhere.

Conclusions

Recent results from phase 2 encompass the evaluation of existing technologies and assessment of the potential for future commercial expansion of processing activities. This work centered primarily on the seven target countries and the three priority products identified in phase 1 (Table 2). We achieved the following results:

- Documented the importance and potential of postharvest activities.
- Generated initial impact through the ready transfer of existing skills and technology.
- Developed institutional linkages necessary for addressing the tasks in phase 3.
- Sharpened the geographic and product-specific focus of future research on technology development.
- Empowered national scientists to achieve their research objectives more quickly through training and workshops.

Based on these results, CIP's collaborative postharvest research now enters phase 3. Greater priority will be given to work on starch and roots for feed in Asia, and flour and fodder in Latin America and Africa.

Selected Reading

Cabanilla, L.S. 1996. Sweetpotato in the Philippines: Production, processing, and future prospects. International Potato Center (CIP) and the University of the Philippines at Los Baños, Lima, Peru. 100 p.

Gitomer, C.S. 1996. Potato and sweetpotato in China: Systems, constraints, and potential. International Potato Center (CIP), Lima, Peru. 183 p.

Table 2. Sweetpotato research sites and products.

Target country	Site	Ecology	Priority products			
					Animal feed	
			Starch	Flour	Roots	Foliage
China	Sichuan	Subtropical	+	–	+	–
Indonesia	Malang	Tropical post-rice	–	+	–	–
Kenya	Houma Bay	Semiarid	–	+	–	–
Peru	Central Coast	Desert lowland	+	+	–	–
	Condebamba	Tropical highland	–	–	–	+
Philippines	Central Luzon	Tropical lowland	–	+	+	–
Uganda	Lira	Semiarid	–	+	–	–
Vietnam	Thanh Hoa	Subtropical	+	–	+	+

Wheatley, C. 1996. Small-scale enterprises: What might the future hold for rural households and root crops? In: Into action research: Partnerships in Asian root crop research and development. UPWARD, Los Baños, Laguna, Philippines. 1996. p. 171-190.

Enhancing the Role of Small-Scale Sweetpotato Starch Enterprises in Sichuan, China

C. Wheatley[1], Lin Liping[2], and Song Bofu[3]

Sweetpotato, *Ipomoea batatas* (L.) Lam., is a major component of small-scale Chinese farming systems, which produce more than 100 million t of fresh roots annually. Since the 1960s, use of the crop has shifted from direct human consumption toward animal feed and industrial uses. Shandong and Sichuan provinces, with annual sweetpotato root production of over 20 million t each, have developed important starch industries based on small-scale extraction of starch and its use in transparent noodles, which also are produced largely on a small to medium scale. In Shandong, some 30-40% of sweetpotato production is used for starch extraction; in Sichuan, about 15%.

In Sichuan Province, where CIP has worked with the Sichuan Academy of Agricultural Sciences (SAAS) for over 7 years, significant progress in upgrading the technology level of small-scale enterprises has been achieved. Manual processing of the roots has been largely replaced by small- and medium-scale mechanized equipment (root washers, grinders/raspers, horizontal and drum separators, and inclined channel sedimentation). The introduction of small-scale, single-screw extruders has allowed increases in productivity and output of sweetpotato starch noodles. Several items of equipment also used for potato starch processing are now manufactured commercially and distributed beyond Sichuan Province.

Sichuan is an inland province, distant from the booming coastal regions of China. The province is densely populated (110 million people). Incomes are below the national average: rural per capita annual income in Sichuan was US$85.00 in 1993 (75% of national average rural income, and only 29% of national average urban income). Consequently, Sichuan is now a major source of economic migrants.

Increased use of sweetpotatoes in Sichuan, whether for feed or starch, offers real potential for rural income generation in those areas where sweetpotatoes are grown, and where the need for poverty alleviation is acute. SAAS and CIP research has, since 1994, focused on evaluating the status of sweetpotato starch enterprises and identifying opportunities for their further development. This has entailed integrating market and technical research.

Materials and Methods

Starch enterprise appraisals

Three starch enterprises in Santai County were selected as case study units on the basis of ownership type (private or collective), scale of operation (0.2-0.8 t fresh roots per h), whether manual or mechanized, and the starch sedimentation method used (natural sedimentation in tanks, sour liquid, or inclined channels). Three batches of fresh roots were followed through the normal process operations for each enterprise.

During November 1994, a participatory appraisal of the small-scale starch extraction enterprises was carried out. Data on the technical operation of the process, through direct measurement and observation of normal operations, were complemented by relevant in-

1 CIP, Bogor, Indonesia.
2 Crops Research Institute, Sichuan Academy of Agricultural Sciences (SAAS), Sichuan, China.
3 Chinese Academy of Agricultural Sciences (CAAS) and CIP.

formation on the food system in which each enterprise operated.

Fresh roots of Xushu 18 from one field plot were used as raw material for all appraisals. To determine the effects of differing raw material quality on technical performance and process economics, at Guanqiao enterprise fresh roots of Mianfen 1 were also processed. Mianfen 1 has a high fresh-root starch content, but lower fresh-root yield, than Xushu 18.

Technical performance of the enterprise was evaluated on a batch basis (per kg fresh roots processed), and then recalculated on a product basis (per ton dried starch produced). Most (60-80%) of the starch was sold or used immediately as wet starch cakes (moisture content 45%) for noodle production. For the purposes of analysis and comparison, however, results are presented as dry starch equivalents.

On a dry matter basis, prices for wet and dry starch are nearly the same. Drying is worthwhile only if the starch is to be marketed or stored.

Economic performance was determined on a per metric ton dried starch basis plus additional revenues from the sale of moist residues. In many cases the residues are used directly for pig feed by the same household, but for the purposes of enterprise analysis the 1994 market price ($2.40/ton wet residue) has been used.

Market research

A 1995 market survey, conducted jointly by the Center for Integrated Agricultural Development (CIAD) of Beijing Agricultural University and SAAS assessed the potential demand for sweetpotato starch in both food and nonfood industries.

We used secondary information to develop an inventory of Sichuan enterprises that use starch as a raw material for the manufacture of food and other products, for selecting a representative sample of enterprises for interviews, and for estimating starch demand in Sichuan. The field study included sweetpotato starch and wholesale markets, sample starch enterprises, and key informant interviews with scientists and industry leaders in Sichuan.

Process research for quality improvement

During 1996, SAAS process research scientists studied two ways in which small-scale enterprises could improve the quality of the starch they produce through (1) process modifications appropriate to their scale, and (2) use of different sweetpotato varieties.

Using Nanshu 88 in an orthogonal experimental design, the effects of varying the ratio of water to weight of fresh roots (3:1, 6:1, and 8:1), mesh size during separation of starch suspension from fibrous residue (80, 100, and 120 mesh), and sedimentation time (8, 16, and 24 h) on starch yield and quality were studied. Starch yield was calculated at standard 14% moisture content.

Analyses of starch (Layne and Eynon method), lipid (Soxhelet extraction), ash (incineration at 525°C for 1 h), and protein (macro-Kjeldahl) of the dried starch samples were carried out by SAAS Central Analytical Laboratories. Whiteness was determined by fluorescence analysis, and by a sensory panel.

Similar analyses were carried out in a second experiment to determine the variation in starch purity across 10 sweetpotato varieties or promising selections.

Results and Discussion

Starch enterprise appraisals

The appraisal data showed that all enterprises were profitable with high returns on investment, despite low use of installed capacity (Table 1), caused by problems in raw material supply. In 1994, drought lowered sweetpotato production in Sichuan, and reduced the length of the processing season.

The dry starch yield (14% moisture content) ranged from 10% to 18%, depending on both process and variety (Table 2). Improvements to process efficiency, especially at the separation stage, would increase profitabil-

Table 1. Principal performance and profitability data from the three sweetpotato starch extraction enterprises from Santai County, Sichuan, China, 1994.

Enterprise	Changping (household, manual)	Gaoyan (collective)	Guanqiao (family)	
Sweetpotato variety processed	Xushu 18	Xushu 18	Xushu 18	Mianfen 1
Yield of dried products (14% moisture content) as % initial fresh-root weight				
Dry starch	10.0	13.4	13.1	18.1
Dry residue	12.0	8.4	12.4	14.4
Production costs (US$/ton dry starch)				
Variable	389	256	264	232
Fixed	22	37	15	15
Total	411	293	279	247
Variable costs (%) due to:				
Fresh roots	85.8	97.4	96.2	96.2
Labor	12.5	1.2	2.4	2.4
Profit				
Net profit/ton dry starch (US$)	48	100	116	146
Total profit 1994 (US$)	315	662	1,525	1,752
Profit as % sales income	10.5	25.5	32.1	37.1
Return on investment	71.1	23.9	140.0	160.8

Table 2. Starch quality (purity) specifications of Sichuan industries compared to the chemical composition of sweetpotato starch produced by small-scale enterprises in Santai County, Sichuan, China, 1994.

Composition	Sichuan industrial specifications for starch purity[a]			Sweetpotato starch[b]
	Super grade	First grade	Second grade	
Moisture content (%)	14	14	14	15-18
Ash (%)	0.10	0.20	0.20	0.38-1.07
Protein (%)	0.35	0.50	0.80	0.21-0.57
Lipids (%)	0.10	0.15	0.30	0.02-0.10

a. Source: Survey of industrial starch users in Sichuan, Center for Integrated Agricultural Development (CIAD) and Sichuan Academy of Agricultural Sciences (SAAS), 1995.

b. SAAS analyses of starch samples from enterprise appraisals.

ity since more starch would be produced per unit of roots processed.

At Guanqiao enterprise, where two varieties were compared, Mianfen 1 yielded more dry starch and greater profits, allowing the enterprise to pay farmers a higher unit price for Mianfen 1 roots. The low labor costs, as a proportion of total costs, in the two mechanized enterprises are encouraging. Any future increases in labor costs should have a small effect on overall enterprise profitability. Use of higher starch varieties (such as Mianfen 1) by farmers should be encouraged by the processing industry, and adequate price incentives should be given, as justified by process economics.

Demand for starch processing equipment is high. One of four starch processing equipment manufacturers in Santai County, Sichuan, reported that from 1992 to 1996 sales of sweetpotato processing equipment more than doubled (240%) for starch extruders, and nearly tripled (288%) for root washers. The sales value of root washers, starch separators, and extruders totaled over US$180,000 in 1996, 85% of total agricultural equipment sales. Between 1992 and 1996, sweetpotato processing equipment sales were valued at $630,000.

Although neither sweetpotato production area nor volume changed appreciably between 1989 and 1995 (production in Santai County varied between 82,000 and 93,000 t/yr), the proportion of sweetpotatoes that were processed increased from 36% to 76%. Of 91,000 t produced in 1995, 69,000 t were processed. That was accompanied by an increase of 70% in the number of pigs produced in the area during the same period (110,000 in 1995). Pig production is closely linked to starch processing through use of residues for feed.

Market research

The results of the market survey were surprising. Companies complained of severe shortages of maize starch (the major starch used) because of (1) insufficient maize production in Sichuan itself, with demand for maize starch exceeding local supply by over 100,000 t in 1995, (2) competition from the feed industry for raw materials, and (3) difficulties in importing starch or maize from other provinces. This last problem was due to congested transport infrastructure and the unavailability of maize elsewhere in China because the richer coastal provinces bought up available supplies for themselves.

This situation represents an opportunity for sweetpotato starch to fill a supply gap. Sweetpotato starch in Sichuan has consistently been priced below maize starch (Figure 1). But sweetpotato starch extraction on a small scale is more profitable than maize extraction on a large scale. At 1994 prices, the net profit on maize starch extraction was $35/ton compared with $60/ton for sweetpotato, even after including the income from maize starch by-products.

Sweetpotato starch product quality, however, was rated poorly by industry. The starch contains impurities such as excessive moisture and ash (Table 1), and is not sufficiently white. Impurities can be reduced through process improvements. Shandong Province produces refined sweetpotato starch using equipment similar to that in Sichuan by additional purification and drying steps.

Research for quality improvement of sweetpotato starch

Mesh size and volume of water used were found to significantly (P=0.0001) affect starch extraction rate and ash content of the extracted starch. All treatments produced starch that met maize starch standards for lipid and protein impurities. Starch whiteness increased with increased volume of water used and finer mesh sizes, but decreased with increased sedimentation time. The ash content of even the best starch samples, however, exceeded acceptable limits (lowest sample value: 0.38%) (Table 2).

For both starch yield and product quality, the optimum processing conditions were found to be 1:6 ratio of root weight to pro-

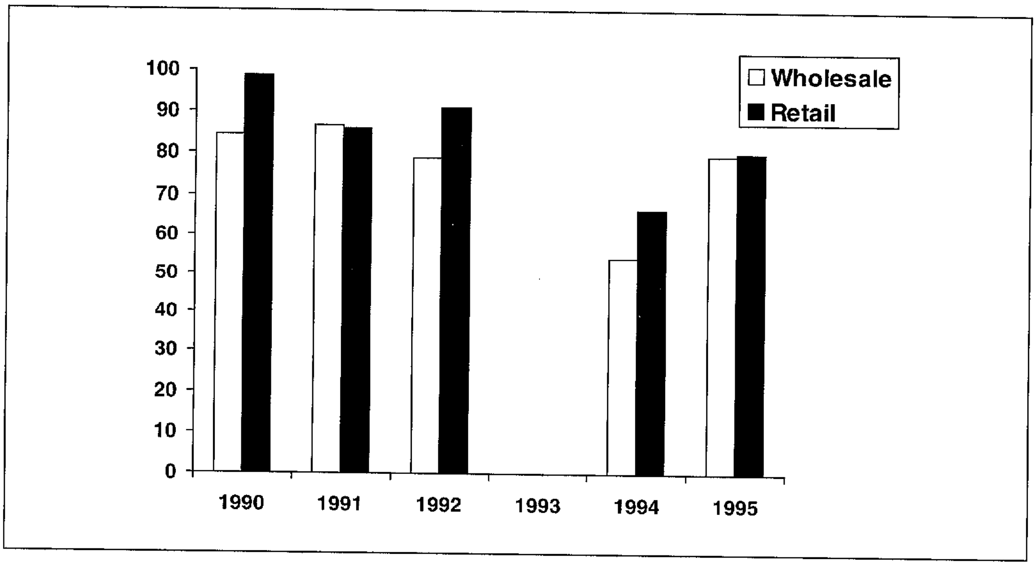


Figure 1. Wholesale and retail price of sweetpotato starch as a percentage of maize starch price in Sichuan Province, China, 1990-95.

cess water, 120 mesh (finest size), and 8 h precipitation. More efficient root washing to ensure more efficient soil removal before processing could reduce ash content of the starch.

Starch was also extracted, under standard conditions, from 10 different sweetpotato varieties/promising selections, from the SAAS Breeding Section. Significant differences were found between the 10 varieties tested for starch content percentage, and lipid and ash content of the extracted starch (Table 3). This suggests a potential to improve starch purity through a varietal approach if the fresh-root and starch yields remain attractive to farmers.

Table 3. Effect of variety on purity of extracted starch (14% moisture content). The varietal effect was significant for all three parameters (starch, lipid, and ash contents). Letters denote mean separation at a=0.05.

Sweetpotato variety/clone	Starch content (%)	Lipid content (%)	Ash content (%)
Chuanshu 27	81.3 a	0.11 e	0.653 b
9014-3	74.9 e	0.32 abc	0.646 a
Chuan 778	73.7 f	0.13 de	0.594 c
53-5	78.9 b	0.13 de	0.492 f
Shengnan	78.9 b	0.43 ab	0.482 d
303	76.6 cd	0.45 a	0.460 a
9102-1	79.5 b	0.30 bc	0.408 g
92-113-70	77.0 C	0.27 cd	0.392 h
Nanshu 88	75.7 de	0.26 cd	0.385 g
89-1524	82.1 a	0.43 ab	0.358 e

Conclusions

Any diversification of markets for sweetpotato starch in Sichuan will depend upon producing a product with greater purity than that currently available in the market. Such a high-grade starch would also permit the production of noodles of higher quality and value. Recent private-sector investment in Shandong Province points to improved starch quality as a prerequisite for producing export-quality noodles.

The starch and noodle agroindustry in Sichuan is predominantly small scale. These rural entrepreneurs have made significant investments in equipment during the last few years, despite the strong seasonal nature of the business. The processing season may last only a few weeks from late October to mid-November each year. Such seasonality is unfavorable for the establishment of large-scale starch extraction plants, which would remain idle for most of the year unless they were involved in processing other raw materials. That situation provides an opportunity for smaller-scale enterprises to benefit from the expansion of market demand for starch in Sichuan, and for the development of noodle products of higher quality and value.

The technical and market research activities between CIP, the Chinese Academy of Agricultural Sciences (CAAS), and SAAS will feed into these and other efforts. Finally, close links have been established with regional centers of excellence in starch research (Hong Kong University and National University of Singapore), which will assist in relevant technical research and professional development of project collaborators in China.

Selected Reading

CIAD and SAAS. 1995. Potential for market diversification of sweetpotato starch and flour in Sichuan Province. Center for Integrated Agricultural Development (CIAD) and Sichuan Academy of Agricultural Sciences (SAAS), Beijing Agricultural University, Beijing, China. 28 p.

Collado, L.S. and H. Corke. 1997. Properties of starch noodles as affected by sweet potato genotype. Cereal Chem. 74:182-187.

Marter, A.D. and W.H. Timmins. 1992. Small-scale processing of sweetpotato in Sichuan Province, China. J. Trop. Sci. 32:241-250.

Feasibility, Acceptability, and Production Costs of Sweetpotato-Based Products in Uganda

V. Hagenimana[1] and C. Owori[2]

Sweetpotato (*Ipomoea batatas*) is one of three staple crops in Uganda, but its postharvest use is remarkably narrow and limited to human consumption in a fresh, boiled form. The small number of ways in which sweetpotato is used, and the limited processing technologies available and adapted to the area, do not permit the potential benefits of the crop to reach farmers and consumers. Research on the identification of potential markets, the assessment of consumer acceptability for new sweetpotato products, and the feasibility and adaptability of new recipes and processes are important in the widening of sweetpotato use.

Sweetpotato is grown everywhere in Uganda. It provides a good part of the dietary starch throughout the year. Fresh sweetpotato is consumed with sauces containing beans, cowpeas, or vegetables. Boiled or steamed fresh sweetpotato is the prevailing form of consumption. To a limited extent, sweetpotato is also chipped or crushed and dried for storage from November through January. The dried sweetpotato is then boiled with sauces or tea, or milled into flour and mixed with millet to process the local porridge called *atapa*.

Myriad products can be made using sweetpotato as a major ingredient, but some attitudes and cultural habits related to acceptability of a new food product need to be overcome. Sweetpotato, either fresh, grated, cooked and mashed, or made into flour, could, with high potential for success, replace the expensive wheat flour in making bread, chapatis (Indian-type flat bread), and mandazis (doughnuts). Sweetpotato-based products are of high quality and could compete with existing products on the market.

This paper reports the results of a study undertaken in Lira District, Uganda, to examine the feasibility and profitability of partially substituting sweetpotato cooked, mashed, or as flour for wheat flour when making bread or buns, chapatis, and mandazis; and the acceptability of sweetpotato products by consumers.

The work was conducted primarily within the community together with women's groups and individuals at Lira's main trading market.

Methods

The method used to collect information in this report was a combination of analysis of available secondary data, informal interviews, formal questionnaires, and new product processing and taste testing by users.

The processing steps of the products had to be adapted to the equipment and utensils available. Members of the community were asked to evaluate samples of a product containing sweetpotato and compare it to the type of product just purchased or usually bought. Most people interviewed were from the Lango ethnic group, and sweetpotato is their staple food.

Results and Discussion

Food production and consumption in Lira

Agriculture is the main economic activity in Lira. Cotton once dominated as a cash crop,

1 CIP, Sub-Saharan Africa region, Nairobi, Kenya.
2 National Agricultural Research Organisation, Kampala, Uganda.

but poor producer incentives and inadequate supplies of cotton seeds have caused a big slump in cotton production. Consequently, farmers are shifting their attention to other, new cash crop opportunities.

As a staple food, finger millet ranks first followed by cassava, sorghum, and sweetpotato. Cassava, which was an important cash crop and famine reserve in the past, has been devastated recently by the high incidence of the African cassava mosaic virus. The price of cassava on the markets of Lira District is now 7-8 times higher than in 1989. In contrast, the price of other major staples has only doubled or tripled. Hence, sweetpotato is becoming an important and cheap staple food in the district because of cassava virus problems and the poor yield and other uses of finger millet and sorghum.

Varieties of sweetpotato in Lira Municipality

Neither sweetpotato retailers nor buyers pay any attention to variety in Lira. During our survey, there were heaps of sweetpotatoes in the market with red-skinned ones mixed with white-skinned ones. The varieties were the local varieties Tedo-Olokeren (white skin, white flesh), Luacer or Edopolap (red skin, white flesh), Mbale or Tanzania (white skin, yellow flesh), Anamuyito (red skin, white flesh), and Odyek-Awili (pink skin, white flesh). Tedo-Olokeren was by far the most common variety. In Lira it is believed that Tedo-Olokeren is hard and resistant to weevil attack. It is also white, starchy, and floury when cooked as are most other varieties generally preferred in Uganda. The price of fresh sweetpotato in Lira's main market was from US$0.01 to $0.02 per 1 kg (US$1.00 = 1,000 Uganda shillings).

Consumer food preferences

As mentioned, finger millet along with sorghum, cassava, and sweetpotato are the staple foods of the area. Breakfast food is usually a light porridge made from a flour mixture of finger millet, sorghum, or cassava. Bread is not a breakfast item, but a rare and expensive snack food. It is usually eaten with tea in the evening. Its consumption was found to be as important as that of mandazis. Chapati was not considered a snack; it was eaten for lunch or dinner as a main food of the meal.

From the ranking exercise for preference of available foods on the market, sweetpotato and bread ranked first, whereas chapatis and mandazis were fourth. About 25% of consumers interviewed ranked cassava second, but most others ranked it sixth or seventh, mainly because of its current low availability. Irish potato chips were less known in the area, because potatoes were not grown in areas near Lira. These chips were ranked mostly last like kabalagala (a sort of cassava-banana pancake).

Availability of baked and fried products in Lira

Table 1 lists the snack products and bread sold daily in different markets of Lira Municipality. The activity of trading mandazis, chapatis, kabalagala, cake, and bread involves an exchange of about US$700/day, and the activity employs more than 100 people. Half of trade is in bread and a third in mandazis.

During the survey, we noted that many households baked buns. We counted 11 small and locally made ovens for bun baking. The bread sold in Lira is mainly locally processed, but there is also bread from Kampala, Jinja, and Kisumu (in Kenya).

The price of bread was US$0.60-0.80 for a 500-g loaf. But few people in Lira can afford to buy a whole loaf. Instead, bread was being sold by the slice for $0.05 each; mandazis and kabalagala were also sold for $0.05 each and were popular in the municipal markets. Women were the major players in selling fried and baked products.

Feasibility and acceptability trials for baked sweetpotato products

Fresh sweetpotato roots used for the trials were purchased from Lira's main market. They were a mixture of white- and red-skinned varieties with white flesh. Sweetpotato flour was processed from dried sweetpotato slices purchased from a farmer

Table 1. Fried and baked products sold in different markets of Lira Municipality, March 1995[a].

Market	Mandazis			Chapatis			Kabalagala		
	Sellers (no.)	Quantity sold (no.)	Price/unit[b] (US$)	Sellers (no.)	Quantity sold	Price/unit (US$)	Sellers (no.)	Quantity sold	Price/unit (US$)
Cuk-Alok	3	1,000	0.05	0	0	0.10	0	0	0.01
Junior Quarter	3	250	0.05	0	0	0.10	0	0	0.01
Main Market	7	1,200	0.05	3	600	0.10	2	500	0.01
Obang Apewany	4	350	0.05	0	0	0.10	4	350	0.01
Kakoge	2	100	0.05	0	0	0.10	4	550	0.01
Soroti Road	4	350	0.05	0	0	0.10	2	250	0.01
Barogole	6	500	0.05	1	60	0.10	3	700	0.01
Kitgum Road	3	550	0.05	0	0	0.10	0	0	0.01
Aduku Road	4	500	0.05	2	50	0.10	1	250	0.01
Total	36	4,800		6	710		16	2,600	
Total (US$)		**240**			**71**			**26**	

a. Bread was sold only at one place near the bus station of Lira Municipality. It was traded as a 500-g loaf or as a 12-bun packet. The cost of a loaf of bread varied between US$0.60 and $0.80 while that of a 12-bun packet was $0.60. About 100 loaves of bread and 450 packets of buns were sold daily. Other baked products at the market were cakes worth $20.00. Each was sold at $0.10.

b. US$1.00 = 1,000 Uganda shillings.

in Lira Municipality, then ground in the usual hammer mill. The wheat flour was that usually used for bun- or bread-making in Lira Municipality.

Bread-baking, chapati, and mandazi processing trials were conducted under local commercial conditions using a mixture containing various proportions of wheat flour, sweetpotato flour, or cooked and mashed sweetpotato roots. The recipes used have been reported elsewhere.

Because chapatis and mandazis are deep fat-fried, the amount of fat absorbed by the products is nutritionally and aesthetically important and influences production costs. In the experiment to determine whether differences in fat absorption varied by the form of sweetpotato (boiled and mashed, raw and grated, or dried flour), we found that substituting 50% of wheat flour with boiled and mashed sweetpotato significantly reduced oil uptake in mandazis (Figure 1).

Acceptability was evaluated by comparing sweetpotato bread, chapatis, and mandazis (using sweetpotato flour or cooked and mashed sweetpotato to substitute for wheat flour) with similar products the consumer has just bought from the market or had ever tasted. Attributes such as overall taste, texture, freshness, appearance, sweetness, and color were judged subjectively by bread, chapati, and mandazi consumers. Consumers were informed that our products contained sweetpotato as an ingredient.

The results (Figure 2) show that bread, chapatis, and mandazis containing cooked and mashed sweetpotato were preferred by consumers for taste, texture, freshness, appearance, sweetness, and color. Consumers expressed a willingness to pay the same price

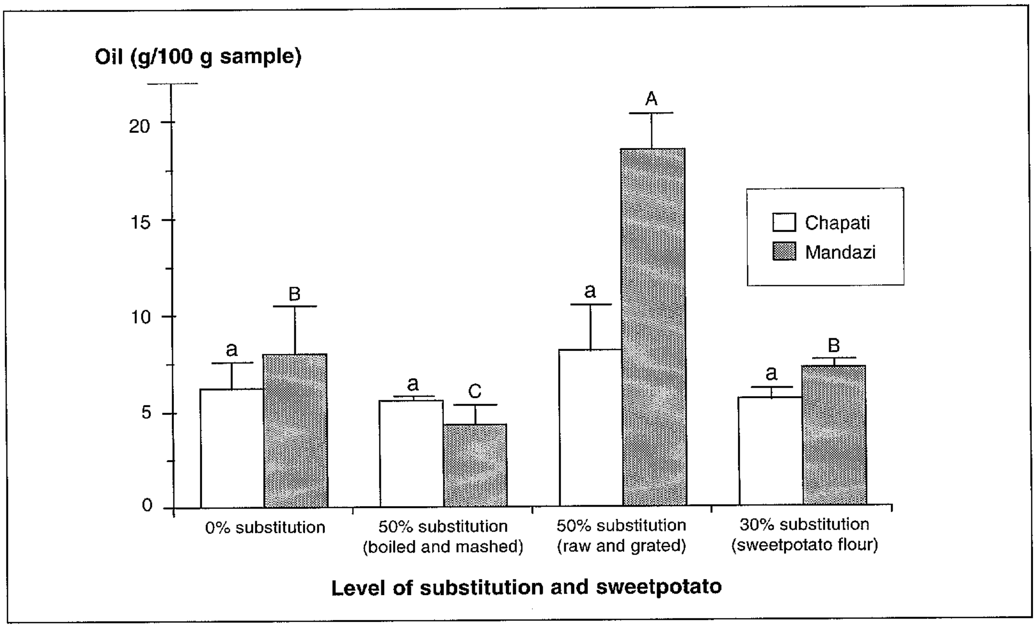


Figure 1. Oil content in processed sweetpotato products. (Means followed by common letters for the same product are not significantly different at the 5% level by LSD.)

for sweetpotato products as for similar products they had been buying. Figure 3 shows the sales trend for sweetpotato buns at a women's group kiosk in Lira over a 7-mo period.

Production costs

The data collected during the study indicated that it was cheaper to produce sweetpotato bread or buns, chapatis, and mandazis than to produce similar products using 100% wheat flour. This was mainly due to the reduction in the amount of wheat flour, sugar, and oil required to make mandazis compared with the cost of ingredients of traditional mandazi recipes that incorporate sweetpotato. Table 2 compares net revenue for chapatis, mandazis, buns, and bread made using only wheat flour and sweetpotato, and shows a significant profit increase when sweetpotato is used.

Conclusions

Baked and fried products having sweetpotato as an ingredient are highly acceptable to the community. Cooked and mashed sweetpotato as an ingredient improves the taste, texture,

Table 2. Comparative gross margins of sweetpotato products and wheat flour products, Lira, Uganda.

Product	Net revenue per product (US$)		
	Wheat flour	Sweetpotato cooked & mashed	Sweetpotato flour
Chapatis (1 piece)	0.032	0.045	0.047
Mandazis (1 piece)	0.014	0.023	0.023
Buns (1 piece)	0.007	0.014	0.015
Bread (1 loaf of 500 g)	0.058	0.065	0.069

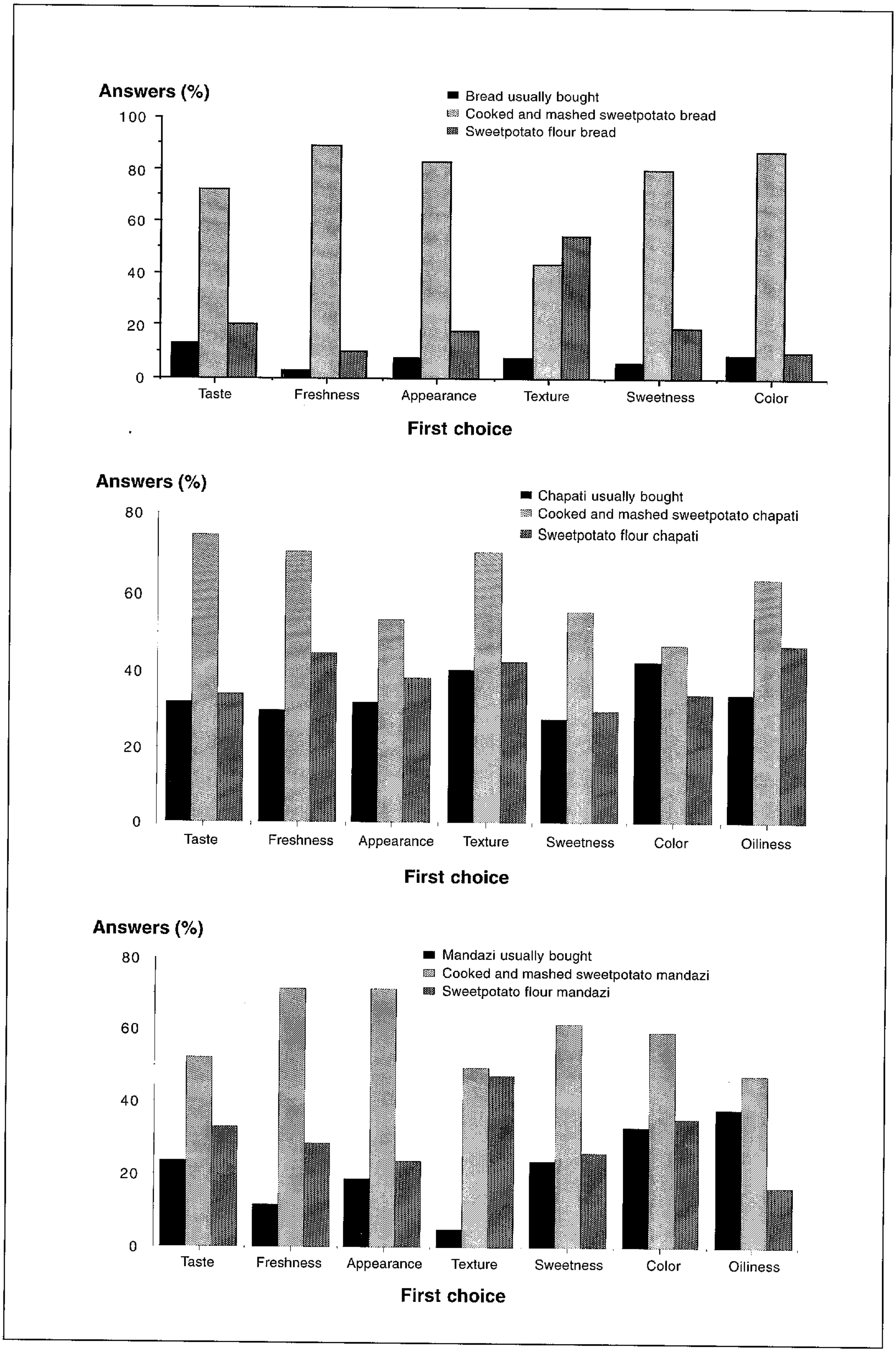


Figure 2. Consumer acceptability of baked and fried sweetpotato products.

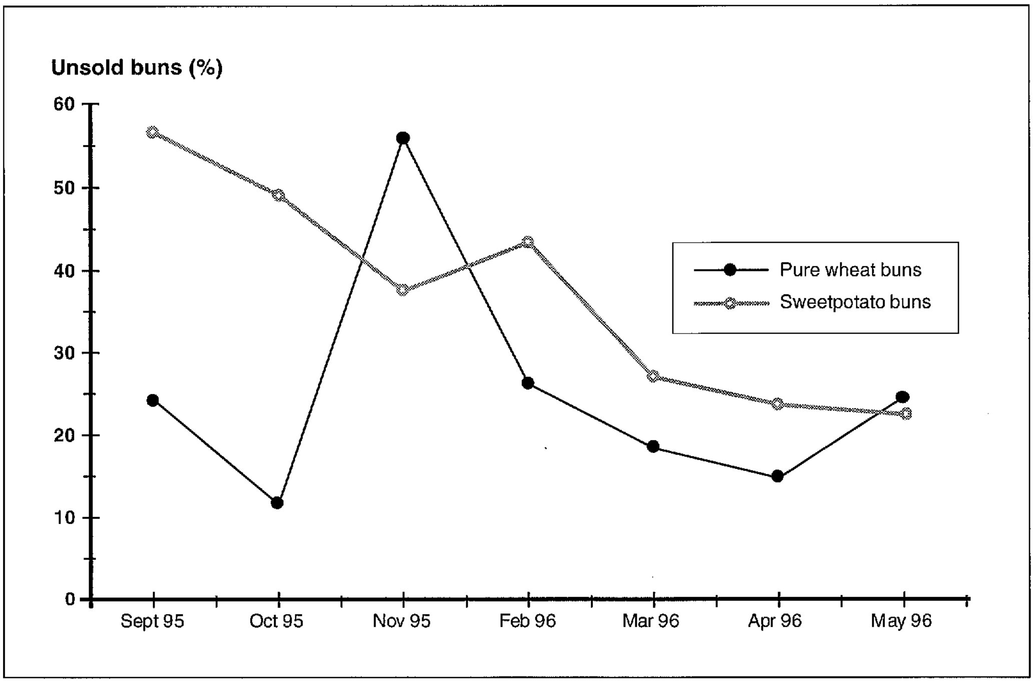


Figure 3. Percentage of unsold buns for the 1st day on the market at women's group kiosk, Lira. Sweetpotato buns accounted for one-third of total buns.

freshness, appearance, sweetnesss, and color of bread or buns, chapatis, and mandazis. It also significantly reduces oil uptake in mandazi and chapati processing. Sweetpotato flour is easy to store and process, and is highly profitable. Still, much more fundamental research is required to upgrade the quality of sweetpotato-based fried and baked products.

Selected Reading

Bashaasha,B., R.O.M. Mwanga, C. Ocitti p'Obwoya, and P.T. Ewell. 1995. Sweetpotato in the farming and food systems of Uganda: A farm survey report. CIP and NARO, Uganda. 63 p.

Hagenimana, V. and C. Owori. 1996. Feasibility, acceptability, and production costs of sweetpotato baked products in Lira Municipality, Uganda: A study report. CIP/NRI and NARO, Nairobi, Kenya.

Hagenimana, V., E.G. Karuri, M.A. Oyunga. n.d. Oil content in fried sweetpotato processed products. J. Food Proc. Pres. (In press.)

Wheatley, C., G.J. Scott, R. Best, and S. Wiersema. 1995. Adding value to root and tuber crops: A manual on product development. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 166 p.

The Potential of Root Crop Processing for Rural Development in Vietnam

G. Prain[1], C. Wheatley[2], and Nguyen Doy Duc[3]

Vietnam is a leading world producer of sweetpotato (*Ipomoea batatas*) and cassava (*Manihot* spp.), and is probably the global leader in area planted to edible canna (*Canna edulis*). Historically, these crops were important seasonal, supplemental, and emergency food sources, but in the past 15 years, they have begun to assume greater importance as raw materials for value-added processing. Feed and starch are the dominant intermediate processed products. Pork, transparent noodles, candies, and baked goods are common end products. The expanded processing activity has been almost exclusively based on household initiative.

1 CIP, Los Baños, Philippines.
2 CIP, Bogor, Indonesia.
3 Post Harvest Technology Institute, Hanoi, Vietnam.

Since the mid-1980s, however, public-sector research agencies have been working to introduce the processing innovations that were developed in villages around Hanoi to other parts of the country. The mixed results from those efforts led CIP and several international and national research partners to begin an assessment, in 1995-96, of current use of root crops in four key sites in north and central Vietnam (Figure 1). The sites were in Bac Thai, Hatay, and Thanh Hoa Provinces in the north, and Quang Nam Da Nang Province in central Vietnam.

Sweetpotato and cassava are the two main root crops grown in farming systems in north and central Vietnam. Edible canna is less important, but was included in the study be-

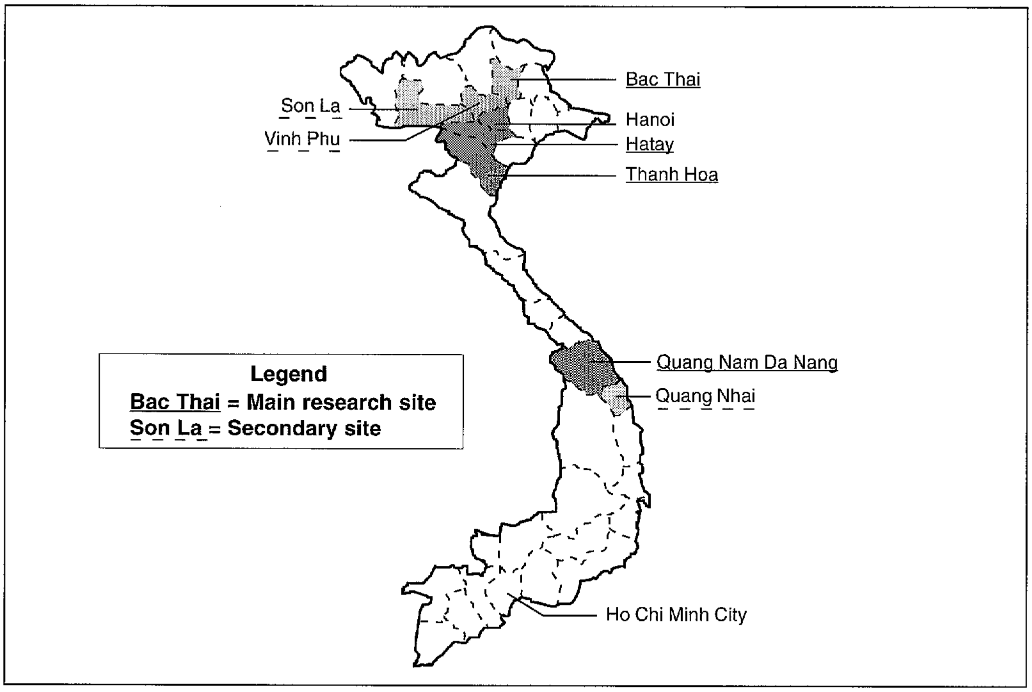


Figure 1. Provinces in north and central Vietnam where root crop utilization research was conducted.

cause of its Andean root crop ancestry and its importance in noodle making.

The majority of farm households in the provinces under study depend on crop-livestock systems to secure a rice-based food supply for the household as well as cash income. Both food and cash depend on an adequate supply of manure for the crops and an adequate supply of feed for the animals. When processing is undertaken for additional income, it provides a further supply of feed in the form of by-product, but it increases demand for raw material.

In Thanh Hoa Province, fresh consumption of sweetpotato by producer households declined from around two-thirds to one-third of total production from 1980 to 1994. A similar decline is also evident in cassava, but the change of function of these two crops has been different. Whereas the primary function of sweetpotato has shifted from household food to household animal feed, cassava has become a cash crop. It is grown primarily as raw material for the growing processing industry, but the processing by-product finds a ready market as animal feed.

Sown area and production trends for cassava over the past ten years show a gradual downward trend throughout the period in all four provinces (Figure 2). The abrupt decline in cassava in Hatay, which is close to Hanoi, can be attributed to a switch to sweetpotato by some farmers and a move from cultivation to more lucrative food processing and nonfarm enterprises. A strong upward trend in sweetpotato began around 1990, especially in Hatay and Thanh Hoa, where it is increasingly cultivated for pig feed.

Role of Root Crops in Pig Raising

From 1985 to 1995, pig liveweight in the north rose from 299,000 t to 580,000 t; per capita pork consumption more than doubled. The massive increase in sweetpotato area in Hatay, from 5,000 ha to more than 20,000 ha between 1990 and 1993, is directly attributable to the use of sweetpotato for feed.

Pig-raising systems

Two household-based pig-raising systems prevail with different implications for pig feed research. In one system, piglets are fattened for slaughter. Many households combine these systems (Table 1).

In Da Nang, households commonly concentrate only on breeding piglets, partly because of better access to the piglet markets of southern Vietnam and Laos. Fattening is the more common practice, especially in the more remote, poorer areas of the north. In Bac Thai, for example, there is an average of three fattening pigs per household, whereas only one in four families has a breeding sow. In high mountain areas of Bac Thai, Thanh Hoa, and Da Nang, cattle are more common domestic animals, mainly because of the availability of open pasture.

There is considerable variation in the numbers of pigs managed by different households (Figure 3), which is an important consideration in technical intervention. Families fattening only one pig are least likely to be interested in innovations. With more pigs, improved performance becomes commercially attractive.

Da Nang again stands out as different from the other sites. Not only do many households have two or more breeding sows, many more households are fattening only one piglet. That suggests the low priority and noncommercial character of fattening in Da Nang.

Bac Thai and Hatay have similar numbers of households engaged in fattening. Both appear to have greater commercial pig-raising than Thanh Hoa. In Hatay and in Thanh Hoa, of households fattening more than four pigs, only five have more than 10 head, and of those the largest operation has 40 head. These are the only large-scale pig-raising enterprises encountered, emphasizing the backyard character of most pig-raising.

Feed regimes

The two most notable findings about swine feed regimes are (1) the dominance of

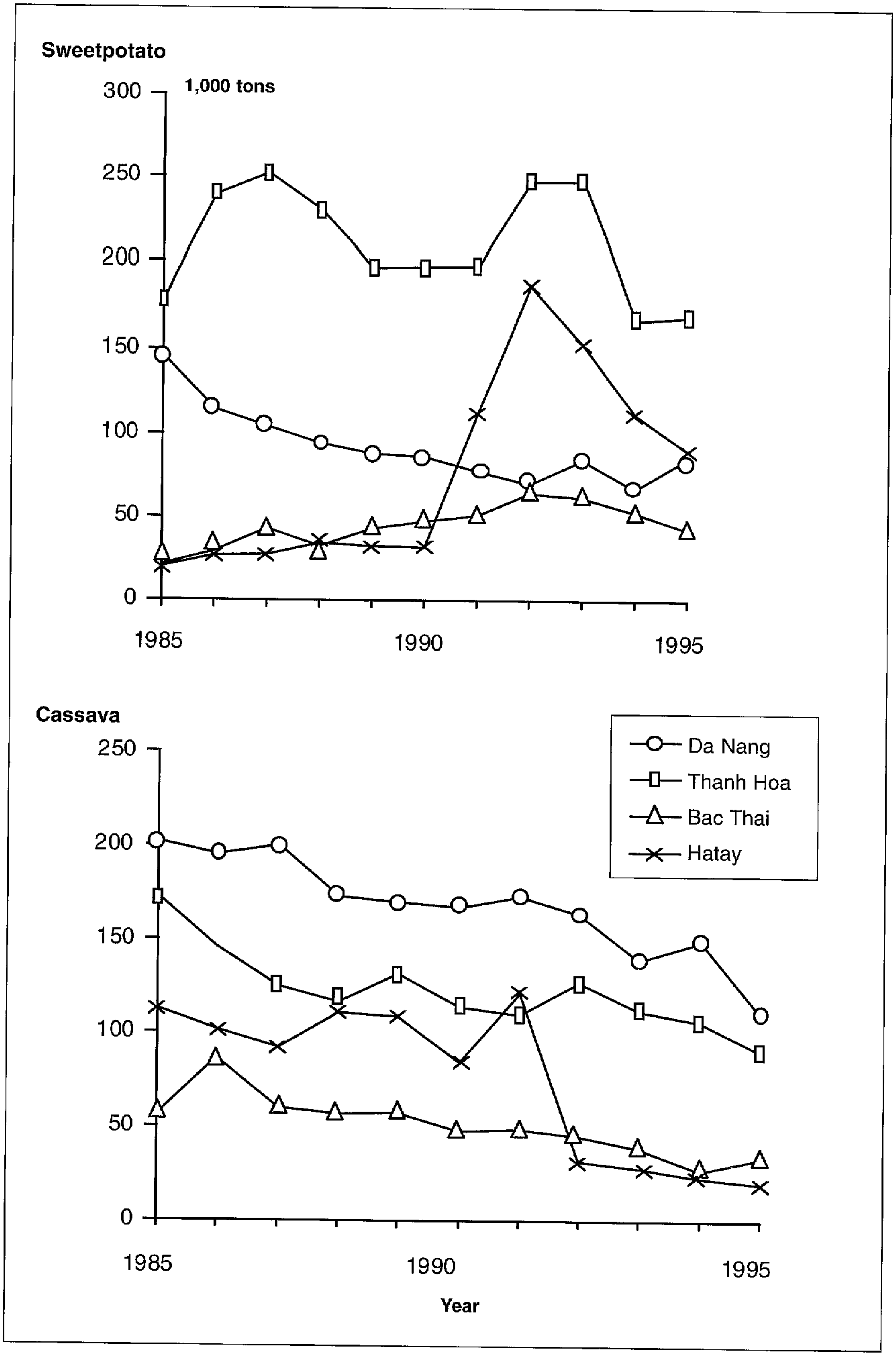


Figure 2. Sweetpotato and cassava production in four provinces of Vietnam, 1985-95.

Table 1. Pig-raising strategies in case households of four provinces, Vietnam, 1995.

Province	Households (no.)			
	Fattening	Breeding	Both	Total
Bac Thai	21	0	9	30
Hatay	15	1	14	30
Thanh Hoa	8	2	7	17
Da Nang	9	5	6	20

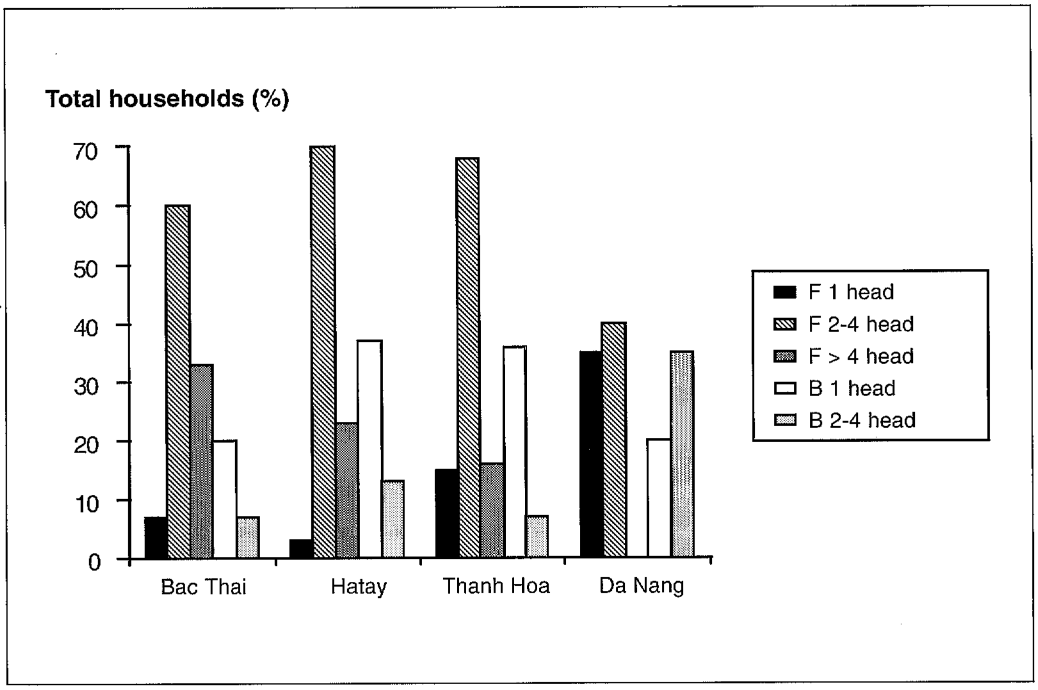


Figure 3. Pig-raising systems among case households in four provinces of Vietnam, 1995. (F = fattening, B = breeding.)

sweetpotato vines over roots, and (2) the limited use of protein-rich supplements, even in coastal areas where fish by-products are relatively cheap.

Vines are the most important component of pig diets in 7 out of 12 pig-rearing households in Bac Thai. In one case, vines accounted for 45% of the approximately 2.4 t of feed given to a single animal over a 12-mo growing period.

Cassava is the most important feed component in mountain households. In Hatay, the by-product from starch-processing villages accounts for up to 80% of total feed, in combination with root crops. A large part of the root crop component, however, is vines rather than roots.

On the coastal plain of Thanh Hoa, sweetpotato roots, both fresh and dried, are much more important as feed than at other sites. This is an area with as many as three harvests of sweetpotato per year and where storage of dried sweetpotato chips is relatively common. Sweetpotato vines are also important as feed.

The feed regime also varies in Da Nang. In the plains, 75% of feed consists of sweetpotato vines and small roots, whereas at higher elevations cassava by-product dominates, although sweetpotato vines still account for about 30% of total feed. Vines dominate over roots in Da Nang because of the concentration of households maintaining sows to produce piglets. Fresh or dried vines, cooked with other vegetative by-products, provide a better diet for piglets than roots.

Socioeconomic importance of pig-raising

In the plains of Bac Thai and in the Red River Delta, pig-raising contributed on average about 40% of income in case households in 1995, ranging from as little as 15% to as high as 64%. However, the purpose of pig-raising in Bac Thai is not primarily to generate direct income. Pig-fattening offers a way to convert nonfood farm output into manure and marketable pork using *surplus* labor—that of the elderly, the young, and the limited spare time of women.

Households that keep breeding sows follow a different strategy. For instance, in Da Nang farmers seek to reduce feed costs and use of nonfood farm output, and to reduce the risk of disease, by selling off piglets early. This system tends to generate less manure for the crop operation. This profit-oriented but risk-averse approach works well in the special circumstances of Da Nang, with its good links to piglet markets.

The highest profits were made by families that had combined breeding and fattening pig operations, and by those with the most animals.

Constraints and opportunities

Pig fattening and piglet breeding pose different constraints and offer different opportunities for intervention in root crop-based feed.

Households involved in multiple pig-fattening are interested in increasing the volume of feedstuffs produced on-farm, feed conversion characteristics of their animals, and the rate of weight gain. In Thanh Hoa, the farrow-to-finish time ranges from 6 to 12 mo. The difference is largely due to diet, both the volume of feed and the inclusion of protein-rich supplements. There are clearly opportunities here for exploring improved vine and root productivity and for evaluating alternative feed regimes.

Starch and Noodles: Prospects for Sweetpotato

Starch production in north and central Vietnam

Major sources. The two major sources of starch in north and central Vietnam are cassava and canna; sweetpotato is only a minor starch source at present. Cassava is by far the largest and cheapest source and small-scale processing occurs in most provinces (Table 2). Canna starch processing occurs on a smaller scale, primarily for the specialty production of transparent noodles. Canna starch enterprises were found in a few villages in Bac Thai and Thanh Hoa close to areas where the root was grown; canna processing is not done in Da Nang. In northern Vietnam, most cassava and canna starch production is concentrated in five villages in Hoai Duc District, Hatay Province, near Hanoi. A total of 5,679 households were processing cassava starch in 1995, consuming between 100,000 and 200,000 t of roots to produce around 50,000 t of starch. In the same area, 276 households processed about 34,000 t of canna into 7,500 t of starch in 1995.

Processing efficiency. The procedures to extract starch from cassava, canna, and sweetpotato are simple and cheap. Roots are washed (cassava roots are peeled first to prevent starch discoloration), grated, and filtered through cloth into a concrete container of water to make a slurry. The slurry is filtered four times and then allowed to settle for 6 h (longer in winter). The water is drained, leaving wet starch of 35-45% moisture content.

From 100 kg of cassava roots, about 42 kg wet starch can be extracted, yielding about 28 kg dry starch. Canna roots convert to 28-30 kg wet starch from 100 kg fresh wt, yielding 21-23 kg dry starch. Sweetpotato has the lowest extraction rate, yielding 25-30 kg wet

Table 2. Costs and benefits[a] of processing 100 kg of cassava roots into starch in four provinces of north and central Vietnam, 1995.

Province	Costs (US$)				Income (US$)				Net profit (US$)
	Fresh roots	Labor	Other	Total	Starch	Black starch	By-product	Total	
Hatay	4.36	0.75	0.32	5.43	6.11	0.32	0.27	6.70	1.27
Bac Thai	3.64	0.91	0.53	5.08	6.36	—	0.91	7.27	2.19
Thanh Hoa	4.18	0.91	0.09	5.18	5.27	0.29	0.73	6.29	1.11
Da Nang	2.21	1.14	0.13	3.54	3.78	0.34	0.91	5.03	1.49

a. The 1995 exchange rate was Vietnam D 11,000 = US$ 1.00.

starch or 17-20 kg dry starch from 100 kg fresh wt, depending on variety and time of year.

Cassava processing benefits. Producers of fresh cassava and canna and a variety of assembler and transport businesses supply the roots over long distances for sale to starch processors in Hoai Duc.

The concentration of processing households in one area in Hatay increases the efficiency of transportation, making it feasible to truck in fresh roots from up to 320 km away. It also facilitates the specialization of processing activities among households and the exchange of products and services. The large volume of final products generated enters a complex marketing system of processed products throughout north and central Vietnam. Consignment arrangements are common in this system between processors and traders.

Costs and benefits vary greatly among the cassava processors studied. Hatay processors have high transportation costs, which increases the price of the roots. But that is partly compensated for with higher processing efficiency. The profitability in Bac Thai is due to a higher selling price for wet starch of US$0.16/kg, compared with between $0.12 and $0.13/kg at the other sites, and a much higher valued by-product.

Though profitability is quite low for cassava starch processors, it represents about 60% of annual income for some households. In Thanh Hoa, the processing season runs from October to March. Average processing during the season for the case households is about 30 t of fresh roots, which yields just under $400 income.

Sweetpotato could be an alternative source of bulk starch in the north. At present there is almost double the quantity of raw material available (1.8 million t compared with 1 million t of cassava). However, the low starch extraction rate of sweetpotato makes cassava ultimately a cheaper raw material.

Transparent noodle supply and demand

Per capita noodle consumption in Vietnam in the early 1990s was 12-20 kg; transparent noodle may represent 10-15% of that. The most common raw material for transparent noodle over the past 30 yr has been canna root.

Canna starch and noodle processing is undertaken on a small scale in Bac Thai and Thanh Hoa, but the major production area is the same intensive processing district of Hoai Duc, Hatay. Unlike cassava-based processing, with its clear division of labor between starch producers and maltose processors, canna starch and noodle processing is often combined. Of the 276 starch-producing households in Hatay, 230 also produce noodles using their own starch.

The long growth duration of canna, usually from March to November, means that the processing season is quite short, generally from November to March or April. Although this covers the period of the Vietnamese New Year when noodles are most in demand, it limits the opportunities for optimizing investment at other times of the year.

In Bac Thai, where up to a ton of fresh roots can be processed in a day, average net profits of case households were around $16/d (Table 3). This compares to around $1/d for agricultural laborers. The bulk of starch and noodle demand is met from Hatay, thus inflating the costs of the final product in areas beyond Hanoi. The lower profitability of starch from Hatay reflects both the more expensive raw material, trucked in over large distances, and a lower starch price.

Noodle processing clearly offers the highest returns of the processing activities studied (Table 4). The net benefit recorded in Thanh Hoa may be overestimated. Unlike the other calculations, the Thanh Hoa calculation failed to include depreciation and underestimated costs for fuel and other inputs. The relatively low profitability of noodle production in Bac Thai is caused by a much lower conversion rate from starch to noodle, which is due to a different and less efficient processing technology that uses manual extrusion rather than steaming.

The potential of sweetpotato starch in noodle enterprises

The relatively narrow adaptation of canna at high altitudes, its remoteness from processing areas, and the long growing season mean that the supply of raw material is limited to a few months. But the period of raw material supply coincides with the period of highest demand for the starch, leading up to the New Year celebrations. Therefore, prices remain high, even during this glut period.

These raw material supply problems, however, have resulted in very little exploration of sweetpotato as an alternative. This is despite the proximity and stable supply of the crop—there are three harvests a year in some areas—and the limited fresh root market for sweetpotato, which frequently results in depressed prices.

Table 3. Costs and benefits[a] of processing 100 kg of canna roots for starch in three provinces of north Vietnam, 1995.

Province	Costs (US$)				Income (US$)			Net profit (US$)
	Fresh roots	Labor	Other	Total	Starch[b]	By -product[c]	Total	
Bac Thai	3.76	0.42	1.52	5.70	7.32	—	7.32	1.62
Hatay	4.09	0.91	0.31	5.31	6.70	0.04	6.74	1.43
Thanh Hoa	3.18	1.09	1.03	5.30	7.00	—	7.00	1.70

a. In 1995 the exchange rate was Vietnam D 11,000 = US$1.00.

b. Based on extraction of 22 kg starch at US$0.30/kg in Hatay, extraction of 22.4 kg starch at US$0.30/kg in Bac Thai, and extraction of 22 kg starch at US$0.32/kg in Thanh Hoa.

c. Canna starch by-product is less valuable than cassava by-product as animal feed because of its fibrousness. It is used mostly as compost.

Table 4. Costs and benefits[a] of processing 100 kg of canna starch into transparent noodle[b] in three provinces, Vietnam, 1995.

Province	Costs (US$)				Income (US$) noodles[b]	Net profit (US$)
	Canna starch	Labor	Other	Total		
Bac Thai	30.00	3.02	2.21	35.24	40.02	4.78
Hatay	30.45	4.09	18.86	53.40	60.36	6.96
Thanh Hoa	31.81	3.64	3.91	39.36	69.36	30.00

a. The 1995 exchange rate was Vietnam D 11,000 = US$1.00.

b. Based on conversion rates from starch to noodles of 1:0.59 in Bac Thai, 1:0.83 in Hatay, and 1:0.88 in Thanh Hoa.

The reluctance has been due to technical and cultural factors. Sweetpotato has a lower starch content than canna and the extracted starch has a grayish color. The noodles made from the starch also tend to be more brittle. Sweetpotato is also perceived as a food and feed crop, not an industrial raw material.

Technology development and participatory pilot studies in Hatay and Thanh Hoa Provinces have shown that it is technically feasible and profitable to use sweetpotato starch in transparent noodles. Using lime during starch filtration improves separation and yields a whiter starch. And combining canna starch with sweetpotato starch overcomes the brittleness of 100% sweetpotato.

Using sweetpotato starch, however, involves more work and processors require a lower price for sweetpotato starch to justify the extra effort. In addition, the supply of sweetpotato starch remains a problem and is not yet stable.

In 1996, pilot work on starch production, begun earlier in a southern district of Thanh Hoa Province, transferred to Hoang Hoa, nearer the provincial capital. Twelve households have enthusiastically adopted sweetpotato and canna starch production, first to supply noodle processors in Thanh Hoa City, and more recently to produce noodles themselves.

Almost all of the sweetpotato/canna noodle produced so far has been marketed and priced as canna noodle. In focus group discussions with a stratified sample of consumers in Hanoi during 1995, high-income consumers reacted negatively to sweetpotato as a raw material. But medium- and low-income consumers, who were more concerned with noodle quality than sweetpotato's image, gave a positive evaluation.

Conclusions and Opportunities

The enormous opportunities for economic development in Vietnam are mostly generated at the base, among rural households. The role of agriculture is increased productivity, of course, in addition to value-added products made available through processing. The processing of root crops for pig feed, starch, and noodles is an important part of that processing potential.

As a result of the appraisal of the use of root crops for pig feed, starch, and noodles, two projects have been established. The first project involves:

- evaluating genetic material for high foliage production and high protein content for use in pig-fattening enterprises,
- evaluating genetic material for high dry matter,
- assessing the use and costs of available

protein supplements to energy-based sweetpotato and other feed, and
- exploring alternative ways of preparing feed to improve digestibility and quality.

The second project aims to improve the efficiency of sweetpotato and canna for starch and noodle processing. It involves:

- supporting pilot units for sweetpotato starch and noodle production,
- evaluating new sweetpotato cultivars for potential in starch processing,
- evaluating new canna varieties for use in starch and noodle production, and
- supporting improved marketing linkages between starch producers and noodle producers.

Perspectives on Sweetpotato: Dual-Purpose Varieties

C. León-Velarde[1], J. Roca[1], J. Arteaga[2], L. Quispe[2], and A. Párraga[2]

Sweetpotato (*Ipomoea batatas*) is one of 12 main plant species used as human food throughout the world. The roots are used for human and animal consumption, and the vines are generally used for animal feed along with crop residue and unmarketable roots.

In the tropics, one of the main limitations to small farmers in mixed crop-livestock production is a reliable, year-round supply of feed and energy. Sweetpotato might help to overcome this limitation with minimal environmental damage. However, small farm size and low income from the crop limit the area grown to sweetpotato for use in livestock production only.

The germplasm collection held at CIP includes a large group of sweetpotato clones and varieties. Breeding efforts concentrate on root production, with emphasis on dry matter content, flour, and starch. One group of clones, however, produces mostly forage with low root production, which makes it ideal for animal feed. Although in recent years demand for these clones has increased, root production is also necessary for human food and as an income component of small crop-livestock farms.

On small crop-livestock operations, dual-purpose sweetpotato clones hold a comparative advantage over single-purpose varieties grown for roots or for forage. In an optimal integrated livestock management system, farmers could take advantage of sweetpotato's regrowth ability by continually or periodically harvesting the vines for animal feed throughout the growing season before finally harvesting the roots for human food. Because there is little information on the management of dual-purpose clones, this work focused on determining a preliminary roots-forage classification, and on developing management strategies for dual-purpose sweetpotato varieties. The work was done jointly by CONDESAN/CIP and the Universidad Nacional Alcides Carrión, Oxapampa, Peru.

Materials and Methods

We first established a preliminary classification for dual-purpose varieties based on the relative contribution of foliage and roots to dry matter (DM) content. Then we looked at how crop management affected the partitioning of DM in foliage and roots in five clones identified as having dual-purpose potential.

Relation of roots and foliage

A data set of 1,168 accessions from the germplasm collection held at CIP was analyzed in 1995 in La Molina, Peru, to establish a preliminary classification for dual-purpose varieties. We identified potential dual-purpose varieties based on the ratio of root to foliage (R/F) contributions in the production of total DM. Calculated values of R/F ranged from 0 to 4, but in some cases actual values exceeded the values in the range considered. As a result, we deleted 11.8% of the information. The extreme values resulted when in some cases a group of two or three plants was considered as one plant. When the germplasm collection was being evaluated, some varieties produced roots more quickly, whereas others did not.

As a consequence, we need uniform data collection over time from germplasm plots to

1 CONDESAN/CIP, Lima, Peru.
2 Universidad Nacional Alcides Carrión, Oxapampa, Peru.

accurately classify potential dual-purpose varieties based on R/F. We also need to complement that information with other bioeconomic characteristics not included in this preliminary classification. Systematized information of that type will be valuable for breeding to produce primarily roots, primarily forage, or roots and forage.

Table 1 shows a classification scheme of five categories based on R/F, ranging from 0, indicating no roots present, to 3-4, indicating high root production. There is some overlapping of categories on root and foliage production. Categories of low dual-purpose and high dual-purpose showed no significant difference for root production. Similarly, categories of high dual-purpose and low root production showed no significant difference for foliage production.

This work indicates the potential of crop varieties from low root production or high dual-purpose categories to perform well as a dual-purpose crop. A multivariate analysis (analysis of principal components) showed that the group of accessions classified within the range established (Figure 1). The forage category shows a wide dispersion, whereas categories 3 and 4 are grouped together, showing the potential of the accessions for dual-purpose use as well as for root production.

Management effects on R/F

The frequency of cutting forage from the growing crop is the main management factor. For livestock production, several cuttings of foliage are required throughout the crop-growth period, even though root production is sacrificed. When crop, rather than forage, production is most important, root development is paramount.

However, in the crop-livestock operation, both foliage and roots are desirable. Therefore, we evaluated potential dual-purpose clones to determine the effect of foliage cutting frequency on forage and root production.

Five clones were evaluated: DLP-3548, R/F 1.43; ARB-265, R/F 0.51; ARB-142, R/F 0.42; RCBIN-5, R/F 0.20; and ARB-UNAP55 (cv. Helena), R/F 0. The evaluation was carried out in Oxapampa, Peru, in 1996 during the dry and wet season, at 1,850 m above sea level. The zone presents an average temperature of 16°C and annual rainfall of 600 mm. Soils are neutral to slightly alkaline.

A split-plot design was used with the five accessions in the main plot, and foliage cuttings at 45, 90, and 135 d as treatments in subplots. Six cuttings were made at 45-d intervals, three at 90-d intervals, and two 135 d apart. DM and protein content were analyzed.

Table 1. Classification of sweetpotato dual-purpose varieties based on the relation of roots and foliage production of dry matter[a], CIP, La Molina, 1995.

Classification	Range R/F	Observations (no.)	Roots (g/plant)[a]	Foliage (g/plant)[a]	R/F
1. Forage	0-1.0	632	136.51 ± 3.21 d	140.72 ± 3.70 a	0.24 ± 0.01
2. Low dual-purpose	> 1.0-1.5	113	164.31 ± 7.60 c	133.58 ± 8.77 a	1.24 ± 0.03
3. High dual-purpose	> 1.5-2.0	82	180.97 ± 8.92 c	104.79 ± 10.29 b	1.74 ± 0.03
4. Low root production	> 2.0-3.0	127	212.04 ± 7.17 b	87.26 ± 8.27 b	2.45 ± 0.03
5. High root production	> 3.0	76	235.89 ± 9.27 a	68.19 ± 10.68 c	3.47 ± 0.03

a. Least mean squares and standard error. In a column, means followed by a common letter are not significantly different at $P<0.05$.

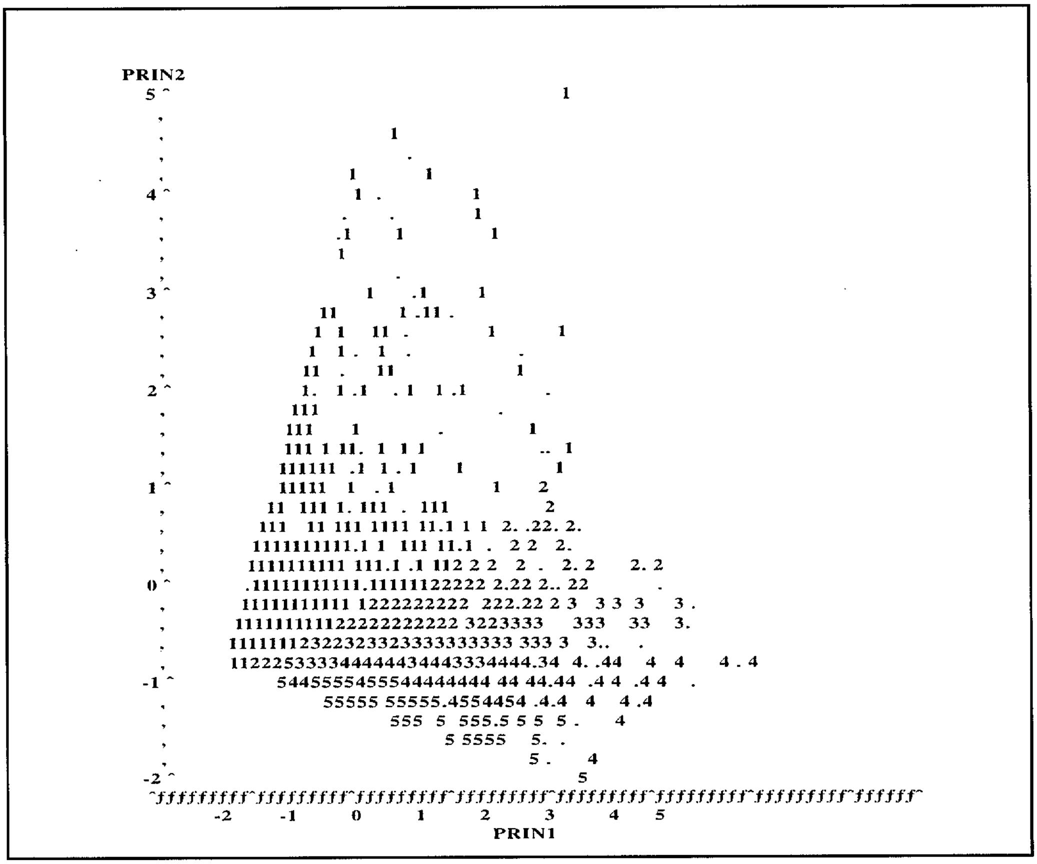


Figure 1. Graph of 1,168 sweetpotato accessions classified within five dual-purpose categories and plotted considering two principal components. The five categories are 1, forage; 2, low dual-purpose; 3, high dual-purpose; 4, low root production; 5, high root production.

Results

Table 2 shows total DM forage production at cutting frequencies of 45, 90, and 135 d. Forage production was significantly higher (P<0.01) in cuttings at 90-d intervals than in cuttings at 45- and 135-d frequencies. Cuttings at 45-d intervals give good forage production, but root production is nil. A cutting frequency of 90 d appears to strike a reasonable balance between forage and root production. A cutting frequency of 135 d increases root production but decreases forage production. R/F values increase as the intervals between cuttings increase, thus indicating better root formation. R/F values are within the range described in Table 1. The choice of a cutting frequency depends on whether forage or root production is the objective of the mixed crop-livestock farm.

The clone ARB-UNAP55 requires special mention. This clone is considered to have an R/F of 0, being strictly considered a forage variety. However, in certain zones such as Oxapampa and in Africa, it has been found to produce some roots, which may be evidence of a genotype x environment interaction. In this study, the R/F of ARB-UNAP55 is less than that of the other clones evaluated, and close to 0.

Table 3 shows the management effects of cutting frequency and fertilization on clone ARB-UNAP55. Although there is a positive effect of fertilization at rates of 60, 120, and 180 kg/ha N, DM production decreases with increased cutting intervals. A similar reduction in DM production was observed when the clone was evaluated for dual-purpose use. Although fertilization increases DM produc-

Table 2. Average production of dry matter in t/ha of forage and roots in five sweetpotato dual-purpose clones, and the relation of roots/forage (R/F), Oxapampa, 1996.

Clones	Frequency (days)								
	45			90			135		
	Forage[a]	Roots[a]	R/F[b]	Forage[a]	Roots[a]	R/F[b]	Forage[a]	Roots[a]	R/F[b]
ARB142	7.1	0.0	0.0	12.38	1.4	0.11	8.1	6.6	0.82
ARB265	10.4	0.0	0.0	14.25	3.7	0.25	9.7	8.3	0.85
DLP3548	9.5	0.0	0.0	14.51	2.4	0.16	10.5	6.7	0.63
RCBIN5	4.5	0.0	0.0	8.40	2.0	0.23	5.9	7.9	1.35
ARB-UNAP55	6.4	0.0	0.0	13.23	2.0	0.15	10.4	3.9	0.37

a. Dry matter production.

b. Relation of DM content of roots and forage; percentage of DM of forage production ranged from 13.1% to 16.1%; percentage of DM of roots ranged from 19.8% to 24.1%.

Table 3. Total production of dry matter (t/ha) of clone ARB-UNAP55 (cv. Helena) at different levels of N fertilization and different cutting frequencies, San Ramón, 1996.

Cutting frequency (days)	Nitrogen (kg/ha)			
	0	60	120	180
45 (6 cuts)	6.7	7.7	8.3	9.1
90 (3 cuts)	6.1	6.8	7.8	8.0
135 (2 cuts)	5.4	5.5	6.0	6.2

tion, the cost of this input must be considered in any technological alternative for sweetpotato forage production.

Conclusions

The analysis done on selected sweetpotato dual-purpose clones indicates that a cutting frequency of 90 d during crop growth gives the best balance between forage and root production. Harvesting foliage is hard work. Whether farmers are willing to invest in the labor required to gain maximum forage production depends on the crop-livestock mix. Studies on grazing cattle are necessary. Considering the wide number of clones available, future selections for consideration as dual-purpose varieties should include those characteristics that favor livestock production.

Selected Reading

SAS (Statistical Analysis Systems). 1986. SAS system for linear models. 1986 edition. SAS Institute Inc., Cary, North Car. 211 p.

Scott, G.J. 1991. Sweet potatoes as animal feed in developing countries: Present patterns and future prospects. In: Roots, tubers, plantains and bananas in animal feeding. Animal Production and Health Papers95. FAO, Rome. p. 183-189.

Woolfe, J. 1992. Sweet potato: An untapped food resource. Cambridge University Press, Cambridge, U.K. 214 p.

Crop Growth and Starch Productivity of Edible Canna

M. Hermann[1], R. Uptmoor[2], I. Freire[1], and J.L. Montalvo[3]

Edible canna (*Canna edulis* Ker-Gawler) is a starchy root crop that is grown sporadically in the tropical highlands for food security. Taxonomists now consider edible canna conspecific with ornamental or feral *Canna indica*. But edible canna's much larger rhizomes, inconspicuous flowers, and high starch content set it apart from *C. indica*. In its native Andean range, as well as in other parts of the developing world, the use of canna for direct consumption is about to disappear, mainly because of the long cooking time required to soften rhizome tissue (>3 h). In Vietnam and southern China, however, there has been a new appreciation of canna as a source for starch in the manufacture of transparent noodles, a luxury food widely eaten across Asia. In Vietnam alone, the canna area is estimated at 20,000 to 30,000 ha.

Canna starch has the largest grains known and it settles quickly out of a suspension of grated tuber tissue. Starch recovery in rural factories is therefore high (>80% of total starch content). The starch is high in amylose and functionally similar to mungbean starch, the traditional raw material for transparent noodles. Canna starch is, however, less expensive to produce.

Canna is an outstandingly versatile and robust crop. It is typically not fertilized and significant pests or diseases as well as replant problems are unknown. Where rice-based cropping systems predominate, as in Taiwan, Vietnam, and Indonesia, canna is grown on unirrigated uplands, in backyard gardens, or other areas where it does not compete with other food crops. In open (unshaded) planting sites, plant development can be exuberant and rhizome yields high. Canna is also a promising candidate for agroforestry systems in tropical mountains where it produces under significant shading and on marginal soils.

Drawbacks to canna are its long crop duration of 1 yr, which limits the crop's use in tight cropping systems. Also, its starch productivity and plant architecture have not been investigated so far. Therefore, this study aims to gain a basic understanding of crop growth and starch formation of canna. Recommendations for crop management and breeding of this poorly known species will be derived.

Materials and Methods

In addition to taking field surveys in several countries, we evaluated plant performance of canna in the greenhouse to determine growth variability and yield characteristics.

Greenhouse experiment

For the greenhouse experiment, we used 26 accessions from the international canna collection held at CIP. The accessions were selected to represent the full geographic range of canna in the Andes and to include diploid and triploid materials. Knowledge of randomly amplified polymorphic DNA in the collection allowed us to identify distinct genotypes for the experiment.

The material was grown in a quarantine screenhouse in the equatorial Andes near Quito, Ecuador, at 2,400 m above sea level. Seasonal temperature variation in Quito is minimal; the diurnal temperature in the screenhouse during the experiment ranged from 12 to 27°C. We planted rooted propagules at a density of 2 plants/m^2 in natural soil of a sandy texture and moderate fer-

1 CIP, Lima, Peru, and Quito, Ecuador.
2 Kassel University, Witzenhausen, Germany.
3 Universidad Central, Quito, Ecuador.

tility. The crop was irrigated 2 or 3 times/ week, but was not fertilized. After 12 mo, we harvested the material and took 4 plants at random from each accession for analysis.

Field study

For the field study, we chose Patate, a farmer community in the highlands of Ecuador (near the equator at 2,350 m), where canna is grown commercially for starch. The highly drained soils in this area range from sand to loamy sand, with neutral pH and high nutrient content. Plant available N was 144 mg/100 g soil; P, 153 mg/100 g soil; K, 30 mg; and Mg, 32 mg. Furrow irrigation was applied weekly, but overall soil moisture was low and most likely represented a growth-limiting factor. Mean monthly temperatures were 15-17°C with diurnal amplitudes of 10-25°C. During the first 5-6 mo after planting, canna was intercropped with potatoes and vegetables. We harvested plots ranging in size from 10 to 20 m^2 in different fields after 6, 8, 10, and 12 mo of crop duration. Four repetitions were used.

We determined dry matter (DM) at 105°C and mechanically extracted starch by a method allowing the recovery of about 90% of total starch. Soluble solids were measured refractometrically. Leaf area was assessed by a linear regression describing the relation of leaf area to the product of leaf length and width. Plant nutrient contents were measured by standard methods.

Results

Canna's plant architecture is typical for a member of the Zingiberales (Figure 1). The plant forms a branching rhizome, which in mature plants consists of several segments or generations that develop consecutively. Each segment carries a shoot, which concludes its development with the formation of a terminal inflorescence and senesces. Simultaneously, a new shoot will give rise to a new rhizome segment. Each segment has the capacity to develop sprouts from several buds. The size of the rhizome segments and different branching modes distinguish rhizome variability between accessions (Figure 2).

Some peculiarities characterize plant growth of canna and its measurement. The dead aboveground plant matter remains attached to the plant and can be gathered and determined at harvest. Canna is also different from most other perennial roots in that thick adventitious roots anchor the rhizomes firmly in the soil and cause strong pulling resistance at harvest.

The youngest rhizome segment (typically weighing 50-200 g) is mostly used as the propagule. It can be stored in the coldest months until planting. In equatorial climates, however, only the uppermost apical tip of the rhizome, with the emerging shoot attached, is used. That minimizes the use of starchy tissue for replanting. Although diploid cultivars form botanical seeds, these are never used to propagate the crop.

At harvest, after 1 yr of crop duration, total plant DM in a collection of 26 canna ac-

Figure 1. Ecuadorian accession of edible *Canna*. Scale indicates 2 m.

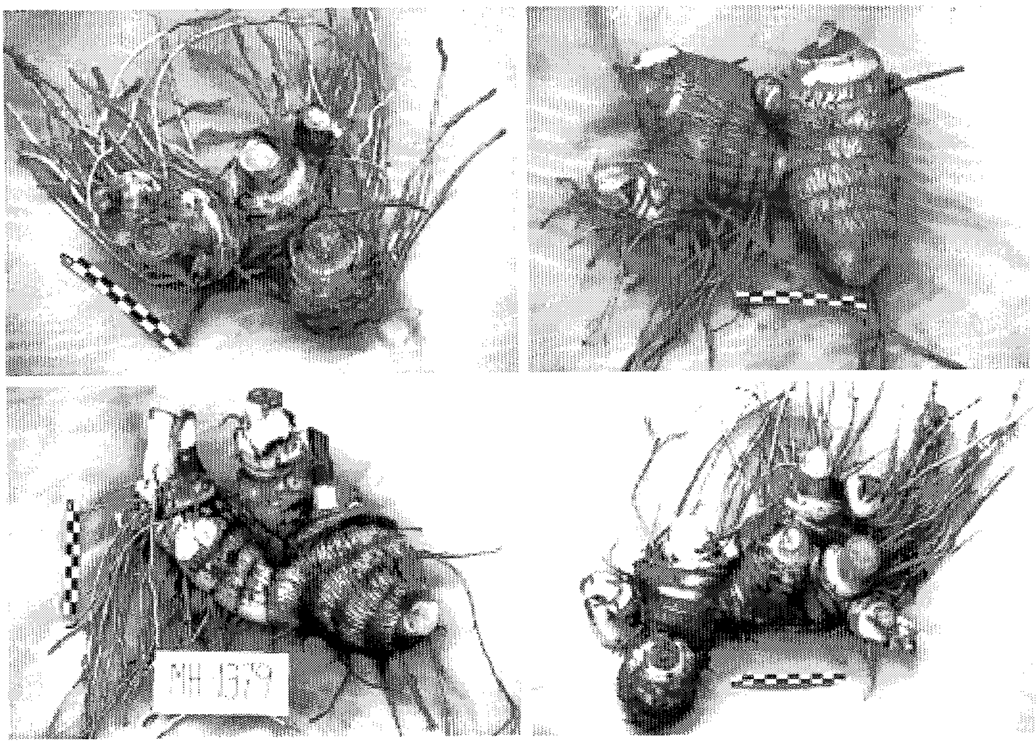


Figure 2. Variability of canna rhizome between genotypes. Scale = 10 cm.

cessions averaged 24 t/ha; one accession achieved total DM accumulation of 54 t/ha or 5.4 kg/m^2. Rhizome yields varied considerably (17-96 t/ha) with an average of 56 t/ha. Harvest index (HI), the fraction of total DM accounted for by the rhizomes, was the second least variable character (56 ± 8%), as indicated by the coefficients of variation (CV). HI was not correlated with rhizome yield (Table 1). On the other hand, the variation of total plant DM explained 69% of the variation in rhizome yield (calculated from the correlation coefficients shown in Table 2).

Although the content of physically extractable starch in the rhizome was low compared with other starchy roots—14 ± 4% of rhizome fresh matter (FM)—canna has respectable starch yields (2.8-14.3 t/ha). As expected, the starch content of the rhizome was closely correlated with rhizome DM content. Surprisingly, it was also positively and significantly correlated to the content of soluble solids (Table 2), which varied between 5 and 11°Brix (Table 1).

This means that accessions that are high in soluble solids also tend to have high starch contents. Starch accounted for only 59 ± 14% of rhizome DM (range 32-88%).

The significance of the number of shoots indicated in Table 1 is that it roughly equals the number of rhizome segments and thus approximates the number of propagules that can be derived from a plant. In other words, it indicates the multiplication rate, and this variable showed the highest variation of the characters (means and standard deviation of 28 ± 16) under study. Interestingly, the number of stems was inversely correlated to HI, meaning that plants with a large number of stems (or a higher degree of rhizome ramification) invested relatively more DM in aboveground plant structures.

Specific leaf weight of canna is comparatively high; it was the least variable character in our evaluation (CV=13%). Table 3 gives data on crop growth, in terms of absolute and relative DM allocation, for a commercial

Table 1. Variation of growth and yield characteristics at harvest in a collection of 26 canna accessions, 1996.

Variable[a]	Unit	Mean	Min	Max	SD[b]	CV (%)
Total plant DM[b]	(t/ha)	24	8	54	9	39
Rhizome yield (FM)	(t/ha)	56	17	96	20	35
Starch yield	(t/ha)	7.8	2.8	14.3	3.1	40
Rhizome fraction of total DM (harvest index)	%	56	35	74	8	15
Starch fraction of total DM	%	33	12	54	11	32
Stem fraction of total DM	%	19	9	34	7	35
Leaf fraction of total DM	%	23	15	46	7	28
Adventitious roots fraction of total DM	%	2.5	1.5	5.0	0.9	35
Shoots per plant	n	28	13	79	16	57
Specific leaf weight	g/dm^2	0.44	0.35	0.54	0.06	13
DM content of rhizome	%	24	12	31	4	18
Starch content of rhizome (FM basis)	%	14	4	22	4	30
Starch content of rhizome (DM basis)	%	59	32	88	14	24
Soluble solids in rhizome	°Brix	8.1	5.0	11.0	1.6	20

a. Starch data refer to physically extractable starch.

b. DM = dry matter, FM = fresh matter, SD = standard deviation, CV = coefficient of variation.

Table 2. Pearson's correlation coefficients between growth characteristics of 26 canna accessions, 1996.

Variable	Total plant DM[a]	Rhizome yield FM[a]	Content of soluble solids in rhizome	Starch content of rhizome (FM basis)	Stem fraction of total DM	Harvest index rhizome fraction of total DM
Total plant DM						-0.32
Number of shoots		0.16			0.68**	-0.57**
Rhizome yield (FM)	0.831**		-0.15	-0.26		-0.10
DM content of rhizome			0.66**	0.66**		0.42*
Starch content of rhizome (FM basis)						0.55**

* Significant at P=0.05, ** significant at P=0.01. Only meaningful correlations are shown.

a. DM = dry matter, FM = fresh matter.

Table 3. Absolute and relative dry matter allocation and leaf area index of edible canna according to crop age[a].

	(t/ha)				(%)			
Plant age (months)	6	8	10	12	6	8	10	12
Leaf blades	0.48 b	1.76 a	2.16 a	1.86 a	23	16	14	12
Stems, inflorescences	0.43 c	2.86 b	4.22 a	3.83 a	21	26	28	24
Dead plant parts	0.16 b	1.17 a	1.17 a	1.60 a	8	10	8	10
Rhizomes	0.93 c	4.77 b	7.02 a	[b]7.83 a	41	43	45	49
Adventitious roots	1.15 b	0.60 a	0.82 a	0.79 a	7	5	5	5
Total plant	2.16 c	11.16 b	15.39 a	15.91 a	100	100	100	100
Leaf area index	0.95 b	3.64 a	3.61 a	3.32 a				

a. Field data taken from a commercial plantation in the highlands of Ecuador (2,350 m). In a row, means followed by the same letter are not statistically different at $P<0.05$.

b. Corresponding to a rhizome fresh matter yield of 36 t/ha.

canna starch crop after 6, 8, 10, and 12 mo of crop duration. DM buildup in canna is slow. Six months after planting, total DM accumulation is only 14% of that achieved at commercial harvest 12 mo after planting. But the proportion of DM allocated to rhizomes has reached 41% at 6 mo and increases during the second half of crop duration to only 49%.

Likewise, the fraction of dead plant parts varies little from 6 to 12 mo, although in absolute terms there is a tenfold increase. This and the insignificant change in leaf area index from month 8 to month 12 illustrate the perennial nature of canna, which does not really become senescent at harvest. The relative DM allocation to leaves and stems does not show the dramatic changes most other crops undergo during canopy development. Starch content of the rhizomes, however, increased significantly from 5% at 6 mo and 7% at 8 mo to 13% at 10 and 12 mo.

The nutrient analysis in rhizomes showed that per ton of harvested rhizomes, or per 120-130 kg of extracted dry starch, nutrient offtake from the field amounted to 0.75 kg N, 0.74 kg P, 3.24 kg K, 2.48 kg Mg, and 0.98 kg Ca. But when extraction residue is returned to the field (the common practice in Ecuador), 28% each of N and P, 3.8% of K, 0.6% of Mg, and 62.5% of Ca removed by the rhizomes are returned to the field. Most of the K (95%) and Mg (>99%), however, is lost in the washing water during starch extraction. Thus, the net nutrient offtake from a canna field would be on the order of 0.54 kg N, 0.53 kg P, 3.11 kg K, 2.47 kg Mg, and 0.37 kg Ca per ton of harvested rhizomes or per 120-130 kg of extracted dry starch.

Discussion

With rhizome yields averaging 56 t/ha in an international germplasm collection, edible canna is clearly a highly productive root crop that compares well with cassava, sweetpotato, and potato. Given an average propagule weight of 50-200 g, and a planting density of 20,000 plants/ha, the seed weight of canna amounts to only 2.5-10% of a typical yield (40 t/ha).

For a *primitive* crop that has never been subjected to systematic plant breeding, canna also has a remarkably high HI ($56 \pm 8\%$). Since this character shows some genetic variation, it should be possible to breed for increased HI. We found only a weakly negative but insignificant correlation between HI and total plant DM (Table 2); therefore, selection for high total DM in breeding does not imply reduced HI as observed in other crops.

On the basis of our germplasm evaluation, we suggest that canna cultivars for starch exploitation should have large rhizomes. Indeed, predominantly commercial cultivars exploited for starch have comparatively large rhizomes. Large rhizomes are found in plants with a low degree of ramification or a low number of shoots. These, in turn, are inversely related to HI. Canna breeding should also aim at increasing starch content, which currently accounts for only 59 ± 14% of rhizome DM. All cultivars have significant concentrations of soluble solids (mostly sugars). If genotypes that polymerize sugars into starch more readily were to be found, the starch productivity of canna could be improved by several percentage points from a current average of 14 ± 4% in rhizome fresh matter.

Another concern for breeders will be to develop cultivars with few adventitious roots. These trap soil and complicate manual harvest for two reasons. First, soil particles contaminate the starch or interfere with its extraction. Second, the metabolically active roots seem to contain high concentrations of oxidases, which are involved in the browning of starch during grating and extraction. In Asia and Latin America, removal of these roots accounts for most of the working hours spent during harvest. Simple washing equipment, however, such as the revolving drum or the static paddle washers used in small cassava starch factories in Brazil, is sufficient to remove dirt from canna's adventitious roots.

Our crop growth data, from plants of commercial canna plantations harvested after 6, 8, 10, and 12 mo, suggest that the causes for the initial slow plant development and resulting long crop duration might be slow leaf area replication during the juvenile phase. Several lines of evidence support this. Leaf area indices remain low well into the second half of crop duration. Although the field crop under study had accumulated only 14% of its final biomass at 6 mo, DM allocated to the rhizomes accounted for 42% of total plant DM. Thus, even before the crop develops significant leaf area indices, it compromises large proportions of assimilates in photosynthetically unproductive structures (the rhizomes).

High HI early during development and the peculiar generational development of the rhizome, however, provide an opportunity to increase planting density and to harvest earlier than is currently done. Further studies are needed to elucidate what effect increased planting densities would have on rhizome starch contents, which seem to remain low during the first 8 mo of crop development in traditional systems.

Our data reveal that canna is a nutrient-efficient producer of starch, especially with regard to the environmentally relevant N and P, of which less than 1 kg is removed per ton of harvested rhizomes. A significant fraction of these nutrients can be returned to fields by applying either fresh or fermented process residue as fertilizer.

The data also show that major quantities of K and Mg are lost in the water used to wash out starch from grated pulp. It would therefore seem important that the washing water be recycled to fields and not discarded into sewer systems as is currently done. Because the amounts of water used in manually extracting and refining starch are enormous (well over 100 L/kg dry starch under Andean conditions), locating extraction plants above growing sites and distributing washing water by gravity would be a preliminary recommendation.

Conclusions

In conclusion, yield potential, efficient DM partitioning, nutrient efficiency, and starch quality make canna an interesting starch crop for resource-poor farmers in the tropical highlands. However, except for some parts of Southeast Asia, where the noodle industry has fueled demand for canna starch, this crop's potential is not being recognized. There is mounting evidence that canna starch could replace potato starch because of a high degree of functional similarities. Product examples include several types of Asian noodles (for which an increasing share of potato starch is used), certain bakery goods, and thermoplastics. Many other applications are likely to be found with appropriate research and development.

Canna starch has a potentially vast demand if industrial-grade starch were to become available. Currently, canna starch does not meet the quality standards required by most users. Moreover, canna starch production is at a disadvantage because of the lack of appropriate harvesting and extraction equipment. Even in developing economies, the excessive labor costs arising from manual processing render canna starch too costly to stay competitive versus inexpensive starch imports. Improvements in the crop's starch productivity must therefore be accompanied by the development of improved extraction technologies.

Further research is needed to address specific crop constraints, such as the long crop duration; experiments designed to clarify the effect of planting densities on crop yields and precocity also seem warranted. Research aimed at evaluating the feasibility of breeding cultivars with improved starch productivity and processing characteristics also deserves attention. Andean canna germplasm has recently become available and superior cultivars can likely be identified for use in areas of narrow genetic variation of this crop, such as in Asia. CIP hopes that interested national programs will join this effort.

Selected Reading

Hermann, M. 1996. Starch noodles from edible canna (*Canna edulis*). In: Janick, J. (ed.). Progress in new crops. Am. Soc. Hort. Sci., Alexandria, VA. p. 507-508.

Imai, K., K. Shimabe, K. Tanaka, and T. Kawana. 1994. Studies on matter production of edible canna (*Canna edulis* Ker.). III. Changes of production structure with growth. Jap. J. Crop Sci. 63(2):345-351.

Ripperton, J.C. 1927. Carbohydrate metabolism and its relation to growth in the edible canna. Hawaii Agric. Exp. Stn. Bull. (Washington, DC) No. 56. 35 p.

Cross-Program Training Courses 1995–1996

Patricio Malagamba

CIP's Training Department conducted diverse activities in 1995-96, mainly involving courses, workshops, conferences, and symposia, of general coverage of subjects across programs. A symposium on "Current Approaches for Developing Concepts and Practices Related to Agricultural Promotion and Development" was organized in collaboration with the Escuela para el Desarrollo, an NGO in Peru and member of CONDESAN, for other national organizations and institutions. The symposium's main objective was to conceptualize and define the baseline required for agricultural development in Peru. Attempts were made to establish the relationship between promotion policies and practices with principles related to development. It also focused on the need to strengthen interdisciplinary interventions that link different sectors by proposing directions and defining concepts and practices involved in agricultural development.

A course on "Agroecology and Rural Development" was organized by the Consorcio Latinoamericano de Agroecología y Desarrollo, CLADES, and directed to scientists and development agents whose activities are related to sustainable development of the rural sector. CIP sponsored the participation of two national scientists from Cusco and Cajamarca. PROINPA sponsored five participants from Bolivia. The course used distance-learning elements and procedures.

A "Production Course on Biological Control in Potato" was held at CIP for staff from the national organization responsible for sanitary control of agricultural products, SENASA. The training program covered biological techniques related to the production of entomopathogens (fungus, virus, and bacteria) and parasitoids.

A two-week "Workshop on Integrated Watershed Management in the Andean Ecoregion" was organized by local developmental organizations in Cajamarca (ASPADERUC and ADEFOR), with support from CONDESAN and CIP. This workshop emphasized theory and practices related to systems analysis, agroecological zoning, simulation models, and geographic information systems as tools for identifying alternatives for the sustainable development of Andean agriculture. Two watersheds were used as case studies, one located on the west side of the Andes (Jequetepeque), and the other an intermontane watershed (Cajamarca). Participants included technical staff working in different disciplines (agriculturists, animal production specialists, ecologists, etc.) as well as policymakers (mayors) from both Cajamarca, Peru, and Carchi Province in Ecuador.

A course on field design, layout, and administration of field experiments was conducted at CIP. It covered five main topics: scientific research methods, experimental plot design and management, competitive effects, mechanical errors in conducting experiments, and characteristics of the major experimental designs.

CIP organized a "Planning Workshop for Mountain Forum Activities in Latin America," sponsored by CONDESAN, to promote the development of policy actions directed to the equitable and sustainable development of mountain regions. Participants were from the Pro-Sierra Nevada Foundation of Colombia, United Nations Development Programme, the Mountain Institute of Huaraz, ASPADERUC, International Conservation, and the Universidad Nacional Agraria La Molina.

A "Workshop on the Application of Crop Simulation Models" was conducted in Cusco, Peru. It was sponsored by CONDESAN in collaboration with the Instituto de Manejo de Aguas y Medio Ambiente, Centro de Estudios Bartolomé de las Casas, and Plan Meriss Inka. The main objective was to expose participants to crop simulation models as a methodological tool for use in more effective decision making with respect to the best use and management of natural resources and to their application in improving the productivity of those crops included in agricultural systems prevailing in the Andean ecoregion.

Sponsored by FAO, IICA, UNEP, CONDESAN, and CIP, a "Regional Conference on Sustainable Agricultural Systems in the Central Andes" was conducted. The main objective of this conference was to evaluate causes and mechanisms related to social and economic deterioration in rural areas as well as to assess the possible consequences of different management strategies. Different strategies for the sustainable development of the Andean ecoregion that could be used to generate technical assistance plans in countries were analyzed and discussed in detail.

Scientific Publications 1995–1996

Abad, Z.G., J.A. Abad, and C. Ochoa. 1995. Historical and scientific evidence that supports the modern theory of the Peruvian Andes as the centre of origin of *Phytophthora infestans*. In: Dowley, L.J., E. Bannon, L.R. Cooke, T. Keane, and E. O'Sullivan (eds.). *Phytophthora infestans* 150: Proceedings EAPR Pathology Section, September 1995, Dublin, Ireland. European Association of Potato Research/ Boole Press, Dublin, Ireland. p. 239-245.

Anguiz, R.J. and H.A. Mendoza. 1995. Correlation between seedling and adult potato plants for resistance to early blight (*Alternaria solani*). Fitopatología 30(2):100-106.

Arbizu, C. 1995. Agroecología de la achira en el Perú. Agroenfoque 70:4-5.

ASPADERUC/CONDESAN-CIP/Fondo Perú-Canadá. 1995. La Encañada: Caminos hacia la sostenibilidad. Proyecto PIDAE/ Asociación para el Desarrollo Rural de Cajamarca/Consorcio para el Desarrollo Sostenible de la Ecorregión Andina-Centro Internacional de la Papa/Fondo Contravalor Perú-Canadá, Lima, Peru. 112 p.

Austin, D.F. and Z. Huamán. 1996. A synopsis of *Ipomoea* (Convolvulaceae) in the Americas. Taxon 45(1):3-38.

Bamberg, J.B., Z. Huamán, and R. Hoekstra. 1995. International cooperation in potato germplasm. In: R.R. Duncan, D.M. Kral, and M.K. Viney (eds.). International germplasm transfer: Past and present. Crop. Sci. Soc. of America Special Publication No. 23. p. 177-182.

Blondet, C. and R.L. Durán. 1996. El impacto potencial de la difusión de tecnología panificadora de camote en panaderías de Villa El Salvador. Documento de Trabajo no. 1996-2, CIP, Lima, Peru. 52 p.

Bouis, H.E. and G. Scott. 1996. Demand for high value secondary crops in developing countries: The case of potatoes in Bangladesh and Pakistan. FCND Discussion Papers no. 14. International Food Policy Research Institute (IFPRI), Food Consumption and Nutrition Division (FCND), Washington, D.C., USA. 46 p.

Bouma, J., A. Kuyvenhoven, B.A.M. Bouman, J.C. Luyten, and H.G. Zandstra (eds.). 1995. Eco-regional approaches for sustainable land use and food production. Proceedings of a symposium held 12-16 Dec. 1994, ISNAR, The Hague, Netherlands. Kluwer Academic Publishers in cooperation with the International Potato Center, Dordrecht, Netherlands. 596 p.

Bradshaw, J.E., R.L. Wastie, H.E. Stewart, and G.R. Mackay. 1995. Breeding for resistance to late blight in Scotland. In: L.J. Dowley, E. Bannon, L.R. Cooke, T. Keane, and E. O'Sullivan (eds.). *Phytophthora infestans* 150. Boole Press, Dublin, Ireland. p. 246-254.

Cabanilla, L.S. 1996. Sweetpotato in the Philippines: Production, processing, and future prospects. International Potato Center, University of the Philippines, Lima, Peru/Manila, Philippines. 100 p.

Cañizares, C.A. and G.A. Forbes. 1995. Foliage resistance to *Phytophthora infestans* (Mont.) de Bary in the Ecuadorian national collection of *Solanum phureja* ssp. *phureja* Juz. & Buk. Potato Res. 38(1):3-10.

Castillo, R. and M. Hermann.1995. Collecting Andean root and tuber crops (excluding potatoes) in Ecuador. In: Guarino, L., V. Ramanatha Rao, and R. Reid (eds.). Collecting plant genetic diversity: Technical guidelines. IPGRI/FAO/IUCN/UNEP. CAB International, Wallingford, UK. p. 639-646.

CIP (International Potato Center). 1995. Vines to roots, sweetpotato breeding for impact: Recommendations and abstracts. International workshop held 1-3 June 1994, Lima, Peru. CIP, Lima, Peru. 46 p.

CIP. 1995. Manual de producción de papa con semilla sexual. Fascículos. Lima, Peru.

CIP. 1996. Marchitez bacteriana. Manual de Capacitación. Lima, Peru.

CIP. 1996. Bacterial wilt manual. Lima, Peru.

CIP. 1996. Manual de manejo de germoplasma de batata o camote (*Ipomoea batatas*). Fascículos. Lima, Peru.

CIP. 1996. Accounting for seed potato production costs: A computer spreadsheet-based management tool. Training Manual. Lima, Peru.

CIP. 1996. La batata en cifras: Un compendio de información clave y análisis para 33 importantes países productores de batata, producción, uso, consumo y alimentación animal. Lima, Peru. v p.

CIP. 1996. Late blight: A global initiative. Lima, Peru. 21 p.

CIP. 1996. Major potato diseases, insects, and nematodes. Lima, Peru. 111 p.

CIP. 1996. Principales enfermedades, nematodos e insectos de la papa. Lima, Peru. 111 p.

CIP. 1996. Sweetpotato facts: A compendium of key figures and analysis for 33 important sweetpotato-producing countries, production, use, consumption, feed use. Lima, Peru. v p.

CIP/COTESU (Centro Internacional de la Papa/ Cooperación Técnica Suiza). 1995. Programa Colaborativo Biodiversidad de Raíces y Tubérculos Andinos. Memorias 1993-1994. CIP/COTESU, Lima, Peru. 322 p.

CONDESAN (Consortium for the Sustainable Development of the Andean Ecoregion). 1995. A post-UNCED progress report on Andean natural resource research. CIP, Lima, Peru. 16 p.

Cottrell, J.E., C.M. Duffus, L. Patterson, and G.R. Mackay. 1995. Properties of potato starch: Effects of genotype and growing conditions. Phytochemistry 40(4):1057-1064.

Crissman, C. and A. Hibon. 1996. Establishing seed potato prices: Concepts, procedures and implications for research and training. Social Science Department. Working Paper Series no. 1996-1, CIP, Lima, Peru. 24 p.

Chávez, R., M. Upadhya, H. Mendoza, J. Espinoza, R. Cabello, P. Siles, G. Bollo, T. Meléndez, J. Eyzaguirre, C. Maquera, E. Guevara, K. Monasterio. 1996. Nuevas hipótesis y avances de selección en el mejoramiento genético de papa y camote para adaptación a suelos áridos y salinos. Rev. Consejo de Investigación (COIN), Ciencia y Desarrollo, Univ. Jorge Basadre Grohmann (Perú). p. 32-54.

Chujoy, E. 1995. Root crops germplasm research in Vietnam. CIP/National Institute of Agricultural Sciences (INSA)/International Development Research Centre (IDRC), Manila, Philippines. 62 p.

Dayal, T.R., G.J. Scott, G.T. Kurup, and C. Balagopalan (eds.). 1996. Sweetpotato in South Asia: Postharvest handling, processing, storage, and use (Proceedings of a workshop). Trivandrum, India, 9-13 Sept. 1991. Central Tuber Crops Research Institute (CTCRI), CIP, Lima, Peru. 137 p.

Díaz, J., P. Schmiediche, and D.F. Austin. 1996. Polygon of crossability between eleven species of *Ipomoea*: Section

Batatas (Convolvulaceae). Euphytica 88(3):189-200.

Engels, C., J. Schwenkel, R. El Bedewy, and B. Sattelmacher. 1995. Effect of the development stage of potato seedlings on recovery after transplanting to the field and on tuber yield. J. Agric. Sci. 124(2):213-218.

Estrada, R.D. 1996. Análisis ex post de la influencia de algunas variables macroeconómicas sobre la competitividad agropecuaria, equidad y conservación de recursos. In: Rivera, B. and R. Aubad (eds.). IESA América Latina 1995: El enfoque de sistemas de producción y la incorporación de criterios de política: Memorias 2. Simposio Latinoamericano sobre Investigación y Extensión en Sistemas Agropecuarios. Santa Fé de Bogotá, Colombia, 7-9 Nov. 1995. Corporación Colombiana de Investigación Agropecuaria (CORPOICA), Bogotá, Colombia. p. 219-230.

Fano, H., O. Ortiz, and T. Walker. 1996. Peru: Inter-institutional cooperation for IPM. In: Thrupp, L.A. (ed.). New partnerships for sustainable agriculture. World Resources Institute (WRI), Washington, D.C., USA. p. 85-98.

FAO (Oficina Regional para América Latina y el Caribe). 1995. Manual técnico de producción de papa a partir de semilla sexual: Curso audiovisual. FAO/Centro Internacional de la Papa/Instituto de Investigaciones Agropecuarias (INIA), Santiago, Chile. 72 p.

FAO/CIP (Food and Agriculture Organization/ International Potato Center). 1995. Potatoes in the 1990s: Situation and prospects of the world potato economy./ La papa en la década de 1990: Situación y perspectivas de la economía de la papa a nivel mundial./ La pomme de terre dans les années 90: Situation actuelle et perspectives de l'economie mondiale de la pomme de terre. Rome, Italy. 39 p., 50 p., 44 p.

French, E.R. and G.R. Mackay (eds.). 1996. Enhancing the global late blight network: Report of the project design meeting on the Global Initiative on Late Blight. CIP, Lima, Peru. 43 p.

Fuentes, S., M.A. Mayo, C.A. Jolly, M. Querci, and L.F. Salazar. 1996. A novel luteovirus from sweet potato, sweet potato leaf speckling virus. Ann. Appl. Biol. 128(3):491-504.

Gibson, R.W., R.O.M. Mwanga, S. Kasule, S. Fuentes, and E.E. Carey. 1996. Sweet potato feathery mottle and other viruses in Uganda. In: Proceedings of the regional sweetpotato workshop. Commission of the European Union, Technical Agricultural Center (TAC), Libreville, Gabon. p. 87-90.

Gitomer, C.S. 1996. Potato and sweetpotato in China: Systems, constraints, and potential. CIP/ Chinese Academy of Agricultural Sciences (CAAS), Lima, Peru. 183 p.

Golmirzaie, A.M. and L.F. Salazar. 1996. Application of biotechnology for conservation and utilization of Andean root and tuber crops and biosafety guidelines. African Crop Sci. J. 3(3):341-344.

Gregory, P. 1996. Global program to develop late blight resistant potato cultivars. CGIAR News 3(3):1.

Gutarra, L., T. Icochea, and E.R. French. 1995. Etiología de pudriciones bacterianas de tubérculos de ulluco (*Ullucus tuberosus* Caldas). Fitopatología 30(2):92-95.

Hagenimana, V., R.E. Simard, and L.P. Vezina. 1996. Method for the hydrolysis of starchy materials by sweetpotato endogenous amylases. U.S. Patent no. 5,525,154. June 11, 1996. 11 p.

Hardy, B. and E.R. French (eds.). 1995. Integrated management of bacterial wilt: Proceedings of an international workshop held in New Delhi, India, 11-16 Oct. 1993. International Potato Center (CIP)/

Indian Council of Agricultural Research, Lima, Peru. 196 p.

Hardy, B., P. Malagamba, and C. Martin (eds.). 1995. True potato seed in the Middle East and Africa: Proceedings of an international workshop held in Cairo, Egypt, 9-15 Apr. 1994. International Potato Center (CIP), Lima, Peru. 97 p.

Hijmans, R.J. and M.K. van Ittersum. 1996. Aggregation of spatial units in linear programming models to explore land use options. Neth. J. Agric. Sci. 44:145-162.

Hoekstra, R. and Z. Huamán. 1995. CIP promotes wider use of root and tuber crops. PROPHYTA Annual 1995. p. 102-103.

Holle, M. 1996. La biodiversidad es una de las bases del desarrollo sustentable. In: Rivera, B. and R. Aubad (eds.). p. 77-78.*

Huamán, Z. 1995. Técnicas citológicas para determinar el número cromosómico y la fertilidad de las papas. Guía de Investigación CIP no. 10. CIP, Lima, Peru. 18 p.

Huamán, Z., F. de la Puente, and C. Arbizu. 1995. Collecting vegetatively propagated crops (especially roots and tubers). In: Guarino, L., V. Ramanatha Rao, and R. Reid (eds.). Collecting plant genetic diversity: Technical guidelines. IPGRI/FAO/IUCN/UNEP. CAB International, Wallingford, UK. p. 457-466.

Instituto Boliviano de Tecnología Agropecuaria (IBTA). 1995. Primera reunión nacional de recursos genéticos de papa, raíces y tubérculos andinos: Memorias. Cochabamba, Bolivia, 7-10 Feb. 1994. IPGRI/CIP/IICA/PROCISUR/COTESU/PNUD, Cochabamba, Bolivia. 341 p.

Jacobsen, S.-E., J. Hill, and O. Stollen. 1996. Stability of quantitative traits in quinoa (*Chenopodium quinoa*). Theor. Appl. Genet. 93:110-116.

Khatana, V.S., M.D. Upadhya, A. Chilver, and C.C. Crissman. 1996. Economic impact of true potato seed on potato production in eastern and northeastern India. CIP, Lima, Peru. 19 p.

Korva, J.T. and G.A. Forbes. 1995. A simple non-destructive technique for healthy and diseased leaf area assessment of potato plants. Potato Res. 38(1):31-37.

Kreul, W. and B. Trognitz.1995. Forschungsschwerpunkte des Internationalen Kartoffel Forschungszentrums - CIP - in Peru. Entwicklung + Landlicher Raum (Germany) 29(5):30-32.

Landeo, J.A., M. Gastelo, H. Pinedo, and F. Flores. 1995. Breeding for horizontal resistance to late blight in potato free of R genes. In: Dowley, L.J., E. Bannon, L.R. Cooke, T. Keane, and E. O'Sullivan (eds.). *Phytophthora infestans* 150: Proceedings EAPR Pathology Section, September 1995, Dublin, Ireland. European Association of Potato Research/Boole Press, Dublin, Ireland. p. 268-274.

Martin, C., P. Demo, D. Njualem, T. Gass, and C. Ntonifor. 1995. Late blight resistant varieties for Cameroon. Am. Potato J. 72(9):513-522.

Martin, C., P. Demo, T. Gass, V. Fondong, and J. Koi. 1995. Development of a seed production system from in vitro in Cameroon: Experiences from the first two years. Am. Potato J. 72(5):299-302.

Martínez, C.A., C. Guerrero, and U. Moreno. 1995. Diurnal fluctuations of carbon exchange rate, proline content, and osmotic potential in two water-stressed potato hybrids. Rev. Bras. Fisiol. Veg. 7(1):27-33.

Mazón Ortiz, N., R. Castillo Torres, M. Hermann, and P. Espinosa. 1996. La zanahoria blanca o arracacha (*Arracacia xanthorrhiza* Bancroft) en Ecuador. Publicación Miscelánea no. 67. Instituto Nacional Autonómo de Investigación Agropecuaria (INIAP)/Dept. de Recursos Fitogenéticos y Biotecnología (DENAREF)/CIP, Quito, Ecuador. 41 p.

*See the entry for Estrada, R.D., for details on this publication.

Mendoza, H.A, E.J. Mihovilovich, and F. Saguma. 1996. Identification of triplex (YYYy) potato virus Y (PVY) immune progenitors derived from *Solanum tuberosum* ssp. *andigena*. Am. Potato J. 73(1):13-19.

Mujica B., E. and J.L. Rueda S. 1996. El desarrollo sostenible de montañas en América Latina: Actas de la segunda consulta regional intergubernamental sobre el desarrollo sostenible de montañas. CONDESAN/CIP/FAO, Lima, Peru. 318 p.

Pallais, N. 1995. High temperature and low moisture reduce the storage requirement of freshly harvested true potato seed. J. Am. Soc. Hort. Sci. 120(4):699-702.

Pallais, N. 1995. Storage factors control germination and seedling establishment of freshly harvested true potato seed. Am. Potato J. 2(7):427-436.

Pallais, N., J. Santos-Rojas, and R. Falcón. 1996. Storage temperature affects sexual potato seed dormancy. HortScience 31(1):99-101.

Prain, G.D., I.G. Mok, T. Sawor, P. Chadikun, E. Atmodjo, and E. Relwaty Sitmorang. 1995. Interdisciplinary collecting of *Ipomoea batatas* germplasm and associated indigenous knowledge in Irian Jaya. In: Guarino, L., V. Ramanatha Rao, and R. Reid (eds.). Collecting plant genetic diversity: Technical guidelines. IPGRI/FAO/IUCN/UNEP, CAB International, Wallingford, UK. p. 695-711.

Programa Colaborativo Biodiversidad de Raíces y Tubérculos Andinos. 1996. Memorias 1994-1995. CIP/Cooperación Técnica Suiza (COTESU)/Consorcio para el Desarrollo Sostenible de la Ecorregión Andina (CONDESAN), Lima, Peru. 370 p.

Querci, M., D.C. Baulcombe, R.W. Goldbach, and L. F. Salazar. 1995. Analysis of the resistance-breaking determinants of potato virus X (PVX) strain HB on different potato genotypes expressing extreme resistance to PVX. Phytopathology 85(9):1003-1010.

Quiroga, J., G. Watson, H. Cardozo, O. Navia, R. Casso, and R. Andrew. 1995. Diagnóstico interdisciplinario del cultivo de la papa en la zona de Iscayachi, Tarija (campaña 1991-1992). Documento de Trabajo no. 1/95. Instituto Boliviano de Tecnología Agropecuaria (IBTA)/ Programa de Investigación de la Papa (PROINPA), Cochabamba, Bolivia. 35 p.

Quirós, C.F., A. Epperson, J. Hu, and M. Holle. 1996. Physiological studies and determination of chromosome number in maca, *Lepidium meyenii* (Brassicaceae). Econ. Bot. 50(2):216-223.

Quiroz, R., C. León Velarde, B. Arce, and D. Genin. 1996. Resultados de ensayos en ganadería con modelos de simulación. In: Rivera, B. and R. Aubad (eds.). p. 113-123.*

Quiroz, R.A., R.D. Estrada, C. León Velarde, and H.G. Zandstra. 1995. Facing the challenge of the Andean zone: The role of modeling in developing sustainable management of natural resources. In: Bouma, J., A. Kuyvenhoven, B.A.M. Bouman, J.C. Luyten, and H.G. Zandstra. Eco-regional approaches for sustainable land use and food production: Proceedings of a symposium held 12-16 Dec. 1994, ISNAR, The Hague, Netherlands. Kluwer Academic Publishers in cooperation with the International Potato Center, Dordrecht, Netherlands. p. 13-31.

Rivera, J.J. and R.D. Estrada. 1996. Cuantificación ex ante del intercambio entre equidad, productividad y sostenibilidad para el diseño de alternativas tecnológicas: El caso del cultivo de arracacha en Colombia. In: Rivera, B. and R. Aubad (eds.). p. 101-112.*

Rodríguez Quijano, P. 1996. La papa y el desarrollo económico en Colombia. CIP/Corporación Colombiana de Investigación Agropecuaria, Lima, Peru. 114 p.

Rousselle-Bourgeois, F. and S. Priou. 1995. Screening tuber-bearing *Solanum* spp. for resistance to soft rot caused by *Erwinia carotovora* ssp. *atroseptica* (van Hall) Dye. Potato Res. 38(2):111-118.

Salazar, L.F. 1995. Los virus de la papa y su control. CIP, Lima, Peru. 226 p.

Salazar, L.F. 1996. Aplicación de la microscopía electrónica en la virología vegetal. In: Castillo de Maruenda, E., N. Rojas Morán, and A. López Milla (eds.). Microscopía electrónica en el Perú. Consejo Nacional de Ciencia y Tecnología (CONCYTEC), Lima, Peru. p. 43-48.

Salazar, L.F. 1996. Potato viruses and their control. Lima, Peru. 214 p.

Salazar, L.F., M. Querci, I. Bartolini, and V. Lazarte. 1995. Aphid transmission of potato spindle tuber viroid assisted by potato leafroll virus. Fitopatología 30(1):56-58.

Sánchez, I., M. Milian, A. Morales, and F. de la Puente. 1995. Prospección de recursos genéticos de raíces y tubérculos tropicales en Cuba en 1991. Cultivos Tropicales 16(1):84-87.

Sánchez, I., M. Milian, A. Morales, and F. de la Puente. 1995. Prospección de recursos genéticos de raíces y tubérculos tropicales en Cuba en 1992. Cultivos Tropicales 16(1):88-95.

Scott, G.J. (ed.). 1995. Prices, products, and people: Analyzing agricultural markets in developing countries. Lynne Rienner Publishers in cooperation with the International Potato Center (CIP), Boulder, Colorado, USA. 493 p.

Scott, G.J. 1996. Paradoxes and projections for potatoes in the 1990s. Entwicklung + Landlicher Raum. 30(3):20-22.

Seminario Cunya, J. and A. Seminario Cunya. 1995. Colección regional de germoplasma de raíces andinas. Universidad Nacional de Cajamarca (UNC)/Programa Biodiversidad de Raíces y Tubérculos Andinos Convenio CIP-COTESU, Cajamarca, Peru. 32 p.

Smit, N.E.J.M. and L.O. Matengo. 1995. Farmers' cultural practices and their effects on pest control in sweetpotato in South Nyanza, Kenya. Int. J. Pest Manage. 41(1):2-7.

Thiele, G., A. Devaux, and C. Soria. 1996. Innovación tecnológica en la papa: De la oferta de tecnología al impacto macroeconómico. In: Rivera, B. and R. Aubad (eds.). p. 79-88.*

Thro, A.M., R.N. Beachy, M. Bonierbale, C. Fauquet, G. Henry, G.G. Henshaw, M.A. Hughes, K. Kawano, C.J.J.M. Raemakers, W. Roca, C. Schopke, N. Taylor, and R.G.F. Visser. 1996. International research on biochemistry of cassava (tapioca, *Manihot esculenta* Crantz) and its relevance to Southeast Asian economies: A Cassava Biotechnology Network review. Asian J. Trop. Biol. 2(1):1-30.

Torres, H., M.A. Pacheco, and E.R. French. 1995. Resistance of potato to powdery scab (*Spongospora subterranea*) under Andean field conditions. Am. Potato J. 72(6):355-363.

Trognitz, B.R. 1995. Analysis of pollen tube growth in situ to investigate self-incompatibility in the wild potato *Solanum commersonii*. Euphytica 86(2):149-156.

Trognitz, B.R. 1995. Female fertility of potato (*Solanum tuberosum* ssp. *tuberosum*) dihaploids. Euphytica 81(1):27-33.

Upadhya, M. 1996. True potato seed technology to fight potato blight in developing countries. Diversity 12(3):67-68.

Upadhya, M.D., B. Hardy, P.C. Gaur, and S.G. Ilangantileke. 1996. Production and utilization of true potato seed in Asia. CIP/Indian Council of Agricultural Research, Lima, Peru. 233 p.

Valdivia, R., E. Huallpa, V. Choquehuanca, and M. Holle. 1996. Monitoring potato and *Oxalis* varieties in mixtures grown on farm family fields in the Titicaca Lake basin, Peru, 1990-95. In: Eyzaguirre, P. and M. Iwanaga (eds.). Participatory plant breeding: Proceedings of a workshop. Wageningen, Netherlands, 26-29 July 1995. International Plant Genetic Resources Institute (IPGRI), Rome, Italy. p. 144-150.

Valkonen, J.P.T., M. Orrillo, S.A. Slack, R.L. Plaisted, and K.N. Watanabe. 1995. Resistance to viruses in F_1 hybrids produced by direct crossing between diploid *Solanum* series *Tuberosa* and diploid *S. brevidens* (series *Etuberosa*) using *S. phureja* for rescue pollination. Plant Breed. 114:421-426.

Van den Berg, J.H., E.E. Ewing, R.L. Plaisted, S. McMurry, and M.W. Bonierbale. 1996. QTL analysis of potato tuber dormancy. Theor. Appl. Genet. 93(2):317-324.

Van den Berg, J.H., E.E. Ewing, R.L. Plaisted, S. McMurry, and M.W. Bonierbale. 1996. QTL analysis of potato tuberization. Theor. Appl. Genet. 93(3):307-316.

Velit Tamanaja, E. 1996. Identificación de virus en papa (*Solanum tuberosum*). In: Castillo de Maruenda, E., N. Rojas Morán, and A. López Milla (eds.). Microscopía electrónica en el Perú. Consejo Nacional de Ciencia y Tecnología (CONCYTEC), Lima, Peru. p. 75-80.

Walker, T.S. and C.C. Crissman. 1996. Case studies of the economic impact of CIP-related technology. Lima, Peru. 157 p.

Walker, T.S. and C.C. Crissman. 1996. Estudios de casos del impacto económico de la tecnología relacionada con el CIP en el Perú. Lima, Peru. 32 p.

Watanabe, K., M. Orrillo, and A.M. Golmirzaie. 1995. Potato germplasm enhancement for resistance to biotic stresses at CIP: Conventional and biotechnology-assisted approaches using a wide range of *Solanum* species. Euphytica 85:457-464.

Watanabe, K.N., M. Orrillo, A.M. Golmirzaie, S. Pérez, J. Crusado, and J.A. Watanabe. 1996. Generation of pest resistance: Diploid potato germplasm with short day adaptation from diverse genetic stocks. Breeding Sci. 46:329-336.

Watanabe, K.N., M. Orrillo, S. Vega, J.P.T. Valkonen, E. Pehu, A. Hurtado, and S.D. Tanksley. 1995. Overcoming crossing barriers between nontuber-bearing and tuber-bearing *Solanum* species: Towards potato germplasm enhancement with a broad spectrum of solanaceous genetic resources. Genome 38:27-35.

Watanabe, K.N., M. Orrillo, S. Vega, M. Iwanaga, R. Ortiz, R. Freyre, G. Yerk, S.J. Peloquin, and K. Ishiki. 1995. Selection of diploid potato clones from diploid (haploid X wild species) F_1 hybrid families for short day conditions. Breed. Sci. 45:341-347.

Watanabe, K.N.. J.P.T. Valkonen, and P. Gregory. 1995. Use of plant biotechnology tools in plant protection, genetic resources management and crop genetic improvement: An interdisciplinary approach with potatoes at the International Potato Center. In: Altman, D.K. and K. N. Watanabe (eds.). Plant biotechnology transfer to developing countries. Academic Press Inc., Texas. p. 179-188.

Wheatley, C., G.J. Scott, R. Best, and S. Wiersema. 1995. Adding value to root and tuber crops: A manual on product development. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 166 p.

Yencho, G.C., M.W. Bonierbale, W.M. Tingey, R.L. Plaisted, and S.D. Tanksley. 1996. Molecular markers locate genes for resistance to the Colorado potato beetle (*Leptinotarsa decemlineata*) in hybrid *Solanum tuberosum* x *S. berthaultii* potato progenies. Entomol. Exp. Appl. 81:141-154.

Zandstra, H.G. 1996. The CGIAR response to new challenges in agroenvironmental research in developing countries. In: Rivera, B. and R. Aubad (eds.). p. 335-342.*

Zandstra, H.G. 1996. Twenty-five years of international potato research, a retrospective and forward look. Potato Res. 39(4):395-401.

Zhang, D., W.W. Collins, and M. Andrade. 1995. Estimation of genetic variance of starch digestibility in sweetpotato. HortScience 30(2):348-349.

CIP Board Members 1995–1996

Dr. Lindsay Innes[1] (Chairperson)
Deputy Director
Scottish Crop Research Institute
Dundee, Scotland

Mrs. Martha ter Kuile (Chairperson)
Ontario, Canada

Dr. Hubert Zandstra
Director General
International Potato Center
Lima, Peru

Dr. Setijati Sastrapradja
Indonesian Institute of Sciences
National Centre for Research in Biotechnology
Bogor, Indonesia

Dr. K. L. Chadha (Vice Chair)
Deputy Director General (Hort.)
Indian Council of Agricultural Research
New Delhi, India

Dr. Klaus Raven
Universidad Nacional Agraria
La Molina,
Lima, Peru

Dr. Durward Bateman
Dean, College of Agricultural and Life Sciences
North Carolina State University
Raleigh, N.C., USA

Dr. Toshihiro Kajiwara[1]
Director, Japan Plant Protection Association
Tokyo, Japan

Dr. Moise Mensah
Cotonou, Benin

Dr. Lieselotte Schilde
Institute of Plant Biochemistry
University of Tubingen
Tubingen, Germany

Dr. Koenraad Verhoeff
Wageningen, The Netherlands

Dr. Chukichi Kaneda[2]
Association for International Cooperation of Agriculture & Forestry
Tokyo, Japan

Dr. Vo-Tong Xuan[2]
Vice Rector & Director
Mekong Delta Farming Systems R & D Institute
University of Cantho
Cantho, Vietnam

Dr. Adrián Fajardo-Christen
Ministerio de la Presidencia
Lima, Peru

Dr. Alfonso Cerrate[1]
Executive Director
Instituto Nacional de Investigación Agraria
Lima, Peru

1 Left in 1995.
2 Joined in 1996.

CIP Staff in 1995–1996

Directors

Hubert Zandstra, PhD, Director General
José Valle-Riestra, PhD, Deputy Director General for Finance and Administration
Peter Gregory, PhD, Deputy Director General for Research
Roger Cortbaoui, PhD, Director for International Cooperation
Edward French, PhD, Associate Director for Research (since May 1996)
George Mackay, MS, Director of Genetic Resources[4]

Program Leaders

Production Systems
Thomas S. Walker, PhD

Germplasm Management and Enhancement
Ali Golmirzaie, PhD

Disease Management
Edward French, PhD (until April 1996)
Luis F. Salazar, PhD (since May 1996)

Integrated Pest Management
Fausto Cisneros, PhD

Propagation, Crop Management
Mahesh Upadhya, PhD

Postharvest Management, Marketing
Gregory J. Scott, PhD

1 Staff who joined in 1995
2 Staff who joined in 1996
3 Staff who left in 1995
4 Staff who left in 1996
5 Staff funded by special projects
6 Project leader
7 Died in 1995

International Cooperation

(*country*) = post location, but activity regional in scope
country = post location

Latin America and the Caribbean (LAC)
Fernando Ezeta, PhD, Regional Representative (*Peru*)

Liaison Office—Ecuador
Charles Crissman, PhD

Sub-Saharan Africa (SSA)
Peter Ewell, PhD, Regional Representative (*Kenya*)

Liaison Office—Nigeria
Humberto Mendoza, PhD[6]

Middle East and North Africa (MENA)
Aziz Lagnaoui, PhD, Regional Representative (*Tunisia*) (from June 1995)
Carlos Martin, PhD, Regional Representative (Tunisia) (until June 1995)

Liaison Office—Egypt
Ramzy El-Bedewy, PhD

South and West Asia (SWA)
Sarathchandra Ilangantileke, PhD, Regional Representative (*India*)

East and Southeast Asia and the Pacific (ESEAP)
Peter Schmiediche, PhD, Regional Representative (*Indonesia*)

Liaison Office—People's Republic of China
Song Bo Fu, PhD

Liaison Office—Philippines
Gordon Prain, PhD

Internationally Recruited Staff
Departments

Breeding and Genetics

Juan Landeo, PhD, Acting Head of Department, Breeder[6]
Edward Carey, PhD, Breeder (*Kenya*)[6]
Enrique Chujoy, PhD, Geneticist (*Indonesia*)
Haile M. Kidane-Mariam, PhD, Breeder (*Kenya*)[6]
Humberto Mendoza, PhD, Geneticist (*Nigeria*)[6]
Il Gin Mok, PhD, Breeder (*Indonesia*)

Genetic Resources

Ali Golmirzaie, PhD, Geneticist, Head of Department[6]
Carlos Arbizu, PhD, ARTC Consultant[5]
Fermín de la Puente, PhD, Germplasm Collector[4]
Marc Ghislain, PhD, Molecular Biologist[6]
Michael Hermann, PhD, Andean Crop Specialist, *Ecuador*[6]
Zósimo Huamán, PhD, Germplasm Curator[6]
Koshun Ishiki, PhD, Associate Expert, *Ecuador*[4,5]
Carlos Ochoa, MS, Taxonomist, Consultant
Peter Schmiediche, PhD, Breeder (*Indonesia*)
Bodo Trognitz, PhD, Geneticist[6]
Kazuo Watanabe, PhD, Cytogeneticist (*USA*)[4]
Dapeng Zhang, PhD, Breeder[6]

Nematology and Entomology

Fausto Cisneros, PhD, Entomologist, Head of Department[6]
Ann Braun, PhD, Ecologist (*Indonesia*)[6]
Aziz Lagnaoui, PhD, Entomologist (*Tunisia*)
Nicole Smit, MS, Associate Expert, *Uganda*[5]
Jean Louis Zeddam, PhD, Entomovirologist

Pathology

Luis Salazar, PhD, Virologist, Head of Department[6]
John Elphinstone, PhD, Adjunct Scientist, *UK*
Gregory A. Forbes, PhD, Plant Pathologist (*Ecuador*)[6]
Edward R. French, PhD, Bacteriologist[6]
Teresa Icochea, PhD, Pathologist, Consultant[6]
Upali Jayasinghe, PhD, Virologist (*Philippines*)[6]
Rebecca Nelson, PhD, Molecular Pathologist[2]
Pedro Oyarzún, PhD, Mycologist (*Ecuador*)[5]
Sylvie Priou, PhD, Bacteriologist[5]
Maddalena Querci, PhD, Molecular Virologist[6]
Lod J. Turkensteen, PhD, Adjunct Scientist, *Netherlands*

Physiology

Mahesh Upadhya, PhD, Breeder, Head of Department[6]
Catherine Brabet, PhD, Associate Expert[2]
Ramzy El-Bedewy, PhD, Breeder, *Egypt*
Vital Hagenimana, PhD, Food Scientist (*Kenya*)[5]
Oscar Hidalgo, PhD, Senior Seed Specialist[6]
Sarathchandra Ilangantileke, PhD, Postharvest Specialist (*India*)[6]
Jukka Korva, MS, Fellowship Agronomist, Ecuador[4,5]
Noël Pallais, PhD, Physiologist[6]
Marian Van Hal, MS, Associate Expert[1]
Christopher Wheatley, PhD, Postharvest Specialist (*Indonesia*)[6]

Social Science

Thomas Walker, PhD, Economist, Head of Department[6]
Johan Brons, MS, Associate Expert (*Philippines*)[2,5]
Alwyn Chilver, MS, Associate Expert, *Indonesia*[5]
Charles Crissman, PhD, Economist (*Ecuador*)[6]
Peter Ewell, PhD, Economist (*Kenya*)[6]
Robert Jan Hijmans, MS, Associate Expert[5]
Jan Low, PhD, Economist (*Kenya*)[4,5]
Dai Peters, PhD, Rural Sociologist (*Indonesia*)[2]
Gordon Prain, PhD, Anthropologist (*Philippines*)[6]
Gregory Scott, PhD, Economist[6]
Julia Wright, MS, Associate Expert[1,4]

Training

Patricio Malagamba, PhD, Head of Department

Communications

Edward Sulzberger, MS, Acting Head of Unit (from Sept. 1996)
Bill Hardy, PhD, English and Spanish Writer/Editor, Acting Head of Unit (until Sept. 1996)

Michel L.Smith, Journalist, Head of Department[4]

Information Technology
Anthony Collins, Head[5]

Directors' Offices

Office of the Director General
Edward Sulzberger, MS, Senior Adviser

Office of the Deputy Director General for Research
José Luis Rueda, PhD, Coordinator, Andean Natural Resources

Office of the Deputy Director General for Finance and Administration
William A. Hamann, BS, Assistant to the DDGF&A[3]

Special Country Projects

FORTIPAPA, Ecuador
Albéric Hibon, PhD, Economist, Team Leader[4,5]
Corinne Fankhauser, MS, Associate Expert[1]

PROINPA, Bolivia
André Devaux, PhD, Seed Specialist, Team Leader[5]
Enrique Fernández-Northcote, PhD, Virologist[5]
Javier Franco, PhD, Nematologist[5,6]
Graham P. Thiele, PhD, Technology Transfer Specialist[5]

Uganda
Nicole Smit, MS, Associate Expert[5]

Consortium CONDESAN
Robert Jan Hijmans, Ir, Associate Expert[5]
Miguel Holle, PhD, Biodiversity of Andean Crops[5,6]
Carlos León-Velarde, PhD, Animal Production Systems[5]
Osvaldo Paladines, PhD, Andean Pastures (*Ecuador*)[5]
Roberto Quiroz, PhD, Land Use Systems Specialist[5]

Joint Appointments with Other Institutions
Walter Bowen, PhD, Nutrient Cycling Specialist, IFDC
Rubén Darío Estrada, MS, Natural Resources Economics (*Colombia*), CIAT[5]

Networks

ASPRAD
Eufemio T. Rasco Jr., PhD, Coordinator (*Philippines*)[5]

UPWARD
Gordon Prain, PhD, Coordinator (*Philippines*)

Controller's Office
Carlos Niño-Neira, CPA, Controller

Office of the Executive Officer
César Vittorelli, Ing. Agr., Acting Executive Officer

Nationally Recruited Staff Departments

Breeding and Genetics
Walter Amorós, MS, Agronomist
Miguel Ato, Food Industries Specialist[3]
Raúl Anguiz, MS, Agronomist[4]
Luis Calúa, MS, Agronomist[4]
T.R. Dayal, PhD, Associate Expert (*India*)
Luis Díaz, MS, Agronomist
Jorge Espinoza, MS, Agronomist
Manuel Gastelo, MS, Agronomist
Shimon Gichuki, MSc, Breeder, *Kenya*
Hugo Gonzales, Ing. Agr., Agronomist, *Chile*
Pamela Jean Lopez, MS, Breeder, *Philippines*
Elisa Mihovilovich, MS, Biologist
Daniel Reynoso, MS, Agronomist
K.C. Thakur, PhD, Breeder, *India*

Genetic Resources
César A. Aguilar, Agronomist, Huancayo
Víctor H. Asmat, Biologist
Milciades A. Baltazar, Agronomist, San Ramón[3]

Jorge Benavides, Biologist
Fausto Buitrón, Agronomist[4]
Patricia G. Cipriani, Biologist[5]
Walberto M. Eslava, Agronomist
René A. Gómez, Agronomist
María del Rosario Herrera, Biologist
Ana M. Hurtado, Biologist[5]
Luis H. Ñopo, Biologist[5]
María Gisella Orjeda, PhD, Biologist[4]
Matilde Orrillo, Biologist
Ana Luz Panta, Biologist
Flor de María Rodríguez, Biologist[5]
Alberto Salas, Agronomist
Roxana Salinas, Agronomist[4]
Jorge Tenorio, Biologist
Judith Toledo, Biologist[2]
Fanny Vargas, Agronomist

Nematology and Entomology
Jesús Alcázar, MS, Assoc. Agronomist[6]
Juan Cabrera, MS, Agronomist[2]
Manuel Canto, PhD, Nematologist[5,6]
Verónica Cañedo, Biologist
Javier Carhuamaca, Ing. Agr.[5]
Wilfredo Catalán, Ing. Agr.[4]
Víctor Cerna, Ing. Agr.[5]
Roberto Delgado de la Flor, Agronomist[3]
Oder Fabián, Ing. Agr.[4]
Erwin Guevara, Ing. Agr., Agronomist[6]
Rocío Haddad, Biologist[3]
Angela Matos, Ing. Agr.[6]
Norma Mujica, Agronomist
María Palacios, Assoc. Biologist[6]
Alcira Vera, Biologist
Wilberto Villano, Agronomist[5]

Pathology
Pedro Aley, MS, Plant Pathologist[6]
Ciro Barrera, MS, Plant Pathologist
Ida Bartolini, MS, Biochemist
Carlos Chuquillanqui, MS, Plant Pathologist
Christian Delgado, MS, Biochemist[6]
Violeta Flores, Biologist
Segundo Fuentes, MS, Plant Pathologist[6]
Liliam Gutarra, MS, Plant Pathologist
Charlotte Lizárraga, MS, Plant Pathologist
Hans Pinedo, Agronomist[3]
Hebert Torres, MS, Plant Pathologist[6]
José Luis Zapata, MS, Plant Pathologist, *Colombia*[4]

Physiology
Rolando Cabello, MS, Assoc. Agronomist
Nelly Espinola de Fong, MS, Nutritionist
Rosario Falcón, Biologist
M.S. Kadian, PhD, Agronomist, *India*
Joseph Koi, MS, Agronomist, *Cameroon*
José Luis Marca, Ing. Agr.
Jorge Roca, Biologist
Sonia Salas, MS, Assoc. Food Scientist
K.C. Thakur, PhD, Breeder, *India*

Social Science
Cherry Bangalanon, MS, *Philippines*
Rosario Basay, BA, Economist
Patricio Espinoza, Economist, *Ecuador*[5]
Hugo Fano, MS, Economist
Cristina Fonseca, MS, Agronomist[6]
V.S. Khatana, PhD, Socioeconomist, *India*
María Lozano, Computer Assistant
Luis Maldonado, BA, Economist
Margaret Ngunjiri, MS, Sociologist, *Kenya*
Oscar Ortiz, MS, Agronomist[4,5]
Maricel Piniero, Ecologist, *Philippines*
Víctor Suárez, MS, Statistician
Inge Verdonk, Ir, Nutritionist, *Philippines*

Training
Nelson Espinoza, Training Specialist
Martha Huanes, Training Logistics
Américo Valdez, MS, Training Material Specialist

Research Support
Víctor Otazú, PhD, Superintendent, Support Unit
Lombardo Cetraro, Biologist, Field & Greenhouse Supervisor, San Ramón
Roberto Duarte, Ing. Agr., Field & Greenhouse Supervisor, La Molina
Hugo Goyas, Ing. Agr., Field & Greenhouse Supervisor, Huancayo
Lauro Gomez, Supervisor, Huancayo[3]
Ulises Moreno, PhD, Physiologist
Mario Pozo, Ing. Agr., Supervisor, La Molina Experiment Station[4]
Miguel Quevedo, Ing. Agr., Off-Station Field Supervisor, Cajamarca[3]

Statistics Unit
Alfredo García, MS, Experimental Statistics
Felipe de Mendiburu, Statistics Eng.

Consortium CONDESAN

Blanca Arce, MS, Assoc. Scientist, *Quito, Ecuador*[4]
Elías Mujica, MS, Anthropologist, Adjunct Scientist[5]
Ana María Ponce, PhD, INFOANDINA Administrator[5]
Jorge Reinoso, MS, Agric. Economics, *Puno, Peru*[5]
Mario Tapia, PhD, Agroecologist[5]
Roberto Valdivia, MS, Agronomist, *Puno, Peru*[5]

Latin America and the Caribbean Regional Office

Sven Villagarcía, PhD[6]

Communications Unit

Cecilia Lafosse, Chief Designer
Godofredo Lagos, Production Chief

Emma Martínez, MS, Spanish Assistant Editor/Supervisor Media Production
Gigi Chang, MS, Photographer, Audiovisual Section Coordinator

Information Technology Unit

Edith Aguilar, Telecommunications Officer[4]
Jorge Arbulú, Telecommunications Systems Supervisor[3]
Mónica Arias, BS, Systems Engineer[1]
Pablo Bermúdez, Systems Analyst[1]
Liliana Bravo, BS, Systems Engineer[2]
Oscar Bravo, Microvax Systems Supervisor[3]
Roberto Castro, BS, Systems Development
Eduardo Manchego, Systems Analyst[4]
José Navarrete, Systems Analyst[2]
Pía María Oliden, Systems Analyst
Eric Romero, BS, Systems Engineer
Edgardo Torres, BS, Systems Engineer
Alberto Vélez, MS, Systems Engineer

Library

Cecilia Ferreyra, Head Librarian

Controller's Office

Miguel Saavedra, CPA, General Accountant
Edgardo de los Ríos, CPA, Senior Accountant
Vilma Escudero, Accountant[4]
Milagros Patiño, BA, Accountant[2]

Accounting Unit

Jorge Bautista, Accountant
Blanca Joo, CPA, Accountant
Rosario Pastor, CPA, Senior Accountant
Eduardo Peralta, Accountant

Budget Unit

Denise Giacoma, CPA, Accountant
Alberto Monteblanco, CPA, Senior Accountant

Treasury Unit

Sonnia Solari, Chief Cashier
Luz Correa, CPA, Accountant (Supervisor)[3]

Office of the Director General

Visitors' Office

Rosa Rodríguez, Manager[7]
Mariella Corvetto, Supervisor

Office of the Deputy Director General for Finance and Administration

Haydée Zelaya, Internationally Recruited Staff Officer

Office of the Executive Officer

Foreign Affairs Liaison

Marcela Checa, Liaison Officer

Travel

Ana María Secada, Supervisor

Logistics and General Services

Aldo Tang, Comdr. (ret.), Manager

Front Desk

Micheline Moncloa

Maintenance

Antonio Morillo, Chief

Purchasing Supervisors

Arturo Alvarez
Roxana Morales Bermúdez[4]
José Pizarro

Security

Jorge Locatelli, Capt. (ret.), Supervisor[4]

Transportation

Hugo Davis Paredes, Vehicle Maintenance Officer

Atilio Guerrero, Vehicle Programmer

Jacques Vandernotte, Pilot[4]

Djordje Velickovich, Pilot[4]

Percy Zuzunaga, Pilot

Warehouse

Jorge Luque, MBA, Supervisor

Human Resources

Lucas Reaño, Manager

Juan Pablo Delgado, Manager[4]

Auxiliary Services

Mónica Ferreyros, Supervisor

Sor Lapouble, Assistant

Compensation

Estanislao Pérez Aguilar, Supervisor

Labor Relations

Luis Caycho, Acting Supervisor[2]

Medical Office

David Halfin, MD

Lucero Schmidt, Nurse

Social Work

Martha Piérola, Supervisor

Acronyms and Abbreviations

ACIAR	Australian Center for International Agricultural Research
ACMVD	African cassava mosaic virus disease
ADEFOR	Asociación para el Desarrollo Forestal, Ecuador
AEZ	agroecological zones
AFLP	amplified fragment length polymorphism
AGERI	Agriculture Genetic Engineering Research Institute, Egypt
AMOVA	analysis of molecular variance
ANOVA	analysis of variance
AP	arracacha potyvirus
APW	Andean potato weevil
ARC	Agriculture Research Center, Egypt
ARTC	Andean root and tuber crops
ASPADERUC	Asociación para el Desarrollo Rural de Cajamarca, Peru
ASPRAD	Asian Sweetpotato and Potato Research and Development, network
AUDPC	area under the disease progress curve
AVA	arracacha virus A
AVB	arracacha virus B
AVRDC	Asian Vegetable Research and Development Center, Taiwan
BAC	bacterial artificial chromosome
BMZ	German Ministry for Economic Development and Cooperation
Bt	*Bacillus thuringiensis*
BW	bacterial wilt
CAAS	Chinese Academy of Agricultural Sciences
CaMV	cauliflower mosaic virus
CGIAR	Consultative Group on International Agricultural Research
CIAD	Center for Integrated Agricultural Development, China
CIAT	Centro Internacional de Agricultura Tropical, Colombia
CIRNMA	Centro de Investigaciones de Recursos Naturales y Medio Ambiente, Peru
CLADES	Consorcio Latinoamericano de Agroecología y Desarrollo
CMP	critical moisture point
CMS	cytoplasmic male sterility
CONDESAN	Consortium for the Sustainable Development of the Andean Ecoregion
CORPOICA	Corporación del Instituto Colombiano Agropecuario
COSUDE	Cooperación Técnica Suiza
CPRI	Central Potato Research Institute, India
CPRS	Central Potato Research Station, India
CpTI	cowpea trypsin inhibitor
CRH	Horticultural Research Center, Canada
DAS	days after sowing
DGIS	Directorate General for International Cooperation, Netherlands
DM	dry matter
DNA	deoxyribonucleic acid
ELISA	enzyme-linked immunosorbent assay

ESEAP	East and Southeast Asia and the Pacific, CIP region
EVS	evaporative rustic stores
FAO	Food and Agriculture Organization of the United Nations
FFS	farmer field schools
FORTIPAPA	Fortalecimiento de la Investigación y Producción de Semilla de Papa en el Ecuador
GA	gibberellic acid
GAAS	Guandong Academy of Agricultural Sciences, China
GATT	General Agreement on Tariffs and Trade
GBF	Society for Biotechnological Research, Germany
GE	genotype x environment
GILB	Global Initiative on Late Blight
GMI	Global Mountain Initiative
GV	granulosis virus
HEC	hen egg cystatin
HI	harvest index
Hi	heterozygosity index
IARC	international agricultural research center
IBTA	Instituto Boliviano de Tecnología Agropecuaria
ICA	Instituto Colombiano Agropecuario
ICAR	Indian Council for Agricultural Research
ICARDA	International Center for Agricultural Research in the Dry Areas, Syria
ICIMOD	International Centre for Integrated Mountain Development, Nepal
ICM	integrated crop management
ICRAF	International Centre for Research in Agroforestry, Kenya
IDIAP	Instituto de Investigaciones Agropecuarias de Panamá
IDM	integrated disease management
IDRC	International Development Research Centre, Canada
IFPRI	International Food Policy Research Institute, USA
IIBC	International Institute of Biological Control, Kenya
IICA	Instituto Interamericano de Cooperación para la Agricultura, Costa Rica
IITA	International Institute of Tropical Agriculture, Nigeria
ILRI	International Livestock Research Institute, Kenya
INIA	Instituto Nacional de Investigaciones Agropecuarias, Uruguay
INIA	Instituto Nacional de Investigación Agraria, Peru
INIAP	Instituto Nacional Autónomo de Investigaciones Agropecuarias, Ecuador
INIBAP	International Network for the Improvement of Banana and Plantain, France
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico
INIVIT	Instituto Nacional de Investigación de Viandas Tropicales, Cuba
IPGRI	International Plant Genetic Resources Institute (formerly International Board for Plant Genetic Resources), Italy
IPM	integrated pest management
KARI	Kenya Agricultural Research Institute
LAC	Latin America and the Caribbean, CIP region
LB	late blight
LMF	leafminer fly
MDS	multidimensional scaling
MENA	Middle East and North Africa, CIP region
MIP	Programa de Manejo Integrado de Plagas, Dominican Republic
MSU	Michigan State University, USA

Mv	marker value
NAARI	Namulonge Agricultural and Animal Production Research Institute, Uganda
NARO	National Research Organization, Uganda
NARS	national agricultural research systems
NASH	nucleic acid spot hybridization
NGO	nongovernmental organization
NPT	neomycin phosphotransferase
NRI	Natural Resources Institute, UK
OCI	oryzacystatin I
ODA	Overseas Development Administration, UK
PAGE	polyacrylamide gel electrophoresis
PapMV	papaya mosaic virus
PBC	Potato Base Collection at CIP
PBRV	potato black ringspot virus
PCR	polymerase chain reaction
PIC	polymorphic index content
PICTIPAPA	Programa Internacional Cooperativo del Tizón Tardío de la Papa, Mexico
PLRV	potato leafroll virus
PMSF	phenylmethylsulfonyl fluoride
PNG	Papua New Guinea
PPRI	Plant Protection Research Institute, Egypt
PQS	Plant Quarantine Station, Kenya
PRA	participatory rural appraisal
PRACIPA	Programa Andino Cooperativo de Investigación en Papa, CIP network
PRAPACE	Programme Régional de l´Amélioration de la Culture de la Pomme de Terre et de la Patate Douce en Afrique Centrale et de l´Est, CIP network
PRECODEPA	Programa Regional Cooperativo de Papa, CIP network in Central America and the Caribbean
PROCIPA	Programa Cooperativo de Investigaciones en Papa, CIP network in Southern Cone
PRODAR	Programa de Desarrollo de la Agroindustria Rural para América Latina y el Caribe
PROINPA	Proyecto de Investigación de la Papa, Bolivia
PRONAMACHCS	Programa Nacional de Manejo de Cuencas Hidrográficas y Conservación de Suelos, Peru
PSTVd	potato spindle tuber viroid
PTM	potato tuber moth
PVP	potato virus P
PVS	potato virus S
PVX	potato virus X
PVY	potato virus Y
QTL	quantitative trait loci
RAPD	randomly amplified polymorphic DNA
R/F	root to foliage ratio
RFLP	restriction fragment length polymorphism
RH	relative humidity
RILET	Research Institute for Legumes and Tubers, Indonesia
RNA	ribonucleic acid
RRD	Red River Delta, Vietnam
RT-PCR	reverse transcription polymerase chain reaction
SAAS	Sichuan Academy of Agricultural Sciences, China
SADC	Southern African Development Community

SANREM	Sustainable Agricultural and Natural Resource Management
SAPPRAD	Southeast Asian Program for Potato Research and Development
SARRNET	Southern Africa Root Crop Research Network
SBTI	soybean trypsin inhibitor
SDC	Swiss Development Cooperation
SEINPA	Semilla e Investigación en Papa, Peru
SENA	Servicio Nacional de Aprendizaje, Colombia
SENASA	Servicio Nacional de Sanidad Agraria, Peru
SINGER	Systemwide Information Network for Genetic Resources
SM	simple matching coefficients
SMC	seed moisture content
SPFMV	sweetpotato feathery mottle virus
SPVD	sweetpotato virus disease
SSA	Sub-Saharan Africa, CIP region
SWA	South and West Asia, CIP region
TALPUY	Grupo de Investigación y Desarrollo de la Ciencia Andina, Peru
TAP	transmission access period
TCRC	Tropical Crops Research Center, Bangladesh
TMV	tobacco mosaic virus
TMV	total marker variance
TPS	true potato seed
UKDW	Duta Wacana Christian University, Indonesia
UMATA	Unidad Municipal de Asistencia Técnica Agropecuaria, Colombia
UMV	ullucus mosaic virus
UNA	Universidad Nacional del Altiplano, Peru
UNALM	Universidad Nacional Agraria La Molina, Peru
UNC	Universidad Nacional de Cajamarca, Peru
UNCP	Universidad Nacional del Centro del Perú
UNEP	United Nations Environment Programme
UNSAAC	Universidad Nacional de San Antonio Abad del Cusco, Peru
UNSCH	Universidad Nacional de San Cristóbal de Huamanga, Peru
UNT	University of Turku, Finland
UPWARD	Users' Perspectives With Agricultural Research and Development
URP	Universidad Ricardo Palma, Peru
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
UVC	ullucus virus C
VASI	Vietnam Agricultural Science Institute
VTMoV	velvet tobacco mottle virus
WARDA	West Africa Rice Development Association, Côte d'Ivoire
WBV	whitefly-borne closterovirus
WWR	watery wound rot
XSPRC	Xuzhou Sweet Potato Research Center, China