PN-AAV-841
47025

Research Highlights 1985

International Maize and Wheat Improvement Center

CIMMYT

The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, CIMMYT is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on food production in developing countries. CIMMYT is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 40 donor countries, international and regional organizations, and private foundations.

CIMMYT receives support through the CGIAR from a number of sources, including the international aid agencies of Australia, Austria, Brazil, Canada, China, Denmark, Federal Republic of Germany, France, India, Ireland, Italy, Japan, Mexico, the Netherlands, Norway, the Philippines, Saudi Arabia, Spain, Switzerland, United Kingdom and the USA, and from the European Economic Commission, Ford Foundation, Inter-American Development Bank, International Bank for Reconstruction and Development, International Development Research Centre, OPEC Fund for International Development, Rockefeller Foundation, and the United Nations Development Programme. Responsibility for this publication rests solely with CIMMYT.

Correct Citation: CIMMYT. 1986. *CIMMYT Research Highlights 1985*. Mexico, D.F. Mexico.

ISSN 0257-8751

Contents

ii **Trustees**

iv **CIMMYT Principal Staff**

1 **Introduction**

5 **Maize Research**
7 Floury Maize Improvement
13 Breeding for Resistance to Downy Mildew
20 Development of Multiple Insect Resistance
28 Assessing Yield Stability
33 Conservation of the Wild Relatives of Maize

41 **Wheat Research**
44 Barley Yellow Dwarf
54 *Helminthosporium sativum*: Inoculation Techniques and Identification of Resistant Material
62 Fusarium Studies at CIMMYT
67 Seed Health Unit
72 Triticale—A Crop for Marginal Environments
81 Breeding Triticale through Crosses with Wheat

89 **Crop Management Research**
89 Wheat Production Research in Pakistan
100 Maize Production Research in Tierra Caliente, Mexico

107 **Data Collection and Analysis**
107 Wheat Marketing and Pricing Issues in Developing Countries
112 National Wheat Pricing Policies

Trustees for 1985

Eduardo Pesqueira Olea
President, CIMMYT Assembly
Secretary of Agriculture and
Water Resources
Mexico

Virgilio Barco
Chairman, Board of Trustees
Consultant
Colombia

Ramón Claverán Alonso[1]
Vice-Chairman, Board of Trustees
Director General, National Institute
of Agricultural Research
Mexico

Doris Howes Calloway
Provost, University of
California, Berkeley
USA

Walter P. Falcon
Director, Food Research Institute
Stanford University
USA

Robert D. Havener[2]
Director General, CIMMYT
Mexico

Phaitoon Ingkasuwan
Professor, Kasetsart University
Thailand

H.K. Jain
Senior Research Fellow
International Service for National
Agricultural Research
The Netherlands

W.A.C. Mathieson
Consultant
United Kingdom

James R. McWilliam
Director, Australian Center for
International Agricultural Research
Australia

Joseph Menyonga
International Coordinator
Organization of African Unity
Semi-Arid Food Grain Research
and Development (SAFGRAD)
Burkina Faso

Jesús Moncada de la Fuente[3]
Chief Executive
National Institute of Forestry,
Agriculture and Livestock Research
Mexico

Stachys N. Muturi
Director of Agriculture
Ministry of Agriculture
Kenya

Lucio G. Reca
Secretary of Agriculture and Livestock
Argentina

Omond M. Solandt
Consultant
Canada

Guy Vallaeys
Advisor to the Director General
Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD)
France

Donald L. Winkelmann[4]
Director General, CIMMYT
Mexico

Tomio Yoshida
Professor of Soil Science
University of Tsukuba
Japan

Zhuang Qiaosheng
Institute of Crop Breeding and Cultivation
Chinese Academy of Agricultural Sciences
People's Republic of China

---

1 Ex-officio position. Resigned August, 1985
2 Ex-officio position. Resigned January, 1985
3 Ex-officio position. Effective August, 1985
4 Ex-officio position. Effective September, 1985

Principal Staff for 1985

Office of the Director General

Donald L. Winkelmann, USA,
Director General[1]
Robert D. Havener, USA,
Director General**
Robert D. Osler, USA,
Deputy Director General and Treasurer[2]
W. Clive James, Canada,
Deputy Director General—Research
Gregorio Martinez V., Mexico,
Government and Public Affairs Officer
Norman E. Borlaug, USA,
Consultant

General Administration

Richard L. Clifford, USA,
Financial Officer
Homer M. Hepworth, USA,
Training Coordinator
José Ramírez S., Mexico,
Administrative Officer
Hugo Alvarez V., Mexico,
Purchasing Officer
Javier Eissa O., Mexico,
Administrative Computer Specialist
Susana Eng, Mexico,
Supervisor of Accounting Services
José Luis Fonseca, Mexico,
Head, Goverment Documents
Carlos García P., Mexico,
Head, Food and Housing
Yolanda Guerrero L., Mexico,
Assistant Supervisor of Personnel Services
Gilberto Lugo A., Mexico,
Head, Building Maintenance

Maize Program

Ronald P. Cantrell, USA,
Director
R.L. Paliwal, India,
Associate Director
James B. Barnett, USA,
Training Officer
Magni S. Bjarnason, Iceland,
Breeder, Quality Protein Maize
James A. Deutsch, USA,
Breeder, Advanced Unit
Gregory Edmeades, New Zealand,
Physiologist
David C. Jewell, Australia,
Wide Crosses
James E. Lothrop, USA,
Breeder, Highland Maize
John A. Mihm, USA,
Entomologist
Hiep Ngoc Pham, USA,
International Testing
Bobby L. Renfro, USA,
Pathologist
Suketoshi Taba, Japan,
Germplasm Bank
Surinder K. Vasal, India,
Breeder, Hybrid Program
Alejandro D. Violic, Chile,
Training Officer
Stephen R. Waddington, UK,
Training Officer

Visiting Research Fellows

Vernon Gracen, USA,
Insect Resistance*
H. Garrison Wilkes, USA,
Germplasm Bank*
Bryan Wescott, UK,
Biometrician*

Associate Scientists

Dana L. Eaton, USA*
Tajul Islam, Bangladesh

Pre- and Postdoctoral Fellows

Narceo B. Bajet, Philippines*
David L. Beck, USA*
Dirk L. Benson, USA
José Luis F. Crossa, Uruguay
A. Michael Foster, UK
Jens Hock, Fed. Rep. of Germany*
H. Renee Lafitte, USA*
Susanne Welz, Fed. Rep. of Germany**

Andean Region

Gonzalo Granados R., Mexico
(based in Colombia)
Shivaji Pandey, India
(based in Colombia)

Asian Region
Carlos de León G., Mexico
(based in Thailand)
Richard N. Wedderburn, Barbados
(based in Thailand)

Mexico, Central America and Caribbean Region
Momcilo Babic, Yugoslavia**
(based in Mexico)
Hugo Cordova, El Salvador
(based in Mexico)
Federico Kocher, Switzerland
(based in Mexico)
Alejandro Ortega C., Mexico
(based in Mexico)
Willy L. Villena D., Bolivia
(based in Mexico)

East African Region
Bantayehu Gelaw, Ethiopia
(based in Kenya)
A.F.E. Palmer, UK
(based in Kenya)
Joel K. Ransom, USA
(based in Kenya)

North Africa/Mideast Region
Wayne L. Haag, USA
(based in Turkey)

CIMMYT/IITA African Maize Program
Yoel Efron, Israel
(based in Nigeria)
Alpha Diallo, Guinea
(based in Burkina Faso)
Ching-Yan Tang, Hong Kong*
(based in Nigeria)
Richard W. Ward, USA*
(based in Zimbabwe)

Ghana
Francisco R. Arias M., El Salvador*
Michael D. Read, USA
Michael Pratt, Canada**

Pakistan
E. John Stevens, New Zealand*

Wheat Program

Byrd C. Curtis, USA,
Director
Arthur R. Klatt, USA,
Associate Director
Maximino Alcalá S., Mexico,
Head, International Nurseries
Arnoldo Amaya C., Mexico,
Head, Wheat Industrial Quality Laboratory
Girma Bekele, Ethiopia,
Pathologist
Pedro Brajcich G., Mexico,
Head, Durum Wheat Program
Peter A. Burnett, New Zealand,
Pathologist
Gerbrand Kingma, The Netherlands,
Head, Wheat Training
Edwin B. Knapp, USA,
Training Officer
A. Mujeeb Kazi, USA,
Head, Wide Crosses Program
Wolfgang H. Pfeiffer, Fed. Rep. of Germany, Bread Wheat Breeder
J. Michael Prescott, USA,
Head, Seed Health
Sanjaya Rajaram, India,
Head, Bread Wheat Program
Ricardo Rodríguez R., Mexico,
Head, Special Germplasm Development
Eugene E. Saari, USA,
Pathologist
Kenneth D. Sayre, USA,
Agronomist*
H. Ayla Sencer, Turkey,
Head, Wheat Germplasm Bank
George Varughese, India,
Head, Triticale Program
Reynaldo L. Villareal, Philippines,
Training Officer

Associate Scientists
L.T. van Beuningen, The Netherlands
(based in Chile, Southern Cone Region)
Neal A. Bredin, Canada
Daniel Danial, The Netherlands
(based in Kenya, East African Region)
Lucy Gilchrist S., Chile*

Mahmood O. Osmanzai, Afghanistan
Ravi P. Singh, India
Marco Van den Berg, The Netherlands
Elizabeth J. Warham, UK
Masao Yoshida, Japan

Pre- and Postdoctoral Fellows
Osman S. Abdalla, Sudan
Thomas C. Barker, USA*
John Bowman, USA**
Walter de Milliano, The Netherlands**
Javier Peña B., Mexico
Tony B. Ramey, USA*
Robert Raab, USA
Lesley A. Sitch, UK*
John Stapleton, Ireland*

Andean Region of South America
Paul N. Fox, Australia
(based in Ecuador)
Patrick C. Wall, Ireland
(based in Ecuador)

Southern Cone Region of South America
Man Mohan Kohli, India
(based in Chile)
Matthew A. McMahon, Ireland
(based in Chile)

North and West African and Iberian Peninsula Region
Santiago Fuentes F., Mexico
(based in Portugal)

East African Region
Douglas G. Tanner, Canada
(based in Kenya)
Enrique Torres, Colombia
(based in Kenya)

ICARDA Region
Guillermo Ortíz Ferrara, Mexico
(based in Syria)
M. Miloudi Nachit, Fed. Rep. of Germany
(based in Syria)

South Asia
H. Jesse Dubin, USA
(based in Nepal)

Southeast Asia
Christoph E. Mann, Fed. Rep. of Germany
(based in Thailand)
David A. Saunders, Australia
(based in Thailand)

Bangladesh
Larry D. Butler, USA
Mengu Mehmet Guler, Turkey

Pakistan
Peter R. Hobbs, UK

Peru
Gregorio Vázquez G., Mexico

Turkey
Hans-Joachim Braun, Fed. Rep. of Germany
Bent Skovmand, Denmark

Economics Program

Robert B. Tripp, USA, Training Officer[3]
James L. Longmire, Australia, Economist

Associate Scientists
Gustavo E. Sain, Argentina
(based in Mexico)

Postdoctoral Fellows
Paul W. Heisey, USA*
(based in Pakistan)
Rigoberto Stewart, Costa Rica

Mexico, Central American and Caribbean Region
Alberic C. Hibon, France
(based in Mexico)
Juan Carlos Martínez S., Argentina
(based in Mexico)
Michael Yates, USA
(based in Haiti)

Asian Region
Derek R. Byerlee, Australia
(based in Pakistan)
Larry Harrington, USA
(based in Thailand)

Eastern and Southern African Region
Ponniah Anandajayasekeram, Sri Lanka (based in Kenya)
Michael P. Collinson, UK
(based in Kenya)
Allan R.C. Low, UK
(based in Swaziland)

Laboratories
Evangelina Villegas M., Mexico, Head, General Laboratories
Enrique I. Ortega M., Mexico, Associate Scientist
Reynald Bauer Z., Fed. Rep. of Germany, Laboratory Supervisor

Experiment Stations
John A. Stewart, UK, Head of Stations and Executive Officer
Armando S. Tasistro S., Uruguay, Assistant Head
Hannibal A. Muhtar, Lebanon, Training Officer
Roberto Varela S., Mexico, (on study leave)
Ricardo Marques L., Mexico, Field Superintendent, El Batan Station
Reyes Vega R., Mexico, Wheat Field Superintendent, CIANO Station
José A. Miranda, Mexico, Field Superintendent, Toluca Station
Jorge Sarquis R., Mexico, Field Superintendent, Tlaltizapan Station
Daniel Villa H., Mexico, Workshop Head

Data Processing Services
Carlos A. Gonzalez P., Uruguay, Head, Data Processing
Russel Cormier, Canada, Computer Specialist
Julio Cesar Ovalle, Mexico, Operations Supervisor
Jesús Vargas G., Mexico, Systems Manager

Information Services
Christopher R. Dowswell, USA, Head, Information Services**
Tiffin D. Harris, USA, Science Writer/Editor and Publications Coordinator
Thomas Luba, USA, Associate A/V Specialist—Training Materials**
Victoria Lynch, USA, Associate Editor—Training Materials**
Nathan C. Russell, USA, Science Writer/Editor*
Edith Hesse de Polanco, Austria, Head, Scientific Information Unit
Linda G. Ainsworth, USA, Head, Visitor Services

1 Appointed Director General September 1, 1985; former Director of the CIMMYT Economics Program
2 Acting Director General, February 1-August 31, 1985
3 Acting Director of the Economics Program beginning September 1, 1985
* Staff appointed during 1985
** Staff resigned during 1985

Introduction

The remarkable progress made by agricultural scientists in improving the genetic potential of maize and wheat is well documented. So, too, is the tremendous impact that these improvements, in combination with other technological components, have had on Third World agriculture. What is perhaps less well understood is why, in the face of record high grain stocks and near record low grain prices, research to improve the productive potential of the resources commited to these vital staples remains an essential investment.

There are two primary arguments for continuing to invest in agricultural research. One rests on a conservative approach to resource allocation and the other on recent perceptions of the role of agriculture in economic development.

The first argument takes into account the longer term nature of agricultural research and its low cost relative to total agricultural output. Improvements in germplasm, for example, tend to come slowly, each new development usually being built upon previous incremental changes in the genetic base. Consequently, there tends to be a long lag period between the initiation of research and the realization of results. This makes it difficult to predict the conditions that will prevail when the fruits of current investments in research finally become available. Add to this uncertainty the fact that agricultural research comprises a small proportion of the value of total agricultural output (about one percent on a global basis) and one must conclude that it is only prudent to continue investing in research. After all, food surpluses are not historically the norm, a fact easily forgotten when one views current stocks, and near-term bounty should not be mistaken for longer-term food security, the primary objective of agricultural research.

As for the second argument, the current view of economic development sees the role of agriculture as central to catalyzing growth. New technologies that increase productivity and reduce costs bring higher incomes to farmers; these higher incomes reverberate throughout the economy in the form of successive rounds of spending and rising income. Underlying these increases, which both reflect and result in improving economic conditions, are the final products of research: improved agricultural technologies. Thus, those concerned with the well-being of the developing world's poor will favor continued investments in agricultural research.

We must recognize that, for all the change that has occurred in developing country agriculture, millions of farmers have yet to enjoy the benefits accruing from the efficient use of improved varieties and agronomic practices. The reasons for this lag are many and comprise the pressing agricultural development issues of our day.

In addressing these issues, CIMMYT focuses on research affecting the productivity of the resources committed to maize and wheat. Matters pertaining to the development and distribution to farmers of improved technologies properly lie in the domain of our clients, the national crop improvement programs of developing countries; our efforts, then, are aimed at enhancing their capacity to provide improved technologies. Accordingly, CIMMYT produces "intermediate products" for use by national programs in their research and development

activities. As the needs of national programs change, CIMMYT responds either by adjusting its own focus where warranted, or by attempting to add the resources needed to address specific problems.

Marginal lands—As an example of this responsiveness, consider how CIMMYT's research agenda has changed during the last five years, giving additional weight to research oriented toward more marginal production environments. These environments are characterized by such limiting factors as a high incidence of disease, drought, acid soils, and/or excessive heat or cold. Millions of resource-poor farmers work these lands, and national research programs increasingly seek to assist them in their efforts. In response, CIMMYT is now devoting more of its research resources to the development of germplasm and to understanding the production practices appropriate to these environments. Some of those activities are covered in this year's research highlights.

In considering the Center's heavier emphasis on marginal lands, however, it should be stressed that the more favored environments of the Third World will continue to receive considerable attention. Clearly, we must assist national programs in their efforts to maintain the gains already realized on these lands and to make additional improvements in yield and output. Yet we also believe that there are great opportunities for improving the productivity of resources deployed on marginal lands. Moreover, we suspect that the research done to improve productivity in those areas will carry with it significant benefits for already productive environments.

Germplasm development—In the Center's germplasm development work, the primary approach used involves applying conventional breeding procedures in search of within-species genetic variation for added resistance to diseases and tolerance for selected environmental stresses. Experimental materials emerging from this work appear to have better resistance to a variety of "minor" diseases and greater tolerance for such stresses as drought, excessive cold or heat, and adverse soils. This approach is supplemented by wide cross research, in which domesticated species are crossed with related crops and wild relatives in an effort to introgress genes that will enhance performance in certain marginal environments.

Crop management research—Much of the agronomy work done to date by CIMMYT has been in concert with selected national programs and has focused on site-specific experimentation to resolve particular production problems. We are seeking ways to broaden our participation in addressing crop management issues and, in so doing, multiply the impact of our agronomic research. We think this can be done by contributing to the formation and coordination of regional and/or in-country networks of scientists. Such networks, should they become a reality, could focus on various aspects of a particular set of production problems (as an example, research on the agronomic complexities inherent in a rice/wheat rotation), and CIMMYT would both participate directly in this research where possible and facilitate the exchange of data and information among the networks. Research of this type will necessarily entail coming to grips with issues beyond those of most concern for site-specific experimentation.

This global networking function would be similar to that performed by CIMMYT relative to germplasm development; hence, the Center would be able to provide certain cross linkages that should intensify the effectiveness of both efforts. In addition, we are strengthening our agronomy training activities, supplementing our in-service curriculum with more extensive in-country training opportunities.

Economics—There exist several key prerequisites to development of the agricultural sectors in most Third World countries: 1) viable research systems capable of generating improved technologies appropriate to the production circumstances of farmers; 2) well-focused investments in agricultural land and water resources, as well as in the infrastructure needed to produce and distribute farm inputs and to transport and store agricultural products; and 3) government policies that stimulate increased productivity in the agricultural sector in ways consistent with the wise use of limited resources.

In concert with CIMMYT agronomists and national program colleagues, our economics staff concentrate on the first and third of these prerequisites. Relative to the first, they strive to enhance the process by which national programs generate new technologies, both through collaborative on-farm research and through in-country training. Regarding the third, that of government policy, the Center is formulating procedures (based largely on farm-level data) that can help decision makers define research objectives more clearly and identify policy modifications that may improve the productivity of resources committed to agriculture.

Germplasm conservation—CIMMYT is aware of the concern over the erosion of the germplasm base in maize and wheat that can occur as improved varieties displace the heterogenous traditional varieties. We share this concern for preserving the genetic diversity of our crops, and have responded by 1) improving our maize and wheat germplasm bank facilities, 2) accepting our role as a long-term custodian of maize germplasm and 3) exploring with the International Board of Plant Genetics Resources (IBPGR, Rome) the specific activities we should undertake in the conservation of germplasm. Moreover, we continue to strive for more effective ways to share with national programs the collections under our care.

The highlights presented this year touch on all these topics and more. In some cases, they are presented as research now complete; in other cases, as research now underway. In all cases, however, the relationship between the work undertaken and the overall mandate and objectives of the Center are clear. It is the sharp focus of our research agenda, among other things, that enables CIMMYT to meet the needs of its national program clients and, ultimately, to help improve the well-being of millions of Third World farmers and consumers.

Donald Winkelmann

Donald L. Winkelmann
Director General

Maize Research

The direction and emphasis of maize research at CIMMYT are dictated in large part by two central facts about maize production in the Third World. First, it is extremely diverse, being characterized by many, varied growing conditions and modes of cultivation. Second, it is most often carried out on a small scale, under marginal conditions, by subsistence farmers, who have only limited access to chemical fertilizers, insecticides, and other inputs. During the 20 years since its inception, the Maize Program has fashioned what it believes to be efficient systems for coping with the seemingly intractable problems implied by these two characteristics.

A Dual Approach to Maize Research for Developing Countries

The Maize Program's approach is twofold. One part involves the development and delivery to national maize researchers around the world of a diverse stock of improved germplasm. Within this array useful materials can be found for all of the principal mega-environments, which are broad areas defined by a certain climatic range and biotic features that affect maize germplasm requirements. The germplasm is divided according to zone of adaptation, time to maturity, grain color, and grain texture and contains valuable traits such as resistances to physical and biotic stresses.

Though superior in many respects, this germplasm is still an intermediate product and often must be further refined and adapted within national breeding programs before it is released to farmers in particular maize-growing niches. By performing that task, national researchers free the CIMMYT Maize Program from the necessity of developing improved varieties for only one or a few regions at a time. That task could not be carried out over a very large part of the developing world in a reasonable length of time and in any case is rightfully the responsibility of national researchers.

This division of labor between international and national institutions might not be practicable, though, at least not in every part of the Third World, without programs of assistance for national researchers. Offering them sound counsel and concrete support is an important function of the other component in the Maize Program's twofold approach—a worldwide network of regional programs complemented by bilateral projects in selected countries. The attention of outreach and headquarters staff is by no means limited to germplasm improvement, though, but includes the whole range of activities (surveys of farmers, on-farm research, and seed production, for example) in which national researchers are engaged. To enhance their effectiveness in this work, CIMMYT staff confer with national researchers at their experiment stations and in farmers' fields and offer various types of training in the regions and at Center headquarters.

Yield Stability

Through the combined efforts of Maize Program staff and their colleagues in national programs, improved germplasm is becoming ever more widely available to farmers in developing countries. Even so, there are still numerous maize-growing niches for which improved varieties are needed, and the materials that are available could be considerably improved to better satisfy the diverse requirements of developing country farmers.

For most of those farmers, particularly the ones whose circumstances force them to place subsistence before surplus production, high yield potential alone is not enough. They often lack the means of realizing that potential and would generally prefer to have a greater guarantee of sufficient production in most years. Farmers have already devised various means of stabilizing their food supply, such as intercropping and staggered planting dates, but could gain added security from maize varieties that have improved yield stability, which is defined here as the capacity of a genotype to perform evenly from year to year at a given location or across locations within a given maize-growing region.

The yield stability of a particular genotype depends on its physiological response to various stresses at critical stages in plant development. Any variety (however great its yield potential) that readily succumbs to disease and insect pest attack, drought, cold, nutrient deficiencies, or other stresses of common occurrence in a given environment will be highly subject to yield fluctuations and could introduce a large element of risk into the production of maize.

In an effort to increase the availability of more stable varieties, the Maize Program has devoted considerable attention to the endowment of its germplasm with genetic tolerance or resistance to various stresses and is in the process of stepping up these efforts. Two such approaches that should contribute to yield stability (both covered in *Research Highlights 1984*) are selection for improved husk cover (which affords better protection against damage by insect pests, birds, and ear rots) and increasing the endosperm hardness of quality protein maize, a measure that, among other benefits, reduces its susceptibility to ear rots.

This Year's Highlights

The five maize research reports included in this year's *Highlights* reflect the Program's growing emphasis on yield stability and reveal the workings of the twofold research approach described in preceding paragraphs. The first report, "Floury Maize Improvement," demonstrates the progression from development of gene pools to formation of experimental varieties that characterizes the Program's approach in providing improved germplasm for different maize-growing environments. In the course of the work on floury maize, most of which was carried out in the Andean region, national researchers received training at CIMMYT headquarters and participated in workshops within the region. The second report, "Breeding for Resistance to Downy Mildew," recounts another successful effort in germplasm improvement, research that was coordinated by the Asian Regional Maize Program. In addition to its work on downy mildew, that program has contributed materially to the advancement of national research in a number of countries.

The second report and a third, "Development of Multiple Insect Resistance," focus on one of the most important means (breeding for genetic resistance to diseases and insect pests) by which yield stability can be improved. The fundamental question of how this improvement can most reliably be measured is dealt with in a fourth section, "Assessing Yield Stability." Maintaining the momentum of improvement in yield stability and other characteristics depends to a large degree on the continued availability to

the Program of wide genetic diversity. A new initiative for conserving unique variation in the wild relatives of maize is the subject of the fifth report.

Population Improvement and International Testing

The reports on maize research included in this section of *Highlights* presume some familiarity with the Maize Program's population improvement scheme and international testing network. What follows is a brief description of those activities.

Variety development in the Maize Program begins with the recombination and improvement, by means of half-sib selection, of 33 normal maize and 17 quality protein maize (QPM) gene pools. These materials, whose handling is the responsibility of the Program's Backup Unit, are large reservoirs of genetic variability that are classified according to zone of adaptation, time to maturity, grain type, and grain color.

From the most promising fractions of these pools, Program scientists have derived 23 normal and 10 QPM advanced populations that are superior in yield potential and other attributes. In a continuous, cyclical process, these populations are further improved within the Advanced Unit according to a modified full-sib recurrent selection scheme under higher selection pressure than the pools.

To broaden the adaptation of the populations, 250 full-sib families from each are sent in International Progeny Testing Trials (IPTTs) to six locations around the world for evaluation by national maize researchers. The results of those trials are used for two purposes. First, based upon information provided by the trial cooperators, Program scientists select the best 50-60 families for within-family improvement, recombination, and regeneration of each population for the next cycle of improvement.

The second and more important use of IPTT results is for the development of experimental varieties (EVs), some of which are derived from the 10 best families at each location (these are termed "site-specific" EVs) and others from the 10 best families across locations (referred to as "across-site" EVs). These varieties are advanced to the F_2 stage and dispatched to cooperators in the form of Experimental Variety Trials (EVTs), each of which is evaluated at 30-50 locations. After the data from these trials have been analyzed, Program staff select the top-performing varieties to prepare Elite Variety Trials (ELVTs), which are distributed to 60-80 locations and conducted in much the same way as the EVTs. Results for all three types of trials are distributed to cooperators, who then decide whether to use test materials as introductions in breeding nurseries or evaluate and release them directly to farmers. Upon request the Program will send reasonable quantities (up to 3 kg) of seed of selected materials to cooperators free of charge.

Floury Maize Improvement

Tropical highland regions are an extremely challenging, and yet relatively neglected, environment for the improvement of maize. The estimated 4.5 million ha planted to the crop in highlands (from about 1800 m above sea level to as high as 3900 m near Lake Titicaca in Peru) are subjected to a number of environmental stresses, including frost, drought, hail, and various soil problems such as erosion, acidity, and salinity. In

addition, much highland maize possesses various debilitating characteristics (weak root systems, poor synchronization between tasseling and silking, a tendency to tiller excessively under high fertility, and an inefficient plant type with a low harvest index) and is beset by a range of diseases and insect pests.

Over the past seven years, the Maize Program has contributed significantly to the improvement of highland maize for the Andean region in cooperation with Ecuador's National Institute of Agricultural and Livestock Research (INIAP). There were several compelling reasons for concentrating the Program's highland maize improvement efforts on that particular environment. Though, in general, highland maize had received little attention from researchers, the floury and *morocho* (Spanish version of the Indian word, *muruchu*, for maize with hard grains) types preferred in the Andes had been especially neglected, and the resulting lack of improved germplasm and agronomic practices was reflected in the region's stagnant production. Yet, maize continued to be the most widely grown cereal there and a vital staple for the small-farm subsistence sector, which included from one-fourth of the population in Colombia to nearly half in Bolivia and Ecuador.

The work with INIAP has now essentially achieved its initial aims in germplasm development. Floury and *morocho* gene pools and populations have been developed and improved; superior varieties have been derived from those materials and tested in on-

A staff member of the Ecuadorian national maize program describes new maize germplasm for the Andean region to farmers and students at a field day held during 1985 in a farmer's field near Cuenca.

farm trials; and seed of the varieties is being multiplied for release to farmers. INIAP and other national maize programs in the region will continue the improvement of floury and *morocho* maize, with some assistance from staff at CIMMYT headquarters and the Center's Andean Regional Maize Program based at Cali, Colombia. The regional program will also provide a framework for continued exchange of highland maize germplasm among the Andean countries.

This progress in the work on floury maize has brought the Maize Program to a watershed in its improvement of the crop for highland areas. Having made considerable headway in meeting the germplasm requirements of the Andean region, the Center's highland maize program, now based at headquarters in Mexico, will place greater emphasis on semident grain types, which are predominant in the highlands of other regions. This report, however, is concerned chiefly with the approach followed and the results achieved in the improvement of highland maize for the Andean countries.

Andean Highland Maize and Its Environment

Floury maize has been widely cultivated in the Andes for hundreds of years and is still the most widely grown highland type in the region. Some maize of this type has very large, soft kernels, and these vary considerably in shape, size, and endosperm texture. The *morocho* types, which have a more or less soft floury endosperm surrounded by a hard, crystalline layer, are presumed to be closely related to floury maize since the two kernel types occur together among different races of maize in the region. Both types are cultivated throughout the Andes primarily as human food, being consumed in a variety of forms, mainly *choclo* (green ears), *tostado* (toasted grain), and *chicha* (fermented grain). In recent years, though, farmers have shown increased interest in growing more flinty *morocho* types for livestock feed.

Both types of Andean highland maize perform poorly outside the region. This is one indicator of the distinct character of the Andean growing environment and of the thorough adaptation of local maize races to it. Cool temperatures prevail, with mean temperatures in the warmer months of less than 20°C. The growing season lasts 7 to 10 months or even longer; planting time is August to November south of the equator and January to March north of it. Most maize in the region is rainfed, though supplemental irrigation is occasionally used.

Highland Gene Pools

Farmers in the Andes grow a few exotic varieties, but by and large, until initiation of the CIMMYT/INIAP cooperative work, not much germplasm from outside the region had been introgressed into local floury and *morocho* materials. To broaden the genetic base of this germplasm and widen the scope for its improvement, six gene pools were formed at the outset of the project and two more in subsequent years. These included samplings of widely grown Andean maize types plus some materials improved by national programs in the region and highland germplasm (mainly from Mexico and Guatemala) held in CIMMYT's maize seed bank.

The pools were established by intercrossing the component materials in a half-sib recombination block, with the aim of recovering in distinct germplasm complexes certain favorable

characteristics found in the diverse array of highland materials available. Highland germplasm from Mexico, for example, contributed resistance to ear rot, while the Andean materials supplied the desired grain types and adaptation. The pools formed in this way were divided according to maturity (early, late) and grain texture (floury, *morocho*) and color (white, yellow) in such a way that each pool would correspond to a particular maize type widely preferred in the region.

To form the *morocho* Pools 7 and 8, floury Pools 2 and 4 were included along with *morocho* materials in the process of recombination. Since considerably more floury than *morocho* germplasm was available, it was felt that using the former would increase the genetic variability of Pools 7 and 8. That the *morocho* grain type could readily be recovered after being intercrossed with floury maize seemed evident from the results of an inheritance study. In a preliminary evalution of the F_2 population derived from crosses between *morocho* and floury types, it had been observed that the pattern of inheritance of the *morocho* type is simple.

In the improvement of the pools, the main objectives have been broad adaptation, high yield potential, early maturity, and resistance to northern leaf blight (*Helminthosporium turcicum*), ear rot (*Fusarium* spp.), and corn earworm (*Heliothis zea*). Even though most local maize in the region is late maturing, four of the six pools developed were early maturing. The idea was to supply farmers with an alternative to late-maturing maize that might offer them an opportunity to bring additional land into use through relay cropping and take advantage of the growing market for green ears early in the season. Afterwards, two additional late-maturing pools were formed, giving an equal number of early and late germplasm complexes.

The early pools proved to be well adapted at elevations of 2,500 to 2,800 m but suffered substantial damage from leaf blight at lower elevations in Ecuador. It was decided that no significant increase in early maturing maize would take place in the country until resistance to the disease had been improved in the early pools. There was also an apparent need in all the pools for better resistance to ear rots, which increase in incidence under the difficult growing conditions of the higher elevations.

To achieve rapid progress in improving the pools for disease resistance and other traits, a shuttle breeding system was devised that involves modified half-sib recurrent selection. During a given cycle the pools are planted at one or two of CIMMYT's highland locations in Mexico and one or two sites belonging to INIAP's Santa Catalina Experiment Station in Ecuador. Thus, in October and November of each year, superior selections made in Mexico and Ecuador during the previous cycle are planted at the sites in Ecuador, and the same half-sib families are then planted during the following March-April at the locations in Mexico.

The breeding efficiency of this system is partly a result of the complementarity of the different sites. Whereas those in Mexico provide good nurseries for ear rot resistance screening (selections are also made for earworm resistance under artificial infestation and for insensitivity to photoperiod), selection for appropriate plant and grain types can be done efficiently at the sites in Ecuador. Through continuous genetic

recombination, the shuttle breeding system has led to successful introgression of exotic germplasm into Andean maize.

Advanced Populations and Experimental Varieties

Six advanced populations have been developed, primarily from the pools, and experimental varieties are being formed from the full-sib progeny of the populations. The first three (Populations 1, 3, and 4) were developed in 1979-1980 at the Santa Catalina station and evaluated first in Mexico during 1981 and then in Ecuador during 1981-1982. In 1982-1983 experimental varieties were formed on the basis of progeny performance at each site and across sites. During the following cycle, full-sib progeny of the populations were tested throughout the region, and the results (given for two of the populations in Tables 1 and 2) confirmed their wide adaptation. Currently, experimental varieties are being developed at the Santa Catalina station on the basis of those trial results. The varieties will be evaluated through cooperative regional trials in which the maize programs of Bolivia, Colombia, Ecuador, and Peru are participating. National researchers have already tested the varieties developed previously from the first cycle of population improvement.

Populations 1, 3, and 4 are all floury materials, differing in maturity and grain color. In view of the increasing interest among Ecuadorian farmers in flint type maize for livestock feed, an additional population (late maturing, yellow flint) was formed in Ecuador during 1983. It was tested by the

Table 1. Performance of the early maturing, white floury Population 1 at various locations, 1983-1984

	Yield (t/ha)			
	El Batan, Mexico	Santa Catalina, Ecuador	Cuzco Andenes, Peru	Cocha-bamba, Bolivia
Mean of selected families (8301)	6.5	6.0	8.6	5.9
Population mean	4.2	5.3	6.2	4.5
Mean of checks	4.0	5.5	5.3	6.5
S.E. of mean	0.8	0.9	0.9	1.1

Table 2. Performance of the intermediate-maturing yellow floury Population 4 at various locations, 1983-1984

	Yield (t/ha)			
	El Batan, Mexico	Santa Catalina, Ecuador	Caja-marca Peru	Cocha-bamba, Bolivia
Mean of selected families (8304)	8.2	8.1	5.6	3.8
Population mean	5.7	6.5	4.2	2.9
Mean of checks	4.9	5.9	3.1	3.2
S.E. of mean	0.7	0.9	0.6	0.7

national maize program as an experimental variety (ADT 81) during 1983-1984 and on the strength of its good performance over various locations in on-farm trials (Table 3) is being multiplied for release as a variety (INIAP 180) in 1985.

Other breeding work that will soon lead to the formation of experimental varieties was the development of advanced populations in 1984-1985 from the best half-sib families of Pools 7 and 8; the progeny of these populations are being tested throughout the region in 1985-1986. In addition, all the gene pools as such were evaluated in regional variety trials; Pools 4, 7, and 8 seemed particularly promising for direct use as varieties.

INIAP 101 [illegible] developed by Ecuadorian [illegible] with germplasm from [illegible], growing in a farmer's field.

Use of Improved Highland Germplasm in National Programs

All of the national maize programs in the Andean region are working with improved germplasm coming out of this project. The Peruvian national program has developed varieties from Pool 1, and Ecuadorian scientists are making particularly thorough use of Cacahuacintle germplasm from Mexico, having already released one variety (INIAP 101) developed from it. They are also preparing to release a late-maturing yellow flint variety, as mentioned previously, and after two years of evaluation are multiplying seed of BA 8104 for release as INIAP 130. BA 8104, along with SC 8104, were among the best-performing experimental varieties in regional trials of intermediate-maturing, yellow floury materials.

An important prerequisite for introducing new varieties into highland cropping systems, namely testing of those materials in farmers' fields, is being met very successfully by national scientists in Ecuador. With some assistance from the staff of CIMMYT's Andean Regional Maize Program, they have been conducting on-farm trials of improved varieties since 1982. In 1983 four promising experimental varieties

Table 3. Results of on-farm variety trials conducted at 24 locations in five provinces of Ecuador, 1983-1984

Variety	Description	Yield (t/ha)
ADT 81	Late, yellow flint	3.2
BA 8104	Interm. yellow floury	3.0
Pool 4 (C3)	Late, yellow floury	3.0
Pool 3 (C4)	Early, yellow floury	2.5
INIAP 101	Early, white floury	2.5
Check mean		2.6
S.E. of mean		0.2

plus local varieties were tested in farmers' fields at 24 locations in six provinces at elevations ranging from 2250 to 3250 m. As indicated in Table 3, the yields of ADT 81, BA 8104, and Pool 4 (cycle 3) surpassed the mean of the local checks by 0.6, 0.4, and 0.4 t/ha, respectively, with a standard error of 0.2 t/ha for the difference between two means.

Breeding for Resistance to Downy Mildew

Disease-resistant germplasm can go a long way toward diminishing the sharp year-to-year fluctuations in yield to which much of the maize production in developing countries is highly vulnerable. Ensuring that national maize researchers are well supplied with such germplasm is a central activity of Maize Program researchers, and one for which they have devised several approaches. At experiment stations in Mexico, for example, scientists routinely select for resistance to ear and stalk rots and to leaf blights and rusts. Further selections for these and other diseases are made by cooperators in national programs when they evaluate CIMMYT germplasm in International Progeny Testing Trials (IPTTs).

In a more intensive effort to control diseases for which selection cannot be done efficiently in Mexico Center maize staff have been engaged since 1974 in cooperative projects with various research institutes and national programs. Largely because this work has been carried out in close contact with national researchers in regions where the diseases are prevalent, rapid progress has been made in the improvement of resistance to corn stunt, downy mildew, and maize streak virus, and resistant germplasm has been deployed fairly quickly by some national programs.

These cooperative projects were described briefly in *Research Highlights 1983*, and in last year's *Highlights*, we gave a more detailed report of progress on maize streak virus in Africa. What follows is a corresponding account of the work on downy mildew (DM) in Asia.

The Scope of the Downy Mildew Problem

At least nine species of fungi are known to cause DM in maize, of which five *Peronosclerospora* species and one of *Sclerophthora* are economically important. The latter, which causes brown stripe DM, is limited to Asia, principally India, which already has

Resistant reaction to downy mildew in maize.

adequate resistance to brown stripe DM in its released cultivars. The important DM species are Old World parasites (their original hosts include sugarcane, sorghum, the millets, and several wild grasses) that have very successfully adapted to a New World crop, causing major yield losses in maize throughout the warm, humid areas of the world.

Since the beginning of this century, DM has reduced maize yields over wide areas of Southeast Asia by as much as 40-60% annually, sometimes resulting in the loss of entire maize fields. Occasionally, the disease has caused significant damage in Africa, Latin America, the Middle East, and South Asia as well. Over the past seven or eight years, however, the DM diseases have been kept in check in many regions of the world by the introduction of DM-resistant varieties, often in combination with introduction of DM-resistant sorghum and sugarcane varieties, control of wild sorghum species, and changes in certain cultural practices. Where susceptible materials are still being planted, the disease has often been controlled by treatment of seed with the systemic fungicide Apron.

Early Efforts to Control Downy Mildew

CIMMYT maize scientists and their predecessors in the Rockefeller Foundation have been concerned about the DM problem since the 1960s. In 1967 the Rockefeller Foundation sent four scientists to Southeast Asia to help formulate research strategies for bringing DM under control. They recommended that the disease be studied more closely, especially the virulence patterns within and among DM species, and that a search be made for DM resistance in exotic germplasm. In cooperation with CIMMYT, the Foundation initiated a program of research on DM, with headquarters at Kasetsart University in Bangkok.

Early steps toward a better understanding of the disease were the distribution by the Maize Program in 1968 of 100 diverse maize entries to two locations in the Philippines and one in Taiwan and the Program's initiation one year later of an international DM nursery for detection of races or strains of the pathogens. Two important discoveries were brought to light by evaluations of this germplasm at locations in Africa, the Americas, and Asia.

Previously, it had been assumed that the only DM resistance to be found in maize existed in local varieties, which are low yielding, poor in other

Systemic infection of maize with downy mildew.

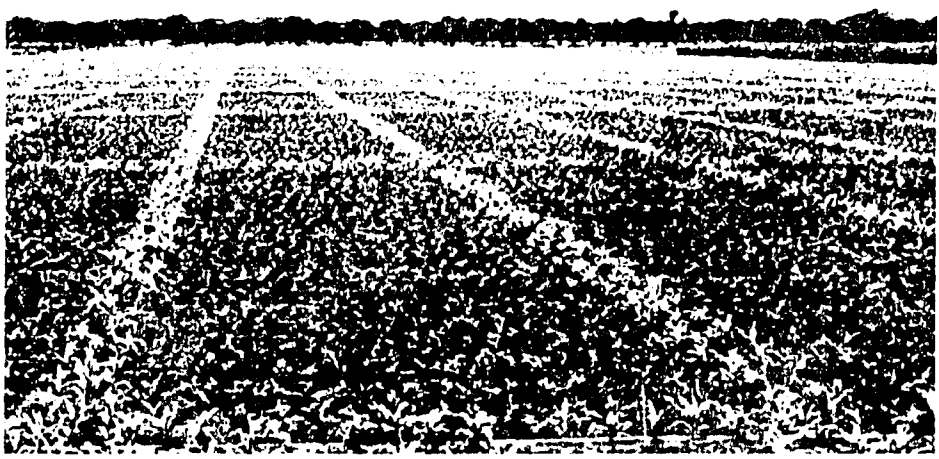
agronomic traits, and early maturing. However, resistance occurring at low frequency was observed in various of the materials that had been included in the CIMMYT nursery, and it proved possible to increase the level of resistance in the germplasm through recurrent selection. In subsequent years materials similar to that germplasm were intercrossed to form DM-resistant gene complexes, which were ther distributed from Center headquarters in Mexico.

The second discovery, which became evident over several years of research bv the Rockefeller Foundation team, was that differences in the pathogenicity of *Peronosclerospora* (known to exist among host genera) are quite small among DM species indigenous to Asia and Africa. In other words, if a plant is resistant to one species, it is also resistant to others. This realization gave national programs strong encouragement to engage in germplasm exchange and cooperative testing for DM resistance, which led to rapid development and deployment of DM-resistant varieties.

Techniques for Resistance Screening

During the 1970s Rockefeller Foundation and Thai researchers accumulated much additional knowledge and experience with various techniques and materials that contributed significantly to the progress of resistance development.

Both systemic and localized DM infection occur. In a number of countries (including India, Indonesia, Israel, Nepal, Taiwan, the US, and Venezuela), sources of resistance to infection were identified, though immunity to the disease was never observed. A plant was considered resistant (or an escape) if not infected



Various means have been developed in Thailand for adjusting the level of downy mildew infection in field trials for testing the reaction of maize to the disease. For example, to achieve moderate to heavy disease pressure, a DM-susceptible variety is planted in alleyways two weeks prior to planting of test materials, as shown in this photograph.

systemically and susceptible if so. The identification of resistance was greatly facilitated by the discovery in Thailand that there is a correlation of 0.9 between the degree of local lesion development and systemic infection. So, when dry or otherwise unfavorable weather arrests fungal growth and subsequent systemic colonization of plants, selections can still be made with confidence on the basis of local lesion development.

A reliable procedure for testing the reaction of maize plants to DM in the field was developed in Thailand. Scientists there determined the concentration of inoculum and timing required to achieve adequate infection for resistance screening and devised various means of adjusting the level of infection, so that the degree of disease challenge could be regulated with some precision. Since there is neither sufficient natural infection nor a secondary host at the experiment station where this work was being conducted, Thai researchers began maintaining a source of inoculum from cultures collected throughout the country.

Development of DM Resistance in CIMMYT Populations

From 1974 to 1980, CIMMYT staff worked closely with the national maize programs of Thailand and the Philippines to develop DM resistance in three broad-based maize populations, using a shuttle breeding approach. During alternate seasons selection for disease-resistance was carried out at locations in Asia where DM pressure is heavy. Resistant selections were then recombined during the following season in Mexico and further selected for desirable agronomic traits. By 1980 four cycles of selection had been completed, and it was apparent that DM resistance had been considerably improved.

That year the Maize Program and Thailand's National Corn and Sorghum Program initiated another project for incorporating resistance into three elite populations—22 (Mezcla Tropical Blanco), 28 (Amarillo Dentado), and 31 (Amarillo Cristalino-2)—while simultaneously upgrading them in other characteristics within the Center's maize improvement scheme (Table 4). Since those materials are among the most frequently used of CIMMYT's tropical maize populations, they should serve national programs well as a source of resistant varieties that can be released directly to farmers or, more likely, used as breeding stock in national maize improvement efforts.

Good progress has been made in the improvement of DM resistance in the populations, even though this trait has received less emphasis than yield and other agronomic characteristics in the selection of 80-100 full-sib progeny to reconstitute the population for the next cycle of improvement (resistance was heavily emphasized, however, during intrafamily improvement). To ensure that genes for DM resistance would be present in each population, companion or "sidecar" backcross (BC) populations were employed as donors of DM resistance. These were either the BC_2 (Population 31) or BC_3 generation (Populations 22 and 28), and the recurrent parent was in two cases the population undergoing improvement and in the case of Population 31 Suwan-2 DMR, a cultivar developed by the Thai maize program that is similar to Population 31 at least in time to maturity and grain color and texture. Up to 50 full-sib progeny from the sidecars were

included among the 250 progeny tested in each IPTT. Some 80 to 100 progeny were selected on the basis of IPTT results to recombine the populations for the succeeding improvement cycle.

This procedure has brought about a marked shift toward higher frequency of DM resistance among the full-sib progenies grown in the IPTTs (Figure 1), the greatest gains having been made in Population 28. The level of resistance in that population and Population 31 is now judged to be sufficient that they can be returned to CIMMYT headquarters for continued improvement. The transfer of that germplasm back to the Center will release resources for conversion of other genetic materials to DM resistance.

When these populations were first received in Thailand, all were highly susceptible to DM. During the first season of 1981, when IPTT-28 and IPTT-31 were conducted there, DM infection was so severe that neither had any value as a yield trial. The trials did, however, prove to be valuable as an opportunity to select for resistance. Disease-free plants were self-pollinated, and where fewer than three selfed ears were saved from the trial, remnant seed was used to resow the IPTT and also sown to make additional selfs during the 1981 second season.

The development of resistance in Population 22 was even more problematic, since the BC_3 (93% recurrent parent) sidecar had only recently been formed and was susceptible. During the first three growing seasons of the project, plantings of this material were destroyed by DM; the few surviving plants were maintained by selfing and recycled into the population. More rapid progress was made with the sidecar, leading to a fairly even

Table 4. Procedure for improving agronomic characters and downy mildew (DM) resistance in Populations 22, 28, and 31

Year 1	**Progeny Generation Nursery**
Season A	• About 300 half sibs planted in duplicate nurseries, one infected with DM and the other protected. • Companion nursery of BC_2 or BC_3 counterparts planted. • 250 full sibs generated for testing; all should come from the DM-inoculated nursery and 30-50 of the total from BC_2 or BC_3.
Season B	**International Progeny Testing Trial** • 250 full sibs plus six local check varieties grown at six international locations in the absence of DM.
Year 2	**Within-Family Improvement**
Season A	• About 170 full-sib progenies (selected on the basis of data from 2-3 test sites) grown in a DM nursery.
Season B	**Family Improvement and Recombination** • 240-300 subfamilies of best 80-100 full sibs (determined from across-site data) planted in DM nursery. • Single best subfamily selected from each original full-sib family. • Best plants selected within the subfamilies and bulk pollinated. • About 300 half-sib ears saved.

distribution of the families among resistance classes that is skewed toward resistance (Figure 2). It is expected that the DM resistance of the population will be adequate within two more cycles, at which point that material, too, will be returned to CIMMYT headquarters.

In further work with the populations, efforts will be made to combine DM resistance with resistance to other diseases on which the Maize Program is conducting research outside Mexico. Regional maize staff in Nigeria have already made good progress in combining DM and maize streak resistances.

During improvement of DM resistance in the three elite populations, their superior agronomic characteristics have remained more or less unchanged. Data from IPTTs conducted in 1983 demonstrate the high potential of these populations in various national programs. As indicated in Table 5, for example, the average grain yield of the selected full-sib families from Population 28 was 22% greater than that of the best local check and 56% over the average yield of six checks. Similar results were obtained in IPTTs conducted during 1982 and 1984 with Population 22. Population 31, on the other hand (which is early to medium in maturity but is often compared with

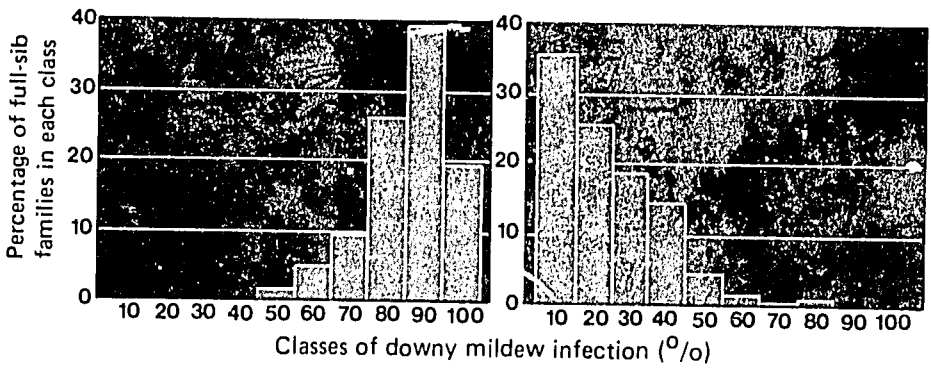


Figure 1. Reaction to downy mildew of full-sib families from Population 28.

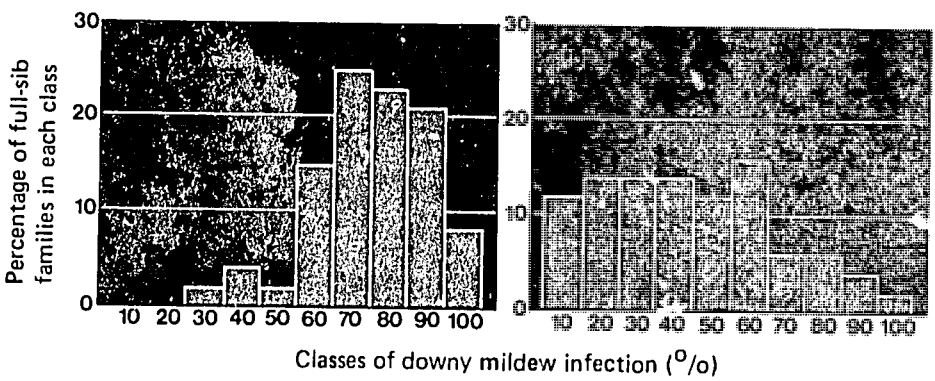


Figure 2. Reaction to downy mildew of full-sib families from Population 22.

late-maturing check varieties in yield trials), was not superior to the best checks in an IPTT conducted during 1983 (Table 6). The mean of the selected families was 6% less than that of the best check, though the mean yield of all families was equal to that of all checks.

Contribution of DM Resistance to Stable Maize Production

In addition to having DM resistance, many improved varieties released by national programs yield more grain, are shorter, and respond better to good management than previously available materials. Examples of those materials are the Thai varieties Suwan-1 and Suwan-2; UPLB Var. 1, released in the Philippines; and Arjuna, a variety developed by Indonesian researchers. The new varieties have had varying effects on maize production in Indonesia, the Philippines, Thailand, and Venezuela, for which national average grain yields are given in Figure 3 for a 15-year period.

In Indonesia and the Philippines, DM has been endemic in maize throughout this century. Spread of high-yielding, DM-resistant varieties in the latter has been fairly limited (around 15% of the maize area), and chemical fertilizers and irrigation are not commonly used. As a result, yields have risen by only about 20 percent in 15 years at a fairly uniform rate, which was roughly the same in the first 6 years of that period as in the last 6. In contrast, Indonesian maize production has experienced a 62% increase in yield over the same 15-year period, attributable at least in part to the gradual but widespread distribution of DM-resistant varieties and to increased use of fertilizers.

Table 5. Summary of results for International Progeny Testing Trial 28, 1983

	Mean grain yield (t/ha)					
	Bolivia	Panama	Dom. Rep.	Burkina Faso	Thailand	Mean
Selected families	9.7	6.6	6.3	4.4	8.9	7.2
All 250 families	7.0	5.1	4.6	3.3	6.7	5.3
Six local checks	5.6	4.2	3.9	2.4	6.9	4.6
Best check	7.5	6.0	5.3	3.0	7.6	5.9
S.E. of mean	1.1	0.4	0.8	0.5	0.5	

Table 6. Summary of results for International Progeny Testing Trial 31, 1983

	Mean grain yield (t/ha)					
	Peru	Panama	Indonesia	Pakistan	Thailand	Mean
Selected families	7.4	4.4	5.7	5.2	8.1	6.1
All 250 families	5.0	3.0	4.4	3.6	5.8	4.4
Six local checks	3.3	3.6	2.7	3.8	8.4	4.4
Best check	8.6	4.8	4.0	5.9	9.3	6.5
S.E. of mean	0.9	–	0.4	0.7	0.5	

DM is a more recent arrival to Thailand and Venezuela. It was first officially reported in the former during 1968, the year of the country's first DM epidemic; three more have occurred since then in 1972, 1977, and 1983. The disease problem was aggravated in those years by drought at the time of planting, which enhanced systemic development of DM in the slower growing plants. Fields that had to be replanted because of drought received inoculum from the original plantings. At the time of the 1972 epidemic, no DM-resistant varieties were available in the country, so yields plummeted 40% from the average yield for the year prior to and the one after the epidemic. By 1977, however, resistant varieties were being planted on 25-40% of the maize area and in 1983 on about 92%. The presence of resistant germplasm appears to have softened the blow of epidemics considerably in those years, as shown in Figure 3, in a country where little fertilizer and irrigation are used.

In Venezuela DM was first observed on a few plants in 1973 but by 1975 and 1976 had reached epidemic proportions, affecting about one-third of the maize-producing area. Many maize fields were abandoned, resulting in a 30% drop during 1975 in area harvested according to official government statistics. In subsequent years DM-resistant maize varieties were rapidly disseminated and proved effective in bringing the disease under control. Grain yields continued their climb to an increase of 41% for the 15-year period.

Development of Insect-Resistance

Insect pests, like diseases, are a major constraint of maize production in the developing countries of the tropics and subtropics and pose a serious threat to yield stability. It has been reliably estimated that farmers in those countries lose 30% of their maize production each year to a wide

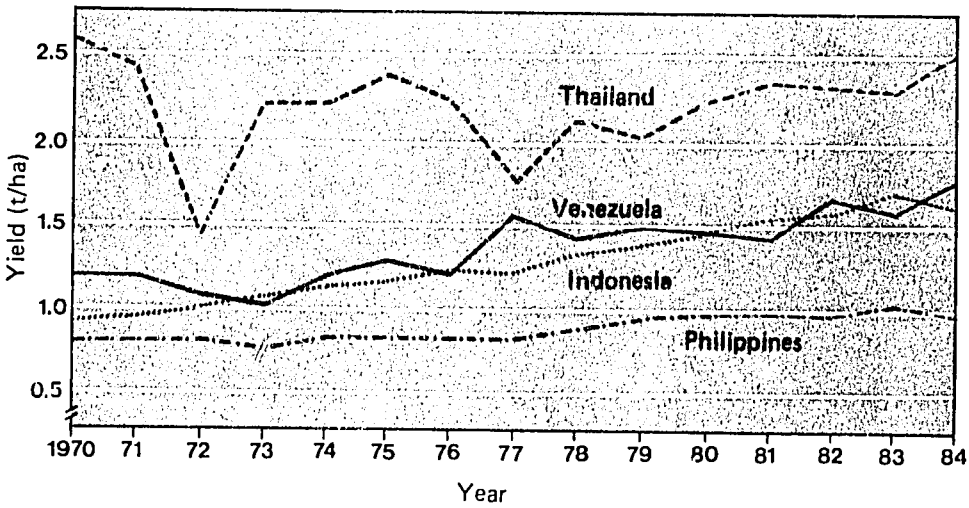


Figure 3. Maize grain yield in four countries, 1970-1984, according to Food and Agriculture Organization statistics.

spectrum of insects, the principal ones being the stem borers, armyworms, and earworms. As with diseases such as downy mildew and maize streak virus, the cheapest, most effective, and least environmentally hazardous means of minimizing crop losses to insect pests is to provide farmers with varieties or hybrids that are genetically resistant to pest attack.

Some years ago Maize Program scientists fulfilled one of the prerequisites for developing host plant resistance. They devised efficient methods of mass rearing; reliable, timely, and uniform artificial infestation; and accurate resistance screening and selection of resistant genotypes for the three major groups of pests. Those methods are described in a series of technical bulletins available from Center headquarters (Mihm 1982, 1983a, 1983b).

Maize Program entomologist John Mihm selecting plants resistant to sugarcane borer in the multiple-borer resistance subtropical/temperate population.

Having developed those capabilities, Program scientists focused for nearly a decade on improving the resistance to a single pest species in each of several pools and populations, following the breeding scheme used by the Backup and Advanced Units in the improvement of those materials. With that approach some gains in resistance have been made at the population level; but they have been small, and progress has been very slow (Mihm 1983c).

During 1983, in an attempt to speed up delivery of resistant germplasm to cooperating national programs, we began developing experimental varieties from families that had shown the best levels of resistance in artificially infested nurseries (Mihm 1985). The first varieties formed were included in preliminary evaluation trials during 1985 to assess their agronomic performance.

In another effort to quicken the pace of insect resistance development, we grew several sets of Mississippi State University's International Lepidoptera Resistance Trials at CIMMYT stations during 1984-1985. Those trials were artificially infested with three of the maize pests on which Center scientists are working: fall armyworm (*Spodoptera frugiperda*), sugarcane borer (*Diatraea saccharalis*), and southwestern corn borer (*D.*

grandiosella). The results indicated that some of the hybrids tested are resistant to all three species tested (Table 7).

Even though the hybrids showed much higher resistance than had been found in any of CIMMYT's maize populations, they were very poor in yield and other agronomic characteristics. To eliminate those deficiencies and take advantage of sources having high levels of multiple-insect resistance, Center scientists began in 1984 to create several special populations called multiple-resistance pools (Mihm 1985).

Multiple-Borer Resistance (MBR) Pool
In creating the MBR pool, a systematic effort was made to obtain seed of all maize that had been reported to be resistant, or was being selected for resistance, to all borer species that attack maize. Many colleagues in temperate, subtropical, and tropical areas of the world sent seed to CIMMYT. These lines, hybrids, synthetics, and varieties, along with selections from the Center's subtropical populations, were recombined by crossing in all possible combinations. Some of the materials were very poorly adapted to growing conditions in Mexico and did not set viable seed. It was possible, though, to use most of them as male parents, with adapted materials as females.

The majority of materials included in the MBR pool were recombined as full or half sibs for two or three cycles. During these initial cycles of recombination, infestation with insects and selection for resistance were done only in materials showing better adaptation to growing conditions in Mexico. Even then, selection pressure

Table 7. Mean leaf feeding ratings in International Lepidoptera Resistance Trials, Poza Rica and Tlaltizapan, Mexico, 1984-1985

Entry	Sugarcane borer	Southwestern corn borer	Fall armyworm
Ab24E x Va35	4.9	6.3	7.0
Sc229 x Tx601	5.5	6.4	6.8
Ab24E x Mp496	4.7	5.9	6.1
Mp496 x Mp701	3.2	4.6	5.4
Mp496 x Mp706	3.1	4.6	5.3
Mp701 x Mp702	3.3	4.4	5.0
Mp704 x Mp706[a]	2.4	5.5	6.5
CIMMYT susceptible check[b]	5.1	5.6	6.4
CIMMYT resistant check[b]	4.1	5.3	5.7
Standard error	0.5	1.3	1.2
Level of significance	0.001	0.05	0.05

Note: Leaf feeding was rated on a scale of 1 to 9, in which 1 is highly resistant and 9 is completely susceptible.
[a] This entry was included only in the 1985 trial.
[b] These checks were different for each trial; they consisted of varieties developed from various populations in which Maize Program staff are selecting for resistance to each insect species.

for resistance was moderate, and some emphasis was given to standability and resistance to ear rotting.

The MBR pool is being improved by recurrent selection using S_1 testing followed by modified half-sib recombination. For two reasons testing for borer resistance is being carried out internationally. First, some of the progeny have shown promise in resistance to borers and armyworms in Mexico. Second, many people in developed and developing countries have expressed an interest in working with insect-resistant maize, and some have expanded their capacity in mass rearing and artificial infestation for screening of progeny at key sites around the world.

In 1985, 368 S_1 progeny were planted at CIMMYT's experiment stations in Mexico for screening for resistance to southwestern corn borer, sugarcane borer, and fall armyworm (though not a stem borer, the latter is an important pest in subtropical and tropical areas). The 130 most resistant progeny were selected for recombination, and 200 half-sib progeny were harvested for testing. The full-sib families will be planted at 10 sites in six countries (see Table 8) and screened for borer and fall armyworm resistance with standardized levels of infestation and damage ratings for two generations of each insect species. In addition, data will be collected on agronomic characteristics. Every cooperator will select the 20-30 most resistant families for each insect and self up to eight of the best plants per row. At harvest they will select the 30-50 best ears and return a seed sample of each to Mexico for planting and recombination under insect infestation.

This international testing will serve three purposes. First, it will provide cooperators with an opportunity to screen new and untested germplasm

Table 8. International testing sites for the Multiple-Borer Resistance Pool

Insect species	Common name	Testing sites
Diatraea grandiosella	Southwestern corn borer	Tlaltizapan, Mexico Mississippi State, US
D. saccharalis	Sugarcane borer	Poza Rica, Mexico
Ostrinia nubilalis	European corn borer	Aurora, New York, US Newark, Delaware, US Antalya, Turkey
Chilo partellus	Spotted stem borer	Mbita Point, Kenya
Sesamia calamistis	Pink stem borer	Ibadan, Nigeria
Eldana saccharina	African sugar-cane borer	Ibadan, Nigeria
Busseola fusca	African maize stem borer	Greytown, South Africa
Spodoptera frugiperda	Fall armyworm	Tifton, Georgia, US Mississippi State, US Poza Rica, Mexico

for improved resistance and good agronomic performance. Since most of the seed of families and plants found to be resistant will remain with the cooperators, they can further test this material and develop lines, hybrids, or varieties from it. Second, the information and seed returned to CIMMYT will enable us to identify the families that performed well across sites and showed the highest levels of insect resistance. The best families will be planted and recombined to further improve the pool for multiple-insect resistance and agronomic performance. A third use of the test results will be to develop resistant experimental varieties or synthetics from remnant seed and to continue inbreeding them to produce resistant lines. Those materials will be supplied to cooperators in national programs that are located in areas where the pest species occur but where scientists do not have the facilities for rearing and artificial infestation techniques needed to develop their own resistant materials.

We expect to continue recurrent selection in this pool for as many cycles as are necessary to obtain materials with good levels of multiple-insect resistance and acceptable agronomic performance. How long the work is carried on beyond that point will depend on the interest of cooperators in continuing the testing and selection.

Multiple-Insect-Resistant Tropical (MIRT) Pool

The experience of researchers at CIMMYT and in other research organizations shows that no maize germplasm will perform well over the whole range of environments in which the crop is grown—from the higher latitudes to near the equator and from the highlands to the lowland humid tropics. This is certainly no less true of the MBR pool than of any other material. In preliminary testing of some families from the pool (at locations ranging from Aurora, New York, in the temperate zone to Poza Rica, Mexico, in the lowland tropics), a few families were found at each site that showed good resistance to the borers, but they were deficient in many other characters.

It was obvious from this testing that the MBR pool would probably never be the best source of resistance to tropical insect species and at the same time supply the disease resistance and agronomic characters needed in maize germplasm for the lowland tropics. To better meet the requirements of maize farmers in that type of environment, the Maize Program has begun developing the MIRT pool.

Although the germplasm on which this pool is based includes some of the same materials used to form the MBR pool, the MIRT pool is composed largely of insect-resistant selections from CIMMYT's tropical populations and pools. Those materials have undergone up to 18 cycles of selection in tropical environments, possess good levels of resistance to tropical diseases, and are excellent in yield and other agronomic traits.

In the formation of this pool, selection is being practiced for resistance to sugarcane borer and fall armyworm. The pool is already showing good resistance to those pests and should be ready for international testing in 1988. By that time we expect this material to be a good source of resistance to the tropical borers and armyworms and to offer an acceptable agronomic type, good disease resistance, and high yield potential in the lowland humid tropics.

Evaluation of Germplasm Bank Materials for Insect Resistance
In an attempt to find additional sources of resistance to insect pests, 50 selected germplasm entries (accessions of Antigua and Caribbean region races) were screened under artificial infestation during 1985 for resistance to southwestern corn borer, sugarcane borer, and fall armyworm. Those accessions were chosen because the Antigua and Caribbean races had in many previous studies shown good resistance to the insects and had served as germplasm sources for several insect-resistant inbred lines developed in the US and elsewhere.

Of the 50 entries screened, eight of the Antigua collections had some plants showing resistance, and 109 selfed ears were selected for rescreening on a family basis during 1986. As is true of many bank accessions, this raw germplasm was agronomically poor; the plants were tall, highly disease susceptible, and prone to lodging. To avoid those problems, which have characterized previous selections from Antigua, care was taken to harvest ears from only the best plants, and in succeeding generations, we will select only resistant plants that have shorter plant height, do not lodge, are free from ear rots, and show reasonable yield potential. As the selections are improved, they will serve as backup germplasm for the MBR and MIRT pools.

Borer Resistance in Wide-Cross Germplasm
A central aim of the maize wide-cross program at CIMMYT is to derive unique germplasm from the maize relative *Tripsacum* spp. for use in the breeding program. Under artificial infestation, *Tripsacum* clones have been found to possess very high levels of resistance to feeding by larvae of the southwestern corn borer. With the hope of gaining one or more additional and probably unique sources of resistance to the insect, we began screening a tripsacoid maize population that was developed by Drs. J.R. Harlan and J.M.J. de Wet at the University of Illinois in the US. The Center's wide-cross program has been working with that material since 1983. The population has a modified B73 background, with genes from *Tripsacum* incorporated into it.

Some resistant plants were found in the population, but, like the germplasm bank materials, they had poor agronomic quality. To obtain the resistance without the accompanying problems, those plants were crossed to the most insect-resistant lines from Population 47 (a subtropical material of intermediate maturity and with white dent grain). In the course of five cycles of recurrent selection, we have recovered the normal plant type and made gains over the original crosses in resistance to both first- and second-brood southwestern corn borers. A synthetic of the five best families from this material is now being formed, from which donors can be selected and fed back into Population 47 or other materials or distributed to interested CIMMYT cooperators as seed supplies permit.

Improvement of Corn Earworm Resistance
In temperate, subtropical, and tropical regions, corn earworm (*Heliothis zea* in the Americas and *H. armigera* in the Old World) has been a pest of the maize crop for decades. Damage inflicted by the insect on field or dent maize in the temperate and subtropical zones is usually minimal, resulting in

grain yield losses of less than 5%. Corn earworms are much more damaging in the less important sweet corn crop, for which economic thresholds are lower. In tropical lowland maize, direct yield losses to corn earworm are also minimal under normal conditions, although the insect can cause important losses indirectly by facilitating the entry of ear rot pathogens, maize weevils, and other ear-feeding pests into the maize ear.

In highland tropical regions, however, where floury maize is widely preferred and grown, both direct and indirect losses to corn earworm can be extremely high, often forcing farmers to discard 50% of harvested ears. So that these farmers can be provided with better means of protecting their crops against the insect, Maize Program staff began screening and selecting for resistance to corn earworm in some Andean floury pools during 1978. As shown in Figure 4, which is a histogram of corn earworm damage for four of these pools, very few families fall into the resistant category (0-3 cm of damage beyond the ear tip), indicating that there is little scope for improving resistance by means of intrapopulation selection.

The alternative that we chose in 1983 was to cross the pools with known sources of corn earworm resistance—Zapalote Chico races of maize and a Navajo race—which have the antibiosis type of resistance with a rating of 0 or 1, meaning that the larva die before reaching the ear tip.

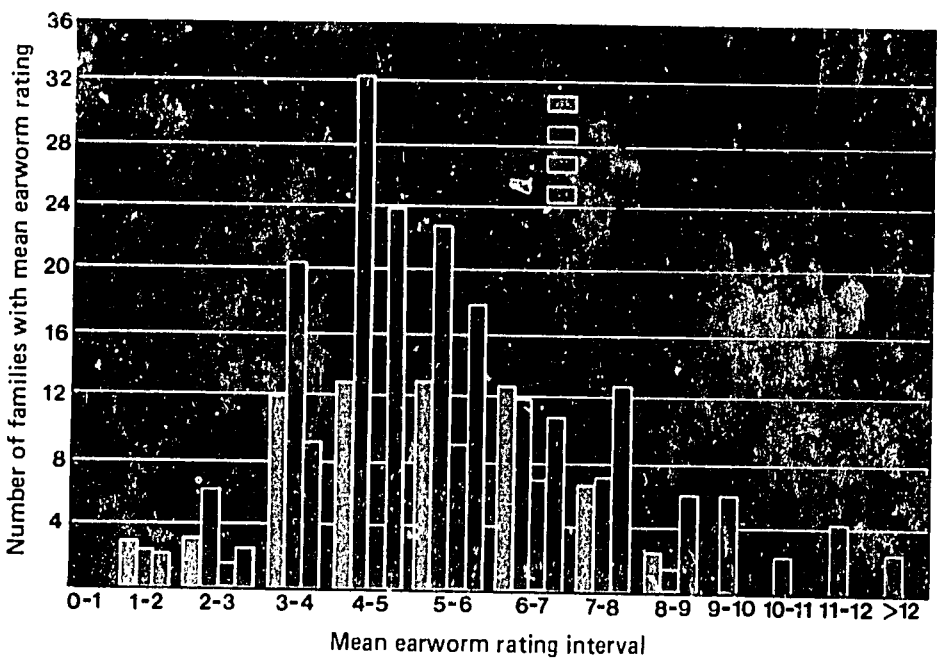


Figure 4. Improvement of corn earworm resistance in Andean highland floury pools.

Although it may not be difficult to transfer this type of resistance to the floury materials, other problems will have to be overcome. The resistance sources perform very poorly in highland areas, giving low yields and showing extreme susceptibility to foliar diseases and undesirable effects on grain type.

In the CIMMYT Maize Program and other breeding programs, attempts have been made in the past to incorporate corn earworm resistance from these sources of resistance into various other materials. The work has usually been dropped after one or a few generations, probably because the crosses showed greater susceptibility to leaf diseases than the original material and it was not possible to screen the segregating materials for corn earworm resistance. Since we now have the screening capability, we will continue for several cycles and, using a backcross selection scheme, attempt to recover the original plant types in the pools that have improved resistance to corn earworm.

Although Maize Program work on this insect is concentrated mainly on materials for countries in the highland tropics, a small effort is being made to develop resistant germplasm for the subtropical zone. In the southeastern US particularly, currently grown hybrids have been observed to be more susceptible to corn earworm than hybrids grown 20 years ago, suffering losses nine times greater (Wiseman et al. 1984). For that reason and because the insect attacks many other important crops (such as peanuts, soybeans, and cotton) after the population has built up on maize, there is renewed interest on the part of some US entomologists in developing new resistant hybrids or converting the ones currently grown to more earworm-resistant types. The Maize Program is assisting researchers in that task by planting a small winter nursery and making some crosses of southeastern US inbreds and hybrids with the Program's sources of corn earworm resistance.

Literature Cited

Mihm, J.A. 1982. *Techniques of Efficient Mass Rearing and Infestation in Screening for Host Plant Resistance to Corn Earworm,* Heliothis zea. CIMMYT Information Bulletin. Mexico, D.F.: CIMMYT.

_____. 1983a. *Efficient Mass Rearing and Infestation Techniques to Screen for Host Plant Resistance to Fall Armyworm,* Spodoptera frugiperda. CIMMYT Information Bulletin. Mexico, D.F.: CIMMYT.

_____. 1983b. *Efficient Mass Rearing and Infestation Techniques to Screen for Host Plant Resistance to Maize Stem Borers,* Diatraea *sp.* CIMMYT Information Bulletin. Mexico, D.F.: CIMMYT.

_____. 1983c. Progress in host plant resistance to fall armyworm in two tropical maize populations and pools. Paper presented at a meeting of the Southeastern Branch of the Entomological Society of America, January 25-27, at Little Rock, Arkansas, US.

_____. 1985. Breeding for host plant resistance to maize stem borers. *Insect Science and Its Applications* 6(3):369-77.

Wiseman, B.R., N.W. Widstrom, and W.W. McMillian. 1984. Increased seasonal losses in field corn to corn earworm. *Journal of the Georgia Entomological Society* 19:41-43.

Assessing Yield Stability

The Maize Program must have a reliable and efficient means of measuring progress in the improvement of yield stability. The need seems particularly great in view of the large investment of time and resources being made in that work, the importance of yield stability for maize production in developing countries, and the large quantity of germplasm that Program staff must evaluate. They can get some idea of the performance of improved germplasm through their contacts with the numerous scientists in national programs who test and use this material, and they also conduct more systematic evaluations periodically. A study reported in *Research Highlights 1984* (page 36), for example, gauged advances in grain yield, yield stability, and other characteristics that have been made in selected populations. Another recent paper prepared by Pham, Waddington, and Crossa (1985) considered the grain yield and yield stability of certain experimental varieties in international testing and of various improved varieties (many derived from CIMMYT germplasm) in on-farm trials conducted at numerous locations.

A Search for Better Methods

Because it is an extremely complex phenomenon, the interaction between maize genotypes and the environments in which they are grown is very difficult to describe and measure. Over the past decade, various statistical models have been devised for doing so. But, though several have been found appropriate for certain situations, none can be considered ideal, having the capacity to identify stable genotypes accurately under all circumstances. There is thus wide scope for investigation and improvement of those methods.

During 1985 the Maize Program became directly involved in the search for more reliable and efficient indicators of yield stability. Under a cooperative arrangement with the Plant Breeding Institute at Cambridge, United Kingdom, statistician B. Westcott spent six months at CIMMYT analyzing data generated through the Maize Program's international testing network. He also made an extensive review of methods for analyzing yield stability, which he divided into four groups (1986): 1) linear regression analyses, 2) multivariate methods, 3) geometrical methods, and 4) stochastic dominance approaches.

Chiefly because of its simplicity, linear regression analysis (Finlay and Wilkinson 1963; Eberhart and Russell 1966) is the approach that has been most widely used by plant breeders and agronomists in applied agricultural research. It was the method employed in both of the above-mentioned CIMMYT studies on the grain yield and yield stability of improved germplasm. Even so, Center researchers are well aware that this method has certain biological and statistical drawbacks and is not equally suitable for all situations.

One of its principal deficiencies is that estimates of regression coefficients can be affected by a few extreme values in the set of data being analyzed. Thus, if some of the sites in a multilocational yield trial are either very high or low yielding, the regression coefficients of some genotypes might be such that their stability is not reflected. Westcott (In press) observed this "masking effect" in analyzing data published by Yates and Cochran (1938). Omitting the lowest yielding site and the highest

yielding one caused changes in the regression coefficients of some varieties. The same phenomenon has been found in analysis at CIMMYT of the 1980 results of Experimental Variety Trial (EVT) 12, and Hill and Baylor (1983) have reached a similar conclusion in examining the yield stability of alfalfa varieties. They found that one low mean yield had more influence on estimates of the regression coefficients than did any of the means obtained in the other environments. On the basis of that finding, they suggested that the linear regression method be used with caution when one of the variety test sites is atypical of the rest. Those results have obvious and serious implications for the Maize Program, since in all the trials coordinated by its international maize testing network, entries are evaluated at extremely varied low-yielding and high-yielding sites.

A Geometrical Method of Stability Analysis

In addition to reviewing a range of stability analysis methods, Westcott devised a new approach that overcomes the main deficiency of the linear regression models. Testing of that method at CIMMYT indicates that it is better than other methods for analyzing yield data that include results from a few extremely high or low yielding sites as well as for analyzing a subset of genotypes separately from the entire group.

How the method works—With this method the testing environments can be divided into two groups according to the mean yields (lowest and highest) obtained in them, or the analysis can be carried out for all sites at once. Which approach one follows depends on the purpose of the analysis, whether it is to determine yield stability over all sites or only for subsets of those environments. In the latter case, variety performance is first analyzed for the lowest yielding site (cycle L1), next for the two lowest yielding sites (cycle L2), and so on. The same procedure is then followed for the highest yielding sites (cycle H1, H2, etc.). For each cycle of analysis, a two- or three-dimensional diagram is developed. In the whole set of diagrams, the genotypes that are above average in performance are *consistently* represented as remote points, whereas the points indicating varieties whose performance is less than average tend to be clustered near the center.

In the diagrams accompanying this report, no values are assigned to the x and y coordinates. Inclusion of those values would have required a lengthier and more detailed explanation than is possible here of the analysis by which the values were derived. It is sufficient for most potential users of diagrams generated by the Westcott method to know that remote points represent high-yielding varieties and points around the center low-yielding materials and that stable genotypes are consistently represented by remote points throughout the entire series of diagrams.

To illustrate, analyses of data from EVT 13 (conducted in 1979) are described below. In that trial 16 varieties were tested at 47 sites. The test locations were arranged in descending order according to their means yields, the top 12 (whose means ranged from 6.94 to 5.02 t/ha) being designated high-yielding sites and the last 12 (with means of 3.21 to 1.94 t/ha) low-yielding sites. Variety performance at those sites was analyzed as explained previously.

The two highest yielding varieties overall, Across 7728 and Sete Lagoas 7728, were remarkably stable in both low- and high-yielding environments, as shown in Figures 5 and 6, where these varieties are represented by points remote from the center (the results shown in these figures are typical of those represented in the whole group of diagrams for this set of data). Figure 5 indicates that Poza Rica 7827 and La Maquina 7827 were also stable, but only at high-yielding sites.

Application to experimental varieties—The Westcott method is being applied in various ways to data on materials tested in international trials coordinated by the Maize Program. Currently, for example, Program staff are using this approach to study trends in the yield stability of experimental varieties for the purpose of identifying sources and methods that give rise to stable materials.

Analyses of late-maturing tropical varieties tested between 1979 and 1983 in numerous countries suggest that the most stable varieties come from Populations 22, 28, and 43; those from Populations 24, 27, and 36 also show a degree of stability. A total of 43 varieties tested over the five-year period has been found to be stable at low-yielding sites, high-yielding sites, or both. As indicated in Table 9, which lists the 11 most stable of the 43 varieties, four stable ones were developed from Population 22 and an equal number from Population 28 (note that the last two numbers in the name of each variety indicate the population from which the variety was derived and the first two numbers the year in which progeny of that population were evaluated and the test results used to form the variety). Across 7728 was found to be stable in trials conducted during 1979, 1980, and 1982. Population 43 produced two stable varieties (La Maquina 7843 and

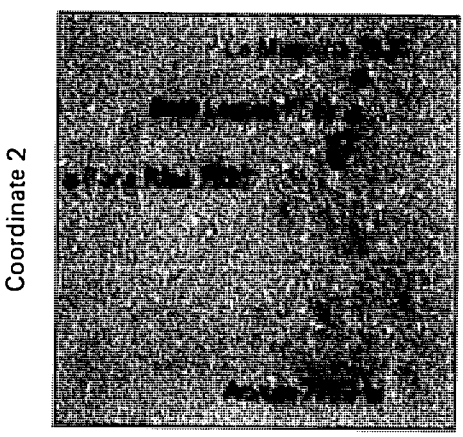


Figure 5. Analysis of yield stability of experimental varieties at the three highest yielding sites out of a total of 47 where EVT 13 was conducted in 1979.

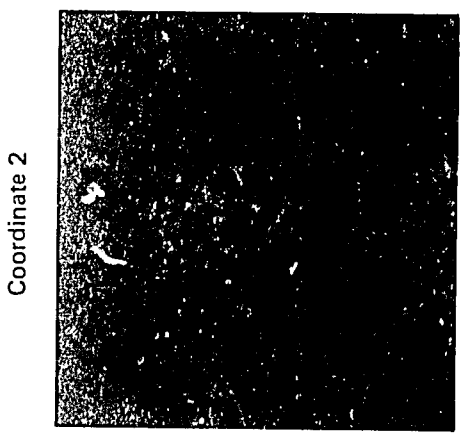


Figure 6. Analysis of yield stability of experimental varieties at the six lowest yielding sites out of a total of 47 where EVT 13 was conducted in 1979.

Across 8043), and from Population 36 one variety was formed that proved to be stable in trials conducted during 1980 and 1981.

The "across" varieties mentioned here were developed on the basis of data (describing the performance of the progeny of a given CIMMYT population) gathered from as many as six test sites. One might expect those varieties to be generally more stable than varieties formed on the basis of data from a single site. But judging from the results of analysis with the Westcott method, that is not necessarily the case. Of the 11 stable varieties listed in Table 9, no more than four are across varieties, though these materials are fairly stable in both low- and high-yielding environments. However, one pattern that does seem evident from the analysis is that varieties developed according to progeny performance at certain sites (particularly Poza Rica, Mexico; Ferkessedougou, Ivory Coast; and La Maquina, Guatemala) have proven to be more stable than materials based on data from other sites.

Application to full-sib families—Another application of the Westcott method at CIMMYT has been to analyze the 250 full-sib families of Population 24 evaluated in an International Progeny Testing Trial (IPTT) at various cycles of selection (Crossa and Deutsch 1985). The families were subdivided into two groups of 100 each (sets 1 and 2) and a third group of 50 families (set 3). The results indicate that there were a greater number of stable families in the more recent cycle of selection (1982) than in the earlier one (1975). In Figure 7 note the slightly larger number of remote points representing the 1982 cycle.

Future investigation of the method—Further studies will be carried out at CIMMYT to verify the utility of the Westcott method in analyzing the yield stability of germplasm evaluated through the Maize Program's international testing network. Depending on the results of those studies, the method will perhaps be adopted as a supplement to regression analysis, in which case it will most likely be applied primarily to the

Table 9. Stability of maize varieties in various EVTs and ELVTs conducted over a five-year period

Variety	1979	1980	1981	1982	1983
Poza Rica 7822	H	H			
Sete Lagoas 7728	B	L			
Across 7728	B	H		B	
Ferkessedougou 7928		H	L		
Ciudad Obregon 7936		L	L		
La Maquina 7843	H		L		
Across 7622	B			L	
Pichilingue 7928				L	
La Maquina 8022				B	H
Across 8043				H	H
Across 7822		B			

Note: H = above average in stability at high-yielding sites, L = stable at low-yielding sites, and B = stable at both types of sites.

experimental varieties. Because the use of the Westcott method requires substantial computer capacity and time, it will not be applicable right away to many national maize programs. Even so, the numerous national researchers who cooperate with CIMMYT in maize testing may profit from more reliable yield stability data generated at the Center and reported to cooperators.

Literature Cited

Crossa, J., and J.A. Deutsch. 1985. Estimate of genetic and genetic x environment variance components in six tropical maize populations. In *Agronomy Abstracts of the 1985 Annual Meetings of the ASA, CSSA, and SSSA*, 51. ASA: Madison, Wisconsin.

Eberhart, S.A., and W.A. Russell. 1966. Stability parameters for comparing varieties. *Crop Science* 6:36-40.

Finlay, K.W., and G.N. Wilkinson. 1963. The analysis of adaptation in a plant breeding programme. *Australian Journal of Agriculture Research* 14:742-45.

Hill, R.R., and J.E. Baylor. 1983. Genotype x environment interaction analysis for yield in alfalfa. *Crop Science* 23:811-15.

Pham, H.N., S.R. Waddington, and J. Crossa. 1985. Yield stability of improved germplasm developed and distributed by the CIMMYT Maize Program. Paper presented at the IFPRI/DSE Workshop on Sources of Increased Variability in Cereal Yields, November 26-29, at Feldafing, Federal Republic of Germany.

Westcott, B. In press. A method of assessing the yield stability of crop genotypes. *Journal of Agriculture Science*.

———. 1986. Some methods of analysing genotype-environment interaction. *Heredity* 56:243-253.

Yates, F., and W.G. Cochran. 1938. The analysis of a group of experiments. *Journal of Agriculture Science* 28:556-580.

Figure 7. Analysis of yield stability of full-sib families (sets 1 and 2, each of which consisted of 100 families) at the two lowest yield sites in an earlier and a more recent cycle of selection.

Conservation of the Wild Relatives of Maize

Over the past 20 years, the CIMMYT Maize Program's seed bank has maintained the world's largest collection of maize landraces, along with germplasm of various wild relatives of the crop (for details on the management of this material, see *Research Highlights 1984*, pages 42-47). The genetic diversity contained in this collection has been vital to advances in plant breeding like those described in the preceding sections on maize research. The germplasm is a highly vulnerable natural resource, though, and must be carefully conserved to meet the future requirements of maize improvement. Toward that end the maize seed bank has recently embarked on a far-reaching program of conservation activities.

That CIMMYT should now redouble its efforts in this task seems particularly appropriate in light of some of the experiences and circumstances of the Maize Program. It possesses the only international maize bank in the Americas that has accepted entire national collections, and its headquarters are located at the center of origin of maize and in the area of its wild relatives' greatest genetic diversity. An even more important consideration is the success with which maize scientists have met in accelerating the spread of improved varieties. That success, ironically, has promoted genetic erosion of the landraces upon which much elite germplasm is based and has thus increased the urgency of gene conservation in seed banks.

It would have been difficult to heed the compelling signs of genetic erosion, however, had the Center not received extra funding for improvements in the bank's facilities (described in *Research Highlights 1984*). These improvements have permitted Maize Program staff to assume a much broader role in exercising their stewardship over the germplasm. They can now undertake a number of tasks (production of a catalog of bank holdings, for example) in addition to their current ones and can strongly encourage and support other activities, such as cooperative research on the landraces of maize in the Americas. Staff will also devote considerable attention to the wild relatives of the crop, whose current status and conservation are the subject of this report.

The Wild Relatives of Maize at its Center of Origin

The wild relatives of maize discussed here are the various taxa of teosinte, found in Mexico and Guatemala, and the genus *Tripsacum*, which has its center of diversity in those countries but is distributed throughout the Americas. This report is concerned principally with the annual teosintes (see photograph).

A highly variable wild plant, teosinte has both annual and perennial types. The seed-producing annuals, all of them diploid ($2n = 20$), are found in eight geographically isolated population clusters, six in Mexico and two in Guatemala (see Figure 8 and Table 10); these occur within the subtropical zone, which receives summer rains. Some of the populations are small, the smallest occupying less than 1 km^2, while the largest covers thousands of square kilometers. There are two perennial teosintes, both of which produce rhizomes, occurring only in restricted habitats in the state of Jalisco, Mexico. One, *Zea*

Chalco teosinte, the most maize-like in appearance of all the teosintes. Note the absence of a central spike in the tassel and the branching along the central stalk. A robust 3-m-tall teosinte plant like this one will produce as many as 250 small ears (spikes) and 2000 seeds. Unlike maize, all teosintes disperse their seed at maturity as single rachis segments and are thus able to survive as wild plants.

diploperennis, is diploid (2n = 20) and the other, *Z. perennis*, is tetraploid (2n = 40).

Throughout the rest of this report, the name "teosinte" refers to the annual form, except where otherwise specified. A conscious effort has been made here to avoid the use of taxonomic terms (races or species and subspecies) for the various taxa of annual teosinte. Instead, we refer to teosinte populations, which together include all named taxa. It is appropriate to do so since the unit of conservation of genetic resources is the population, not the named taxa.

The Habitats of Teosinte

The distribution of teosinte along the escarpment of Mexico and Guatemala parallels that of the ancient Mexican and Mayan civilizations, whose staple food was maize. Teosinte hybridized readily with the crop, producing a robust and fertile F_1 hybrid. Subsequent introgression of teosinte through repeated backcrossing is recognized in more than half of the approximately 50 landraces of maize in Mexico.

Even today the habitats of teosinte are found on some of the country's best agricultural land. In the states of Jalisco, Guanajuato, and Michoacan, the plant grows mostly along stone fences bordering maize fields, not as a weed invading the fields, but as a rare survivor making its last stand in this narrow strip of untilled soil. In a few places, such as Chalco, teosinte has successfully invaded maize fields as a "mimic" of the cultivated crop. The two are so similar in appearance that farmers cannot readily distinguish them and thus do not weed teosinte from their fields during the early part of the

crop cycle. The largest population, and the one least likely to disappear in the near future, is that which occupies hundreds of square kilometers in the mountains around the Rio Balsas, primarily in the state of Guerrero (see photo).

The Threat of Extinction

At several sites on Mexico's central plateau, teosinte has died out in recent times because of more intensive land use and pasturage. In general, the distribution of the plant is contracting, and some vulnerable populations are nearing extinction, though none is threatened with immediate elimination. The chief reasons for the contraction of teosinte populations are 1) intensified land use (which is related to the development of roads), 2) genetic "swamping" of small, isolated stands that outcross to maize and thus lose their ability to disperse seed, and 3) cultivation of a cash crop such as short-stature sorghum instead of maize, making the presence of teosinte as a weed more obvious. By the best estimates, the current distribution of teosinte is about half of what it was in 1900. The disappearance of remaining populations will accelerate as more roads are built and land use is intensified. Just 20 years ago, a third of the teosinte populations were far from any road, and another third were accessible by dirt roads that could be travelled only with difficulty. Now all are accessible by roads that can easily be negotiated by automobile.

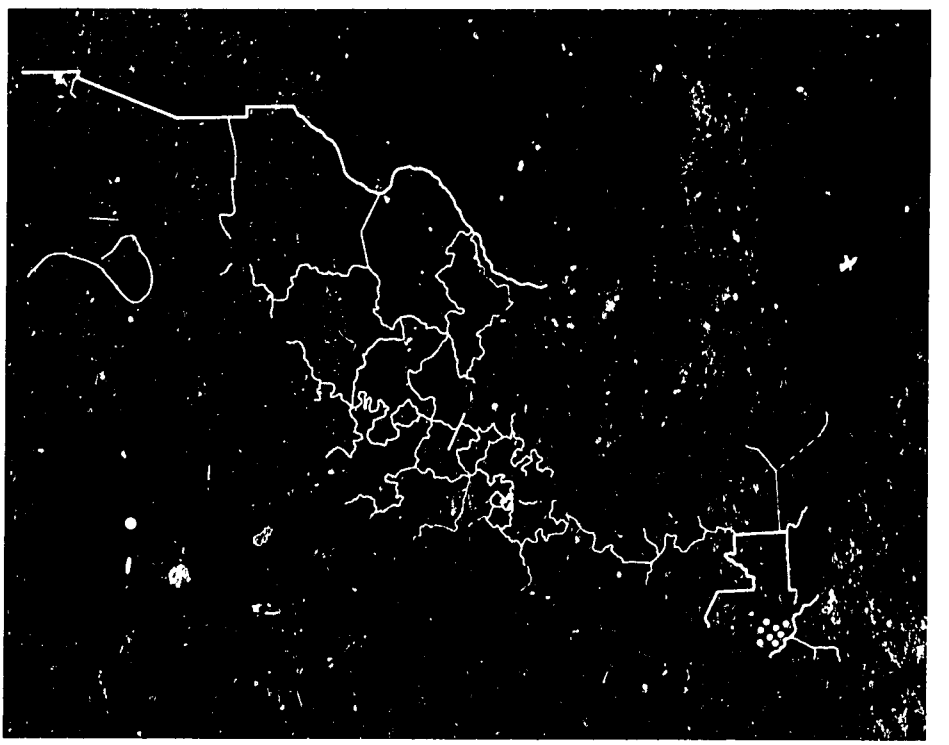


Figure 8. Current status of teosinte populations in Mexico and Guatemala.

Table 10. Teosinte populations in Mexico and Guatemala

Population and its status*	Common name	Location
Nobogame ●	*maicillo*	Tarahumare Valley in the Sierra Madre of the state of Chihuahua about 16 km northeast of Guadalupe y Clavo.
Durango ●		Valley of Guadiana 10 km outside Durango in the state of Durango
Central Plateau ■	*maiz de coyote*	Isolated populations throughout the entire central plateau in the states of Jalisco, Michoacan, and Guanajuato. Largest continuous population is in region north of Lake Cuitzeo.
Chalco ▲	*accece* or *acece* (unwanted or disagreeable)	Valley of Mexico from Amecameca to Xochimilco, Chalco, and Los Reyes. Isolated populations around Texcoco.
Balsas ▲	*maiz de huiscatote* (roadrunner) *maiz de pajaro* (bird) *atzitzintle*	Hills surrounding Rio de las Balsas Basin. Population distributed discontinuously, with one located south of Chilpancingo in the state of Guerrero and the other on the northern rim of the basin.
Oaxaca ●	*Cocoxle* (ground dove or roadrunner)	San Francisco de Honduras, 5 km from San Pedro Jucnatengo in the Sierra Madre del Sur of Oaxaca.
Huehuetenango ■	*milpa de rayo* (where lightning strikes the fields) *salic*	Hills and valleys of the Departamento de Huehuetenango around the Guatemalan town of San Antonio Huista, near the Mexican frontier.
Guatemala	*milpa silvestre* (wild corn) *teocintle*	Distributed discontinuously in southeastern Guatemala across the hills and valleys of Jutiapa, Jalapa, and Chiquimula.

* ● - rare, occurring at a single location; ■ - indeterminate; ▲- stable; O- endangered.

Extent	Habitat
No more than 50 km^2 on the valley floor.	Along margins of maize fields and in willow thickets bordering streams.
No more than 50 km^2.	Limited to wasteland along irrigation canals.
Once a continuous population covering thousands of square kilometers but now occurs in scattered, isolated pockets rarely larger than 10 km^2.	Occurs in cultivated fields and along field margins or stone walls and in areas protected from grazing.
Main populated centered in a 300-km^2 area around Chalco.	Found almost exclusively in maize fields as a "mimic" of the maize but also as a weed along roadsides.
Population south of Chilpancingo covers hundreds of square kilometers, while the other extends over throusands of square kilometers in the states of Guerrero, Michoacan, and Estado de Mexico.	Sometimes observed in maize fields but generally in dense stands on hillsides, especially along gullies or other areas where there is rain runoff.
No larger than 50 km^2, although there may be outlying, isolated pockets.	Grows on hillsides and in maize fields surrounding the town.
Probably not larger than 300 km^2.	Found along trails, in fields, and on hillsides of deserted *milpas*, or maize fields.
Was once distributed continuously, covering 500 or more km^2, but is now fragmented, the largest population covering no more than 1 km^2.	Occurs at small, isolated sites along the margins of fields or in other areas protected from grazing.

Although it is difficult to define danger of extinction with much precision, some helpful criteria have been established by the Species Survival Commission of the International Union for Conservation of Nature and Natural Resources (IUCN) in Switzerland. Six categories proposed by the IUCN—extinct, endangered, vulnerable, rare, and indeterminate—can readily be applied to teosinte. Some populations (Honduras C.A., for example) are already extinct, and at least one (Guatemala) is endangered and cannot be expected to persist much longer as a naturally occurring population. Most of the teosintes, though (the exception is Balsas), can be considered vulnerable; that is, they are declining to such an extent that if nothing is done they will become endangered. The populations thought to be rare (Nobogame, Durango, and Oaxaca) are scarce enough that they could be eliminated easily, but they are currently under no immediate threat and are more or less stable. Indeterminate populations (Central Plateau and Huehuetenango) are those whose status is uncertain.

Teosinte growing along the margin of a maize field near Teloloapan, Guerrero, in the mountains along the Rio Balsas at an elevation of 1500 m.

Curbing the Threat

Although neither teosinte nor *Tripsacum* is likely to provide any means for short-term or intermediate agronomic improvement of maize, they probably contain genetic variation not found in any maize breeding program. Thus, when they are gone, there will be no close, living relative of maize to serve as a source of such variation. So as better to protect this vital part of the genetic foundation of the world's maize crop, the Maize Program considerably expanded its monitoring activities this year.

Maintenance in the germplasm bank—The two perennial teosinte taxa are being maintained in two forms: 1) as clones in a perennial garden along with *Tripsacum* spp. and 2) as seed in the bank's cold storage facilities. The *Tripsacum* garden is kept at Tlaltizapan (one of CIMMYT's research stations in Mexico) as part of the Maize Program's work on wide crosses. This garden is being enlarged in an attempt to include all the known taxa, and additional collections are being made by maize staff. The bank will monitor the quality and documentation of the *Tripsacum* holdings and conduct some research in conjunction with work on the teosintes.

Seed of the perennial and annual (seed-propagated) teosintes can be regenerated by the gene bank only with some difficulty, since their pollination cannot be controlled as easily as that of maize and since they disperse their seed at maturity. For those reasons the bank continues to hold teosinte collections dating back to the 1960s that have not been regenerated and made bank accessions. This year it was decided that wild collected seed of teosinte should be made accessions directly, and that only endangered populations should be regenerated. In addition, large accessions of 5 kg (or more than 500,000 seed) of teosinte are being put into long-term storage for future research using laboratory techniques.

In general, requests for seed of the teosintes will be filled largely from the wild seed that is being held in the active collection, which contains 1.5 kg of every accession. Teosinte seed will be regenerated to meet requests only for populations that have become very small and are nearing extinction. For all other populations, fresh seed of teosinte will be collected during in situ monitoring of populations, which was begun this year in cooperation with maize seed bank staff of Mexico's National Institute of Forestry, Agriculture, and Livestock Research and with the national maize program of Guatemala.

In situ monitoring—The aim of this conservation activity is to keep a watch on the populations in their natural habitats. This work is not to be confused with in situ preservation, which would be a much more time-consuming and complicated endeavor. The approach chosen by CIMMYT maize staff and their colleagues in the national programs is simply to make yearly checks on the status of each population. Since most of the monitoring sites are no more than a day's drive from Center headquarters, this is clearly the most flexible and efficient approach and yet provides a sufficient guarantee that the material will be closely watched. If the status of a recognized population appears to be changing and has been placed in immediate danger of extinction, there will be time for Program staff to respond in cooperation with the appropriate national organizations.

In situ monitoring offers other advantages as well. As mentioned previously, the monitoring can be done in conjunction with seed collection. Moreover, since the distribution of *Tripsacum* parallels that of teosinte, scientists can check sites of the former while making the rounds of teosinte populations.

Cooperative research—The activities outlined above are an important safeguard against the loss of genetic variability that will be essential to the success of maize improvement efforts over the coming decades. In addition to this holding action against the extinction of valuable and increasingly rare resources, much additional and more basic work (for example, on the taxonomy, biochemistry, and subcellular structure of the wild relatives) should be done to improve our understanding and documentation of these plants. It would be neither appropriate nor possible for CIMMYT to engage in that research itself, but the Center will actively seek possibilities for cooperative arrangements with universities and other institutions, within whose realm this work properly falls.

Wheat Research

The CIMMYT Wheat Program strives to align its breeding priorities with the most pressing needs of national agricultural research programs. Over time, these needs change as the environmental, technological, and political realities affecting Third World agriculture change. Given the dynamic framework within which national programs operate, a major goal of the Wheat Program is to develop broadly adapted, disease-resistant, and high-yielding advanced lines that may be used by colleagues in developing countries in their crop improvement programs. Collaterally, the Program strives for a better understanding of the agronomic principles and practices that can enhance resource productivity in wheat production. In both cases, the Wheat Program develops "intermediate products" that national programs can refine or otherwise use to strengthen their own research efforts.

Germplasm for Mega-Environments
The research priorities adopted by the Wheat Program are shaped by the exigencies of crop production in certain large target areas. The target areas, termed "mega-environments," for which CIMMYT develops its materials, comprise the following areas in which wheat is either now a major food crop or in which its consumption is rising quickly:

- Irrigated areas;
- Rainfed areas (more than 500 mm annually);
- Rainfed areas, occasionally drought-stressed (350 to 500 mm annually);
- Rainfed, drought-stressed areas (less than 300 mm annually);
- Acid-soil areas where wheat production is limited by aluminum toxicity; and
- Warmer areas where sudden increases in temperature are common.

The latter four mega-environments, — all marginal production areas—comprise a significant portion of the wheat-growing terrain in the developing world. National programs are expending scarce research resources on the problems associated with these marginal lands in the belief that productivity increases in such areas can be large if an appropriate mix of technological components is applied. In response, during the late 1970s the Wheat Program began giving a higher priority to various research activities that will aid national programs in their efforts to improve agricultural productivity in these areas, while maintaining its research for the more favored environments.

This Year's Highlights
The highlights reported here are, in part, representative of the germplasm improvement research being done by the Wheat Program to enhance performance in marginal environments. As wheat production expands from favored to less-favored areas, diseases that were once considered of minor importance (compared, for example, to the rusts) take on a new significance, due either to their greater incidence or severity, or both. Several so-called "minor" diseases of wheat provide one focus for this year's highlights. Barley yellow dwarf (BYD) is a ubiquitous disease affecting wheat and other grass species. Losses attributable to the disease vary, ranging consistently

from 1% to 3%, but have been reported to reach as much as 30% in some locations. With funding from the Diapartimento Cooperazione Allo Suilluppo (DCAS) of the Republic of Italy, CIMMYT has intensified its BYD research; the methods being used and some preliminary results are presented in this publication.

Also widespread is the pathogen *Helminthosporium sativum*, which causes a variety of diseases depending on the growth stage of the host plant at infection. In the tropics and subtropics, the diseases caused by *H. sativum* probably do more to limit wheat yields than those caused by any other facultative pathogen. Included in the highlights for 1985 is a report on recent developments at CIMMYT in inoculation techniques and the identification of resistance.

Head scab, caused by various *Fusarium* species, is fairly widespread and can be a devastating disease. In 1985, Argentina lost some 30% of its wheat crop to a fusarium epidemic. China regularly loses a significant portion of its crop to the disease, which is also of economic importance in such countries as Brazil, Paraguay, Uruguay, Ethiopia, and Zambia. The Wheat Program has been engaged in collaborative research with Brazil and China in an effort to develop resistant materials, and highlights of the program follow.

Also highlighed this year is the establishment of a new seed health support unit, the purpose of which is to help prevent the dissemination of pathogens and pests along with experimental seed. Though the seed health unit serves both the Wheat and the Maize Programs, it is highlighted under Wheat because much of the unit's resources are currently being used to address the problem of Karnal bunt, a seed-borne disease of wheat that is begining to restrict the international flow of experimental wheat seed. The Karnal bunt research program is also reported in some detail.

Finally, a report on triticale indicates that the crop holds clear promise for areas with acid soils, dryland zones, and tropical highlands. Triticale demonstrates a convincing superiority to wheat in these more marginal environments and, through extensive crossing to bread wheats (also highlighted), further improvements in test weight, milling and baking quality, and resistance to certain diseases will likely speed triticale's acceptance as an alternative crop.

Breeding Procedures

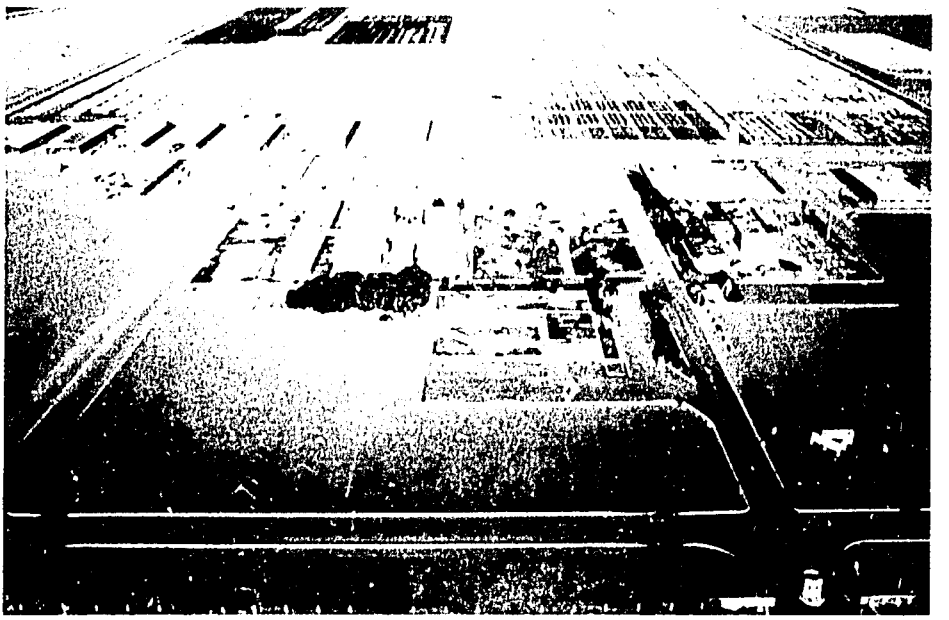
The following reports presume some basic knowledge of the Wheat Program's breeding procedures. The characteristics that distinguish CIMMYT materials—broad adaptation within mega-environments, coupled with high and stable yields—are developed by applying two interrelated breeding strategies, shuttle breeding and multilocational testing.

Shuttle breeding allows the Program to take advantage of two crop cycles per year in Mexico. During the summer cycle at Toluca (17.4°N, 2640 masl) and El Batan (18°N, 2240 masl), genotypes are screened for resistance to leaf, stem, and stripe rust, as well as to *Septoria* and *Fusarium* spp. Yield and agronomic type are also evaluated. Because Toluca is a typical highland location, materials can be evaluated there for highland environments throughout the world.

At the close of the summer cycle, selected materials are shipped 1850 km north to be grown and evaluated during the winter cycle at the Yaqui Valley Agricultural Experiment Station in northwestern Mexico (27.2°N, 39 masl). Materials are screened there for resistance to leaf and stem rust, among other diseases, and their yield potential is evaluated under high-input conditions. Breeders then identify the best-performing materials and send them south once again for another cycle of selection.

These three primary sites are supplemented by a variable number of smaller sites around Mexico at which germplasm is screened for resistance to specific diseases (e.g., septoria) or tolerance to certain environmental problems (e.g., drought).

Although this combination of cycles and sites in Mexico gives researchers great flexibility in screening materials, multilocational testing outside Mexico is essential to further assess and confirm the performance of promising lines. These materials, many of which come from cooperating national programs, are assembled into yield, disease screening, and segregating generation nurseries for testing at numerous locations throughout the world. Data from most of these nurseries are supplied to CIMMYT by the cooperators who grow and evaluate them; the Center then collates, evaluates, and publishes the data, making them available to an extensive international network of agricultural researchers.



During the winter cycle, germplasm is screened at the Yaqui Valley Agricultural Experiment Station of the Northwestern Agricultural Research Center (CIANO) for disease resistance and evaluated for yield potential.

Barley Yellow Dwarf

Barley yellow dwarf (BYD) is a cereal disease caused by an aphid-transmitted virus belonging to the luteovirus group, members of which cause the yellows diseases. The virus, known as barley yellow dwarf virus (BYDV), is actually a group of closely related viruses. Barley yellow dwarf virus is persistently transmitted, meaning that once an aphid acquires the virus, it will transmit it for life. The virus is not known to multiply in the insects; newborn nymphs (young aphids) are virus-free and acquire the BYDV by feeding on infected plants.

Even though BYD was not discovered until 1951, earlier reports reveal numerous instances of cereal disorders that can probably be attributed to BYD. It is likely that the disease is much older than any of the recorded cases indicate, and it is probable that the landrace cereals, especially the Ethiopian barleys that exhibit resistance to the virus, evolved along with it.

Barley yellow dwarf has been recorded in most areas of the world, and its distribution is well documented (*CIMMYT, 1984*). Losses due to the disease vary, ranging from 1% to 3% annually, though in some years and some locations, losses may be as high as 20-30%. In some cases, crops have been totally destroyed.

Symptoms—Because its presence is often masked by other diseases, such as the rusts, BYD should be considered a second-generation disease whose effects become much more apparent once resistance to these primary diseases has been developed. The virus partially plugs the phloem, interfering with translocation, and infection can cause severe stunting of plants, inhibit root formation, delay heading, and reduce yield. Disease symptoms vary depending on the crop species or cultivar affected. On oats and some wheats, the leaves of diseased plants show a yellowing or reddening, but often the symptoms of BYD in bread wheat, durum wheat, and triticale are not particularly apparent, and even experienced cereal workers may have difficulty recognizing them.

Formerly, the only practical method for diagnosing BYD was by aphid transmissions to indicator plants with the resulting development of typical disease symptoms. With the development of the enzyme-linked immunosorbent assay (ELISA) an alternative method of diagnosing the disease became available. In many parts of the world, however, researchers do not have the facilities to carry out either aphid transfers or ELISA, and BYDV must still be diagnosed on the basis of symptoms. One of the disquieting facts emerging from recent reports is the number of asymptomatic BYDV-infected cereal plants that are being discovered. However, in most places where BYD-resistant materials are selected, selection is being done to some extent on symptoms. This research area requires a great deal of additional study.

Vectors—The principal vectors of BYDV are the aphids *Rhopalosiphum padi*, *R. maidis*, *Sitobion avenae*, *Schizaphis graminium*, and *Metopholohium dirhodum*, although more than 20 other aphid species can transmit BYDV as well. All of the principal vectors are present in Mexico,

and preliminary work indicates that *R. padi* and *S. avenae* may be the most important local vectors (these results need further study). In some countries, long-distance movement of cereal aphids may be important in the epidemiology of the disease.

Isolates of BYDV have been grouped according to their vector specificity.

Dr. Peter Burnett, CIMMYT pathologist (left), examines symptoms of barley yellow dwarf (BYD) in wheat with Dr. Paul Fox, CIMMYT outreach scientist posted to the Andean Region, where BYD is prevalent.

The groups are designated by the initial letters of their principal vector or vectors:

RPV - transmitted specifically by *Rhopalosiphum padi*
RMV - transmitted specifically by *R. maidis*
MAV - transmitted specifically by *Macrosiphium avenae*, now called *Sitobion avenae*
SGV - transmitted specifically by *S. graminium*
PAV - transmitted non-specifically by *R. padi* and *S. avenae*

These five groups can be divided into two categories using serological comparisons. The grouping agrees with that produced by the comparison of ultrastructural changes observed in infected plants.

Control—Because of the extremely wide range of BYDV hosts among long-lived grass species, there is very little chance that the virus will be eradicated through the elimination of these hosts, which may play an important role as a virus reservoir. However, in some areas of the world BYD can be partially controlled by adjusting planting time to avoid the period when aphids are more likely to move into the seedling cereal crops. Partial control may sometimes also be obtained through the judicious use of insecticides against aphids, thereby limiting the spread of BYDV. In some countries or regions biological control of aphids has reduced incidence of the disease. None of these methods are completely satisfactory and it is thought that the most efficacious means of control is host plant resistance.

The development and distribution of germplasm is part of CIMMYT's mandate, and thus it is appropriate for the Center's BYD research to focus primarily on breeding for resistance. Host plant resistance to BYDV in barley has been demonstrated by using a single gene (Yd_2) transferred from Ethiopian landrace varieties. This gene, which appears to be strong as well as durable, was first exploited by Dr. C.W. Schaller of the University of California at Davis and has been used throughout the world to provide BYDV resistance. Although similar resistance genes have not been identified in other cereals, testing done to date has not been exhaustive.

Over the last six years, and more intensively over the last two years, BYD-resistant material has been selected at CIMMYT. This work was strengthened by the establishment of the barley yellow dwarf research program at CIMMYT in 1985. The program is funded for three years by the Diapartimento Cooperazione Allo Suilluppo (DCAS) of the Republic of Italy.

Through this research program, CIMMYT aims to establish a network of cooperators in developing and developed nations, and to act as a clearinghouse providing information and germplasrn to these cooperators. Resistant germplasm will be made available to any interested party.

The program's initial efforts have concentrated on screening germplasm, particularly advanced lines produced by CIMMYT's breeding programs and selected materials from various cooperators. Funds have also been made available to enable CIMMYT to support BYD research by national programs.

Methodology

Even before screening for BYD began in 1980, selection pressure for BYD existed because breeders had noted a degree of stunting, probably partly due to BYD, in material grown in the winter. Since 1980, CIMMYT has used Toluca, where natural epidemics of BYD occur, as a site for screening winter and spring materials. Screening was initially done only in winter, and barley yellow dwarf observations were (and still are) taken on breeders' plots because of limited space. In 1984 and 1985, it was found that Toluca could be used in spring as a BYD screening site if materials were sown 15-20 cm apart later in the growing season. This plant spacing increases the intensity of BYDV infection.

In the spring plantings, entries are hand seeded in two-row, one-meter plots with 5-6 seeds per meter. Plots are separated by a space of one meter, and two replicates are planted (the program experimented with using single rows of two meters, but the two-row plots proved to be superior in Toluca). Observations on symptoms are taken using a 0-9 scale in which 0 is resistant and 9 is fully susceptible (Schaller and Qualset 1980). Because foliar symptoms enable general symptoms of BYD to be noted more easily, the program is experimenting with spraying the plots with fungicides every two weeks to eliminate other diseases.

The program is now concentrating on screening advanced lines from CIMMYT breeding programs, in

addition to materials that have been reported to be resistant to BYD elsewhere. Material appearing resistant in these tests is selected and maintained by the program for retesting and distribution.

Results

Spring bread wheat—The preliminary bread wheat nursery for BYD was obtained from initial screening done in Toluca during the 1981-82 winter cycle, and contained 89 entries that appeared resistant to BYD at that site. Two check resistant cultivars, Anza and Nacozari, were included every 20 entries. Usable data were obtained from Canada (A.I. Comeau), New Zealand (J.M. McEwan), and the USA (C.O. Qualset). Eight lines appeared to exhibit resistance at all three sites (Table 1), but other lines showed resistance at one site and were susceptible at another. This variation emphasizes the need for multilocational testing for BYD resistance.

Systematic screening of CIMMYT's advanced bread wheat lines began in Toluca in the summer of 1984, and continued in the summer of 1985. During the first year, 228 lines were selected in Toluca, and were retested in the subsequent year at Toluca and Davis, California (USA). Table 2 lists lines that exhibited resistance in Toluca in 1984 and 1985, and at Davis in 1985. These lines will be tested in Quebec this year and the best lines distributed to other sites for testing.

Table 1. Entries in the preliminary BYD bread wheat screening nursery that showed resistance at Sainte-Foy, Quebec (Canada); Palmerston North (New Zealand); and Davis, California (USA)

Fln/Acc//Anza
Prl 'S' (2 lines)
Jup/Emu 'S'//Gjo 'S' (3 lines)
Dodo 'S'
Era/MN69146//Pum 'S'

Table 2. Selections that showed resistance to BYD in Toluca over two years (1984 and 1985), and then exhibited resistance at Davis, California (USA)

PC BYD No.	Variety or cross and pedigree	PC BYD No.	Variety or cross and pedigree
4	Toni	47	Rrv/WW15/3/Bj 'S'/2*ON//Bon/4/Nac* CM65202-3M-2Y-1M-1Y-0M
12	Amd 'S'/HN4//Coc SWM6838-35Y-1Y-1Y-2Y-0Y	58	Anb 'S'/Jup CM68198-2Y-1M-2Y-3M-0Y
27	Buc 'S'/Pvn 'S' CM52359-2M-3Y-1Y-2M-1Y-0M	74	But 'S'/CEP75195 OC3229-1M-1Y-4M-1Y-0M
38	Mrl 'S'/Buc 'S'* CM61949-3M-4Y-1M-2Y-1M-0Y		

(continued)

Table 2. (cont'd)

PC BYD No.	Variety or cross and pedigree	PC BYD No.	Variety or cross and pedigree
76	F1271/Coc SWM5784-17Y-1M-4Y-5M-1Y-0B	175	Sap 'S'/Mon 'S' CM40392-17M-1Y-0M-191M-0Y
82	Yaco 'S' CM41195-J-7M-1Y-0M-12Y-0B	184	Mascarenhas
87	Buc 'S'/Flk 'S' CM50070-24Y-1M-1Y-0Y	187	RPB70971/Coc SWM6845-9Y-1Y-1Y-1Y-0Y
93	Nepal 133	189	R37/GHL121//Kal/Bb/3/Klt 'S' CM64609-5Y-4M-4Y-0M
114	Lira 'S' CM43903-H-2Y-1M-5Y-2M-1Y-1M-0Y	193	Anb 'S'/Yaco 'S' CM67618-2Y-3M-3Y-2M-0Y
121	Bjy 'S'/Coc CM55651-4Y-2Y-1M-4Y-0M	197	Anb 'S' CM20707-A-1Y-8M-1Y 0Y-4PTZ-0Y
124	R37/GHL121//Kal/Bb/3/Klt 'S' CM64609-6Y-3M-1Y-0M	198	Prl 'S' CM25988-8Y-3Y-2Y-1M-0Y
141	PF72640/PF7326//PF70 65/Ald 'S'	202	F3570/Mo//Nac CM43367-E-3Y-1M-3Y-6M-1Y-2M-0Y
142	Thb 'S'* F11915	203	Par/H56771 CMH77A260-2B-1Y-7B-1Y-1PTZ-0Y
144	PF79782 F11915-A-502M-8Y-2 F-702Y-2F-700Y	206	Yr/Trf 'S' CM36749-10Y-3M-5Y-2M-1Y-0M
145	PF79765 LOTE137/8	210	Cim 'S'/M_2A//Ttm 'S CIT-616-1B-2Y-2Y-0M
156	E7408/Pam 'S'//Hork 'S'/PF73226 F13906-F-2Y-4M-1Y-0M	217	Flk 'S'/Hork 'S' CM39816-1S-1AP-0AP
166	RC7201/2*BR2 F13796-4F-1F-1F-703Y-1F-701F-7F-0Y	220	T8020 Noruega
168	ALV110/2*IAS54/6/Tp/4/Tzpp/Sn64//Napo/3/Cno67/5/PF6968 F15183-A-901F-901F-903F-3026F-0Y**	221	Buck Mapuche
		224	Rsk/TiResel//Coc CM43274-BB-2Y-1M-1Y-2M-0Y

* Other lines from the same cross also showed resistance.
** Two lines from this cross showed resistance.

Table 3 lists nine lines from the 16th IBWSN selected for resistance in Sainte-Foy, Quebec (Canada) in 1983. These lines have now been tested at Toluca and Davis, and exhibit resistance at both sites.

Table 3. Bread wheat lines that exhibited BYD resistance at Toluca (Mexico); Sainte-Foy, Quebec (Canada) and Davis, California (USA)

Variety or cross and pedigree
Jup/4/7C/Pato B/3/LR64/Inia66/ /Inia66/Bb/5/Ana CM37760-C-21Y-2M-1Y-3M-0Y
Pato/On//Maya 'S'/3/Bb/Ron//Maya 'S' CM40739-36M-1Y-1M-1Y-1M-0Y
Hus 'S'/Ptm//Maya/Ald 'S' CM47740-A-3Y-1M-1Y-2M-1Y-2M-0Y
PF70354/Ald 'S' CM47090-14M-1Y-1F-703Y-10F-705Y-3F-0Y
Tob//Cc/Pato/3/Bb/Gil/4/Nac CM49624-14Y-5M-1Y-1Y-2M-2Y-0M
Buc 'S'/Flk 'S' CM50070-24Y-1M-1Y-0Y
Buc 'S'/Chrc 'S' CM52421-10M-6M-1Y-1M-1Y-0M
IAS58/IAS55//Ald 'S'/3/Mrng/4/ Ald'S'/
IAS58.103A/Ald 'S' CM55517-B-1F-701Y-1F-707Y-1F-0Y
Ald 'S'/Pima//CMH74A.630/Bui 'S'//CMH74A.630 CM57542-H-8Y-8B-4Y-0B

A second BYD screening nursery, containing 146 lines, has been assembled for distribution to sites where BYD is usually present. This nursery is composed of selections from the original BYD nursery, as well as some of the the 228 lines selected in Toluca in 1984. As more information becomes available, reselections for the succeeding nurseries will be carried out.

Winter bread wheat—Many nurseries were scored visually in Toluca for resistance to BYDV. Lines that exhibited resistance over a number of years are listed in Table 4. In 1986 these lines, in addition to others that look promising in Mexico, will be distributed in a special winter nursery. The best lines will be used in Mexico as parents for making winter x spring crosses to transfer BYDV resistance to spring wheats.

Durum wheat—Resistance in durum wheat seems to be limited. During the last two years most of the nurseries have been checked but only a few promising lines were found. Table 5 lists entries that showed good resistance at Toluca in 1984 and 1985 and also exhibited resistance in Sainte-Foy. A preliminary BYD screening nursery of 29 entries has been distributed for further testing to sites that normally experience BYD epidemics.

Wide crosses—Materials produced in CIMMYT's wide crosses program have been screened and some lines involving crosses with *Elymus gigantus* show promise. However, these are preliminary results and further testing is required.

Spring barley—Lines were selected in Toluca for inclusion in the BYD screening nurseries, and to date four

Table 4. Winter wheat lines that have shown resistance to BYD at Toluca over a number of years

Line or cultivar	No. of years	Line or cultivar	No. of years
NS974/NB69565 711068	4	NR72.837	4
Pyn CI17717 78ST 621	4	F4472	4
OK77164 78LA 168	4	Anza/Sut//Ctk C0810001	3
Sdy	4	Anza/Sut/Ctk C0810002	2

Table 5. Durum wheats selected in Toluca in 1984 and 1985 for BYD resistance, and which also exhibited a level of resistance in Sainte-Foy, Quebec (Canada)

Variety or cross and pedigree	Variety or cross and pedigree
Cr 'S'/Gs 'S'//Pg 'S' CM-13454-5Y-1M-4Y-0Y Cit 71	Gediz 'S'/Cit71 CD-32575-1B-1Y-1M-0Y
Moa 'S' CD 3935-1Y-1M-0Y	Yav 'S'/Snipe 'S'/3/Mexi 'S'/P66.270//Gta 'S' CD-33863-1B-3Y-2M-0Y
Afn 'S'/Ibis 'S'//Coo 'S'/3/Goo 'S' CD-22951-5Y-1M-1Y-2Y-1M-0Y	Yav 'S'/Snipe 'S'/3/Mexi 'S'/P66.270//Gta 'S' CD-33863-2B-3Y-2M-0Y
Carc 'S' CD-24831-E-3Y-3M-1Y-1Y-0M-22Y-0B	PI178083/Frig 'S'//Goo 'S' CD-34957-D-2Y-3M-1Y-0M
Gs 'S'/Cr 'S'//Sba81/3/Ho/4/ Mexi'S'/5/Memo 'S' CD-27215-5B-2Y-1Y-0M	Qfn/Memo 'S'/3/Oyca 'S'//Ruff 'S'/ Fg'S' CD-35212-A-1Y-1M-2Y-0M
Sco 'S'/Rabi 'S'/Mexi75 CD-28164-B-2M-1Y-2Y-0M	Zud ICD-74122-2L-1AP-0AP-1KE-0Y
Mo 'S' CD-29063-3Y-4Y-3M-0Y	

BYD barley screening nurseries have been distributed. Final data have been received from the first two nurseries, and preliminary data are available from the third.

The first nursery, distributed in 1982, consisted of 169 entries (129 spring and 40 winter barleys). Usable data were received from three cooperators: A.I. Comeau (Canada), J.M. McEwan (New Zealand), and J. Hernando Velasco (Spain). Table 6 lists the spring materials that exhibited resistance at all sites. The second barley BYD screening nursery contained 43 entries that were not known to contain the Yd_2 gene for resistance. Table 7 shows the 10 best lines with scores from the eight sites

Table 6. Lines from the 1st barley BYD screening nursery that appeared resistant at 3 sites: Sainte-Foy, Quebec (Canada); Palmerston North, (New Zealand); and Madrid (Spain)

Promesa
Caco 'S'
Sutter
Ben 4d
Chino 'S'
Asse/Nackta//Villa Robledo/3/Pyd
Ojl 'S' (2 lines)
Lignee 640
Api-CM67//Apm/IB65/3/Api/CM67/ /11266 L2696669/4/Ben
Ore 'S'//Api/CM67
Ore 'S'//Indian Dwarf/CM67
Api/CM67//Ager
Alamos 'S'

Table 7. Disease scores of selected lines from the 2nd barley BYD screening nursery[a]

Variety or cross and pedigree	Sites[b]								Mean
	1	2	3	4	5	6	7	8	
P12325/MagnII102//Cossack CMB78-452-2Y-1B-1Y-1B-1Y-0B	3	4	1	1	0	2	3	2	2.0
79W41762	3	1	1	0	1	4	6	3	2.4
Teran 75 G134/Apm//CI0897/3/Api/11012-2//	3	4	1	0	5	2	3	2	2.5
P7186 CMB76A-1362-A-1B-1Y-1B-2Y-1B-0Y	5	6	1	0	1	3	3	4	2.9
Duchicela	5	3	2	1	3	3	4	2	2.9
Lignee 640	5	3	–	1	0	5	3	3	2.9
Gus	5	5	2	1	3	3	3	2	3.0
Nigrinudum	3	7	1	3	1	5	3	1	3.0
G8W40785	5	5	2	0	5	4	3	1	3.1
GAW125.5 48K Fincha	3	7	1	5	3	2	3	1	3.1

a Scores taken using a 0-9 scale (Schaller and Qualest 1980) in which 0 is resistant and 9 is fully susceptible.

b BYD screening sites: 1 = Tunisia-Beja, Tunisia; 2 = Beijing, China; 3 = Montpellier, France; 4 = Lleida, Spain; 5 = Madrid, Spain; 6 = Toluca, Mexico; 7 = Pendleton, Oregon, USA; 8 = Manawatu, New Zealand.

where usable data were obtained (complete data for this nursery will be published in the nursery report). Even within this limited group, scores vary greatly across sites. For example, Nigrinudum and GAW 125.5 48k FINCHA scored 7 (susceptible) at site 2, but at the seven other sites they showed resistance. Many other lines looked good at five or six sites but received high scores at the other sites.

Table 8 lists three of the checks included in the 2nd BYD screening nursery, Triumph and the isogenic lines Atlas 57 (-Yd_2) and Atlas 68 (+Yd_2). California Mariout (-Yd_2) and CM67(+Yd_2) were also included, but it appears that they are not good indicator test lines because they mature too rapidly, and the onset of maturity can often be mistaken for BYD susceptibility. These check lines also reveal great variation in the disease score across sites.

The best entries from the Crossing Block tested for their reaction to BYD in 1984 are presented in Table 9. These entries have been tested again and exhibit good resistance in Mexico; some entries also show good resistance at other sites.

Winter barley—During the last two winter cycles at Toluca (1983-84 and 1984-85), approximately 50 winter barley lines having disease scores of 5 or below over two successive years have been identified. Some of these lines, such as Post, a winter barley from Missouri, are known to be resistant to BYD in other areas of the world although they are not known to contain the Yd_2 gene. In an effort to combine both kinds of resistance, the program will cross these lines with lines known to contain the gene.

ELISA Testing of Virus Isolates from Mexico

Since 1984, leaf samples have been taken from the field and sent to a number of laboratories for ELISA analysis to determine the presence of BYDV. Results to date indicate that the main BYDV type in Mexico is a MAV type. Some of the samples tested

Table 8. Disease scores of check lines from the 2nd barley BYD screening nursery[a]

	Sites[b]								
	1	2	3	4	5	6	7	8	Mean
Triumph	9	8	2	1	3	5*	7	7	5.3
Atlas 57	9	5	4	6	3	6	8	5	5.8
Atlas 68	5	5	1	7	1	4	3	2	3.5

* More often 7 at this site.

a Scores taken using a 0-9 scale (Schaller and Qualset 1980) in which 0 is resistant and 9 is fully susceptible.

b BYD screening sites: 1 = Tunisia-Beja, Tunisia; 2 = Beijing, China; 3 = Montpellier, France; 4 = Lleida, Spain; 5 = Madrid, Spain; 6 = Toluca, Mexico; 7 = Pendleton, Oregon, USA; 8 = Manawatu, New Zealand.

Table 9. Barley lines resistant to BYDV in Toluca, 1984

Variety or cross and pedigree	Disease score[a]
Dorada	4
MCU33/Fza//Tib/3/PI356456 DII-3958-27D	3
CI2325/CI12225/Boy(2)/ Surb(3)II15263-3PT-3V	4
Boy/MCU3048.1D//CI1463.3D II14127-1P1-5V	4
PI14116.13D/CI12225/ /CI12917.37D II1516-1PV-1PV-1V	3
CI2375/CI12225//Can/ MCU29/3/Tib/4/ CI12225.23D II14845.3V	4
Boy(2)/Surb(3)//CI12225-2D II15199-1PV-5V	5
Row 906.73	5
Proctor/Prior/Gospick E-II-69-117-5E-2E-7E	5
ESCII-72-83-3E-7E-5E-1E	2
Cedro CMB77-1267-B-1Y-1BV-1Y-1B-1Y-1B-0Y	4
CM72	3
Sutter	4
UC566	3
CI 3906.1	5
Promesa	4
79 W 40762	3
79 W 41762	3
PI 382406	3
79 AN/MN 123-NV-1B-0Y	5
M66.85/Aths/3/Api/Cm67/ /Ds/Apro CMB75A-1617A-7B-500Y-500B-0Y	4
Api/Cm67//Ager CMB76-408-27Y-1B-4Y-1B-1Y-0B	4
Yoa 'S' CMB77-125-1Y-1B-1Y-2B-1Y-0B	5
Brea/Sutter//F3 Bulk Hip CMB79A-1062-C-501B-1Y-1B	4
Ojillo 'S' CMB79A-1362-B-501B-1Y-1B	3
Ojillo 'S' ACMB79A-1362-B-501B-3Y-1B	4
Palo Santo 'S' CMB79A-1524-D-500B-1Y-1B	2
CI 3208.2	5
Yori 'S' CMB-77A-402-1B-1Y-4B-3Y-1B-0Y	5
PI 2325/Mag102//Cossack CMB/78-452-2Y-1B-1Y-1B-1Y-0B	4

[a] Highest score from two dates of scoring on two replications. Scores taken using a 0-9 scale (Schaller and Qualset 1980) in which 0 is resistant and 9 is fully susceptible.

appeared to be non-specific, transmitted by both *R. padi* and *S. avenae*, but very few samples were RPV.

Transmission tests using aphids were done in Mexico and *R. padi* seems to be a common vector. Again, these results are preliminary and further testing is needed.

Discussion and Conclusion

Many other research institutes throughout the world have conducted BYD screening for a number of years, and most of the materials selected as resistant are being cycled through the barley yellow dwarf program at CIMMYT. So far, the program has concentrated on selecting parents that appear resistant to BYD in the field in Mexico. Lists of these parents are given to the breeders of all CIMMYT programs, who use these parents in crosses. The crosses, as segregating materials, are then returned to the BYD program for selection. The program is still mainly in the parent identification phase, but the initial screening of segregating materials has started.

It seems that it is quite possible to take advantage of the natural epidemics that occur in Mexico for selecting materials. *Diuraphis noxia*, an aphid that secretes a toxin, can cause such severe damage that it can mask the symptoms of BYD. This problem will be overcome once the rearing of aphids begins, because then it will be possible to infest materials with viruliferous aphids and spray on a regular basis to eliminate *D. noxia*.

Current data are preliminary and further testing is required at a greater range of sites before reliable data are obtained.

The strength of the CIMMYT program will be its ability to draw on the network of institutes that have been screening materials, and to act as a distribution center for those materials.

References

CIMMYT. 1984. *Barley Yellow Dwarf: A Proceedings of the Workshop*. Mexico, D.F.: CIMMYT.

Schaller, C.W. and C.O. Qualset. 1980. Breeding for resistance to barley yellow dwarf virus. In *Proceedings, Third International Wheat Conference, Madrid, Spain*. Lincoln: University of Nebraska, pp.528-41.

Helminthosporium sativum: Inoculation Techniques and Identification of Resistant Material

Helminthosporium sativum (*Cochliobolus sativus*) is one of the most widely distributed cereal crop pathogens, attacking wheat, triticale, barley, and many other grasses at various growth stages. This voracious pathogen may cause such diseases as spot blotch, root and crown rots, node cankers, black point, and head and seedling blights. Root and crown infections occurring before or during flowering usually kill plants before seeds are formed.

In parts of the tropics and subtropics, diseases caused by *H. sativum* probably reduce wheat yields more than diseases caused by any other facultative pathogen. Recognizing the need for broadly adapted germplasm that performs well in such environments, CIMMYT has placed increased emphasis on breeding for resistance to the fungus. This report

highlights recent developments at CIMMYT in inoculation techniques and the identification of resistance to *H. sativum* in wheat.

Research Methodology and Materials

Isolates are obtained from leaves of different wheat varieties and advanced lines grown in Poza Rica, Mexico (21°N latitude, 60 masl). Diseased leaves were cut into small pieces, disinfected with 5% calcium hypochlorite for 60 seconds, and transferred to petri dishes containing potato dextrose agar (PDA).

The isolates are maintained on sterilized wheat grain media prepared by soaking the grain in distilled water for 24 hours, then draining away the excess water and sterilizing the grain in an autoclave at 120°C for 2 hours. The isolates are kept in this media under refrigeration (4°C) until required.

To increase the inoculum, the infected grains are transferred to petri dishes with PDA and kept in a growth chamber at 22°-24°C. After seven or eight days, the inoculum is ready for use. A spore suspension is prepared by washing the PDA plates with distilled water and filtering the spore suspension through gauze. The spore concentration is then standarized to 60,000 spores per/ml, using a hemocytometer.

Inoculation and Evaluation in the Greenhouse

Ten to twelve seeds of the materials to be tested are placed in envelopes made from glassine bags lined with absorbent paper towels. The 60 envelopes, supported and separated with strings, are arranged in two rows in 22 cm x 30 cm trays. Each tray is then filled with distilled water, which supplies the humidity necessary for germination and plant development.

In the tropics and subtropics, helminthosporium diseases probably reduce wheat yields more than diseases caused by any other facultative pathogen.

Inoculation is done at the two-leaf growth stage about 8-10 days after germination, using a hand sprayer. Each tray receives approximately 100 ml of inoculum. Inoculated plants are kept in a mist chamber, where they receive 2 hours of continuous misting, and then 15 minutes of misting every 2 hours thereafter for 24 hours. Later, the seedlings are transferred into a chamber and kept at 20-24°C and 75-80% relative humidity for 5-7 days.

After the 5-7 day period, inoculated materials are evaluated according to the following 0-5 scale:

0 = No visible symptoms.

1 = A few small black lesions on leaves.

2 = More black lesions, some with small chlorotic halos.

3 = Lesions surrounded by chlorotic halos, many of which start converging; some drying at leaf tips.

4 = Broad lesions with ample necrotic zones; drying over a large part of the leaf.

5 = Large lesions; drying of the whole leaf.

Inoculation and Evaluation in the Field

Field screening is carried out at Poza Rica, where the moderate mean temperature and high relative humidity during the crop cycle are conducive to developing excellent epidemics of *H. sativum*. During the 1983-84 cycle, the relative humidity was between 90% and 100% for more than 95% of the growing cycle (Figure 1). The optimum average temperature for the development of the fungus (18-24°C) was recorded during approximately 75% of the growing cycle (Figure 2).

If necessary, artificial epidemics are created by using helminthosporium-infected straw saved from the previous years's crop. The straw is chopped into pieces and scattered between the rows at tillering. Various foliar

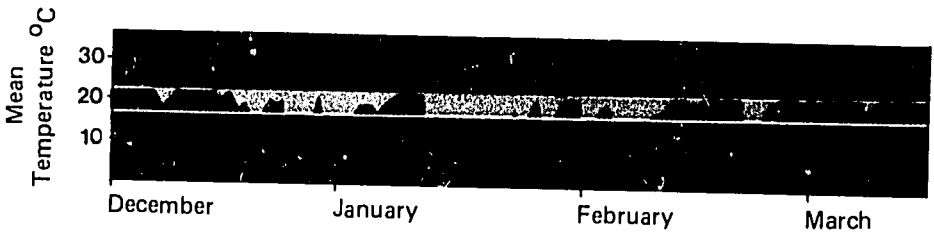


Figure 1. Mean temperature during the 1983-84 crop cycle in Poza Rica.

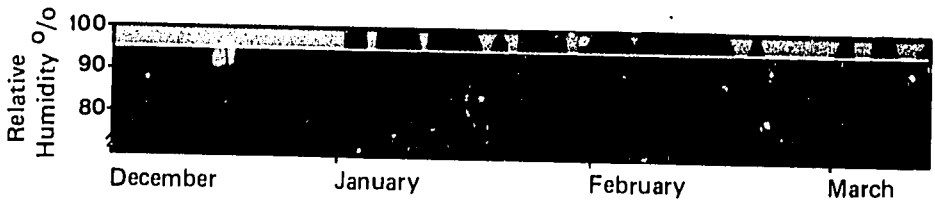


Figure 2. Relative humidity during the 1983-84 crop cycle in Poza Rica.

evaluations are made, using the 0-9 scale described by Saari and Prescott (1975). After the field evaluation, selected lines are harvested at maturity and the grains are evaluated for percentage of diseased grain and the severity of the damage, using the 0-5 scale (Figure 3).

Selection of individual plants or lines in segregating generations is based on the following characteristics:

- Slow development of the diseases;
- Acceptable agronomic characteristics;
- Disease-free, fertile, bright spikes at maturity; and
- Disease-free seeds with good phenotype.

Screening Materials

Various international bread wheat screening nurseries, Crossing Block (CB) advanced lines, and introductions provide the base germplasm for the identification of resistant materials. More than 2500 lines were tested during the 1983-84 and 1984-85 cycles. To further improve resistance in the germplasm, these resistant lines are used each crop cycle in crosses with high yielding, widely adapted germplasm and with resistant lines. Segregating populations from such crosses are also screened at Poza Rica.

One hundred-forty different grass species with potential for transferring *H. sativum* resistance to wheat were supplied by the wide crosses program for evaluation in the greenhouse. About 10,000 segregating and advanced lines derived from

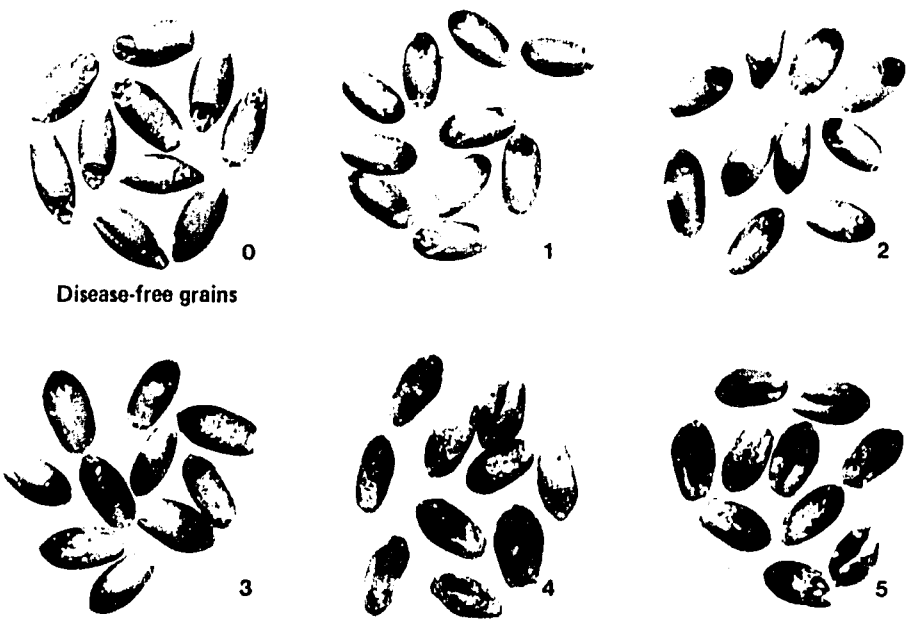


Figure 3. Zero to five scale used at CIMMYT for scoring severity of disease damage on wheat grains.

interspecific and intergeneric crosses, also from the wide crosses program, were evaluated during the 1983-84 and 1984-85 seasons in the field at Poza Rica.

Research Results

Of the thousands of advanced bread wheat lines tested during the last four years, only a small number have repeatedly demonstrated good levels of resistance. Those listed in Table 10 are the best lines having CIMMYT germplasm as their base, and are as good as or better than BH 1146, a check variety from Brazil. It was not surprising to find that only a small portion of the germplasm was resistant, because previously no efforts were made to breed for resistance. The resistant lines identified so far are being used extensively in the crossing program to further improve yield potential, adaptation, and the level of *H. sativum* resistance. Since these lines have CIMMYT germplasm as their base, they provide additional advantages over resistant lines with unacceptable agronomic characteristics. Each year resistant lines identified at Poza Rica are distributed internationally in the Helminthosporium Resistance Screening Nursery.

At Poza Rica, segregating populations derived from crosses made with the objective of combining helminthosporium resistance with resistance to other tropical diseases and high yield were screened, resulting in the identification of various resistant lines. The most advanced material at this stage is in the F_5 generation, and more generations of selection are required to obtain homozygous resistant lines.

Dr. Lucy Gilchrist screening for helminthosporium resistance in wheat at Poza Rica, Mexico.

Table 10. Best semidwarf advanced lines of br[illegible] wheat resistant to *Helminthosporium sativum* when tested at Po[illegible]ca, Mexico, various years

Cross and pedigree	Seedling infection type[1]	Highest foliar infection[2] recorded at milk stage	Highest black point infection type[3]
Kea 'S' CM21335-C-9Y-3M-1Y-1M-1Y-0B	3	5	4
Pato(R)/3/Tzpp/Sn64//Nar CM21974-4R-4M-2E-4M-20-0Y-0P-0Y	3	5	3
CI/14227/Trm//Mad 'S' CM47943-V-5M-3Y-1M-0Y	2	5	2
Aldan 'S'/IAS58 CM53481-6Y-1Y-4M-1Y-1M-1Y-0M	3	6	3
Bjy 'S'//Tob/Cha CM55912-10Y-3Y-1M-3Y-1JO-0JE	2	5	3
Bjy 'S'//Tob/Cha CM55912-10Y 3Y-1M-3Y-2JO-0JE	2	5	3
IAS54/Ald 'S' CM56805-3Y-1Y-4M-1Y-1M-1Y-0M	1	6	2
HI669/4/Tor 'S'/2*HD832//Tob/3/ Tor 'S'/2*HD832 CM62550-1Y-1M-2Y-1M-3Y-0M	3	6	1
Rrv/WW15/3/Bj 'S'/2*On//Bon/4/Nac CM65202-3M-2Y-3M-0M	3	6	3
Sn64/SS2//Ald 'S'/3/Ti Resel/Coc/4/ IAS58/3/IAS20//Wte"3/Nar CM67208-B-3M-2Y-2M-1Y-0M	3	6	2
Au/UP301//GII/SX/3/Pew 'S'/4/ Mai 'S'/Maya 'S'//Pew 'S' CM67245-C-1M-3Y-1M-6Y-1M-0Y	2	5	2
Kea 'S'/4/Kal/Bb//Cj 'S'/3/Ald 'S' CM646!7-9M-1Y-1M-0Y	2	6	2
Anb 'S'/Yaco 'S' CM67618-2Y-3M-3Y-2M-0Y	1	6	2
Vee 'S'/CEP7713 OC3597-4M-2Y-0Z-1Y-0M	2	5	2
BH1146 (resistant check)	2	5	2
CIANO 79 (susceptible check)	5	9	5

1 Using a 0-5 scale.
2 Using a 0-9 scale.
3 Using a 0-5 scale.

Seventeen of the 140 different grass species tested in the greenhouse showed a very high level of seedling resistance to *H. sativum* (Table 11). These species belong to the genera *Agropyron*, *Aegilops*, *Elymus*, and *Haynaldia*. Twelve of the 17 resistant species were successfully hybridized with bread wheat by the wide crosses program. Ten homozygous advanced lines from the crosses of four alien species with various bread wheats possessing good resistance to *H. sativum* were also identified (Table 12).

All the wheat varieties used in the wide crosses advanced germplasm were susceptible (Table 12), but it is not yet certain that the resistance of the selected lines came from the alien parent. It is believed that the resistant alien sources listed in Table 11 could provide new genetic variability to the wheat germplasm.

Conclusions

Satisfactory methods have been developed to screen for resistance to *H. sativum* under greenhouse and field conditions. Poza Rica, a tropical location in Mexico, has climatic conditions ideal for developing natural epidemics of the disease. A number of lines with an acceptable level of resistance in the field at Poza Rica have been identified. These semidwarf lines have good agronomic features

Table 11. Alien species exhibiting seedling resistance to *H. sativum* in the greenhouse at El Batan, 1984

Alien species	Chromosome	Disease score[a]
Agropyron junceum **	2n/2x/14	1
Agropyron elongatum **	2n/2x/14	1
Agropyron yezoense	2n/4x/28	1
Agropyron scabrifolium **	2n/4x/28	1
Aegilops squarrosa (several accessions)	2n/2x/14	1
Aegilops triuncialis	2n/4x/28	1
Haynaldia villosa **	2n/4x/28	1
Agropyron campestre **	2n/8x/56	2
Agropyron scirpeum **	2n/4x/28	2
Agropyron rechingeri **	2n/4x/28	2
Agropyron trachycaulum **	2n/4x/28	2
Agropyron ferganensis	2n/4x/28	2
Agropyron subsecundum **	2n/4x/28	2
Agropyron scythicum **	2n/4x/28	2
Elymus junceum	2n/2x/14	2
Elymus dahuricus **	2n/6x/42	2
Elymus arenarius **	2n/4x/28	2

a Scoring scale: 1 = Resistant, 5 = Susceptible.
** Hybrid germplasm available in CIMMYT.

and will serve as basic resistant germplasm for further improvement. Lines identified as resistant at Poza Rica are being distributed throughout the world in the Helminthosporium Resistance Screening Nursery.

Various alien species related to wheat possess good resistance to *H. sativum*. The wide crosses program has hybridized several of these related alien species with wheat to transfer *H. sativum* resistance to bread wheat. Some homozygous advanced lines with acceptable levels of resistance are also available.

References

Saari, E.E. and J.M. Prescott. 1975. A scale for appraising the foliar intensity of wheat diseases. *Plant Disease Reptr.* 59:377-380.

Table 12. Homozygous advanced lines, derived from crosses of alien species with bread wheats, that showed good resistance to *H. sativum* in Poza Rica, 1983-84 and 1984-85

Cross	No. of lines	Highest black point infection type*
Cs/*E. gig.*//Cs/3/2*Pvn 'S'[2]	2	2
Cs/*E. gig.*//Cs/3/3*Pvn 'S'[5]	2	1
Cs/*E. gig.*//2*Cs/3/Cno79[5]	1	1
Cs/*E. gig.*//Za75/3/Nac76[5]	1	2
Inia66/*A. dist.*//Inia66/3/Gen81[6]	2	2
Cs/*A. elong.*//3*Nac76/3/Gen81[6]	1	3
Cs/*A. cuv.*//Glen81/3/Gen81[2]	1	2
Ciano (Susceptible check)		5

E. gig. = *Elymus giganteus* (2n/4x/28)
A. dist. = *Agropyron distichum* (2n/4x/28)
A. elong. = *Agropyron elongatum* (2n/10x/70)
A. cuv. = *Agropyron curvifolium* (2n/4x/28)

[a] Using a 0-5 scale.

Note: Although detailed leaf infection scores were not made, all the advanced lines included in Table 12 showed infection scores of 4 or less during 1983-84 and 1984-85.

Fusarium Studies at CIMMYT

Fusarium head scab is a common wheat disease in many parts of the world where the crop is grown at low elevations under warm, humid conditions and lingering cloud cover. The disease is also economically important at high elevations where there is continuous, daily rain and predominant cloud cover during the wheat growing cycle, especially from flowering to physiological maturity. Scab is caused by various *Fusarium* species, including *F. equiseti*, *F. culmorum*, *F. avenaceum*, and *F. nivale*, but it is *F. graminearum* (perfect stage: *Gibberella zeae*) that generally causes the major scab epidemics and yield losses. The other species of *Fusarium* are of lesser importance, and occur only under conditions extremely favorable to their development.

The incidence of the disease is much higher when proper crop rotation and soil preparation are not practiced, or when a single crop is cultivated year after year. A wheat crop grown after maize or rice can be heavily damaged, because the fungal inoculum can build up on the stubble of the previous crop. Scab is economically important in wheat-growing areas of China (especially southern China and the Yangtze River Basin, an area of 6.7 million hectares), Brazil (Rio Grande do Sul and Paraná), Paraguay, Bolivia, Uruguay, Argentina, Zambia, Ethiopia, South Korea, and Japan.

Dr. Girma Bekele screening for resistance to fusarium head scab at Toluca, one of three high-elevation sites where CIMMYT germplasm is evaluated under natural and artificial scab epidemics.

Climatic conditions in parts of China and Brazil favor the development of scab to such an extent that fungicides must be used to protect the crop. A devastating scab epidemic, in conjunction with other diseases, destroyed a large part of Argentina's wheat crop in 1985; preliminary estimates indicate that production was reduced by 30%. Epidemics such as these, which cause wheat yields to fluctuate greatly in many developing countries, prompted CIMMYT to embark on collaborative research with Chinese and Brazilian scientists to develop materials resistant to the pathogen.

Research Methodology

Pure cultures are prepared using spores isolated from infected grains or glumes taken from single infected spikelets. Each year, isolates are obtained from three locations in Mexico: Toluca, Patzcuaro, and El Tigre. Infected grains or glumes are crushed into fine particles, which are then placed on corn meal agar (CMA) medium in petri dishes. Petri dishes are incubated for 10 days at 10°C. At the end of incubation, specimens are checked for contamination and pure cultures are obtained from uncontaminated dishes. The growth of pure culture is enhanced by placing petri dishes under fluorescent light at temperatures of 21-23°C. Large increases of inoculum are made from the pure cultures on sterilized cornstalk nodes, in mung bean extract (MBE) medium, or on sterilized wheat kernels. All three media produce large quantities of spores in a short time.

A spore suspension is extracted by blending the medium with distilled water and filtering the mixture through several layers of sterilized cheese cloth. The spore concentration is then standardized to 30,000-50,000 spores/ml.

Inoculation Methods

Two different inoculation methods currently used are:

- The cotton method: In this procedure, developed at CIMMYT, a tiny tuft of cotton permeated with the inoculum suspension is placed in a floret by opening the glumes of a spikelet in the middle part of the head with a pair of tweezers. The head is then covered by a glassine bag to prevent any damage. This method is very precise for controlled scab studies in the greenhouse and the field.

- The spray method: This procedure was modified at CIMMYT to suit current research requirements. The inoculum suspension is applied with a sprayer over the heads until they are soaked (any kind of hand-held sprayer can be used effectively). This method is suitable for both greenhouse and field inoculations.

A third method, widely used in China, is under evaluation. In this method, scab-infected wheat kernels are scattered between rows of plants at the rate of 60 kg/ha, and applied at the boot and flowering stages of the crop.

To accelerate the development of the disease and prevent disease escape from lack of moisture, a fine mist from an overhead sprayer provides supplementary humidity when rain and cloud cover are limited. The greenhouse is also equipped to provide sufficient humidity for disease development.

Disease Scoring
Disease scoring is done six weeks after inoculation according to a 0-5 scale, which is used by researchers at CIMMYT and in Brazil and China (Table 13). The scale assesses scab resistance based on head symptoms.

Screening Materials
Since 1980, various international bread wheat and triticale screening nurseries, Crossing Blocks (CBs), advanced lines, and introductions from different areas of the world affected by scab have provided the base germplasm for identifying resistant materials. Screening is also done on segregating populations obtained from crosses made to combine fusarium resistance with high yield, wide adaptation, stability, and resistance to other important diseases.

Three high-elevation sites in Mexico (Toluca, Patzcuaro, and El Tigre) are excellent sites for natural scab screening, and artificial epidemics are also created at Toluca. El Tigre is currently used as a screening site for F_3 and F_4 materials, whereas the F_2 and F_5 generations are exposed to scab at Toluca. Advanced lines and varieties are tested at Toluca and Patzcuaro.

Research Results
Since 1980, thousands of CIMMYT bread wheat, durum wheat, and triticale lines have been screened using the methods described above. Although strong scab resistance was lacking in much of CIMMYT's high-yielding, widely adapted germplasm, screening helped identify a number of bread wheat lines possessing some resistance. Triticales and durums generally showed high levels of susceptibility. A list of the best CIMMYT and CIMMYT-Brazilian lines with moderate resistance to scab is presented in Table 14. In areas where head scab is not very severe, these lines may be useful; in areas where the disease is severe, these lines may be grown with one application of fungicide to control the disease. The diverse origin of these lines makes it likely that intercrossing will yield lines with better resistance (assuming that genetic variability for resistance exists).

Table 13. The 0-5 scale used to assess resistance to fusarium head scab

Scale	Infected spikelets in a spike	Resistance level
0	0	Immune
T	1	Highly resistant
1	1-2*	Resistant
2	2-4	Moderately resistant
3	3-6	Moderately Susceptible
4	7 and above	Susceptible
5	All spike and peduncle	Highly susceptible

* The first numbers (1, 2, etc.) represent the amount of disease spread on one side of the point of inoculation; the second numbers (2, 4, etc.) are the sum of the amount of disease spread on both sides.

The collaborative program with China has resulted in the introduction of highly resistant germplasm into CIMMYT's materials. A number of introductions were made during different years from several wheat-growing regions of China affected by scab: a list of the best varieties or lines is presented in Table 15. Several of these lines performed well during the 1985 scab epidemic in Argentina, and will serve as excellent sources of resistance for incorporation into CIMMYT's high-yielding, widely adapted germplasm.

Table 14. CIMMYT or CIMMYT-Brazilian lines with good resistance (infection type '1' or less on a 0-5 scale) to head scab at various locations in Mexico

Variety or cross and pedigree
Mei 'S'
SWM4585-30M-1Y-4M-1Y-1M-1Y-0B
Bow 'S'
CM33203-H-8M-8Y-1M-1Y-1M-1PTZ-0Y
Bow 'S'
CM33203-K-9M-1Y-1M-3Y-0M-100R-0B
Icta Sara 82
CM38088-G-1Y-4M-1Y-3M-1Y-0M
F6.74/Bun 'S'//Sis 'S'
CM60042-M-1Y-2M-2Y-1M-1Y-0M
Tuc 'S'/Mon 'S'//Vee 'S'
CM62001-6Y-1M-2Y-2M-1Y-1M-0Y
Tuc 'S'/Mon 'S'//Vee 'S'
CM62001-6Y-1M-2Y-2M-1Y-2M-0Y
Spb 'S'
CM64340-4M-1Y-1M-4Y-3M-0Y
Maya 'S'/Sprw 'S'//Vee 'S'
CM64958-27Y-1M-5Y-0Z-8Y-1M-0Y
Mrng/Buc 'S'//Blo 'S'/Psn 'S'
CM69191-A-5Y-1M-1Y-2M-2Y-2M-0Y
Mrng/Buc 'S'//Blo 'S'/Psn 'S'
CM69191-A-5Y-3M-2Y-1M-1Y-2M-0Y
CEP7593/OC731070
OC3235-2M-5Y-0Z-2Y-1M-0Y
CEP7593/OC731070
OC3235-2M-5Y-0Z-6Y-1M-0Y
PF74354//Ld/Ald 'S'
OC3551-3M-6Y-1M-1Y-4Z-0Y
Thb 'S'
F11915-A-502M-1Y-1F-701Y-3F-0Y-1PTZ-0M
Thb 'S'
F11915-A-502M-1Y-3F-701Y-15F-0Y

Using Resistant Germplasm to Breed Suitable Cultivars

Breeding for resistance to fusarium was initiated in 1982 after resistant and moderately resistant germplasm was identified. The introduction of the

Table 15. Chinese varieties/lines with excellent resistance (infection type 'O' to 'trace') to head scab when tested at various locations in Mexico

Variety or cross and pedigree
Nanjing 7840
Sumai 3
Yangmai 6
China 7
Ning 7840
Aurora/Anhui No.11//Sumai No.3
Ning 8026
Aurora/Sumai No.3//Yangmai No.2
Ning 8176
Ning263/Fanxiu No.5//Ningmai No.4/3/Ning7840/Yangmai
Ning8331
Yangmai No.4/Ning7840
Ning8343
Yangmai No.3/3/Ningmai No.3/Sumai No.1//Sumai No.3/Aurora
Wuhan 3
Qian Feng 2

germplasm from China broadened the scope for resistance breeding, and this material is being used extensively in crosses with CIMMYT's bread wheat germplasm. Segregating generations are screened under natural or artificial scab epidemics in Mexico. Through the bilateral program between CIMMYT and China, some segregating material is selected at Shanghai and Chengdu under heavy natural scab epidemics. The F_6 generation is currently the most advanced material from the crosses made and selected for scab resistance.

Germplasm with excellent resistance to scab is being used by CIMMYT's triticale program in crosses with rye to form new primary triticales. A successful transfer of scab resistance to triticale will increase the crop's adaptability in highland environments where scab generally limits production.

International Scab Resistance Screening Nursery

The First International Scab Resistance Screening Nursery (SRSN), formed at CIMMYT in 1982, comprised mainly CIMMYT bread wheat germplasm identified to be resistant and moderately resistant to *Fusarium* spp. in Mexico. This nursery was sent to various parts of China for evaluation. The results indicated that although the resistance of these materials was generally adequate for Mexican conditions, it did not hold up under severe scab epidemics in China. Nevertheless, the data helped identify wheat lines with superior resistance. The 2nd SRSN produced similar results. The 3rd and 4th SRSNs included not only CIMMYT germplasm, but also lines and varieties introduced from China, Brazil, and other parts of the world; all of the material had shown good scab resistance in Mexico. These two nurseries were distributed internationally to cooperators in locations where scab is economically important. Preliminary data from these nurseries indicate that the Chinese varieties show excellent scab resistance at testing sites throughout the world. Various national programs are now making use of the Chinese material in their breeding programs.

Conclusions

Satisfactory methods have been developed to screen resistance to *Fusarium graminearum* under greenhouse and field conditions, and sites at Toluca, Patzcuaro, and El Tigre in Mexico have ideal climatic conditions for generating natural scab epidemics. Durum wheat and triticale germplasm generally lack variability for resistance, but some CIMMYT bread wheat lines have been found to have acceptable levels of resistance under Mexican field conditions. However, the resistance of these lines is not acceptable under conditions of severe fusarium infection in China.

Advanced lines from CIMMYT's breeding programs, as well as introduced germplasm possessing an acceptable level of resistance in Mexico, are distributed internationally in the Scab Resistance Screening Nurseries. Among the introduced germplasm, the Chinese varieties or lines are highly resistant, not only in Mexico but also in other areas of the world. The Chinese varieties are being combined with CIMMYT germplasm to produce high-yielding, widely adapted material with yield stability and resistance to fusarium.

Seed Health Unit

CIMMYT is well aware of the need to prevent the dissemination of pathogens and pests along with the seed it distributes. In 1984, the Center established a seed health unit to provide more comprehensive and coordinated services for its germplasm development programs and its cooperators abroad (previously, this work was done by the individual crop programs). The activities of the seed health unit are performed in close collaboration with Sanidad Vegetal, Mexico's plant protection agency.

The new seed health unit is responsible for:

- Conducting all standard tests for seed-borne pathogens in germplasm destined for international distribution;
- Developing improved methods of detecting seed-borne pathogens;
- Determining which seed-borne pathogens are present in Mexico;
- Determining improved methods of treating seed for pathogens present in Mexico;
- Testing the efficacy of chemical seed treatments; and
- Conducting all research on the Karnal bunt disease.

Seed health measures—The Center practices several principal seed health measures in the management of its germplasm. Seed intended for international distribution is produced only at CIMMYT research stations or the cooperating research stations of INIA. Harvested from apparently healthy plants, spikes, rows, and/or plots selected by CIMMYT senior scientists, the seed is carefully cleaned and dried to acceptable moisture levels.

Prior to packaging and distribution, all seed is treated with a mixture of approved fungicides and insecticides to protect against pathogens and pests present in Mexico and to prevent their establishment outside the country. Upon completion of these procedures, a phytosanitary certificate for each seed shipment is requested from Sanidad Vegetal.

Additional activities—The seed health unit is working with different seed organizations and quarantine groups to standardize testing methods for pathogens and pests. Training is also a significant part of the unit's activities.

Karnal Bunt

One of the unit's primary activities is to conduct research on the problem of Karnal bunt. This soil-borne disease of wheat and certain other small grains is caused by *Tilletia indica* (syn. *Neovossia indica*), and was first reported in India in 1931. The disease appeared in Mexico more than 15 years ago in the Yaqui Valley, near Cd. Obregon, Sonora, but is still confined to a small part of the wheat-growing area of northwest Mexico.

Tilletia indica teliospores have been reported to remain viable in the soil for up to five years. Even so, very specific environmental conditions are required for infection to occur. Yield losses due to this nonagressive pathogen are negligible, but a sufficiently high incidence of disease (3% or more) can

adversely affect the flavor of products made from teliospore-contaminated flour.

Karnal bunt is a floral-infecting, nonsystemic, seed-borne disease. *Tilletia indica* teliospores can be deposited onto the soil at harvest or may contaminate the surface of the seed. Each teliospore, upon germinating at the soil surface, gives rise to a promycelium that bears 32-128 or more primary sporidia. These primary sporidia, or the secondary sporidia that develop later, are carried to the wheat spike either by air currents or by splashing water (Figure 4).

Although Karnal bunt is a minor disease, it is having far-reaching effects on the international movement of germplasm. In 1983, with the aim of averting losses in international trade that could be incurred if Karnal bunt spores were detected in commercial grain shipments, the USDA Animal and Plant Health Inspection Service (APHIS) placed quarantine restrictions on the movement of experimental germplasm from Karnal bunt-infected areas into the USA. Sanidad Vegetal has also restricted the movement of untreated grain from such areas to other locations within Mexico. Since many developing countries adopt quarantine regulations and actions similar to those of the USA, the APHIS restrictions could eventually limit CIMMYT's international wheat nursery system. These restrictions are presently hindering the movement of nursery materials from Mexico to the USA, Canada, and, to some extent, China and several other countries.

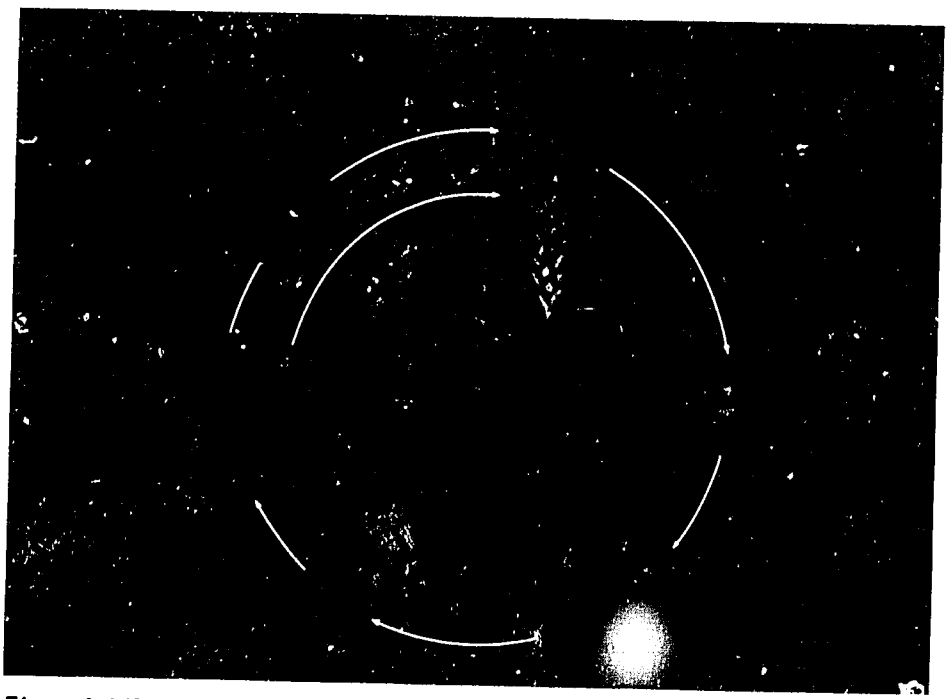


Figure 4. Life Cycle of *Tilletia indica*.

Expanded Karnal Bunt Research Program
In anticipation of the APHIS action, CIMMYT initiated an expanded Karnal bunt research program during the 1983-84 crop season (preliminary research had been conducted previously). The program's initial objectives were to:

- Identify germplasm resistant to the disease;
- Identify methods of controlling the disease in the field;
- Screen chemicals for their effectiveness in preventing the transmission of the disease via seed; and
- Develop efficient inoculation techniques.

This research has become a full-scale cooperative effort involving Mexico's National Institute of Forestry, Agriculture, and Livestock Research (INIFAP) together with research programs in the USA, India, Pakistan, and Nepal. Research in Mexico is conducted by CIMMYT, INIFAP, and Sanidad Vegetal, with participation by scientists from the USA; the overall program is coordinated by CIMMYT.

Because Karnal bunt is a minor disease that has received almost no research attention in the past, little baseline information on the disease and its causal organism is available. For this reason, the cooperative research program includes such components as the effects of weather and other environmental factors on Karnal bunt infection, studies of teliospore dissemination, an assessment of survey techniques, and sporidia-trapping studies.

Field testing for host plant resistance—Since the 1982-83 season, more than 24,000 lines of bread wheat, durum wheat, triticale, barley, rye, and miscellaneous selections from the *Triticum* species have been field-tested for Karnal bunt resistance. From this material, 290 bread wheats, 510 durum wheats, 739 triticales, and 364 lines from miscellaneous sources have been selected for apparent resistance. These materials showed no Karnal bunt infection in two successive years of field testing.

In 1985, resistant materials were planted at CIANO at three different dates for extensive artificial inoculation, and at five other locations in the Yaqui and Mayo Valleys for screening under natural conditions. Ten sets of these materials were also sent to India, Pakistan, and Nepal for testing. When data are obtained from these tests, the resistant materials will be introduced into the crop programs to serve as parents.

Greenhouse screening—All entries identified as resistant in the field are routinely retested under severe disease pressure in the greenhouse with the spray inoculation technique. All entries tested to date have shown some infection, indicating that physiological resistance may not exist or is very rare. (However, the sporidia concentration used in these tests is high, about 50,000 sporidia/ml of water.) Nor are there apparent differences between bread wheats, durum wheats, and triticales under these conditions. Some 35 lines have shown less than 15% infection under these severe conditions, and will be tested again in the greenhouse.

Since over half the bread wheat lines showing resistance in the greenhouse included either TZPP or Alondra in their parentage, more attention is being given to materials containing these parents in their pedigrees. In addition, the CIMMYT rye collection, various rye addition lines, and that portion of the world wheat collection resistant to bunts and smuts have been screened for Karnal bunt resistance. *Triticum carthlicum* and ryes have generally shown much lower infection. Ryes might serve as a source of physiological resistance, and consequently all wheat germplasm containing the 1B/1R translocation is being screened for this possible trait.

A total of 86 accessions of 21 *Aegilops* species were also evaluated under greenhouse conditions; all accessions of *Aegilops biuncialis*, *Ae. columnaris*, *Ae. crassa*, *Ae. juvenalis*, *Ae. ovata*, and *Ae. speltoides* demonstrated resistance. Several accessions from other *Aegilops* species showed good resistance as well, indicating that *Aegilops* species may be a source of resistance that can be incorporated into bread wheat. Further studies will be conducted, including the screening of *Aegilops* addition lines.

Fungicide seed treatments—Several systemic fungicides were tested in the field to assess their effects on teliospore germination. None proved effective as a seed treatment, however, because they did not remain active long enough to protect the spike between heading and anthesis.

Controlling Karnal bunt in the field—It has been determined that the application of Terrazan 75WP (PCNB) to the soil prior to heading inhibits teliospore germination for up to 6-8 months. When this treatment is coupled with a foliar application of a sporidia-lethal fungicide, nearly complete control of Karnal bunt can be achieved. The most effective sporidia-lethal fungicides tested to date are Tilt, Vangard, Maneb 80, Manzate 200, Busan 38A, Captan, Duter, Baytan, and Terrazan 75WP.

Participants in the Karnal Bunt Workshop examine random samples of wheat seed for signs of *Tilletia indica* infection. The seed was gathered from nursery plots treated with various sporidia-lethal fungicides.

Inoculum production—Since large quantities of inoculum are needed to conduct artificial inoculation studies in the field at CIANO, much time has been spent perfecting techniques for producing inoculum. Potato-dextrose agar (PDA) is presently used for increasing inoculum, and the procedure works well.

A technique to produce primary sporidia in liquid cultures on shakers was also developed. This is a much faster method for producing inoculum, but its usefulness is uncertain since primary sporidia have generally given lower levels of infection in the field. An experiment using higher inoculum concentrations of both primary and secondary sporidia was done in the 1984-85 cycle and will be repeated in 1985-86 to determine whether primary sporidia can be used as inoculum.

Inoculation techniques—Two inoculation techniques were compared in the greenhouse with susceptible cultivars: boot inoculation, in which a water suspension of secondary sporidia is injected with a hypodermic needle into the boot; and spray inoculation, in which a water suspension of secondary sporidia is sprayed on the spike between heading and anthesis. The boot inoculation technique is the most reliable, but only screens for physiological resistance. The spray inoculation technique more closely resembles natural field infection, and therefore screens for morphological and, to a lesser extent, physiological resistance. Because this technique requires high relative humidity to ensure infection, it is unsuitable as a field screening technique. In the greenhouse, where conditions can be controlled, spray inoculation is the most rapid and efficient technique.

Additional Studies

A number of other Karnal bunt research activities are being pursued in Mexico. These include 1) studies of the effects of Karnal bunt on seed germination; 2) an investigation to determine which environmental factors affect secondary sporidia production; 3) the effect of Karnal bunt on seed and protein quality; 4) the effects of long- and short-term feeding of Karnal bunt-infected grain to poultry and swine; 5) determination of fungicide residuals in seed following fungicide application at heading time; 6) recovery of and determination of the number of teliospores from soil samples; and 7) the role of irrigation in preventing Karnal bunt infection.

Quarantine Status

In the 1985-86 cycle, the Wheat Program will grow all wheat and triticale materials destined for international distribution in a Karnal bunt-free area near Hermosillo, Sonora, Mexico. Entry of germplasm into the USA and Canada will be permitted if Karnal bunt surveys and laboratory inspection during and following harvest in April and May, 1986 are negative.

Future Research

CIMMYT will continue screening germplasm for resistance to Karnal bunt. Priority will be placed on germplasm developed by CIMMYT and cooperators in areas where Karnal bunt is a problem. Since preliminary findings indicate that there is good resistance among the germplasm from China and Brazil, germplasm from these countries will also be screened. In addition, materials from CIMMYT's wide cross program will be examined for resistance to the disease, and an effort will be made to screen various winter wheats.

Triticale—A Crop for Marginal Environments

Triticale (X *Triticosecale* Wittmack), an amphiploid resulting from the crossing of wheat and rye, is an excellent example of evolution by design. The first reported hybrid between wheat and rye was sterile (Wilson, 1875), and not until 13 years later was the first fertile triticale reported (Rimpau, 1888). For many years triticale was treated as not much more than a biological curiosity. Then, in 1935 Arne Miintzing (Sweden) began a lifelong effort to improve this man-made species. Along the way, triticale captured the imagination of other pioneering scientists as well. Principal figures in the development of the crop include Kiss (Hungary), Sanchez-Monge (Spain), and Shebeski, Jenkins, and Evans (Canada).

While the research needed to "evolve" triticale into a species having commercial potential actually began in 1935, it was not until the mid-1950s that a concerted effort was made to remedy the species' severe defects; most of the research now embodied in the modern triticale plant occurred during the past three decades. The first commercial varieties were released 17 years ago in Hungary, Spain, and Canada. Today, the crop is grown in some 30 different countries around the world, and covers approximately 750,000 hectares (Table 16).

The greater adaptability of triticale as a crop is reflected in results from the International Triticale Yield Nurseries (ITYNs). Each year for nearly 20 years, CIMMYT has sent this nursery for testing throughout the world, and its results have repeatedly confirmed the species' capacity to adapt to a wide range of environments. Triticale manifests considerably higher yield potential than wheat in acid soils, at high elevations, and under semiarid conditions. This adaptability makes the crop especially suitable for these particular marginal environments, where production gains are more difficult to achieve. The work on triticale reported here is one promising approach to expanding the productivity of resources devoted to agriculture in such areas of the world.

The Evolution of Triticale at CIMMYT

CIMMYT began a large-scale, field-oriented triticale breeding program in 1965. At that time, the plants were generally photoperiod-sensitive, tall, late-maturing, and partially sterile with shrivelled seed. Finding solutions to these problems thus comprised the initial objectives of CIMMYT's research efforts.

The problem of photoperiod sensitivity was resolved by 1) expanding the triticale germplasm base, using the Center's wide range of wheat germplasm, and 2) by shuttling breeding material between Mexico's CIANO Experiment Station near Ciudad Obregon (27.2°N latitude) and CIMMYT's Toluca and El Batan stations near Mexico City (18°N latitude). Using day-length-insensitive wheats in crosses, and selecting lines that performed well at both latitudes, quickly resulted in photoperiod-insensitive triticales.

The discovery in 1968 of the "Armadillo" strains was a milestone in the evolutionary path of triticale. Armadillo is a "substituted" triticale that resulted from a spontaneous outcross with an unknown semidwarf bread wheat located among the F_3

progeny of the cross X308. In addition to having excellent fertility, the Armadillo strains were insensitive to daylength, matured earlier, contained one dwarfing gene, and had improved test weights and higher grain yields. Also, Armadillo lines were generally more cross-compatible with bread wheat, durum wheat, and rye. Because of these outstanding traits, Armadillo lines were used extensively in CIMMYT's crossing program.

Table 16. World distribution of triticale, 1985

Country	Growth habit	Area (ha)
Argentina[1]	S	10,000
Australia[2]	S	160,000
Austria	W	*
Belgium[1]	W	400
Brazil[1]	S	1,500
Bulgaria[1]	W	10,000
Canada[2]	S + W	6,500
Chile	S	*
China[1]	W	25,000
Federal Republic of Germany[2]	W	27,000
France[2]	W + S	120,000
Greece	S	*
Hungary[1]	W	5,000
India[2]	S	500
Italy[1]	S	15,000
Kenya	S	*
Luxemburg[1]	W	400
Madagascar	S	*
Mexico[1]	S	8,000
Netherlands[2]	W	1,000
New Zealand[2]	W + S	150
Pakistan	S	*
Poland[2]	W	40,000
Portugal[2]	S	7,000
South Africa[1]	W + S	15,000
Spain[1]	S	9,000
Switzerland[2]	W	5,000
Tanzania[2]	S	380
Tunisia[2]	S	5,000
UK[2]	W	10,000
USA[1]	W + S	60,000
USSR[1]	W	250,000
Total		771,830

1 Estimate.
2 CIMMYT survey, 1985.

S = Spring type.
W = Winter type.

Fifteen years of yield data from the International Triticale Yield Nursery (ITYN) document constant progress in the yield potential of the crop. The introduction of genetic variability through the creation of new "primary" triticales (original crosses between wheat and rye), as well as crosses with semidwarf bread wheats (and then selecting types with reduced height and stiff straw), contributed greatly to improvements in yield potential. The best triticales now yield on a par with the best bread wheats, when grown in favorable environments. The first of these triticales were selections from a cross between Armadillo and Maya II (an octoploid primary triticale based on INIA 66 bread wheat and an unknown spring rye).

Poor endosperm development, resulting in shrivelled seed and low test weights was (and still is to some extent) a major problem limiting the acceptance of triticale. Progress in the improvement of test weight has been slow but constant (Figure 5). It is not difficult now to obtain triticale test weights of up to 76 kg/hl, when the crop is grown under favorable production conditions. However, many of these same lines tend to have poorer test weights under adverse growing conditions. Fortunately, selections having good test weights under adverse conditions also produce good test weights under optimal conditions.

Until 1979, both the number of countries growing triticale and the area covered by the crop were quite limited. As the area devoted to triticale expanded, disease problems increased. For example, three new races of stem rust (*Puccinia graminis* f.sp. *tritici*) appeared in three successive years in Australia. A similar disease development seems to be occurring in the case of stripe rust (*P. striiformis*) in East Africa and in South America.

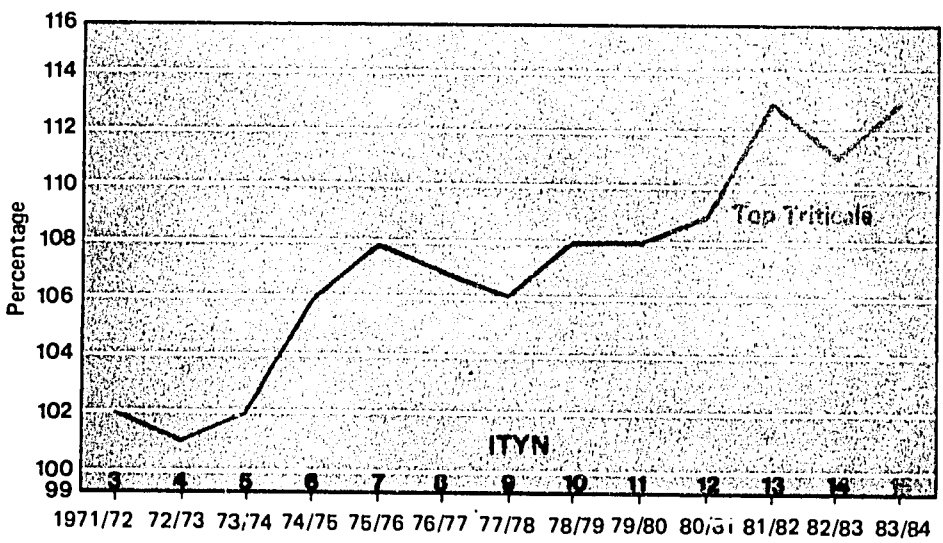


Figure 5. Test weight of the best yielding triticale line as percent of long term check in International Triticale Yield Nursery (ITYN), average of all locations.

Head scab (*Fusarium* spp.) and helminthosporium diseases (*Helminthosporium* spp.) are serious problems in the more humid environments.

Adaptation

The breeding philosophy and methodology used by CIMMYT were instrumental in producing broadly adapted germplasm with high and stable yields. Theoretically, the genomic constitution of triticale provides a "built-in" potential for adaptation to a wider range of conditions than other small grain crops. It was, however, impossible to test the validity of this hypothesis until the inherent negative traits of the species were largely corrected. It was also necessary to produce a wider range of genetic material with good yield potential.

The ITYN provides an excellent means of analyzing the yield potential, yield stability, and adaptability of advanced generation triticales under a range of agroclimatic conditions. Figure 6 compares the performance of the top five triticale varieties to that of the top bread wheat in all the ITYNs, in all years and at all locations. Until the 4th ITYN, when the Maya II/Armadillo crosses were first included in the nursery, triticale yield levels were always inferior to the bread wheat check. Since the 4th ITYN, the top five triticales have outyielded the top bread wheat check. Caution should be used in interpreting these data, however, because wheat tends to perform poorly in the triticale nurseries.

The 14th ITYN is the most recent nursery for which all data are available. The nursery had a good balance

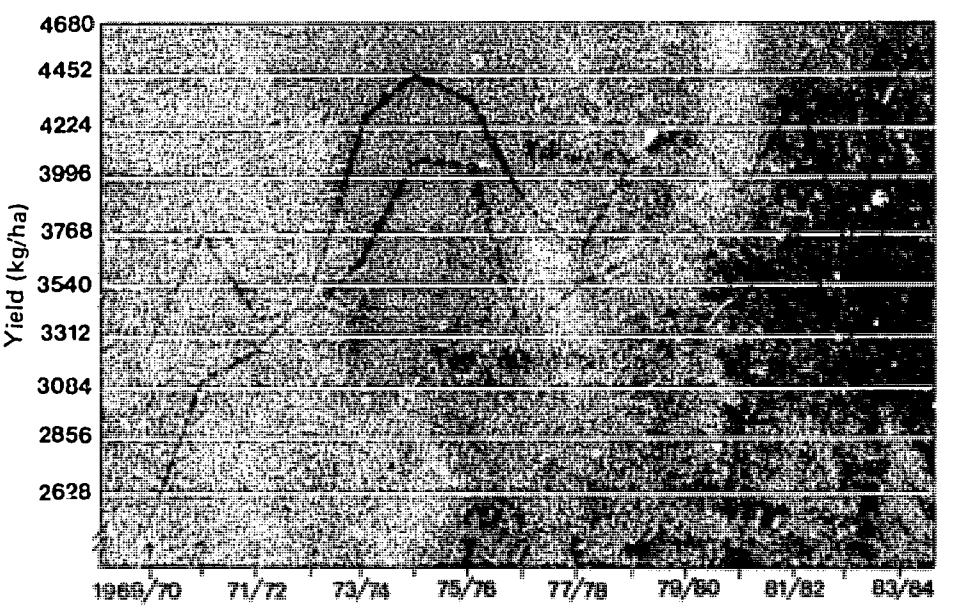


Figure 6. Average yield of top five triticale lines in comparison to top bread wheat in the International Triticale Yield Nurseries (ITYNs), average of all locations.

between the number of improved complete and substitution type triticales (the homeologous 2R rye genome displaced by the 2D genome of wheat). Figure 7 compares the average yields of the top five triticales with the top bread wheat (Genaro 81), durum wheat (Yavaros), and the local small grain check variety for each of the following five environments: 1) irrigated subtropical conditions (9 locations); 2) Mediterranean climate (13 locations); 3) dryland conditions (5 locations); 4) tropical highlands (8 locations); and 5) acid soils (5 locations). Comparisons are also made in Figure 7 of the relative performance of complete and substitution type triticales in each of the five environments. The bread wheats used in these trials were always the best available at the time and the local varieties in most locations were high-yielding bread wheats.

The data show that under the irrigated subtropical and well-watered Mediterranean environments, triticales had high yields but were not superior to the bread wheat variety Genaro 81. In both environments, they were superior in yield to the durum variety Yavaros. The triticales yielded a little less than the local check in Mediterranean climates, but were superior in the irrigated subtropics. The substitution type triticales seemed to have a slight advantage over the complete types in both of these environments.

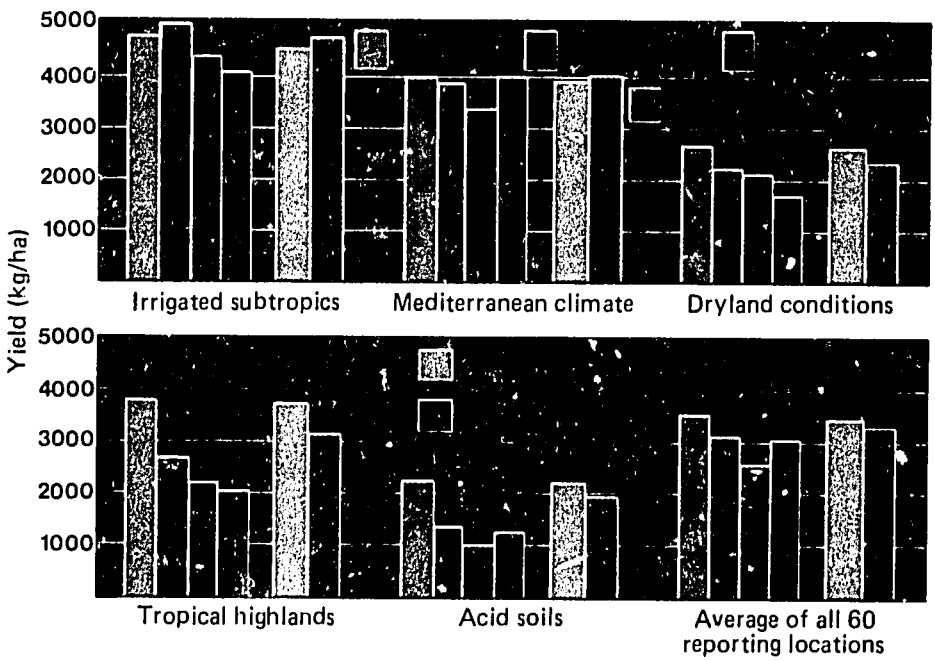


Figure 7. Relative yield performance of triticales under specific agroclimatic conditions compared to the average of all 60 reporting locations and the long term check varieties. (Based on the 14th ITYN results, 1982-83).

Under acid soil, dryland, and tropical highland conditions, the data indicate that triticales were clearly superior to the bread wheat Genaro 81, the durum wheat Yavaros, and the local small grain varieties. Also, data indicate that complete triticales are superior to the substitution types in these more marginal environments.

Averages from the 60 locations reporting data indicate that the five top triticales yielded about 13% more than the bread wheat Genaro 81 and the local check. Also, triticales yielded 37% more than the durum wheat Yavaros.

While the triticale yield levels and milling rates cited later in this highlight are an accurate description of the crop's performance in selected environments, it should be noted that, for certain environments, the advantages are at this time more apparent than real. For example, in subtropical and well-watered areas, spring triticales yield on par with wheat, but their milling rates are sufficiently lower under farm conditions to result in price discounts, which reduces the crop's advantages over wheat. This situation, combined with the risk associated with such a new crop, makes it readily understandable why triticale has not moved rapidly in those areas. On the other hand, its yield superiority in other environments, such as in acid soils, is so large that even its lower milling rate is unable to offset the advantage. Such considerations have lead CIMMYT to focus its breeding efforts on environments in which th yield advantage of the species appears to be largest, with the aim of reducing the adverse effects of triticale's few remaining problems.

Potential Areas for Triticale in Developing Countries

Except for Tunisia and Argentina, all major triticale producers are developed countries. As awareness of the crop's potential in certain environments becomes more widespread, and as more favorable pricing policies are introduced, the area devoted to triticale is likely to expand in developing countries.

Table 17 provides estimates of potential areas for triticale production in developing countries, and Table 18

Table 17. Potential areas for triticale production in the developing world

Countries	Crop substitution	New areas	Total	Type
East Africa	**56,000**	**1,668,000**	**1,724,000**	
Burundi	6,000		6,000	HL/AS
Ethiopia		35,000	35,000	HL/AS
Kenya	35,000		35,000	HL/AS
Lesotho		10,000	10,000	HL/AS
Madagascar		113,000	113,000	HL/AS
Malawi	1,000	10,000	11,000	HL/AS
Rwanda	4,000		4,000	HL/AS

(continued)

Table 17. (cont'd)

Countries	Crop substitution	New areas	Total	Type
Tanzania	5,000		5,000	HL/AS
Uganda	5,000		5,000	HL/AS
Zambia		1,500,000	1,500,000	HL/AS
North Africa	**595,000**		**595,000**	
Morocco	280,000		280,000	SA
Algeria	170,000		170,000	SA
Tunisia	100,000		100,000	SA
Libya	45,000		45,000	SA
Asia	**2,105,000**		**2,105,000**	
India	425,000		425,000	SA
Pakistan	90,000		90,000	SA
China	500,000		500,000	HL/AS
Turkey	700,000		700,000	SA
Syria	75,000		75,000	SA
Jordan	10,000		10,000	SA
Afghanistan	130,000		130,000	SA
Iran	100,000		100,000	SA
Iraq	75,000		75,000	SA
Southeast Asia		**540,000**		
Burma		150,000		HL/AS
Thailand		50,000		HL/AS
Vietnam		30,000		HL/AS
Philippines		35,000		HL/AS
Malaysia		5,000		HL/AS
Indonesia		250,000		HL/AS
Laos		20,000		HL/AS
South and Central America	**535,000**	**12,500,000**	**13,035,000**	
Peru	25,000		25,000	HL/AS
Mexico	50,000		50,000	HL/AS
Brazil	450,000	12,500,000	12,950,000	HL/AS
Ecuador	10,000		10,000	HL/AS
Total	**3,291,000**	**14,708,000**	**17,999,000**	

HL = Highlands in the tropics
AS = Acid soils
SA = Semiarid

classifies these areas according to growing conditions. Over three million hectares currently in wheat, barley, or rye could be sown to triticale because of its superior productivity.

Another 15 million hectares, which do not now support small grain production, could become available to crop production in the future. These areas mainly comprise the Cerrados of Brazil, the northern regions of Zambia, and the tropical highlands found in many Southeast Asian countries. Triticale is also a potential crop for the semiarid areas of Asia, the Middle East, and North Africa.

Other potential production areas comprise the tropical highlands and acid soils of East Africa, Brazil, and Southeast Asia. Triticale clearly outperforms wheat in these environments and, if only 25% of the land in these locations were shifted from wheat to triticale production, about one million hectares could be quickly devoted to the crop. In addition, these regions possess an enormous potential for expanding agricultural area and output in the future. If only 10% of this expansion were devoted to triticale, some 15 million hectares would come under the crop. Eastern Europe is another region in which triticale area is expanding rapidly, with winter triticales replacing winter rye.

Uses of Triticale

From the beginning of the CIMMYT program, emphasis was given to improving triticale as a human food. Many triticale lines now combine the various properties needed to make good bread. Most of these lines are substitution types. A few of the complete triticales show improved dough strength and bread-making quality. At present, however, these lines are exceptions in this regard. Since complete triticales show better adaptation to marginal production conditions, these few lines are being

Table 18. Potential triticale area in developing countries

	Highland/acid soil conditions			Semiarid conditions		
Location	Crop substitution	New	Total	Crop substitution	New	Total
East Africa	.06	1.67	1.72	—	—	—
North Africa	—	—	—	.60	—	.60
Asia	.50	—	.50	1.61	—	1.61
Southeast Asia	—	.54	.54	—	—	—
South and Central America	.51	12.50	13.01	.03	—	.03
Total	1.07	14.71	15.77	2.23	—	2.23

crossed extensively in an effort to improve the industrial quality of the complete types. Triticale in general tends to behave like a soft wheat and, as a result, is good for making biscuits, cookies, cakes, pancakes, chapatis, and tortillas.

Triticale is being used in stock feeding rations as a complete or partial substitute for wheat, maize, sorghum, barley, and rye. Quality requirements for feed use are often different from those for human food. Bread-making quality is unimportant in animal rations, whereas yield, protein content, and protein quality are essential.

Triticale also shows good promise as a forage crop, because of its inherent high biomass production potential. Observations in many marginal environments indicate that biomass production of triticale is significantly higher than that of wheat, oats, barley, and rye. Also, unconfirmed reports suggest that animals prefer triticale over other small grain crops grown as pasture. At present, triticale is grown successfully as a forage crop in parts of the USA, Argentina, and Spain.

The Future

Triticale appears to hold great promise for marginal crop production conditions, where its inherent qualities give it a significant advantage over most other small grains. It is anticipated that improvements in milling and baking quality, greater stability of test weights (and hence milling rates) under unfavorable production conditions, and improved sprouting tolerance will enhance the acceptance of triticale as a viable commercial crop. In addition, better tolerance to fusarium head scab and helminthosporium diseases (for the highlands and acid soils areas) will likely contribute to the acceptability of the crop.

Triticale (left) performs better than wheat in acid soil such as this in Patzcuaro, Mexico.

Breeding Triticale through Crosses with Wheat

CIMMYT's germplasm development unit performs a special role in relation to the Wheat Program's other breeding programs: the unit provides assistance in developing materials with special characteristics and in incorporating these characteristics into lines with good yield and plant type. The breeding programs later use this material to develop new CIMMYT lines for international distribution.

One aspect of the germplasm development unit's work is triticale improvement: the unit seeks to correct triticale's shortcomings and exploit the crop's desirable qualities. Through the extensive use of triticale x wheat crosses, some progress has been made in reducing triticale's tendency to lodge, shortening its growing cycle, and improving fertility and grain filling. These crosses may eventually provide the additional improvement that could give the crop a production prominence equal to wheat's, especially in less favorable environments where triticale's adaptability can be used to advantage.

Precedents

The crossing procedure currently used by the unit is based on the performance of the first wheat x triticale crosses made in Mexico at CIANO during the 1962-63 cycle. In that experiment, dwarf wheats were used as the female parents and tall, late-maturing, large-spiked triticales as the male parents. The F_1 seeds were very shrivelled, producing phenotypes halfway between wheat and triticale. These plants showed acceptable growth, were shorter and earlier maturing than triticale, but were almost completely sterile. From the few F_2

Through triticale x wheat crosses, progress has been made in reducing triticale's plant height.

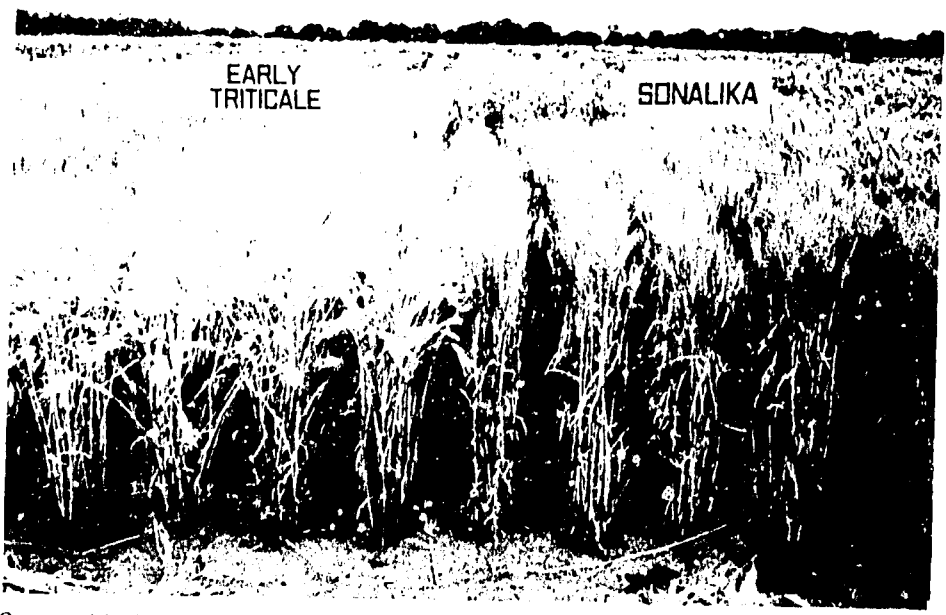
seeds collected, plants that were phenotypically like triticale were obtained, but their growth cycle and height resembled those of the wheat female parent.

In 1972, another cross demonstrated the feasibility of transferring wheat's dwarfing characteristic to triticale and stabilizing that characteristic in the germplasm base. A triticale line derived from H277.69 was crossed with a derivative of the Tor 'S'-Tob 66 wheat possessing TomThumb dwarfism, producing lines halfway between wheat and triticale with the dwarfism of wheat. These lines were later backcrossed toward triticale and finally, in the CMH74.1211 cross, very uniform triticale type lines with TomThumb dwarfism were recovered.

During the 1975-76 cycle, the late-maturing, tall, bearded triticale "Beagle" was crossed with a short, early maturing, awnless wheat. In the segregating populations, lines were obtained that were phenotypically triticale, with a height of 50 cm, early maturity, short awns, and acceptable fertility. This kind of cross confirmed that genes could be transferred from wheat to triticale and vice versa, although it is not certain whether all characteristics can be freely exchanged.

Improving Wheats and Ryes for Producing Primary Triticales

Materials developed in the bread and durum wheat programs are used to improve wheats and ryes for primary triticale production. The germplasm



Some triticales now mature at about the same time as the early maturing bread wheat Sonalika.

development unit has a small, parallel breeding program for developing short-stemmed, early maturing, disease-resistant, and large-spiked ryes with good grain quality. The unit now has lines showing acceptable uniformity in height (from 230 cm to more than 130 cm) and growing cycle (from lines that flower at 70 days, to lines flowering at 90 days or more), and has also developed long, large-spiked, red- and white-grained ryes with uniform heights and growing cycles. Several lines of this material are already used by the triticale program to produce primary triticales.

Intraspecific Crosses

Crosses are made between triticale lines and varieties to consolidate in complete or substituted triticales the greatest number of characteristics for increased production and quality. The unit has played a prominent part in this work. Special attention has been given to reducing plant height and growing cycle and, more recently, to increasing the number of spikelets per spike. Concurrent attempts have been made to improve grain quality, which may alter gluten and milling and baking quality.

Interspecific Crosses

So far, only triticale x bread wheat (*Triticum aestivum*) crosses have been made by the germplasm development unit. Through these crosses, dwarfism, early maturity, short awns, and stiff straw have all been transferred from

Table 19. Hardness index of triticale lines derived from hexaploid triticale x bread wheat crosses, CIANO, 1984-85

Variety or cross	Hardness Index
Panda 6	39.0
Yogui 'S'	36.5
ZEBRA 31	37.5
Pnd6/CMH77.1135//Pnd6	32.5
CMH73A.785/SX//CMH77A.1165	32.5
Drira/2*CMH77A.1165	32.5
No. 1008.3/Bgl//CMH73A.785/3/CMH75A.1165	32.5
CMH73A.785/SX//CMH77A.1165	32.5
Pnd6/CMH77A.1165	32.5
CMH77A.1165/CMH76.1330	32.5
CMH73A.785/SX//CMH77A.1165	31.0
CMH73.802/CMH73.648//CMH77.1135/3/CMH77A.1165	32.5
CMH77A.1165/3/CMH72A.576/CMH74.1072//Gd	32.5
CMH77A.1165/3/CMH72A.576/CMH74.1072//Gd	32.5
Pnd6/CMH77.1135//Pnd6	32.5
CMH73A.785/SX//CMH77A.1165	32.5
CMH73A.785/SX//CMH77A.1165	32.5
CMH72A.576/FS477//Gd/3/CMH77A.1165	32.5
CMH72A.576/FS477//Gd/3/CMH77A.1165	31.0
Genaro 81 (bread wheat)	32.5
CIANO 79 (bread wheat)	32.5

* Lesser values correspond to greater hardness.

wheat to triticale in a homozygous condition and with acceptable stability. A current priority is improving grain milling and baking quality, as well as incorporating resistance to preharvest sprouting. For wheat, the main goal of these crosses is establishing disease resistance. Selected aspects of this research are briefly discussed below:

Hardness index—Several lines of CMH80.1157 (CMH73A.785/SX//CMH77A.1165) show acceptable agronomic type and excellent vitreous grain, and are the program's main source for transmitting grain hardness to triticale. These lines possess grain hardness (hardness index 32.5%) comparable to conventional bread wheats Genaro 81 and CIANO 79 (Table 19).

Test weight—Figures for some lines are now on a par with test weights for the best conventional wheats. Two lines have test weights of 78.6 kg/hl and 78.0 kg/hl at CIANO, which approach the test weights of Genaro 81 and CIANO 79 (Table 20).

Bread loaf volume—Loaf volume is the deciding factor for judging the viability of a particular triticale for making bread, and some lines with loaf volumes superior to those of triticale checks, and quite similar to those of Genaro 81 and CIANO 79, have been obtained through crosses with wheat possessing good baking quality (i.e., CMH72A.576/NAC76//CMH77.1135, with a loaf volume of 820 cc) (Table 21).

Alpha-amylase activity—A serious problem in triticale is preharvest sprouting, a phenomenon highly correlated with alpha-amylase enzyme activity. When alpha-amylase activity is high, the sprouting problem increases; with low activity, the problem

Table 20. Test weight of triticale lines derived from hexaploid triticale x bread wheat crosses, CIANO, 1984-85

Variety or cross	Test weight (kg/hl)
Panda 6	75.6
Yogui 'S'	77.0
Zebra 31	74.5
Pnd6/CMH77A.1165	77.2
CMH72A.576/FS477//Gd/3/CMH77A.1165	77.2
Bgl//S948A1/4*Bza/3/2*M_2A/Cml	78.6
Ira/Cml//2*Nor67	76.5
Ira/Cml//2*Nor67	78.0
CMH73A.785/SX//CMH77A.1165	76.0
CMH73.802/CMH72.648//CMH77.1135/3/CMH77A.1165	77.4
CMH73A.785/SX//CMH77A.1165	76.7
CMH73A.785/SX//CMH77A.1165	76.7
CMH72A.576/FS477//Gd/3/CMH77A.1165	77.2
CMH72A.576/FS477//Gd/3/CMH77A.1165	76.6
CMH72A.576/FS477//Gd/3/CMH77A.1165	76.4
Genaro 81 (bread wheat)	81.5
CIANO 79 (bread wheat)	81.0

Table 21. Bread loaf volume of triticale lines derived from hexaploid triticale x bread wheat crosses, CIANO, 1984-85

Variety or cross	Loaf volume (cc)
Panda 6	625
Yogui 'S'	520
Zebra 31	545
CMH72A.576/Nac76//CMH77.1135	710
M_2A/Cml/3/IAS20/H567.71//4*IAS20	875
M_2A/Cml//Frtr/CMH76A.977	760
CMH72A.576/H569.71	700
CMH72A.576/Nac76//CMH77.1135	820
CMH72A.576/Nac76//CMH77.1135	750
Pnd6/CMH77.1135//Pnd6	745
CMH77.1135	740
Genaro 81 (bread wheat)	820
CIANO 79 (bread wheat)	775

Table 22. Values for alpha-amylase activity in triticale lines derived from hexaploid triticale x bread wheat crosses, CIANO, 1984-85

Variety or cross	Falling no. (seconds)
Panda 6	98
Yogui 'S'	77
Zebra 81	389
CMH77.1135/2*CMH77A.1165	493
Drira/2*CMH77A.1165	465
No. 1008.3/Bgl//CMH73A.785/3/CMH77A.1165	409
CMH73.802//Fta/Cj71/3/CMH77.1135/4/CMH75.1070	438
CMH72A.576/2*Nac76	516
CMH72A.576/2*Nac76	537
CMH72A.576/2*Nac76	457
CMH72A.576/2*Nac76	502
CMH72A.576/Mrng	408
CMH77A.1165/3/CMH72A.576/CMH74.1072//Gd	509
CMH77A.1024/CMH77A.1165	495
Pnd6/CMH77.1135//Pnd6	433
CMH77A.1024/CMH77A.1165	404
CMH72A.576/FS477//Gd/3/CMH77A.1165	427
CMH72A.576/FS477//Gd/3/CMH77A.1165	417
Genaro 81 (bread wheat)	1017
CIANO 79 (bread wheat)	810

Note: Lesser falling number values correspond to greater alpha-amylase activity; greater values correspond to lesser alpha-amylase activity.

diminishes. The degree of alpha-amylase activity is measured by the falling number test. Falling number values higher than 400 seconds are considered excellent in triticale, and the unit has several lines for which such values have been recorded (Table 22).

The Future

Many improvements in triticale's unfavorable characteristics have been obtained through the crosses described above, and substantial prospects for further improvement exist. It should be noted that most triticales produced through these crosses are phenotypically similar to substituted triticales, although a few may be complete types.

Wheats derived from triticale x wheat crosses also possess certain advantages. Rust-resistant triticales crossed with rust-prone wheats produce near-wheat phenotypes with rust resistance and, in some cases, more spikelets per spike (Table 23). Triticale germplasm improves disease resistance and yield, and is clearly an excellent vehicle for transmitting rye genes to wheat in a fairly simple way.

Ing. Ricardo Rodriguez of CIMMYT's germplasm development unit evaluates triticale in the field.

Table 23. Some characteristics of wheat lines derived from hexaploid triticale x bread wheat crosses,

Variety or cross	Leaf rust	Stripe rust	Spikelets/ spike
CMH73.802/Nv//2*Nac76	TMR	20MS	33
CMH73.802/Nv//2*Nac76	TMR	0	33
CMH73.802/Nv//2*Nac76	0	0	29
CMH73.802/2*Nor67	5MR	0	35
Pnd6/Inia66	10MR	5MR	–
Pnd6/Inia66	5MR	10MR	–
Pnd6/Inia66	TMR	5MR	–
CMH72A.576/3*Nac76	20MR	20MR	–
CMH72A.576/3*Nac76	20MR	20MR	–
CMH72A.576/3*Nac76	20MR	–	–
CMH72A.576/3*Nac76	20MR	–	–
CMH72A.576/4*Nac76	20MR	–	–
CMH72A.576/4*Nac76	10MR	–	–
Pnd6/Ald3	TMR	–	–
Pnd6/Ald3	TMR	–	–
Nac 76	60S	60S	–
INIA 66	60S	40MS-S	–

Note: Rust data from El Batan, 1985.
Spikelets per spike at CIANO, 1984-85.

[a] Number equals percentage severity; TMR = Trace severity with a moderately resistant reaction; MR = Moderately resistant; S = Susceptible; MS = Moderately susceptible; MS-S = Moderately susceptible to susceptible.

CIMMYT's agronomists and economists concentrate most of their efforts on issues related to technology generation in maize and wheat, working largely in collaboration with national program scientists. CIMMYT's involvement in such work takes two forms: (1) collaborative research to develop and demonstrate on-farm research procedures, as well as follow-up experiment station procedures, and (2) training and advisory services to develop national crop management research programs. Responsibility for the actual crop management research, however, resides in the collaborating national programs.

As part of its crop management research efforts over the past decade, CIMMYT has been involved in the development of procedures, in cooperation with colleagues in national research institutions, which help to focus agricultural research activities on the needs of farmers. The research methodology that has emerged has three operational phases: (1) identifying farmers circumstances and assessing these for research opportunities, (2) ranking the potential research opportunities in terms of their probable payoffs, and (3) undertaking experimentation, largely conducted on farms but also on experiment stations, that focuses on high-priority research opportunities.

This type of work, often described in the context of location-specific projects, is useful not only for developing short-term improvements in production technology for specific groups of farmers, but also for improving the efficiency of longer-term research on a national scale. When these techniques are seen as an integral part of a national crop program, they can contribute to the definition of research goals as well as suggest policy modifications that can improve the productivity of resources devoted to agricultural production. In other words, farm-level data become the basis to address national-level concerns. Following are two examples of this research methodology in action: in three irrigated wheat-growing areas of Pakistan, characterized by post-Green Revolution production systems, and in a rainfed maize-growing area of Mexico.

Wheat production in Pakistan has moved into what could be described as a "post-Green Revolution phase." Over the past 20 years, improved varieties have come to occupy 85% of the total wheat area and nearly all farmers apply fertilizer, with the average dosage now approaching 90 kg/ha of nutrients. Extensive irrigation development projects—canal-based systems and tubewells—have led to a considerable intensification in cropping, with most areas double cropped. The results of these technological and infrastructural developments on wheat production have been striking. National production has quadrupled since 1965, driven primarily by improved varieties, increased fertilizer use, and access to irrigation which have doubled average yield levels. Through the increasing intensification of agriculture, overall farm and rural incomes have also grown considerably, resulting in higher farm wages and growing mechanization of certain phases of the production system.

It is the success of Pakistani wheat farmers that provides the new challenges facing national researchers. Encouraged by the rapid increases in wheat production in the 1960s and 1970s, Pakistan's policy makers in the Sixth Five-Year Plan (1982-87) had evisioned continued growth in wheat yields and in production, with an exportable surplus of 2.5 million tons projected by the end of the period. In 1985/86, however, the country imported about 2 million tons of wheat, thus casting serious doubt on the validity of previous projections. One major reason for concern is an apparent plateau in wheat yields since 1980-81. Some of the levelling off in yields undoubtedly relates to unfavorable weather in 1984 and 1985; other factors, however, are also coming into play. Few wheat-producing areas remain that still grow traditional varieties, an indication that the introduction of improved varieties will no longer be a major factor to spur dramatic yield increases (although their introduction will remain important in avoiding yield declines due to diseases). Further, the initial period of strong growth in fertilizer use per hectare is largely over. As fertilizer subsidies are removed there is little expectation of a rapid increase in its use. In addition, Pakistani farmers have also been intensifying their crop production, leading to increasing water scarcity in overtaxed irrigation systems and problems of nutrient extraction and pest build-up. The intensification has also led to certain compromises in the management of the wheat crop, such as late planting, in order to accommodate other crops in the rotation.

These observations do not mean that there is no potential for substantial increases in wheat productivity; indeed there are significant opportunities for

The current wheat production situation implies a need for new approaches to research. Dr. Peter Hobbs (right), CIMMYT wheat agronomist, is working with Center economists and national program colleagues to develop and implement viable research alternatives.

increasing wheat yields in all areas of the country. But the current situation does imply the need for a new approach to research, extension, and agricultural policy. Pakistani wheat researchers must decide where to go next, not only with respect to local-level producer recommendations, but also with respect to setting research priorities at a national level.

The Research Program

During 1982-85 the Pakistan Agricultural Research Council/CIMMYT Collaborative Wheat Project worked with scientists from the National Agricultural Research Center and provincial research institutes to conduct research in farmers' fields in three irrigated areas representing the dominant national cropping systems in which wheat is grown (Figure 1). In the course of this research program, approximately 1,000 farmers were surveyed through informal and formal survey methods to gain a clearer understanding of their production circumstances. In addition, more than 200 on-farm trials were conducted.

This research program has departed from the methods traditionally applied in Pakistan in three important respects:

1) Researchers have viewed wheat as an integral part of a *cropping system*, and technological issues in wheat production have been analyzed in relation to the total productivity of the cropping system. A fundamental premise has been that research and extension priorities must be largely tailored to each cropping system.

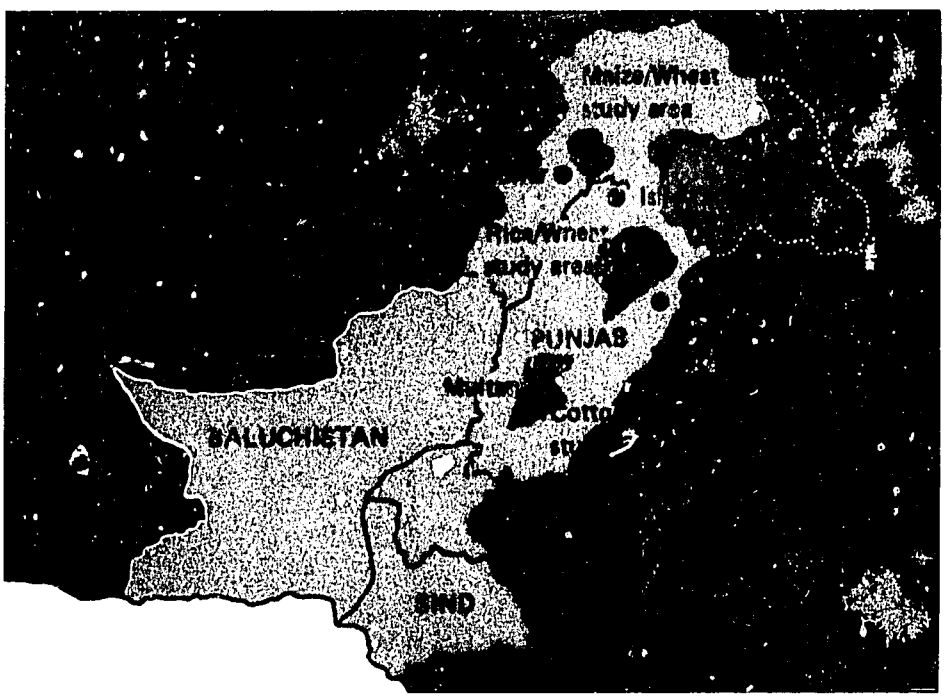


Figure 1. Map of Pakistan indicating irrigated study areas for on-farm wheat research.

2) The research program has been *multi-disciplinary* in character, involving both agronomists and economists in the definition of problems, design of research, and formulation of recommendations. This represents one of the few projects in Pakistan where social scientists have actively participated with biological scientists in this type of research.

3) The research has been *farmer focused*. Researchers observe farmers' situations and problems first-hand, and test promising technological alternatives under farmer conditions.

The Research Area

In this program, three research areas were chosen as representative of the major wheat-based cropping systems in Pakistan. Together, the following systems represent 3.7 million hectares, about two-thirds of Pakistan's total irrigated wheat area:

1) The rice/wheat system of Gujranwala and Shaikhpura Districts in the Punjab.

2) The cotton/wheat system of Multan and Bahawalpur Districts in the Punjab.

3) The maize/wheat system of the Mardan District in Northwest Frontier Province (NWFP).

In each of these systems, wheat is planted in the rabi season (Nov-May) and other crops are planted in the kharif season (May-Nov). In each of the three research areas, informal surveys were carried out during the cropping season, which in turn guided the development of formal surveys employing a short questionnaire and a crop cut at harvest time. This diagnostic information was used to design the first year's on-farm experiments, whose results were used to develop experiments for the following year. Reported here are the results of two years of research in these three cropping systems. Some of the characteristics of the three systems are illustrated in Table 1.

Trends in Irrigated Cropping Systems

In the last two decades cropping intensities in these irrigated areas have increased sharply, which has placed downward pressures on wheat yields. In all of the target areas studied, cropping intensities have exceeded the capacity of the canal systems and significant water scarcities at key periods in the cropping cycle often occur. For example, in the cotton/wheat area the canal system was designed for a cropping intensity of 66%, but current intensities are now around 130%. Further, the low pricing of canal water has not promoted efficient water allocation. Farmers with better access to canal water often apply more than the economic optimum, while other farmers depend entirely on tubewell water which costs about ten times the cost of canal water. (Electrical-powered tubewells are often undependable because of power blackouts and diesel-powered systems are very expensive to operate.) To date, there is little research to guide efficient use of water. Moreover, recommendations for other cultural practices, such as fertilizer, have been developed assuming plentiful water supplies and optimum irrigation schedules.

Research Results

The results of the surveys and on-farm experiments have allowed researchers to look at a series of production

problems in the context of the three cropping systems. The problems vary in importance and in their amenability to solution in each of the three systems. A summary of the results in variety, planting date, fertility, land preparation, and weed control is presented below.

Variety—The introduction of newly released wheat varieties has been slow in Pakistan. Only the rust epidemic of 1977/78 induced a change of varieties after the introduction of the new semidwarf varieties in the late 1960s. Survey work showed that in 1983/84 over 80 percent of the area in the three cropping systems was planted to rust susceptible varieties. This percentage has declined somewhat in 1985/86, but Pakistan's wheat crop is still at serious risk of a rust epidemic (Table 2).

On-farm experiments have consistently shown the superiority of newly released varieties under farmer conditions. In over 50 experiments planted between 1983 and 1985, Pak 81 provided an average yield increase of more than 20% over the farmer variety. Investigation has led to four

Table 1. Characteristics of the target research areas

	Cropping system		
	Punjab rice/ wheat	Punjab cotton/ wheat	NWFP maize/ wheat
Area (000 ha)	1,010	2,560	130
* Yields (t/ha)	1.78	2.29	2.78
* Average farm size (ha)	8.4	8.2	2.7
* Percent of fields tenant operated	41	37	59
* Percent that use a tractor in wheat production	82	57	81
* Percent fields sown continuously to wheat in Rabi cycle 3 or more years	72	51	27
* Percent wheat fields planted after			
rice	72	6	4
cotton	—	49	—
maize	12	15	59
sugarcane	1	—	29
fallow	16	30	3
other	—	—	5

* Survey data

possible causes for the slow acceptance of the new varieties: (1) farmers prefer certain characteristics of the older varieties, (2) farmers are unaware of the danger associated with the banned varieties, (3) information is slow to reach farmers through the extension service, and (4) seed distribution is inadequate. New work is now underway to further understand these factors and to analyze alternative policy measures.

Planting date—In double cropping systems there are often difficulties in planting at the optimal time. In Pakistan, wheat yields are quite sensitive to late planting dates because of the risk of high temperatures in the flowering and grain-filling stages. For the Punjab it is estimated that for every day's delay in planting past the end of November, wheat yields decline 30-45 kg/ha. Nevertheless, many farmers plant wheat late, as can be seen in Table 3. The problem is most pronounced in the cotton/wheat area, where 20% of the fields are planted in January. Analysis has shown, however, that this late planting of wheat is a rational practice, since the returns to one additional cotton picking are more than double the value of wheat lost due to delayed planting.

Although one possibility is to plant earlier maturing varieties of cotton or rice, it is unlikely that this is the best strategy, given the current prices of these crops relative to wheat. Instead, solutions will probably have to be provided by wheat research. Although it has been assumed that early maturing varieties would alleviate the problem of late planting, recent evidence indicates that some new

Table 2. Variety use in irrigated wheat areas, Pakistan

	Punjab rice/ wheat	Punjab cotton/ wheat	NWFP maize/ wheat
Year of survey	1984	1985	1984
	(percent of fields)		
Variety classification			
New recommended (Pak 81, Punjab 81, etc)	16	15	16
Old recommended (Sonalika, Bluesilver)	18	24	37
Banned, rust susceptible (Yecora, WL711, other)	66[a]	61[b]	47[c]

[a] Mostly Yecora
[b] Mostly WL711
[c] Variety classification for the maize/wheat area is approximate since many farmers do not recognize variety names. Also, a mixture of varieties is grown in many fields.

wheat varieties of longer maturity have tolerance to heat stress and perform well over all planting dates. These factors will have to be taken into account as wheat breeders work to improve the productivity of the total cropping system.

Fertility—Fertilizer has been an important contributor to increased wheat production in Pakistan. Fertilizer use is now at moderate-to-high levels in all three of the research areas. Researchers have traditionally provided one fertilizer recommendation for all irrigated wheat, with little economic justification. Farmers, on the other hand, have adjusted fertilizer doses to reflect different cropping patterns and resource availability. The on-farm experiments have looked at differential response to fertilizer by crop rotation, with the objective of deriving more appropriate fertilizer recommendations for homogeneous groups of farmers based on realistic estimates of costs and acceptable rates of return on capital. Table 4 shows current fertilizer use, recommended use calculated from experimental data, and current recommended rates for the maize/wheat and rice/wheat rotations.

In NWFP, there appears to be little technical basis for a recommendation based on a 2.5:1 ratio of N to P.

Table 3. Distribution of planting dates and wheat in irrigated areas of Pakistan

Planting date	Punjab rice/ wheat	Punjab cotton/ wheat	NWFP maize/ wheat
	(percent of fields)		
Recommended (before December 1)	60	29	66
Somewhat late (December 1-15)	30	29	19
Very late (After December 15)	10	41	15

Table 4. Actual fertilizer use, recommendations based on experiments, and current official recommendations

Rotation	Fertilizer used by farmers		Recommendation based on experiments		Current recommendation	
	N	P	N	P	N	P
Maize/wheat (NWFP)	91	27	103	82	136	57
Rice/wheat (Punjab)	77	44	155	49	136	111

Farmers could probably benefit from relatively higher levels of P on wheat planted after maize. Experimental evidence and farmer experience indicate that relatively higher doses of N are appropriate for wheat planted after sugarcane in NWFP (another important cropping pattern in this area), although the current recommendation is the same as for wheat after maize. In the Punjab, on the other hand, wheat planted after rice would appear to benefit from relatively higher doses of N.

Differential responses to fertilizer by crop rotation relate in part to the effect of carry-over fertility from the previous crop and, in some cases, to delayed planting of wheat as well. Research to clarify these effects is only just beginning. In addition, insufficient research has been conducted on sulfur, and micronutrient deficiencies in these intensive crop rotations.

Land Preparation—Land preparation appears to be an important constraint only in the rice/wheat area, where the average farmer conducts 6 tillage operations. Even so, the resulting seedbed is often inadequate to achieve a good stand of wheat because of difficulty in working the puddled, compacted soils from the preceeding rice crop and because of the problem of incorporating residues of the rice crop. In addition, the high number of tillage operations contributes to late planting.

Experiments using a specially designed drill have shown that direct drilling of wheat using a zero-tillage system could reduce turn-around time without any loss in wheat yields. Further

[illegible] in Pakistan. For example, [illegible] planting past November 30 reduces yields [illegible]

experimentation on this technological component is a priority for the rice/wheat area, not only to foster earlier planting but to improve stand establishment and eliminate the cost of land preparation, the major production cost factor in the area.

Weed Control—Less than 25% of the wheat farmers in the three areas do any post-emergence weed control. Figure 2 shows that weeds are a serious yield limiting factor for wheat in the rice/wheat area (*Phalaris minor*) and the maize/wheat area (broadleaf weeds). The problem with grassy weeds is directly linked to the number of years of continuous rabi season planting of wheat. In fields that are rotated with row crops or with fodder crops in the winter season, the problem is less severe.

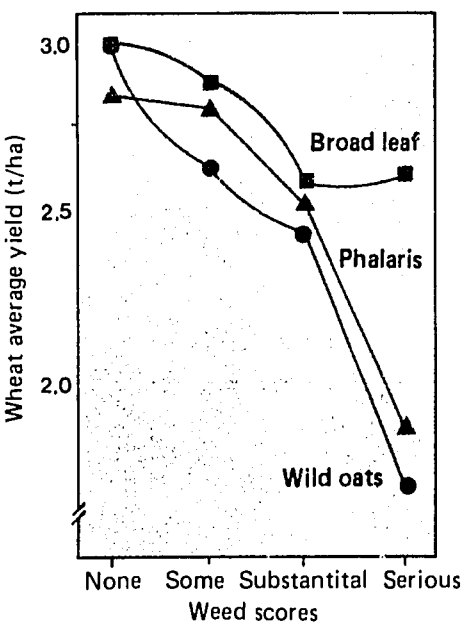


Figure 2. Average wheat yield according to weed scores, maize/wheat area, NWFP.

A possible solution for the weed problem is herbicides. In the maize/wheat area, experimental data have shown very attractive rates of return (240%) for the use of phenoxy herbicides to control broadleaf weeds. Farmers in the area are anxious to use herbicides, but an inadequate extension effort and apathy on the part of suppliers has so far limited their adoption.

Limited experimental data on the use of grassy weed herbicides suggest they do not provide sufficient economic returns. Further work is needed on (1) reduced dosages and costs of application, (2) improved stand establishment, (3) viable alternative rotation crops such as oilseeds, and (4) stronger measures to reduce weed seed dispersed by canals, threshers, and dirty crop seed.

Summary

The on-farm research in three important wheat producing areas has led to progress in three directions: (1) technology generation for specific groups of farmers, (2) strategies for longer-term research, and (3) suggestions for policy research (Table 5). In some cases, the research results are appropriate for all of the areas. Research on wheat varieties is a good example. There is good evidence that new varieties, such as Pak 81, will bring real benefits to wheat farmers in all cropping systems. Similarly, longer-term breeding efforts on varieties appropriate for later planting, e.g., varieties with heat tolerance late in the season, will have applicability across all areas. And policy-oriented research to examine bottlenecks in seed production and distribution is also relevant to all areas.

Table 5. Summary of short- and longer-term research findings and recommendations for further research

Type of research	Punjab rice/ wheat	Punjab cotton/ wheat	NWFP maize/ wheat
Near-term technology generation			
Variety	**	**	**
Fertility	Nitrogen	Phosphorus	Phosphorus
Land preparation	Direct drilling and zero tillage	Reduced turnaround	
Weed control			Broadleaf herbicide
Longer-term research			
Late planting	---Varieties adapted to a range of planting dates---		
Fertility	---Long-term fertility maintenance in multiple-cropping pattern---		
Irrigation	---Greater efficiency in use of scarce water---		
Weed control	---Grassy weed control---		
Policy research			
Variety	---Seed distribution and extension---		
Weed control			Herbicide availability
Cropping alternatives	---Oilseeds as a profitable rotation crop---		

** Several varieties are available that meet the disease resistance requirements of each area.

In many other cases, however, the research has led to different conclusions for the three areas. In technology generation, it is obvious that fertilizer recommendations will be quite different among the areas. And even within one area, specific rotation patterns (e.g. sugarcane/wheat versus maize/wheat in NWFP) and resource differences will distinguish farmers (and fields) into separate groups. Similarly, for longer-term research, work on grassy weed control will assume priority for researchers in the rice/wheat area. Even some of the policy issues assume different priorities across the areas, with herbicide availability being an important issue in the maize/wheat area and alternative rotation crops representing an important policy research priority for the rice/wheat and cotton/wheat areas.

Several conclusions are clear from this work. First, for many production recommendations, technology generation is most efficient if farmers are stratified into relatively homogeneous groups. In the present research, farmers were first divided by cropping pattern, and then by other relevant circumstances such as rotation practices, soil type, or access to irrigation. Second, although breeding will continue to play a crucial role in advancing and stabilizing wheat production in Pakistan, it is obvious that there are great opportunities for crop management research. Third, it can be seen that advances in wheat productivity will not come from advancing complete technological "packages" but rather by carefully setting research priorities to develop improved technological components for well-defined groups of farmers.

Some of these research priorities are being addressed over the short term, while others will require more time to achieve results. This implies a stepwise, iterative process which

Although breeding will continue to play a crucial role in improving wheat production in Pakistan, great opportunities exist for crop management research.

produces a continual flow of research advances. Finally, it should be obvious that this research strategy is most efficiently implemented through a decentralized research organization which has the commitment and sufficient resources to work at the farm level. Such decentralization, it would seem, leads not to a fragmentation of research effort but rather, as in the case of Pakistan, to the strengthening of national crop research efforts.

Source

Byerlee, D., P. Hobbs, B.R. Kahn, A. Majid, R. Akhtar, and N. Hashmi. 1986. *Increasing wheat productivity in the context of Pakistan's irrigated cropping systems: A view from the farmers' field.* Islamabad, Pakistan: Pakistan Agricultural Research Council and the International Maize and Wheat Improvement Center (PARK/CIMMYT paper 86-6).

In 1983 Mexico's national agricultural research institute, INIA (now INIFAP) approached CIMMYT to discuss the possibility of a small project to assess the utility of on-farm research procedures for Mexico. It was decided that the work should concentrate on southern Mexico, the poorest part of the country, and that maize should be the principal focus. After considering several possible areas for the research, two locations in the states of Guerrero/Michoacan and Chiapas were selected. INIA assigned two agronomists to be responsible for on-farm research activities in each of the two areas, and CIMMYT committed an economist full-time and a maize agronomist one-quarter time to the work.

In each of the two research areas, work began with reviews of available secondary data and informal farmer surveys. These were followed by a formal survey and other studies in the areas, with the initial diagnostic work completed in 1983. This information was used to plan the first set of on-farm experiments in 1984. The second year of experiments was planted in 1985. Following is a description of the progress to date in one of the areas, Tierra Caliente, located in the states of Guerrero and Michoacan.

The Research Area

The region called Tierra Caliente spans two states of Mexico: northern Guerrero and southern Michoacan; as a whole it represents 80,000 ha of maize grown during the summer rainy season. An area of 6,000 hectares with 2,600 farmers was identified within this region in the *municipios* of Tlapehuala and Fungarabato, Guerrero, for the on-farm research project (see Figure 3). The research was managed by INIFAP agronomists attached to the Campo Experimental "CAETICA", at Ciudad Altamirano, Guerrero. Maize is the principal crop, occupying 85% of the cultivated area; sesame and sorghum are also grown (see Table 6).

The research concentrated on *ejido* (land reform) farmers, who have an average of 2.6 hectares of cultivatable land per family. Intercropping is an important practice in the area; 90% of the maize is sown with either squash or squash and beans. Squash is particularly important for these farmers, as a kilogram of squash seed

Table 6. Characteristics of the research area, Tierra Caliente

Average farm size	2.6 ha
Percent of area planted to:	
Maize	85%
Sesame	13%
Sorghum	1%
Area with maize-squash association	54%
Area with maize-squash-field bean association	36%
Farmers engaged in off-farm employment	66%

fetches at least five times the price of a kilogram of maize in the market. The majority of the maize land is prepared by tractor, but weeded by hoe and ox plow. About 90% of the farmers use fertilizer on their maize. Average maize yields for the period 1978-82 were only 1.68 t/ha, with a slight downward trend evident.

The first year of experiments—The diagnostic work carried out in 1983 revealed a number of potential causes of the low yields found in the area. Strong evidence was obtained that the low yields were associated with a high proportion of barren plants. Most farmers were also planting advanced generations (with considerable yield depression) of a hybrid "'H-507") that had been introduced into the area about ten years ago and subsequently has been mixed with local open-pollinated materials. In addition, it appeared that weed control by farmers was not as cost efficient as it might be. Soil insects and inappropriate

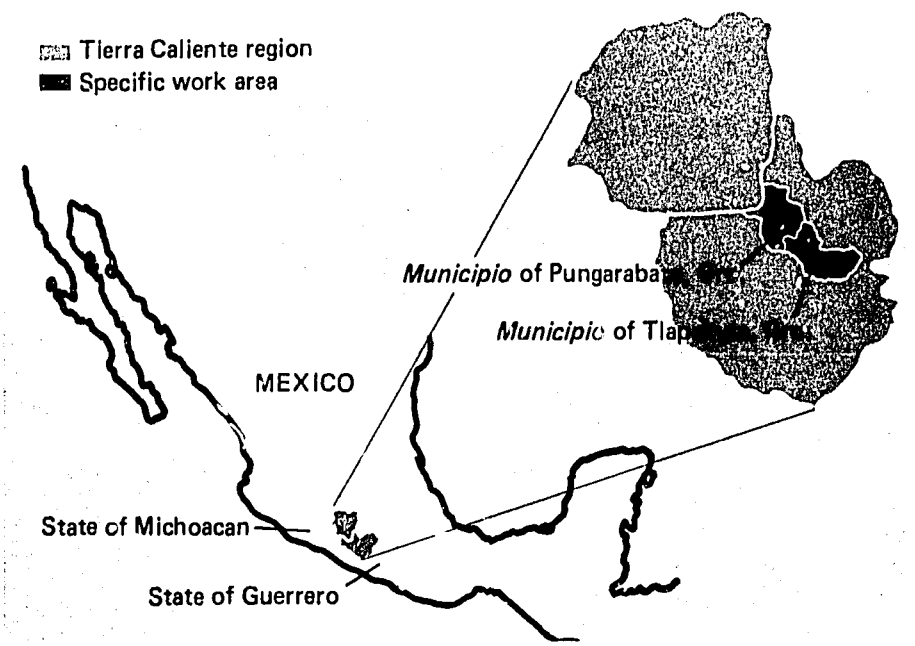


Figure 3. Geographic location of the Tierra Caliente region and the specific work area.

spatial distribution of maize plants were also cited as possible contributing factors.

Technical solutions to these tentative problems were tested in an exploratory experiment planted at 10 locations, 8 of which were harvested. The experiment was a 2^4 factorial, with each of the four factors (variety, weed control, soil insect control, and spatial arrangement) set at two levels, that of the farmers' and an alternative. All non-experimental variables were left under farmer management.

Each of the four alternatives to farmers' practices showed significant increases in yield, with no significant interactions (Table 7). The response to the change in variety was singled out for short-term attention because it represented the greatest yield increase at the lowest cost. The INIA variety V-455, which has a phenology very similar to the farmers' variety, consistently outyielded the local variety at all sites, with an average difference of 490 kg/ha. It was decided to expand testing of "V-455" the following year.

Spatial arrangement and weed control trials were also carried forward into the following year. Both of these are complicated by the farmer practice of intercropping maize with squash. But the cost of labor is quite high in the area, and farmers were interested in the possibility of reducing the cost of weeding. Several alternatives to combine mechanical/chemical weed control practices by substituting the use of herbicides compatible with squash for traditional hoeing are being evaluated.

The experience during the first year of experiments also turned up some additional information regarding maize varieties. The area receives an average of 900 mm of rainfall during a rainy season that may last only 100-105 days. Planting is often delayed, for various reasons. At times early and heavy rains render the clay soils

Table 7. Summary of exploratory trials, Tierra Caliente, 1984 (8 locations)

Treatment	Average yield (t/ha)	Difference (t/ha)
Farmers' weed control	2.38	
Alternative weed control (herbicide)	2.59	0.21
Farmer's spatial distribution	2.33	
2 seeds per hill, 0.85 x0.50 m (50,000 plants/ha)	2.64	0.31
No control of soil insects	2.37	
Carbofuran seed treatment	2.61	0.24
Local variety	2.24	
V-455 (INIA) (open-pollinated)	2.73	0.49

unmanageable and farmers have to wait until their fields dry out before entering with a tractor. At other times a delay in the rains forces late planting. An analysis of rainfall data from the area showed a 38% probability of water deficits in June (planting time), a 23% probability in early July, and a high 40% probability in early October during the grain-filling phase of the local variety. As a consequence, with the local genotypes, farmers typically have only two to three weeks in which to prepare their land and plant their maize if they are to avoid the risk of a water deficit at the end of the season.

The results of the first year's experiments clearly showed the effects of late planting on yield (Figure 4). For every week after June 12 (normal planting time and the date when the first experiment was planted), average trial yields were reduced by an average of 420 kg/ha. Investigators thus decided to look at the possibility of earlier maturing maize varieties for the Tierra Caliente area.

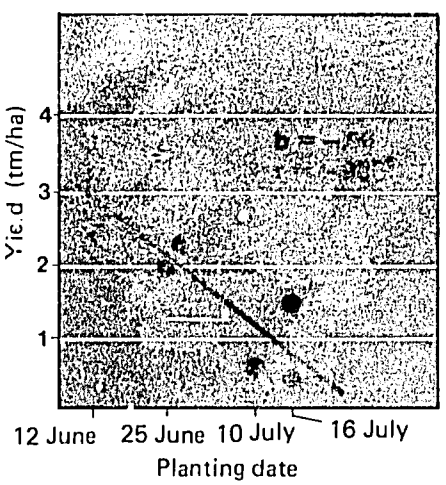


Figure 4. Linear regression of the yield (at each site) on the planting rate, for 8 sites; Tierra Caliente, Mexico, 1984.

The second year of experiments— Three types of experiments were planted in Tierra Caliente during the 1985 season. The excellent performance of V-455 the previous year led to validation experiments (large plots) in which the local variety was tested against V-455 under farmer management. To pursue the possibility of offering earlier maturing varieties for the area, variety trials were also planted that included the local variety, V-455, and two earlier maturing materials. In addition an experiment examining alternative methods of weed control and plant spacing was conducted.

The results of the variety trial showed that earlier maturing materials may indeed be useful for the area and that they certainly merit more investigation. Table 8 shows that the early maturing variety V-424 yielded as well as V-455, and that both outyielded the local variety by more than 900 kg/ha. The trials also awakened farmer interest in earlier maturing maize varieties, and there is now a growing demand for such materials.

Table 8. Summary of variety trials, Tierra Caliente, 1985 (3 locations)

Variety	Days to physiological maturity	Average yield (kg/ha)
Local	117	2,600
V-455	117	3,540
V-424	104	3,580
V-425	100	2,790

The variety V-455 also performed very well in the validation experiments (Table 9). At six representative locations, and with the

nonexperimental variables set being normal farmer practices, V-455 outyielded the local variety by an average 710 kg/ha. An analysis across 14 sites over two years showed that, under a wide range of conditions, V-455 consistently outyielded the local variety (Figure 5). These results encouraged INIFAP to multiply seed of V-455 during the winter season and have a supply ready for 1986. It will be distributed to farmers and grown in 0.25 ha demonstration plots.

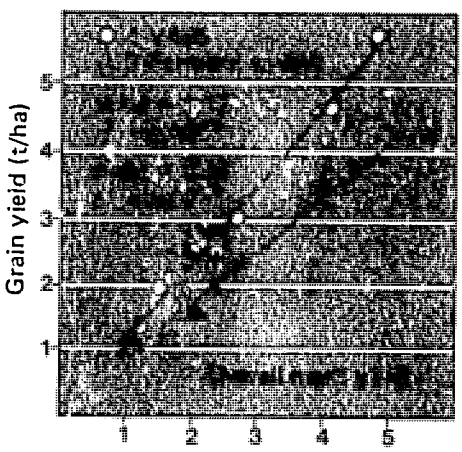


Figure 5. Linear regressions of variety yield on the mean grain yield at a site for V-455 and the local variety at 14 sites in Tierra Caliente, Mexico, 1984 and 1985.

The results of the weed control and spatial arrangement trials were also interesting. Because of their current weeding methods, farmers plant their maize at a relatively wide spacing. A change in spatial distribution showed gains of about 800 kg/ha over the local method. This change, however, would only be feasible with chemical weed control. Experiments using the herbicide Paraquat (directed so as not to damage the intercropped squash) showed yields equivalent to those with farmer weed control methods, but at a cost savings equivalent to about 200 kg/ha of maize (see Table 10). There is thus the possibility of both increasing yield and lowering costs of production through improvements in weed control and spatial arrangement.

The results of the work in Tierra Caliente illustrate the progress that can be made through a well-focused program of on-farm research. Initial diagnostic work identified a series of

Table 9. Summary of validation trials, Tierra Caliente, 1985 (6 locations)

Variety	Average yield (kg/ha)
Local	1,790
V-455	2,500

Table 10. Summary of exploratory trials, Tierra Caliente, 1985 (3 locations)

Spatial arrangement	Weed control	Yield (kg/ha)	Net benefit	Variable costs
			('000 pesos/ha)	
Farmers' practice	Farmers' practice	1,980	46.3	28.5
2 seeds/hill 0.85 x 0.5 m, 50,000 plants/ha	Mechanical/ chemical	2,760	83.3	20.9

problems. Considerable progress has been made on an alternative to the local maize variety and V-455 is now available for the farmers of Tierra Caliente. The issues of weed control and spatial arrangement are more difficult, and will undoubtedly absorb more of the researchers' time over the next few years. In addition, the issue of delayed planting became obvious to researchers during their first year of experimentation, and this has led to the investigation of early maturing varieties.

Finally, it can be seen that the benefits of the on-farm research are not limited to the farmers in Tierra Caliente. INIFAP itself, as well as CIMMYT, have been able to take advantage of the information developed during the project to improve efficiency in their research resource allocations. There is now clear evidence of the advantages of the maize variety V-455 that had been released several years ago, but never targeted to particular groups of farmers. INIFAP can now help develop well-focused extension efforts to introduce V-455. In addition, the importance of early maturing varieties and more efficient methods of weed control point the way toward well-defined research priorities for INIFAP scientists.

Sources

Hibon, A., F. Lorenzana, and R. Sánchez. 1985. *Generando tecnologías apropriadas para los producdores de maíz de Tierra Caliente: resultados del primer ciclo de experimentos exploratorios*. México, D.F.: INIA/CIMMYT.

Hibon, A., F. Lorenzana, R. Sánchez, and S.R. Waddington. In press. *Investigación en Campos de Agricultores en México: El Caso de Tierra Caliente*. México, D.F.: INIFAP/CIMMYT.

On-farm research not only benefits the farmers of Tierra Caliente, but INIFAP and CIMMYT researchers as well.

106

Data Collection and Analysis

CIMMYT economists regularly analyze data relevant to the world maize and wheat economies. Ongoing products of this work include two serial publications, produced in alternate years, which look at developments in maize and wheat production and consumption. In 1985, the Economics Program published *CIMMYT World Wheat Facts and Trends, Report Three: A Discussion of Selected Wheat Marketing and Pricing Issues in Developing Countries.* Besides summarizing recent trends in world wheat production, trade and prices, this edition also reviewed some of the issues related to wheat marketing and pricing. In addition, Economics Program staff also conducted another study in 1984-85 that addressed the question, "Is there a bias against producers in national wheat pricing policies?" Highlights of both these research efforts are included in this year's report.

Wheat Marketing and Pricing Issues in Developing Countries

Across the spectrum of economic development, there exists a fascinating breadth of technologies used to transport wheat from the farm, process it, and deliver bread and other wheat products into the hands of consumers. The Third World wheat market has undergone dramatic changes during the past 15 years, associated with rising consumption and imports, as well as with an increased marketable surplus in major wheat-growing regions. These changes are expected to continue well into the next century, when the growing urban centers of the developing world will require vast amounts of wheat and wheat products to feed their populations. This rapidly growing demand also makes the issue of production incentives to farmers in developing countries a matter of significant concern. Because most governments intervene in the marketplace in the setting of wheat prices, and are likely to continue to do so, wheat pricing mechanisms are of paramount importance to those concerned with the role of wheat in agricultural development.

Wheat Marketing and Economic Development

Important changes are occurring in the marketing of wheat and wheat products, especially in the developing world. First of all, during the past 15 years a number of countries—notably Argentina, Bangladesh, China, India, Pakistan, and Turkey—have increased their domestic wheat production at rates well ahead of the wheat-producing countries of the industrialized world (Figure 1). One consequence of this rapid increase in production has been that the amount of wheat entering the marketplace, the so-called "marketable surplus," has increased rapidly in the Third World.

Although precise data are not available, it is estimated that about 75% of global wheat production now enters into market channels. Even in countries where considerable wheat is still consumed on the farm, such as China, India, Pakistan, and the wheat-growing countries of North Africa and the Middle East, the proportion of wheat going to markets is increasing (Table 1). With the growth of personal income in developing countries, and the continuing trend toward urbanization, it can be expected that wheat marketing will play an increasingly important role in future years. As economic development

proceeds, changes will occur in the demand for types of wheat products as well as in the way that wheat product marketing services are organized.

Table 1. Estimated amounts of wheat that enter markets, by region, 1984

Region	Percent[a]
World	75
Developed market economies	95
Eastern Europe and USSR	80
Developing economies	50
Eastern & Southern Africa	40
North Africa	30
Middle East	50
South Asia	35
East Asia	45
Latin America	90

a/ Rounded to nearest 5%
Source: National agricultural research contacts and USDA regional reports. Aggregated according to production.

Changes in demand for wheat products—One noticeable result of economic development is that the amount of wheat sold as flour declines and the amount sold as more highly processed products increases. For the lowest-income countries of the wheat-consuming developing world, over 90% of the milled wheat is bought as flour for home baking and cooking. As per capita income increases, this percentage drops rapidly (Figure 2). It appears that wheat products baked outside the home replace flour during early stages of economic development and at relatively low levels of consumer income.

The relationship between changes in consumer income and demand for wheat products varies between developed and developing countries. In developed countries, as incomes rise flour consumption declines while the consumption of baked products increases, and bread consumption is largely unresponsive to changes in consumer income. In the developing

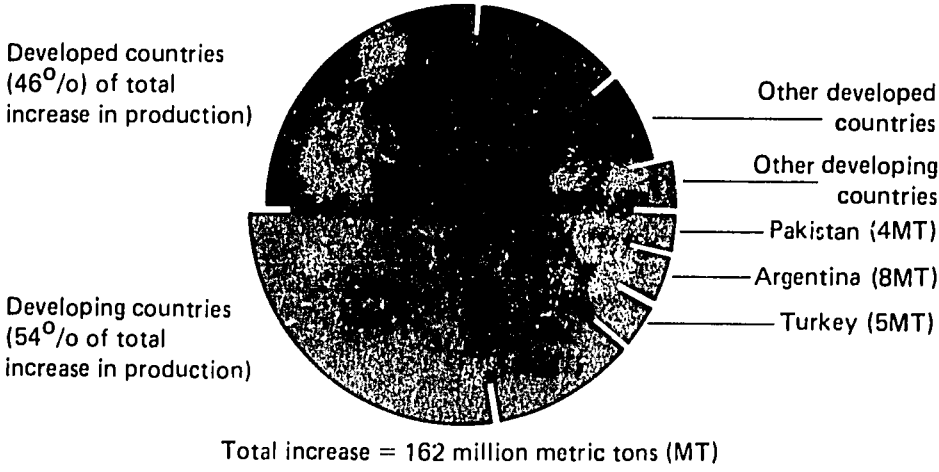


Figure 1. Expansion in world wheat production, 1970-72 to 1982-84, and where the additional production occurred.

world, on the other hand, both the demand for bread and the retail demand for flour are positively related to rising income. For baked products, every 1% increase in income generally results in a greater than 1% boost in consumption.

Changes in wheat marketing services—As wheat marketing assumes greater importance in a country during its development, changes in milling and other marketing facilities occur to take advantage of the changing cost of capital versus labor and economies of scale. In general, the number of milling establishments tends to decrease, while their size tends to increase. For the small mills commonly found in rural areas of developing countries, labor costs represent more than half of total costs. (In the case of home grinding of wheat, labor is the only major cost.) In large mills in both developed and developing countries, on the other hand, labor comprises as little as 25-35% of total costs. Milling and other wheat marketing processes generally become more capitalized with development—using more infrastructure and other facilities—thus raising the productivity of labor.

Marketing margins for wheat products—A useful way of examining how wheat marketing is affected by economic development is to look at changes in marketing margins. Marketing margins represent the difference between the price received at one level of the market, and that at a higher level. The total marketing margin for bread, for instance, is the difference between the price paid by consumers for the end-product and the payment received by farmers for their grain.

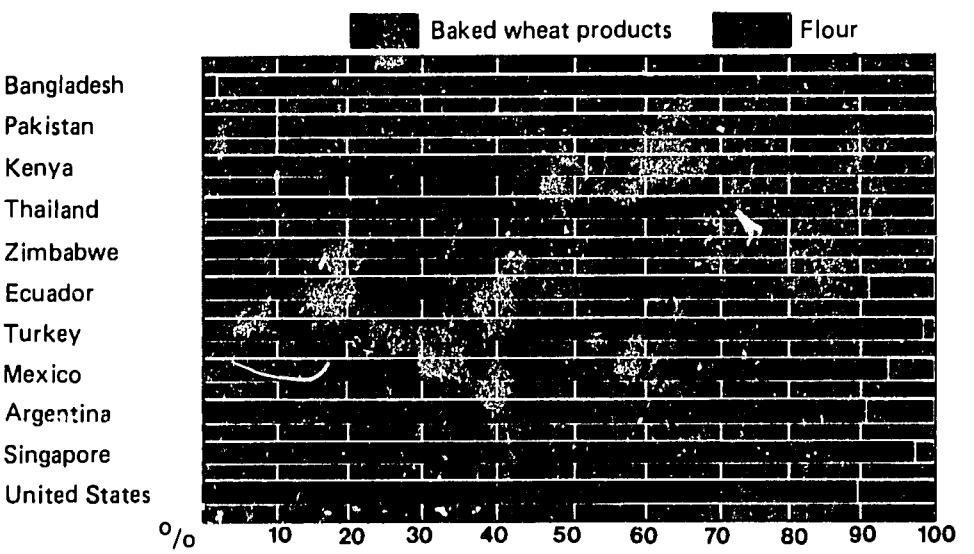


Figure 2. Share of wheat sold as flour and as baked wheat products in 11 countries with differing per capita incomes.

The total value added in the marketing of wheat-to-bread increases strongly with economic development (see Figure 3). In Pakistan the total value added in marketing bread is about US$ 370/ton of wheat, of which farmers receive almost 30%. Contrast this with the marketing of bread in the USA, where the total value added is over US$ 1,400/ton, and the farmer's share is under 10%.

A convenient way of evaluating the prices of marketing services is to calculate the amount of wheat that must be sold to pay for them. Table 2 presents these conversions for five countries, arranged in order of increasing per capita income. In most developing countries, the value of the bread made from one ton of wheat is equal to the value of two to three tons of wheat. In developed countries, on the other hand, 7-14 tons of wheat are required to pay for the marketing of wheat-to-bread.

These differences in marketing margins are best understood by looking at their individual components. With respect to transport, storage, and handling, there appears to be no strong relationship between their cost and the level of economic development. While developing economies have much less in the way of wheat transport, storage, and handling facilities, the costs for moving and storing wheat are about equal to those of the developed world. This is largely because of lower wages and prices of other inputs, as well as a much greater use of labor-intensive technologies in providing these services in developing country wheat markets.

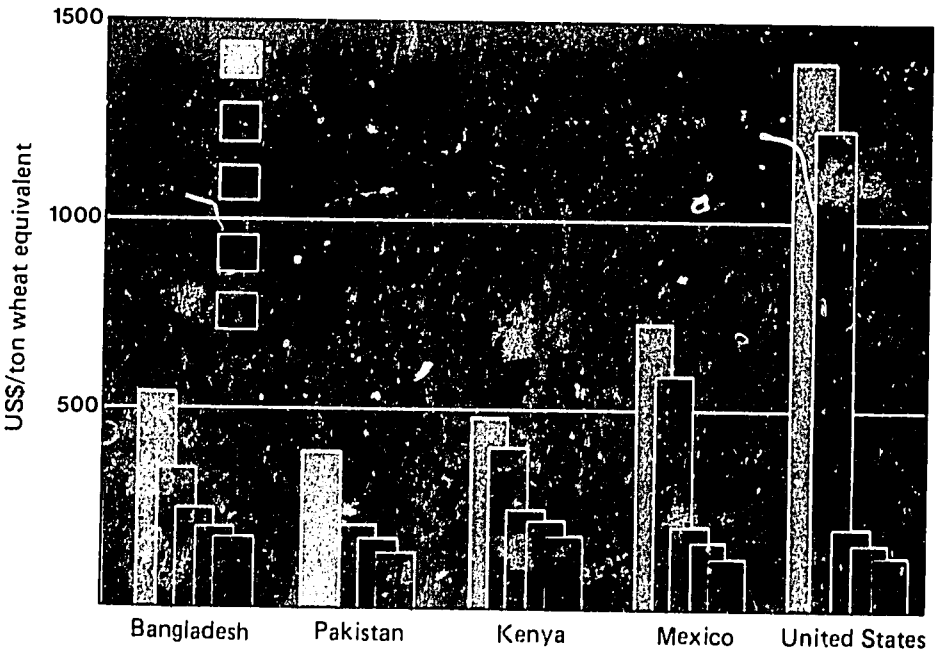


Figure 3. Marketing margins, wheat-to-bread, in five countries.

Similarly with milling, there is no evidence of declining margins with increasing levels of economic development. Lower wages and other input prices in developing countries appear to offset the increased volume of throughput, higher labor productivity, higher capital intensity, and infrastructure advantages of developed economies. For some developing countries, milling technology and throughput at the main ports or in large urban areas is now very similar to that found in industrialized countries.

The baking component contributes most to the difference in marketing margins between developed and developing countries. As incomes increase, consumers are willing to pay more for baking services. The baking sector's higher marketing margins probably reflect the greater array of ingredients included in the end products, as well as the fact that the baking process remains more labor intensive than others in the marketing chain. To meet these higher costs, especially for wages, markups for baked goods are higher in the more developed countries.

Retailing margins for bread generally appear to be fairly constant across countries. Although other pricing strategies may be used by retailers, markups on the order of 15 to 20% on the wholesale price of bread are common. In many developing countries, where baking and retailing often is done by the same establishment, the markup on baked foods will include an allowance for both services.

Table 2. Kilograms of wheat needed to pay for the different services in the wheat marketing systems of selected countries

Country	Product	Farm or import price of wheat[a] (US$/t)	Transport, storage, & handling	Kilograms of wheat for: Milling	Baking	Retailing	All services
Bangladesh	Bread	159	117	286	698	1210	2310
Pakistan	Bread	108	191	281	—1960—		2430
Kenya	Bread	157	251	188	1050	500	1990
Mexico	Bollilo	121	267	199	—2590—		3060
	Bread	121	267	199	3300	1210	4980
USA	Bread	125	221	282	8570	1410	10480

a For Bangladesh, the import price of wheat is used; for other countries the farm price is used

Note: Prices as near as possible to January 1, 1985.

National Wheat Pricing Policies

Research for the 1985 *CIMMYT World Wheat Facts and Trends* also included a review of wheat pricing policies for major wheat-growing countries. In particular, consideration was given to the methods that countries use to set support prices for wheat at the farm level. Governments intervene in setting commodity prices for various reasons. One of the most important of these is stability. Domestic prices that are exposed to fluctuating world commodity prices comprise an additional risk to farmers. At times governments may intervene for welfare reasons in commodity pricing in order to reshape income distribution, e.g., by raising the price of a commodity produced by a poorer sector of the country. The issue of food security may also prompt a high support price for a particular commodity, in order to ensure stable domestic supplies. The food security concern is sometimes also linked to an attempt to save foreign exchange expenditure on commodity imports by promoting local production.

A variety of methods may be used to set support prices for wheat. They include arbitrary negotiation, indexing to inflation, reference to cost of production, a moving average of world prices, and the use of current market prices. The relative importance of these alternatives in 48 major wheat-growing countries is shown in Table 3. It can be seen that arbitrary negotiation is the predominant method for setting wheat prices. This is understandable when one considers the importance of food and food agencies in the political process, but reliance on such negotiations entails several pitfalls. Support prices can easily move out of line with markets, resulting in financial imbalances for governments and,

Table 3. Pricing policies practiced in major wheat-growing countries

Wheat pricing approach	No. of countries using this method	Example of countries & regions using this method
Cost of production	13	Brazil, Sudan, Iran Turkey
Indexing (from year-to-year)	4	Uruguay, Peru, Japan
Moving average of market prices	2	Australia
Abitrary negotiation	24	Bangladesh, Mexico, Morocco, Pakistan, EEC
Current market prices	5	Argentina

Source: Collaborators in developing countries and numerous reports describing wheat pricing policies published by International Wheat Council, FAO, and USDA.

especially, their marketing authorities. Various interest groups may bring pressure to bear for prices that give inappropriate signals to producers, consumers, or marketing agencies. These may lead to inefficiencies in the production and distribution of food.

To account for inflation, governments at times try to index the wheat price to the general inflation rate or to increases in specific farm input prices. Two serious problems with this method are: (1) choosing a base period for setting support prices, and (2) ensuring that the indexed support price stays in line with market cirumstances over the longer term.

Another alternative for setting support prices is the use of cost of production data. Information obtained by farmer surveys can be used to estimate the cost of producing a ton of wheat. After defining a reasonable return for farmers, a support price of wheat can be set. Although this method is used by a number of countries, it entails some serious drawbacks. In the first place wheat, especially in the developing world, is usually grown on multiple-enterprise farms, where isolating the costs of production of one commodity may be quite difficult. In addition, costs of production will vary according to the productivity of the farm. An average cost of production figure masks this variability in productivity.

Another possibility is to link farm support prices to a moving average of world prices. Such moving averages are often calculated using a 3 to 5 year period, with support prices arbitrarily set at a fixed percentage of the moving average. Although few countries currently use this method, it offers several advantages: (1) it ensures that support prices reflect market trends over the longer term, while providing considerable buffering against short-term price fluctuations and (2) it is a relatively low-cost method for setting price supports.

Finally, a few countries allow their wheat prices to be freely linked to the international market. Most countries, however, are too concerned about fluctuations in prices to have such direct links to world markets.

Wheat Pricing Policy: Bias against Agriculture?

In a related research area, members of the Economics Program have been investigating whether wheat pricing policies in the developing world tend to be biased against producers or consumers. Given that wheat-producing countries use a variety of methods to set producer prices, it is important to gain a better understanding of the effects of these policies. In particular, a number of recent studies have indicated that producer prices were kept low in many developing countries, as a way of taxing the agricultural sector and/or supporting low food prices for the urban sector. If this is true, it has serious implications for incentives for adoption of improved wheat technologies. This hypothesis was tested by looking at farm-level price data from 31 countries that represent 97% of the wheat produced in the developing world. The analysis suggests that such price discrimination against agriculture, at least in the case of wheat, may be less prevalent than previously reported.

Information on producer prices was obtained in 1980 and 1982 through questionnaires that were sent to agricultural researchers who had frequent contact with wheat farmers in

these countries. The questionnaire asked for the post-harvest wheat price, the price of nitrogenous fertilizer, and rural wage rates. For each of the countries the producer price was compared to the world price. The latter was calculated by estimating the price of imported wheat in the largest city of the country, using the CIF price of Hard Red Winter Wheat No. 2 from Rotterdam and adjusting for freight rates and, where appropriate, land transport. Long-run trends in world prices for both wheat and freight rates were calculated for the period 1980-82, rather than using the actual rates prevailing in that period, in order to avoid comparing domestic prices with fluctuating world prices.

A Nominal Protection Coefficient (NPC) was then computed, where NPC = p_d/p_w, and p_d is the price of domestic wheat at the consumption point and p_w is the price of imported wheat. The calculations were made using the official exchange rate, and again using a corrected exchange rate for countries where the currency was overvalued (or undervalued). NPCs ranging between 0.85 and 1.15 was considered to be neither significantly below nor above the world price.

The results are presented in Table 4. It can be seen that the most significant difference between the two exchange rates is the greater proportion of producers who are classified as subsidized (when, in fact, an artificially

Table 4. Distribution of countries according to the Nominal Protection Coefficient (NPC) and adjusted NPC for producers

	NPC at official exchange rate	NPC at corrected exchange rate
	(percent of countries)	
Domestic wheat price 85% or lower than world price (NPC less than 0.85)	36	37
Domestic wheat price within 85-115% range of world price (NPC between 0.85 and 1.15)	29	40
Domestic wheat price 15% or more above the world price (NPC greater than 1.15)	36	
Average NPC	1.14	1.03

high exchange rate has taxed producers). But under either assumption, only about one-third of the countries significantly undervalue the price paid to their wheat producers, with an NPC of less than 0.85.

A second way of looking at pricing incentives is to measure the ratio of the wheat price to that of a tradeable input such as fertilizer (see Table 5). It has the advantage of eliminating the problem of exchange rate conversion. Using international prices of wheat and urea, the cost of nitrogen in wheat equivalents was expected to range from 2.5 to 3.2. Only six of the countries (23%) had a ratio above this range; that is, there were negative incentives to wheat growers for using fertilizer. Moreover, there was a correlation of -0.5 (significant at 1%) between the fertilizer/wheat price ratio and the NPC.

Table 5. Distribution of countries according to the ratio of price of nitrogen to the price of wheat

Ratio of Nitrogen to wheat price[a]	Percent of Countries
less than 2.5	50
2.5 to 3.2	27
Over 3.2	23
	100

[a] The average for all countries is 2.7

The results of the study show a wide variation in producer price policies across countries. The reasons for this variation were not examined in the study, but two interesting relationships emerged. First, there seems to be a weak relationship between pricing domestic wheat below the world market and the contribution of agriculture to national income, with a slight tendency for countries with a high share of GDP from agriculture to price domestic wheat less than in the world market and, therefore, tax producers. A stronger relationship exits between domestic producer prices lower than the world price and those countries where wheat is both an important staple in urban areas and where the majority of the wheat supply is from domestic production. The majority of the countries in the study who price domestic wheat lower than in the world market were at least 90% self-sufficient in wheat (e.g. India, Pakistan, Nepal, Turkey, Uruguay).

The study also looked at consumer prices (for bread) in these same countries using an estimated bread price of US$ 0.75/kg (based on the import price of wheat). Countries were divided into those with bread prices that fell within 85-115% of this price, those 15% or more above and those 15% or more below. Using official exchange rates, 62% of the countries subsidize bread for consumers; using corrected exchange rates the proportion climbs to 80%. But it is significant that in only a few of the countries that subsidize bread has this policy been implemented at the direct expense of the producer. In most cases, explicit government fiscal subsidies to consumers have played a much large role than low producer prices in maintaining low urban food prices.

The study concludes that in most wheat producing countries, producer price incentives are not the major constraint to increased productivity. It would appear that development of technologies appropriate to farmers, and support of input delivery and extension systems, play a more important role.

In addition, the study suggests that it is low consumer prices, rather than low producer prices, that have played a major part in the rapid rise in wheat imports by developing countries in the 1970s.

Source

Byerlee, D. and G. Sain. In press. Food pricing policy in developing countries: Bias against agriculture or for urban consumers? *American Journal of Agricultural Economics*.