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TRUE POTATO SEED :

Past and Present Uses

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FOREWORD

Since its founding in 1971, the International Potato Center (CIP) has focused its research on making one of humankind's most valuable staple food sources - the potato - available in areas of the world where nutritional resources are limited.

Over-population, shortage of arable land, and inadequacy of food production are most acute in developing countries, the majority of which are located in the tropical zones. For this reason, much of CIP's research has focused on developing genetic materials with adaptation to warm climates. By capitalizing on the potato's exceptional adaptability, its cultivation can be extended into areas where traditional cultivars and production methods are not suitable.

One of the most revolutionary of CIP's research areas is the use of true potato seed (TPS) for potato propagation. This is not a new technology, as the following report illustrates. Nonetheless, the potential of TPS propagation methods in helping to alleviate food shortages in highly populated areas of the developing world has only begun to be exploited.

By outlining the history of TPS use, and by analyzing the specific conditions which determine the appropriateness of its adoption, this report aims to provide information and guidelines to agricultural researchers and policymakers for determining conditions in which the various forms of TPS use presently available can be applied best. It also sets forth the current limitations to TPS use, and the topics which will continue to demand research attention.

CIP currently collaborates with numerous national agricultural research and development programs throughout the world, providing a continuos flow of improved TPS progenies and testing their adaptation. This study provides information which can contribute to the expansion of these efforts and thus help in improving human welfare by making this valuable food resource available to a greater sector of the population of the developing world.

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INTRODUCTION

In the past decade the demand for potatoes in developing countries has increased at a rate that supersedes the rate of population growth (Horton, 1987). The major factors limiting potato production have included scarcity, high cost, and poor quality of seed tubers. These limitations have been more severe in warm, tropical regions (below 1000 m), where potato cultivation could potentially be introduced or expanded if market and price conditions were favorable (Swaminathan and Sawyer, 1983). It is believed that more than half of the potato growing area in tropical regions is comprised of mid-elevation, irrigated arid zones and lowland mesothermal areas. Population is dense in these areas - particularly in Asia and Africa - and nutritional needs are high (Paulino and Mellor, 1984). Thus, the development of technologies to aid in removing limitations to the expansion of potato cultivation and consumption in the warm areas of the tropics has special significance.

National potato programs in developing countries have made progress in recent years with research in and practical application of three major new seed technologies: tissue culture or micropropagation, rapid multiplication using cuttings or sections of different plant parts, and true potato seed, or TPS (Table 1). Whether used alone or in combination, these methods for efficient propagation of healthy potato materials have a wide range of applications.

Table 1. Seed technologies being researched or applied in production by national potato programs of developing countries (1984).

	Number of countries involved in:*	
Technology	Research	Production
Micropropagation	30	16
Rapid multiplication	43	23
True potato seed	36	5

* Total number of countries surveyed = 98
Source: Internal Regional Research Reports. CIP, 1984.

Tissue culture and rapid multiplication techniques are utilized mainly in basic seed production schemes, where they are effective in limiting the spread of seed-borne diseases, especially viruses. Rapid multiplication techniques have shown applicability at the farmer level in warm environments. They are being used for local production of planting material in some areas of Southeast Asia (Vander Zaag, 1985), and by many other seed production programs throughout the tropics. Practical systems for the use of true potato seed, especially in areas where traditional potato propagation methods present limitations, are being investigated. As potato's adaptation expands from the temperate zones to the warm areas of the tropics, increasing difficulties are encountered in obtaining healthy planting material at acceptable prices. In this context, use of TPS instead of tubers for propagation offers several advantages (Sadik, 1983; Malagamba *et al.*, 1984):

- It reduces the cost of the planting material needed per unit of land area to up to 1/10 of what farmers usually pay for quality seed tubers.[1] As the cost of seed tubers represents 20-60% of the total production cost, savings resulting from use of TPS can be up to 50% of total costs.

- It minimizes problems associated with tuber-transmitted disease, as true seed transmits fewer pathogens, in particular viruses. This signifies a great advantage for small farmers since it allows for an extended seed tuber renewal cycle and reduces the operating capital needed to obtain healthy starting material.

- True seed can be stored inexpensively in warm and/or humid areas for several years. This represents further savings for farmers, as it reduces the need for specialized storage facilities and eliminates storage losses resulting from insect damage, disease, and environmental stress.

- Many areas of consumer-potato production in the tropics are located far from the areas where seed tubers are produced. Seed tubers are bulky and perishable, hence transport costs are often very high. Transport of TPS from the production site to

[1] Approximately 2 t of seed tubers are needed to plant 1 hectare using traditional propagation methods, while just 100 to 150 g of TPS serve the same purpose. Preliminary results obtained by CIP in India, Peru, and Chile indicate that the cost of producing 1 kg of hybrid TPS without emasculation varies from 40 to 150 US$ (CIP *Annual Report*, 1984-1986).

the farmer - even in areas of difficult access - is inexpensive and relatively simple, and planting quality is not normally affected during transit.

- Use of TPS could help farmers to be less dependent on conventional seed tuber certification schemes. In many developing countries, technical, economic, and institutional problems - related primarily to the volume of material to be produced, handled, and distributed - have often hampered the applicability of seed certification schemes (Whyte, 1977; Monares, 1981). TPS adoption in selected areas of these countries could reduce the scale of seed certification schemes to more manageable sizes. Farmers would benefit by having access to various sources of healthy planting material with differing cost and technology requirements.

—— AGROECONOMIC CONDITIONS THAT FAVOR ADOPTION OF TPS ——

Potential users of TPS in developing countries include national and regional seed programs, commercial potato producers, and small farmers or household producers. Based on present knowledge of TPS utilization, several basic conditions under which the adoption of TPS is more likely to be successful can be identified. These conditions are particularly relevant for small-scale food production systems. The farming characteristics which determine suitability of TPS (Monares *et al.*, 1983) include environmental conditions, availability of quality seed tubers, availability of skilled labor, farm size, and consumer preference.

Environmental Conditions

In general TPS can be successfully utilized in all areas where environmental conditions are suitable for traditional potato production and in many areas where traditional methods are not suitable. Direct seed sowing and transplanting to produce potatoes for immediate consumption seems especially favorable in areas where temperatures are moderate, rainfall is well-distributed or irrigation is available, and soils are of adequate physical structure (Sadik, 1983). In areas where climatic conditions are favorable throughout a long season, the availability of potatoes for consumption can be greatly extended by periodic transplanting of TPS seedlings to the field. In areas with favorable tuber storage conditions during the off-season, the use of TPS for producing seedling tubers as planting material for the following season can be applied. For more restricted environments, seedling tubers can be produced in protected areas during the off-season and used for planting after a short storage period, once dormancy is naturally broken (Wiersema, 1982).

Availability of Quality Seed Tubers

Most potato farmers in developing countries have difficulty in obtaining healthy seed tubers at a reasonable price. Many of them must use either costly imported material or deteriorated, locally produced seed tubers. The desirability of TPS will of course be greater in areas where there are difficulties in obtaining quality seed at a low cost.

Skilled Labor

Labor requirements depend on the system of TPS utilization to be applied, and on environmental conditions. In general, both transplanting and direct sowing of TPS for the production of consumer potatoes or seedling tubers require more farming operations and labor than traditional planting methods. This is especially true under the stress conditions usually present in regions with high potential for TPS adoption. Thus, shortage of skilled labor may restrict the adoption of this technology in some areas. In small-farm areas or within the context of small-scale food production systems, where family labor predominates and/or skilled labor is abundant, the likelihood of TPS adoption is greater.

Farm Size

Known TPS utilization systems appear to be particularly suitable for small plots, regardless of the total farm size. Better performance of crops grown from TPS is generally achieved when greater care is provided during the first two months after sowing, i.e. during the period of seedling growth and at transplanting. This makes TPS technology compatible with the family labor surplus usually found in small-farm areas at this time. This is supported by the fact that in most developing countries, as the area under potato cultivation on individual farms increases a greater degree of mechanization is found.

Consumer Preferences

Consumer preference with relation to specific tuber characteristics (e.g. size, skin color, taste, etc.) varies greatly between countries and within regions of a given country. In mountainous areas, where potato has become a traditional small-farm crop, consumers are often more demanding with respect to tuber taste or storability. In highly populated urban areas or areas where the crop is either not grown or is of secondary importance, tuber size, color, and general appearance may be less important. Although relatively high uniformity is being achieved in TPS material, prospects for TPS adoption are still greater in areas where consumer preference for specific tuber characteristics is not too strict.

EARLY USES OF TPS

Although no records are available concerning the history of TPS use by farmers, in some isolated locations of the Andean region a traditional form of TPS utilization is still applied. This practice apparently dates from many centuries past, probably from the time of initial potato cultivation. The Incas, who utilized advanced agricultural practices and knew how to transplant, may have learned to use TPS out of curiosity. Salaman (1970) maintains that early South American cultivators occasionally developed new varieties from naturally produced TPS. The native cultivars still grown extensively in certain locations probably originated from selections made by farmers according to local preferences for plant types, tuber characteristics and culinary quality. The large number of varieties in traditional potato growing zones, as well as the numerous differences in plant and tuber characteristics within a variety, support this hypothesis. Thus, the several types of Ccompis, Imilla, and other very popular varieties in the Andean highlands may have resulted from selections made by farmers from segregating populations grown from TPS. Howard (1968) supports the theory of conscious selection of cultivars for tuber qualities in ancient South America. Mc Kay (1961) gives a similar explanation for the multiplicity of potato varieties cultivated in Europe in the nineteenth century.

Another probable reason for using TPS in the early days of potato cultivation in the Andean highlands may have been the need for recuperating the yield potential of native cultivars, gradually lost after several growing seasons. It can be ventured that experienced farmers noticed that there were fewer weak and low-yielding plants in their fields when true seed was used, or that plants grown naturally from true seed looked healthier than the stands from seed tubers. Also, when the tubers produced from true seed were utilized for planting the following season, a considerable yield improvement was most probably observed.

Since the rate of virus spread in these regions is naturally low, the full impact of TPS in producing virus-free tubers was probably only evident after several years, or possibly several decades of utilization. Jones[2] (personal communication) points out that native varieties from South America have much higher levels of resistance to virus infection than modern ones, "which

[2]Jones, R.A.C. Virologist. Harpenden Laboratory: Ministry of Agriculture, Fisheries and Food, England.

would account, at least in part, for the need to sustain the latter with seed programs involving the taking of active control measures against virus spread."

The major role played by TPS in the past - sporadically creating new varieties or restoring the yield capacity of degenerated varieties - involved rather simple and small-scale field operations; the development of special techniques for TPS use was not required. The increasing need in recent years to expand potato cultivation into warm areas of the tropics has evidenced a new and potentially important role for TPS as a steady source of low-cost, high-quality planting material for small farmers.

Hawkes, cited by Salaman (1970), reported that TPS is used in northern Ecuador (Pichincha) and southern Colombia (Pasto) to produce tubers which are, in turn, planted the next season for consumer potato production. Ochoa[3] (personal communication) has observed that farmers in the central and southern highlands of Peru (Mantaro Valley, Abancay, and Cusco) use TPS to produce tubers that correspond to desirable quality types and are free from tuber-transmitted diseases. Franco (1981) presented a case of farmers in Peru (Chincheros, Cusco) who use TPS to counter varietal degeneration.[4]

[3]Ochoa, C. Taxonomist. CIP: Lima, Peru.

[4]Varietal degeneration refers to the gradual yield losses, off-type tubers, and abnormal foliage color resulting from the continued use of infected seed tubers.

MODERN USES OF TPS

TPS seems to have been used by farmers and gardeners in the last part of the nineteenth century in many parts of the northern hemisphere. In 1888 the *Rural New-Yorker*, "a journal for the suburban and country home," published some recommendations to growers for raising potatoes from TPS. The main purpose of that article was to provide information on TPS utilization methods and to encourage growers to use TPS to identify clones better adapted to given soils than those introduced by the seed industry.

In 1906 TPS was advertised in a Canadian catalog for vegetable seed. Small packages of "carefully hybridized potato seed" were offered to growers "for securing a new variety by planting in two years." Similar packages of TPS are again being advertised in catalogs of seed companies in the USA, and in some cases potato seedlings are sold directly for transplanting into fields of organic-garden growers.

In recent years farmers in several developing countries have started to produce potatoes using TPS. At the same time the major constraints to TPS utilization at the small-farm level are being removed through research. In this section we will examine the use of TPS in several countries that have followed a successful institutional strategy for evaluating and/or promoting this new technology.

China

An interesting example of TPS utilization in recent years is found in reports made by Chinese scientists. In China the need for increased productivity in certain potato-producing areas resulted in interest in TPS as an alternative to traditional potato planting material. True seed appeared to be appropriate in areas where high incidence of virus diseases was reducing potato yields to unacceptably low levels.

Research on TPS started in China during the late 50's, in the Inner Mongolia region. Promising results motivated a governmental decision to launch a large-scale farmer-oriented program in the early 70's. Large volumes of TPS from high-yielding, late-blight-resistant potato varieties were produced under natural conditions in selected farmers' fields and were distributed to other regions. The use of TPS technology on a commercial scale

in this area evidenced numerous agronomic requirements to be met before its adoption could be considered economically feasible for use at the small-farm level in this area.

At present the most important area for growing potatoes from TPS in China covers three provinces in the mountainous region of the Southwest, where true seed is sown in seedbeds to produce seedlings for transplanting. Small-farmers of the southwestern region have been trained in special vegetable-growing skills, as these techniques were found to adapt well to the general ecological and socioeconomic conditions of that area. Although the primary objective of TPS utilization in that region is to produce potatoes for consumption, the smaller tubers are kept as seed for the next planting season. After initial tuber production and transplanting, the crop can normally be propagated using seed tubers for five to six growing seasons before there is a need for using TPS again. In recent years the system has developed further and at present some farmers have specialized in the production of high-quality potato seedlings for sale to other farmers.

In the Inner Mongolia region TPS also continues to be utilized, although to a lesser extent than in the Southwest. Inner Mongolia has a much shorter growing season for potatoes due to low rainfall and early frosts. Therefore, in this region TPS is used only for direct sowing to protected nursery seedbeds for seedling tuber production. Because of the climate, seedling tubers of more than 20 g produced in these beds are preferred for planting the following season. The tubers are multiplied for about four consecutive seasons before reverting to TPS.

It is estimated that more than 15,000 ha of potatoes are presently cultivated from TPS in China (Bo Fu, 1984).

Rwanda

The use of TPS in Rwanda was proposed for some of the potato producing areas as a potential complement to the systems for potato breeding used in official programs (Devaux, 1984). The first objective of TPS research for this country was to obtain TPS families resistant to late blight *(Phytophthora infestans)*, which is the major constraint to potato production in Rwanda. Selected TPS progenies were compared to local varieties at the small-farm level: many hybrid progenies and some open-pollinated progenies gave excellent yields and showed good resistance to

late blight. The best progenies were evaluated under a range of utilization systems. National scientists found that under Rwanda's conditions the use of seedling tubers produced in seedbeds showed very favorable results.

The model for TPS use proposed by national scientists to farmers in Rwanda consisted of three stages (Haugerud and Nyirazinkwiye, 1986):

- Farmers produce seedling tubers by sowing TPS in seedbeds of 1-3 m^2.

- The seedling tubers obtained from the seedbeds are planted, and their yield and other characteristics are compared to those of the native varieties. At harvest, a selection of the best material is made by the farmer, based on plant and tuber characteristics.

- The crop is grown from the selected tubers, and their productivity is compared to that of varieties usually grown at the farm.

The above system was sucessfully tested with farmers in four production areas: Cyeru, Butaro, Kinigi, and Karago. The main limitations identified were scarcity of water during the nursery stage, and the large-scale planting required in order to obtain the necessary amount of seed tubers for the cultivated area of each farm. However, other factors - such as greater labor requirements or the heterogeneity of the tubers - were not reported to have restricted farmer acceptance of TPS.

The average farm size in Rwanda is only one hectare, yet three to six different potato varieties are usually grown simultaneously on a farm (Durr, 1983; Monares, 1984). Diversity of varieties is considered by the farmer to be advantageous in reducing losses due to pathogens, pests, excess rainfall, or extended drought. This strategy is also considered to be a means of satisfying multiple production objectives, and of extending the period of food and cash availability (Haugerud and Nyirazinkwiye, 1986).

Thus, the use of TPS to produce seedling tubers for multiplication fits well into Rwanda's production system: first, it increases the diversity of varieties cultivated by farmers and therefore reduces the vulnerability of the potato crop to envi-

ronmental stresses and other risks; and second, it allows the farmer to personally select the best clones for multiplication, and to gradually replace old local varieties.

Sri Lanka

Of the cases that illustrate high potential for extensive adoption of TPS, that of Sri Lanka is perhaps the most interesting. All of the major advantages offered by TPS are significant within the agro-economic conditions present in the production areas of this island. Also, the characteristics of various farming areas of Sri Lanka represent, to a great extent, the ideal conditions required for massive adoption of TPS technology.

Seed tubers utilized by potato growers in Sri Lanka are normally imported from Europe and their cost represents 40 to 50% of total production costs. This is reflected by the subsequent high price of consumer potatoes in the local markets. At present the government is attempting to reduce the annual expenditure of scarce foreign currency on imported seed tubers, and has therefore provided the incentive for developing a program to use TPS as alternative planting material. Vegetable growing paractices are well developed throughout the potato growing region - on farms normally no larger than half a hectare - and thus the skills required for TPS use are frequently encountered.

TPS research has made rapid progress in Sri Lanka in recent years, and TPS technology is reaching many farmers' fields. Through applied research and an aggressive extension program, local scientists are evaluating and adapting several alternative methods of TPS use to suit conditions in areas of high potential.

Attempts by farmers to use TPS commercially in Sri Lanka apparently date back several years. One farmer from an important potato growing area received a government award for his successful pioneering work using open-pollinated TPS of the most popular variety in the country. Based on this experience, a program to produce seedlings for distribution to private farmers on government farms was initiated in the early 80's. These seedlings were utilized for the production of both ware and seed tubers. The field performance and yield capacity of the open-pollinated TPS used initially by the program were not sufficient to allow for a more extensive use of the technology. However, the recent introduction of hybrid TPS has increased prospects for further adoption. The use of new hybrids ensures greater plant vigor, more uniform tuber characteristics, and higher yields.

Each year more farmers become familiarized with TPS technology and are incorporated into the program. The few grams of seed distributed to individual farmers is normally used for producing seedling tubers either by transplanting or directly sowing TPS in plots (Fig. 1). Also, it has been proposed that TPS be used as the starting material for a basic seed tuber production program on a government seed farm in the highlands. The basic seed tubers are multiplied by selected growers for further distribution to ware-potato growers (Fig. 2).

Vietnam

Vietnam illustrates the case of a country where TPS has been successfully adopted by farmers of two agroecological regions - the Dalat highlands and the Red River Delta - for different

Fig. 1. Seedling tuber production by a farmer in Sri Lanka. Seedlings are transplanted into several seedbeds.

Fig. 2. Production of consumer potatoes in a farmer's field in Sri Lanka, using seedling tubers previously obtained from a government seed farm.

agroeconomic reasons (Vander Zaag *et al.*, 1987). In both areas farmers commonly grow transplanted rice and vegetables, and local consumers are not selective regarding tuber shape, flesh color and taste.

TPS was introduced in Vietnam in 1983 and testing was begun on a small scale. In 1985, relatively large amounts of open-pollinated TPS of two new cultivars, Atzimba and CFK-69.1, were collected from farmers' fields in the southern highland area of Dalat (1300 m). Because the crop produced from TPS of these two cultivars gave tubers of acceptable quality, farmers used the seed to produce many small tubers, which were then stored and replanted the following season for the commercial crop. The main advantages of these cultivars are their superior plant vigor and their resistance to late blight and viruses. During the 1985-1986 season, over 20 kg of TPS produced in the highlands of Dalat were distributed by the government to cooperatives in the Red River Delta in northern Vietnam. In this area farmers grow approximately 50,000 ha of potatoes during the cool winter

months, following two rice crops. At harvest, small tubers are usually stored in the farmers' homes and used for planting the next season. Because of the long storage period (9 months) and high temperatures, storage losses can be as high as 50% and subsequent low yields (about 9 t/ha) result from using seriously degenerated seed. Under these limiting conditions, tubers from TPS have shown considerably lower storage losses and have been more productive than those from the local variety. In 1986, about 300 farmers were producing potatoes commercially from TPS.

The relative ease of obtaining seed, the high yield of tubers obtained from transplanted seedlings, the reduction of storage losses, and the superior yields of subsequent commercial crops have encouraged farmers to adopt the TPS approach. A very strong government training and extension program coupled with large-scale seed production have been critical factors in the rapid progress made in TPS use by farmers, particularly in the Red River Delta area. The prospect of wide TPS adoption in Vietnam will improve as superior progenies with longer tuber dormancy and better adaptation to short, cool days are developed.

Similar conditions to those mentioned for China, Rwanda, Sri Lanka, and Vietnam are found in many developing areas of the world. The introduction of TPS could result in a reduction in potato production costs, as well as in considerable other benefits to farmers and consumers. The application of modern techniques and improved hybrid genetic materials will permit the expansion of TPS technology to farmers of many of these areas on a more extensive scale. Great progress has been made in recent years in improving both the quality of TPS materials and the field practices for TPS crops; this will ensure more uniform and better yields. The basic information developed on TPS utilization systems has been evaluated in farmers' fields. As a result of these evaluations, several modifications and variations have been proposed.

PRODUCTION OF TPS

A key factor determining the appropriateness of TPS in developing countries is the availability of suitable, low-cost methods for production of high-quality TPS. Climatic, technological, economic, and institutional factors may limit the possibilities of commercial TPS production in the tropics. Knowledge and experience to date indicate that there are three major factors that determine where, how, and in what amount TPS can be commercially produced (Upadhya *et al.*, 1984; Kidane-Mariam *et al.*, 1984; Monares, 1984; Pallais, 1987): flowering characteristics of the parent material, quality of TPS produced, and production costs.

True potato seed can be either open-pollinated or hybrid (Table 2). Production of open-pollinated seed requires neither special skills nor big investments in land or facilities. This is, therefore, a practical alternative for use by individual farmers, cooperatives, and national potato programs. Open-pollinated seed from local varieties has performed well under certain agroecological conditions. In Vietnam, for example, about 50 hectares were planted with open-pollinated seed locally obtained in the 1985-86 season. In Sri Lanka, ware potatoes are produced on small farms using open-pollinated seed from the most popular local variety (Bryan, 1986).

Table 2. TPS production.

Type of seed	Type of producer
Open-pollinated	Farmers (private cooperatives)
	National potato programs
Hybrid	Private seed companies
	State-managed seed institutions
	National potato programs

Among the greatest advantages of open-pollinated seed over hybrid seed are its relatively easier production and its lower cost. Peloquin (1979) estimated that under natural conditions in the field, seed yields of 10,000-50,000 per plant are possible. However, natural pollination in potatoes normally results in seed that is almost entirely self-pollinated. For this reason, reduced tuber yields due to inbreeding depression are usually expected when using open-pollinated TPS. More efficient pollination methods that could lead to increased outcrossing rates are being investigated, as are procedures such as the use of synthetics and the identification of materials with low yield depression after several generations of selfing (Kidane-Mariam *et al.*, 1984; Golmirzaie, 1985).

For commercial potato production, hybrids offer several advantages over open-pollinated TPS progenies. The success of genetic manipulations to develop and incorporate desirable traits into TPS progenies (e.g. higher yields, tuber and plant uniformity, earliness, and resistance to insects and diseases) is more likely to be obtained with bybrids than with open-pollinated materials. Hybrids also exhibit major traits that are particularly important when using TPS: they produce seedlings of high early vigor, they present a better capacity for fast recovery following transplanting, and they can overcome the tendency to produce generally small tubers, a character of marked heritability.

Production of hybrid TPS is technically much more demanding than production of open-pollinated seed. Thus, this means of production does not seem feasible for the immediate future at the small-farm level in the tropics. Instead it appears likely that hybrid TPS will be produced by seed companies, state-managed agencies or national potato programs that have suitable facilities, skilled personnel, and already-developed, efficient seed distribution and marketing networks. In massive production of open-pollinated TPS, current research indicates that considerable improvements can be achieved in seed quality, uniformity, and yields. More effective methods for producing large quantities of low-cost hybrid seed also need to be developed.

In southern Chile, through a collaborative project involving the National Institute of Agricultural Research (INIA) and CIP, several aspects of the large-scale production of hybrid TPS have been studied. Socioeconomic information on four progenies,

recorded during the 1985-86[5] season, indicated that production costs vary from US$178 to US$244 per kilogram of TPS when produced with emasculation of the flowers of the female plants (CIP, 1986). Emasculation was the most expensive procedure in the production cycle, accounting for 26% of total costs. Hence, the production cost per kilogram of seed when flowers were pollinated without previous emasculation decreased to US$129 - US$176.

On the average, only 75 m^2 of land and 24 man/days were needed to produce one kilogram of TPS with emasculation. Due to the experimental nature of the TPS production process, technical management was the most expensive input. As more experience is gained on TPS field production practices, costs can be reduced through a substantial increment in labor and management productivity.[6]

Some important conclusions can be drawn from the INIA-CIP project. First, pollination without emasculation is by far the easiest and least costly means of large-scale hybrid TPS production. Current economic estimates suggest that the cost of hybrid TPS would probably be less than the cost of the tomato seed commonly used in most developing countries. In that case, farmers would spend less than 10% of the amount usually spent on seed tubers, since only 100-150 g of TPS are needed to plant one hectare of potatoes. Thus, it would appear that the cost of current TPS production schemes has already reached a level that makes commercial production of hybrid progenies economically feasible.

The most significant implication of the studies conducted in Peru, Chile, and India is that there remain two research areas far more important than reduction of production costs: improvement of TPS quality, and development of efficient methods for large-scale TPS production. Future progress in these critical research areas could significantly influence the extent to which TPS will become a viable technology for developing countries.

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[5]Progenies included in the economic calculations were Atzimba X DTO-28, Atzimba X R-128.6, Serrana X DTO-28, and Serrana X LT-7.

[6]Upadhya (1987) estimates that under Indian land and labor conditions the cost of 1 kg of hybrid TPS would be approximately US$37, without emasculation.

UTILIZATION SYSTEMS

Perhaps one of the greatest advantages of TPS utilization is the flexibility offered by the diversity of possible systems available, permitting its adaptation to numerous climates and farming conditions. Climate, because of its great influence on the quality of seed tubers, is probably the major factor influencing whether TPS should be used every growing season to produce consumer potatoes, or whether it should be used to produce consumer and/or seed potatoes for planting the following season. The cool regions normally have an advantage in maintaining quality of potato seed tubers through several field generations. In warm regions the only alternatives may be either to produce ware potatoes from expensive seed tubers from other areas, or to use TPS.

Traditional Potato Production Zones

Traditional potato-producing areas range from areas where basic seed tuber production can be conducted to those where only one or a few multiplications of original seed stock can be made. Basic seed tuber production areas are normally located in the upper potato-growing highlands of the tropics and in the higher latitudes of the temperate regions, whereas seed multiplication areas are usually located at lower altitudes where ware potato production is the main activity.

Use of TPS in Basic Seed Tuber Production Areas. In these areas seed tuber stocks - if properly managed - maintain a high quality-standard after many field generations. TPS could constitute the starting material for the development of a seed tuber certification scheme. The use of TPS in these conditions would simplify the maintenance of clonal material, i.e. it would eliminate the pre-basic-seed-production steps as well as the associated virology testing work. It may also signify the possibility of introducing low-cost, clean planting material - as in the early days of TPS utilization in the Andean region - for improving the effectiveness of local informal seed systems.

Use of TPS as the basis for a seed tuber production scheme permits the attainment of high levels of efficiency due to its high multiplication rate: this is particularly true in nursery production of seedling tubers. In a nursery, growing conditions can be controlled to ensure optimum seedling growth, as well as to prevent contamination by tuber-transmitted diseases. Nurser-

ies in cool regions can be located in open areas with seedbeds of differing degrees of elaboration.

In general, the more favorable an ecology is for seed tuber production the greater the number of field multiplications that can be made after the original nursery production of seedling tubers. The initial number of seedling tubers to be produced will depend on the final area to be planted for ware potato production, and on the number of multiplications possible according to the rate of disease build-up in subsequent tuber generations. In basic seed-tuber-producing regions characterized by low vector activity, the number of multiplications can be significantly greater than if clonal material were to be used, since the virus content of the original stock of tubers from TPS would be nil.

An interesting aspect to consider in a seed tuber production scheme based on TPS is that experiment stations or possibly experienced farmers could easily undertake the responsibility for the nursery production of the initial stock of seedling tubers, while specialized seed growers could further propagate them

Fig. 3. Production of a basic stock of seedling tubers from TPS. Seedbeds at an experiment station in a basic seed production area in Puno (Peru).

(Fig. 3). This would introduce a higher degree of specialization into the scheme.

Of course, when fewer multiplications or a larger amount of seed tubers are required in each step, the nursery area and the amount of TPS used to start the scheme can be adjusted accordingly. For example, in an area where 1,000 ha of consumer potatoes are grown, a very simple three-field multiplication scheme - starting with 20 g of TPS produced at an experiment station or a farmers' cooperative - can be applied (Table 3). The seedling tubers produced in 100 m^2 of seedbeds can be multiplied the following season in the station fields to produce 20 tons of foundation seed tubers. The tubers from the following two multiplications - herein mentioned as seed tuber class A and B - can be produced in farmers' fields, where roguing and other specialized practices for potato seed tuber production can be applied.

It is important to note, however, that traditional potato growing zones are normally characterized by exacting market requirements; thus, potatoes grown from true seed must meet consumer preferences. In seed tuber production areas, uniform tuber quality may be as important as high yield. For this reason, selection of proper plant and tuber types during each stage of multiplication must be considered.

Table 3. Seed tuber production scheme for potato in a growing area of 1,000 ha, using TPS as starting material.

Area (ha)	Planting material produced or utilized	Class of produce	Type of producer
0.01 →	50,000 units	Seedling tubers	Exp. station/ cooperatives
1.00 →	20 t	Foundation	Exp. station/ cooperatives
10.00 →	200 t	Class A seed	Seed growers
100.00 →	2,000 t	Class B seed	Seed growers
1000.00 →	20,000 t	Ware potatoes	Potato producers

Fig. 4. Seedbed production of seedling tubers in a farmer's field in Cañete (coastal area, Peru).

Use of TPS in Seed Tuber Multiplication Areas. In areas suitable only for multiplication of seed tubers, potato crops are normally grown under climatic conditions which favor the fast spread of virus disease. Significant seed tuber quality losses occur after every growing season, limiting the number of multiplications that can be made from an original stock of tubers. For this reason seed tubers utilized in multiplication areas are imported from other areas (basic seed areas), at a frequency that depends both on rate of quality deterioration and cost. Under such circumstances, TPS offers an attractive alternative to imported seed tubers, especially in the areas of greatest frequency of replacement.

Seed tuber multiplication areas, because of their mild climate, are normally characterized by intensive cropping methods that call for skillful and opportune cultivation practices. Under such conditions, TPS utilization technologies can be applied

without major agronomic difficulties: field seedbeds directly sown with TPS (Fig. 4) can supply enough seedling tubers for planting the following season, or seedlings can be transplanted into a larger field area to produce both consumer potatoes and seedling tubers.

Among seed tuber multiplication zones, vegetable growing areas in the tropics such as those found in valleys of the central coast of Peru have a particularly high potential for TPS adoption. In these coastal areas only one seed tuber multiplication is possible yearly, yet potatoes are grown twice during the year. For the main crop season, high-quality seed tubers imported from basic seed producing areas in the highlands are utilized. The high yields obtained compensate for the lower market price for potatoes during that season. Part of the tubers produced are stored on the farms during the hot summer for planting in the following early season. The degeneration of the seed tubers as a result of virus contamination and high temperatures during stor-

Fig. 5. Potato seedling production in a 10 m^2 seedbed. Farmer's field in El Callao (coastal area, Peru).

Fig. 6. Seedlings transplanted to a 500 m^2 plot.

age greatly affects yields, but the high price of consumer potatoes normally obtained in the market at this time of year brings good returns. For the next main-season crop, farmers purchase new seed tubers from the highlands.

Fig. 7. Half-hectare planted with seedling tubers.

The applicability of TPS in these areas has been evidenced in various on-farm evaluations carried out by CIP. One of the most successful utilization systems consisted in producing seedlings during the main season in a 10 m^2 seedbed (Fig. 5) and then transplanting them to a 500 m^2 seedling tuber plot 35 days after sowing[7] (Fig. 6). The seed-size tubers produced were kept and used to plant half hectare in the following early season (Fig. 7), while a similar volume of large-size tubers was sold to the local market.

The economic analysis of this experience shows that growers can obtain higher yields and returns using TPS than using locally produced seed tubers (Table 4). As expected, TPS technology was

Table 4. Costs and returns of TPS versus traditional technology in the early season, El Callao, Peru, 1985.

	Traditional technology	TPS technology*
Input components (%)		
Labor	9.2	13.3
Seed	27.7	9.2
Equipment	14.7	19.8
Pesticides	44.8	30.3
Fertilizer	3.6	27.4
	100.0	100.0
Marketable yield (t)	14	21
Budgetary summary per hectare (in US$)		
Value of output	1290	1806
Cost of inputs	599	520
Net return	691	1286
Net return of TPS over traditional technology		595

* Using seedling tubers produced the preceeding season.

[7]In the seedling tuber plot, transplanting density is about double the normal density for producing ware potatoes; this permits the use of regular farm equipment, field practices are easily conducted, and the size of tubers obtained is adequate to allow for a significant number of them to be marketed as consumer potatoes.

less expensive than conventional propagation methods. However, it is interesting to note that the main advantage of the new technology was not the cost reduction, but rather the higher yield obtained in comparison with the highly infected planting material used by farmers in the early season.

Potential Zones for Expansion

The potential zones for expansion of potato production using TPS include extensive warm tropical areas where there is at least one season of approximately three months duration of climatic conditions favorable to potato cultivation; they also include areas where seed tubers are imported every season. In warm tropical areas - due to generally high virus vector activity, high incidence of tuber-borne diseases, and, especially, difficulties in maintaining quality in seed tubers stored under elevated temperatures - potato cultivation has been severely limited. Since seed tubers must be imported every season from temperate areas at costs that may represent up to 60% of total production costs, potato becomes a luxury vegetable with a restricted market. The potential impact of TPS in these environments is high: by making planting materials readily available and by lowering production costs this technology can greatly encourage potato cultivation.

Fig. 8. Eggplant seedlings growing under shade on a farm in the Philippines.

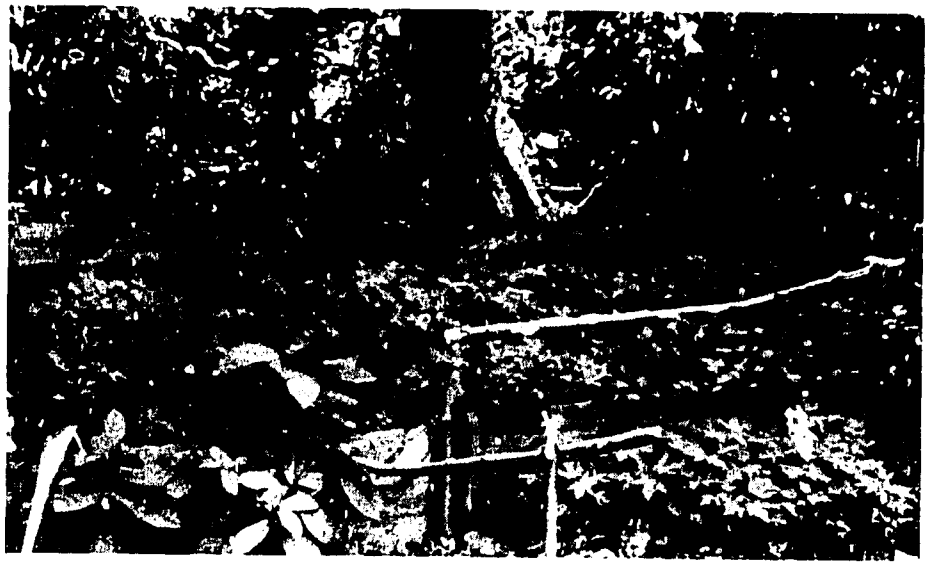


Fig. 9. Potato seedlings transplanted as a relay crop of maize in a warm-humid tropical location (San Ramon, Peru).

The introduction of new varieties, of new agricultural practices, and/or of new crops are among the most efficient ways of making traditional farming systems in tropical zones more productive. In many subsistence agriculture areas of the warm tropics, farmers do not grow potatoes because they do not have access to good-quality seed, or because they have not found a viable technology for storing seed tubers under high temperatures. The adoption of TPS makes potato production feasible, and thus expands the range of staple crops grown by small farmers, making greater nutritional resources available.

In areas of potential expansion of the potato crop, particularly in warm tropical regions, production of ware potatoes

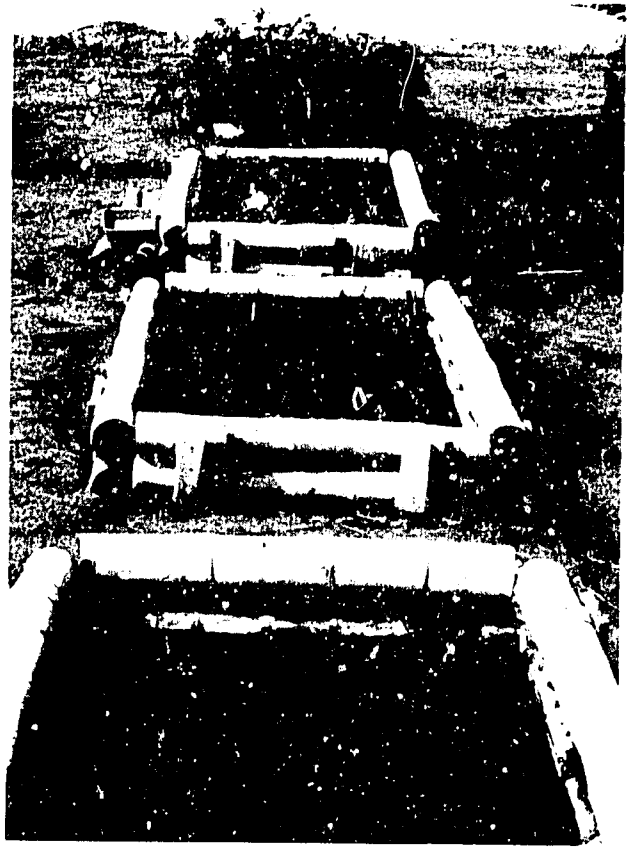
through direct transplanting of seedlings to the field appears to be a very suitable system. Among other advantages, it makes it possible to produce vigorous seedlings in seedbeds and to transplant whenever conditions are appropriate for production of ware potatoes. This system permits efficient use of land and avoids the limitations of direct sowing of TPS in the field in a high-stress environment. Vigorous potato seedlings can easily be obtained in seedbeds with similar characteristics to those used for many other vegetables cultivated in warm tropical areas, i.e. protected from excessive heat produced by radiation (Fig. 8). Once the seedlings have reached a desirable size, excellent growth and field performance are obtained by transplanting them either between the rows of a preceeding crop - such as maize that is finishing its growth cycle (Fig. 9) - or in association with other crops of compatible growth habits. When conditions are favorable, part of the tubers produced from transplanted seedlings can also be utilized as planting material for the following season.

Under milder conditions, when off-season production of seedling tubers is possible, seedbeds with transplanted seedlings or with directly sown TPS can provide seedling tubers for planting in similar crop associations.

TPS IN SMALL-SCALE FOOD PRODUCTION

In recent years, small-scale rural and urban food production at the household or community level has increasingly attracted the interest of policy makers, urban planners, and development specialists (UNICEF, 1984). According to Niñez (1984), "household gardens are the most ancient and persevering form of cultivation and today represent one of the last frontiers for increasing food production in the struggle against world hunger and malnutrition." They are a universal subsistence strategy for production of food in the areas of highest concentration of population and where productive land is scarce, helping to improve the human nutritional balance and creating employment and income not otherwise offered by local economies.

Fig. 10. Sequential production of ware potatoes in seedbeds in a tropical farmyard (Rio Colorado, Peru).



The potato as a staple crop lends itself to small-scale production on marginal land with simple garden technology. This explains, in part, why the combinaton "household garden - potato" was highly successful in alleviating famine and food shortages in nineteenth century Europe (Salaman, 1970), and why this continues to be an important food production strategy in times of need for all types of societies (Niñez, 1985).

TPS can play a significant role in expanding household-level food production. Apart from providing access to a nutritional source in many cases not otherwise available or affordable, it allows farmers to experiment with new genetic material before it is used in the field. In urban centers, use of TPS can help in meeting other household-related needs, e.g. by generating cash from the sale of the product.

In warm, tropical areas, household garden production of crops for consumption at the family level is a very common practice. In the backyard garden, plants are grown at different times of the year in order to expand their availability as fresh produce. Since ware potatoes deteriorate rapidly and can very rarely be kept for periods longer than one month, the year-round availability of TPS could expand the production period of potatoes in backyard gardens. According to average per capita consumption per year in several warm areas, the amount of potatoes required would be about 10 kg per month for a family of six. The above amount can be achieved by using a series of 2 m^2 beds sown and harvested in sequence every month (Fig. 10). If conditions permit, part of the tubers can be saved to plant a larger plot.

CONCLUSIONS

The flexibility with which TPS can be incorporated into production systems shows promise for alleviating the critical scarcity of healthy seed potatoes in most developing countries. Environmental and socioeconomic factors set boundaries for the adoption of this technology and determine the ways in which it must be applied. The potential use of TPS in a particular area is directly related to the rate of quality deterioration of seed tubers and their replacement cost. Factors such as the need for skilled labor and the heterogeneity of harvested tubers are becoming less restrictive as new, improved hybrid progenies become available and as simplified agronomic practices are developed and applied by farmers.

The experiences of China, Rwanda, Sri Lanka, and other countries show that TPS can be utilized following at least three distinct strategies: it can be used as a source of starting material in official seed tuber production schemes, it can be directly distributed to farmers for production of tubers for further multiplication, and it can be distributed for direct production of consumer potatoes at the small-farm or household level.

The use of TPS in the development of seed tuber certification schemes reduces and simplifies the maintenance of clonal material, including associated virology tests. This is particularly attractive for developing countries whose governments cannot afford to establish large-scale, conventional certification programs due to lack of specialized human resources and advanced laboratory testing facilities.

The advantage of the second strategy is the possibility of developing seed systems that are partially or totally independent of official seed tuber supply programs. In countries where these programs are small or inefficient, and where available varieties do not yield well under local production conditions, the farmers themselves can select the best clones derived from TPS and gradually replace old, local varieties. Farmers from more-developed areas can use improved hybrid materials - which usually have yields as high as the alternative sources of seed - for commercial potato production with limited government assistance. Helping farmers to be self-sufficient in producing or obtaining acceptable planting material is a socially efficient way of solving the severe scarcity of quality potato seed that affects most developing countries.

As progress continuous to be made in improving TPS progenies, the third strategy for TPS use - potato production for immediate consumption at the household level - is expected to expand significantly.

With regard to TPS sources, low-cost open-pollinated progenies will probably be the choices prefered by small farmers in areas where potato flowering and fruit setting are abundant. However, for more extensive adoption of TPS in developing countries, effective and large-scale seed supply systems need to be developed. Experimental data from Peru, Chile, and India show that the cost of production of hybrid seed without emasculation is low enough to make commercialization profitable. Future research should focus on improvements in seed quality and on the design of methods and institutional schemes for efficient production and distribution of large amounts of TPS.

The need to increase the supply of healthy potato seed in developing countries has stimulated research in and promotion of micro- and macro-propagation techniques. Many of these techniques, particularly tissue culture and rapid multiplication, have improved the efficiency and viability of national seed programs by reducing the number of field multiplications needed to meet production goals. Since the use of such techniques requires careful management and adequate agro-ecological conditions, they have only been successfully applied on a limited scale, mostly in zones where specialized labor is available and which are free of environmental stresses during the plant establishment period. These conditions are also favorable to TPS use. Thus, various seed technologies can be implemented in a region either simultaneously or complementarily, to solve shortages of quality seed. Available evidence indicates that the alleviation of the chronic scarcity of quality seed in developing countries will not depend on the use of a particular seed technology, but rather on innovative adaptations and combinations of various propagation methods, including traditional strategies and practices for seed procurement and use.

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