

WHEAT ♦ PROGRAM ♦ SPECIAL ♦ REPORT

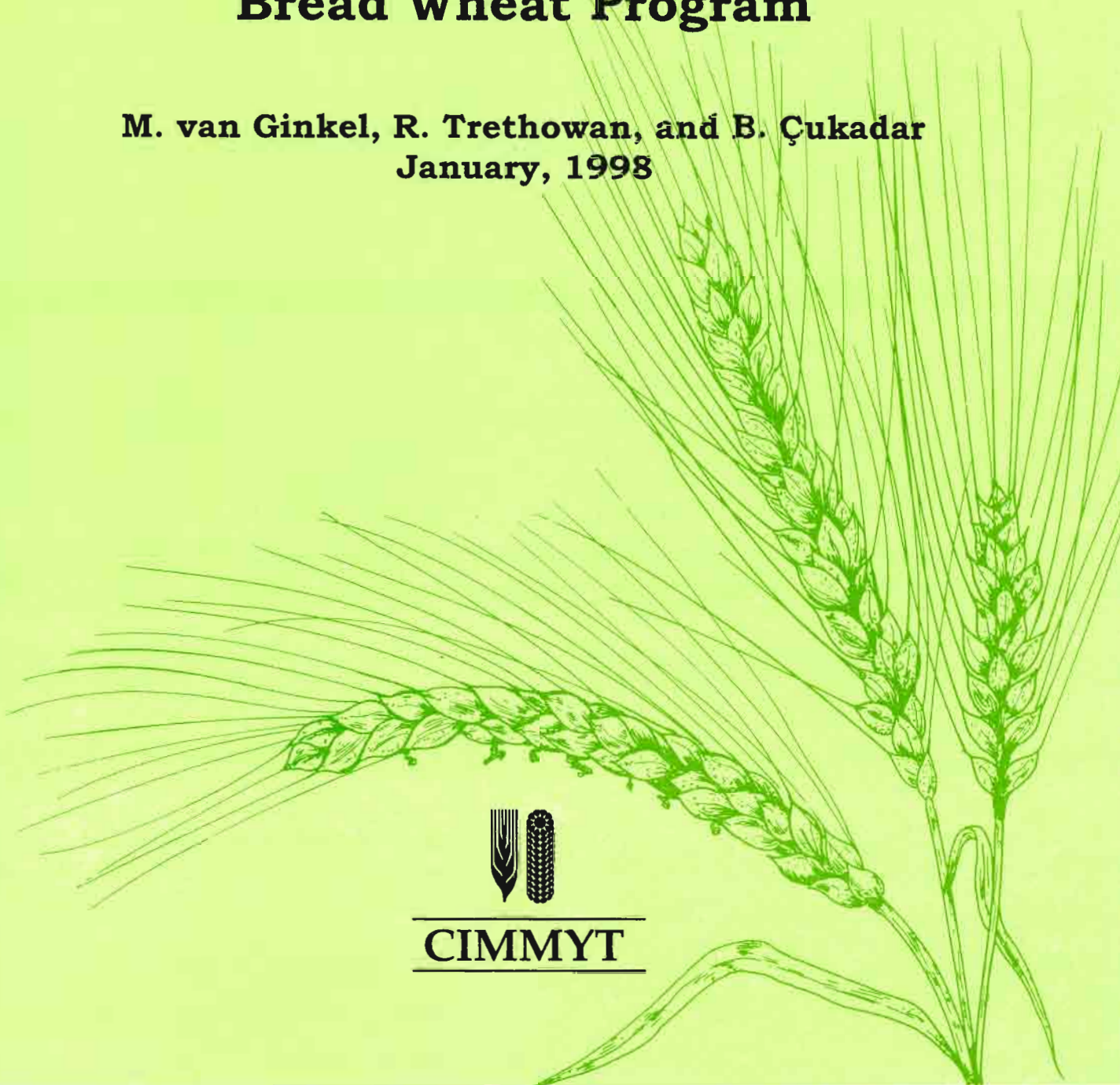
WPSR No. 5

A Guide to the CIMMYT Bread Wheat Program

M. van Ginkel, R. Trethowan, and B. Çukadar
January, 1998



CIMMYT



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Bread Wheat Program**

**M. van Ginkel, R. Trethowan, and B. Çukadar¹
January, 1998**

¹ The authors are Head, Senior Breeder, and Hybrid Bread Wheat Breeder, respectively, of the CIMMYT Bread Wheat Program.

CIMMYT is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center works with agricultural research institutions worldwide to improve the productivity and sustainability of maize and wheat systems for farmers in developing countries. It is one of 16 similar centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR comprises over 50 partner countries, international and regional organizations, and private foundations. It is co-sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP).

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Preface

This special report is an updated introduction to the CIMMYT Bread Wheat Program. It is designed to help acquaint trainees, visiting scientists, mid-career fellows, and other interested persons with the Program's philosophy, objectives, organization, structure, and activities.

We thank Alma McNab, Wheat Program Writer/Editor, for assisting in the preparation of this document.

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Head, Bread Wheat Program

Coordinator, Wheat Germplasm Enhancement Global Project 3 (GP3)

A Guide to the CIMMYT Bread Wheat Program

M. van Ginkel, R. Trethowan, and B. Çukadar

Introduction

The precursor of the present CIMMYT Wheat Program originated in 1944 under the sponsorship of the Rockefeller Foundation and the Office of Special Studies of the Mexican Ministry of Agriculture. In 1966, CIMMYT was established as a non-profit organization responsible to an internationally elected board of trustees. The Ford and Rockefeller Foundations joined Mexico as the initial principal supporters of CIMMYT. Presently CIMMYT has about 60 donors, including public and private foundations, and individual countries, including 17 developing countries.

The CIMMYT Bread Wheat Program currently distributes advanced lines to more than 60 countries. Primary clients are the national agricultural research systems (NARSS) (which include both the public and private sectors) of developing countries. Germplasm distribution and utilization are dependent upon their close cooperation. The Bread Wheat Program has attempted to address the specific problems and limitations associated with wheat production in these countries.

In order to develop effective breeding strategies, various agro-ecological zones or mega-environments (MEs) have been defined. Germplasm developed for a given ME will withstand the major stresses present within that ME, but not always the significant secondary stresses. However, an attempt is made to include genetic diversity for additional traits of importance within the ME. How these products are used and distributed within an ME to address the needs of specific agro-ecological niches is the responsibility of the individual NARSSs.

The development of broadly adapted, “durably” disease resistant, high yielding, and stable germplasm within the context of each ME is the Program’s primary goal. While soil, temperature, and moisture factors influence crop stability and productivity, resistance to biotic factors such as diseases and insects, and tolerance to abiotic factors such as drought, heat, and soil acidity, can be critically important in maintaining high yields, thus contributing significantly to the adaptation of a given cultivar over time and across locations. Emphasis is also given to maintenance of genetic diversity within each ME to counter the effects of genetic vulnerability.

To breed for wide adaptation and high yield potential, the breeding program shuttles segregating material between alternate sites within Mexico, while pyramiding genes that

carry “durable’ resistance to various pathogens. International multi-locational testing, through the distribution of the International Nurseries and Yield Trials with the cooperation of the NARSs, provides vital information for use in the Bread Wheat Program’s crossing and selection activities.

Bread Wheat Program Staff

The breeding program at CIMMYT Headquarters (in Mexico) has a current staff of 18 members, comprising three internationally recruited breeders, seven research assistants, eight field assistants, and one secretary. Twelve international staff at base and twelve outreach staff support program activities. Wheat directing staff provide major administrative support. Staff members are listed below:

Core Breeding Staff

- Maarten van Ginkel (The Netherlands): Bread Wheat Program Head and Senior Breeder
- Richard Trethowan (Australia): Senior Breeder (special responsibility: abiotic stress tolerance)
- Belgin Çukadar (Turkey): Hybrid Bread Wheat Breeder

Associated Physiology/Breeding Staff

- Janny van Beem (Colombia): Physiology and Adaptation

Research Assistants

- Eduardo Hernandez (MSc) Data Analyst and Assistant Breeder
- Ramon Gil Coordinator, Toluca/Spring Wheat Cycle
- Ing. Jorge Montoya Coordinator, Cd. Obregon Cycle, and Co-Coordinator, Toluca/Spring Wheat Cycle
- Ing. Horacio Vega Coordinator, El Batan/Spring Wheat Cycle
- Ing. Mario Albarran Coordinator, Toluca/Winter Wheat Cycle
- Ing. Jose Borja Co-Coordinator, Cd. Obregon/Spring Wheat Cycle
- Ing. Armando Miranda Coordinator, Hybrid Bread Wheat

Field Assistants

Spring Wheat Cycle (Cd. Obregon and Toluca or El Batan)

- Jose Luis Coss
- Salvador Madrigal
- Martin Rodriguez
- Leopoldo Salazar
- Jose Terrazas
- Alfredo Valencia

Winter Wheat Cycle (Toluca)

- Reyes Colin
- Valentin Ramirez

Secretarial Support

- Lolita Mir

Supporting Station Management Staff

- El Batan: Francisco Magallanes
- Cd. Obregon: Rodrigo Rascon
- Toluca: Antonio Miranda and Fernando Delgado

Collaborating Training Staff at Base

- Reynaldo Villareal (Philippines): Head, Training

Collaborating Breeding Staff at Base

- Wolfgang Pfeiffer (Germany): Head, Durum Wheat Breeding
- Mohammed Mergoum (Morocco) Head, Triticale Breeding
- Hugo Vivar (Ecuador) Head, Barley Breeding

Collaborating Pathology Staff

- Ravi Singh (India): Rusts
- Lucy Gilchrist (Chile): Fusarium, Septoria, Seed Health

- Guillermo Fuentes-Davila (Mexico): Bunts and Smuts
- Monique Henry (France): BYDV

Collaborating Agronomy Staff

- Ken Sayre (USA): Agronomy Support to Breeding
- Ivan Ortiz-Monasterio (Mexico): Nutrient Efficiency

Collaborating Physiology Staff

- Matthew Reynolds (UK): Physiology

Collaborating Genetic Resources Staff

- A. Mujeeb-Kazi (USA): Wide Crosses
- Bent Skovmand (Denmark): Germplasm Bank

Supporting International Nursery Staff

- Paul Fox (Australia): International Nursery Distribution and Data Analysis

Supporting Industrial Quality Staff

- Javier Peña (Mexico): Industrial Quality

Supporting Staff in Outreach

- Osman Abdalla (Sudan): Breeder, Semi-arid Wheat, Aleppo, Syria
- Hans Braun (Germany): Breeder, Winter/Facultative Wheat, Ankara, Turkey
- Etienne Duveiller (Belgium): Pathologist, Kathmandu, Nepal
- Peter Hobbs (USA): Agronomist, Kathmandu, Nepal
- Mohan Kohli (India): Breeder, Montevideo, Uruguay
- Craig Meisner (USA): Agronomist, Dhaka, Bangladesh
- Alexei Morgunov (Russia): Breeder, Winter/Facultative Wheat, Ankara, Turkey
- Guillermo Ortiz Ferrara (Mexico): Breeder, Kathmandu, Nepal
- Thomas Payne (USA): Breeder, Addis Ababa, Ethiopia
- Douglas Tanner (Canada): Agronomist, Addis Ababa, Ethiopia

- George Varughese (India): Breeder, Harare, Zimbabwe
- Patrick Wall (Ireland): Agronomist, Santa Cruz, Bolivia

CIMMYT Liaison Office

- He Zhonghu (China): CIMMYT Liaison Officer, Beijing, China

Recognition is extended to associated NARSs and advanced research institutes (ARIs) for their cooperation.

Objectives within Each Mega-Environment

The Bread Wheat Program addresses 12 mega-environments (MEs): six define environments for the production of spring wheats, three define the facultative wheat environments, and three the true winter wheat environments. ME delineation is based on water availability, soil type, temperature regime, production system, and associated biotic and abiotic stresses. Consumer preferences for grain color, and industrial- and end-use quality are also considered.

Spring wheat

ME1: Favorable, irrigated, low rainfall environment

ME1 represents the optimally irrigated, low rainfall areas of the world. The climate during the wheat growing period ranges from temperate to conditions of late heat stress.

Representative areas include the Gangetic Valley (India), the Indus Valley (Pakistan), the Nile Valley (Egypt), irrigated river valleys in parts of China (e.g. Chengdu), and the Yaqui Valley (Mexico). This ME encompasses 36 million hectares spread primarily over Asia and Africa between 35°S - 35°N latitudes.

Breeding objectives involve high yield potential, input responsiveness, lodging resistance (which includes maintenance of *Rht1* and/or *Rht2* dwarfing genes), improved industrial quality, “durable” resistance to the three rusts, and mostly resistance to Karnal bunt.

Greater emphasis will be given to the problem of saline soils and high temperature tolerance for late-sown materials. Ten million ha are affected by Karnal bunt and hence resistance to that disease is being incorporated. White (amber)-grained types predominate in most areas.

ME2: High rainfall environment (> 500 mm rainfall during the cropping cycle)

ME2 is defined by representative high rainfall locations in the West Asia and North Africa (WANA) Region, the Southern Cone and Andean Highlands of South America, Kulumsa (Ethiopia), Izmir (Turkey), and Toluca (Mexico). Total area exceeds 8 million hectares.

Stripe rust, *Septoria tritici*, and pre-harvest sprouting are major production constraints. Resistances to leaf rust, BYDV, fusarium head scab, bacteria, and powdery mildew must also be considered in many parts of ME2. For high yield potential, semi-dwarf stature is essential. Red grained wheat provides better sprouting tolerance than white grained wheat. Red grain type is generally preferred, with the exception of a few areas (e.g. Ethiopia).

ME3: High rainfall, acid soil environment

Disease and stress problems are similar to ME2; however, aluminum and manganese toxicities, plus phosphorus deficiency, are major constraints to production. Area is estimated at just under 2 million hectares, mostly in Brazil, the Himalayas, and Central Africa. Red grain is generally preferred, except in the Himalayas.

ME4: Low rainfall environment

Three distinct types of drought or sub-MEs have been identified based on the stage of plant development at which drought is most severe. These are:

- ME4A: Winter rain or Mediterranean-type drought associated with post-flowering moisture and heat stress typical of the WANA region. Also late frosts may occur. Representative locations include Aleppo (Syria) and Settat (Morocco). Total estimated area: 6 million ha.
- ME4B: Winter drought or Southern Cone-type rainfall associated with pre-flowering moisture stress. Marcos Juarez (Argentina) is a representative location. Resistances to leaf and stem rust, *Septoria* spp., and *Fusarium* spp. are requirements. Pre-harvest sprouting is also a common problem. Total estimated area: 3 million ha.
- ME4C: Stored moisture after monsoon rains results in continuous or Subcontinent-type drought under receding moisture conditions. A representative location is Dharwar (India). Total estimated area: 2-3 million ha, and probably decreasing.

The Bread Wheat Program attempts to combine high yield potential with drought resistance for MEs 4A and 4B. Other, more specifically adapted germplasm is needed for ME4C. Most breeding research for ME4A is carried out by the CIMMYT Outreach breeder based at Aleppo, Syria. The combination of water-efficiency and water-responsive traits plus yield potential is important in drought environments where rainfall is frequently erratic across years. When rains are sufficient in certain years, the crop must respond appropriately. For ME4A and ME4C, white grain is a requirement. However, in ME4B red grain is preferred, to avoid sprouting problems.

ME5: Warmer area environment (areas 23°N - 23°S, < 1000 m altitude)

The mean minimum temperature of the coolest month in this environment is >17°C. In humid locations, resistances to *Helminthosporium sativum*, leaf rust, and sprouting are major objectives. Representative humid locations are Joydebpur (Bangladesh), Chiangmai (Thailand), Encarnacion (Paraguay), and Poza Rica (Mexico). Kano (Nigeria) and Wad Medani (Sudan) are typically dry locations. The estimated area is about 9 million hectares.

ME6: High latitude environment (> 45°N or S)

Wheat is spring-sown in this ME, as winters are too severe for survival. The higher latitude requires that the materials have a certain level of photoperiod sensitivity unlike that in all other spring MEs. Harbin (Heilongjiang, China) is a representative location, with pre-anthesis drought followed by rainfall during flowering and grainfill. Resistances to *Fusarium* spp., *Helminthosporium tritici-repentis*, stripe rust, leaf rust, stem rust, and sprouting are breeding objectives. A very dry representative region is the northern Kazakstan wheat belt. The total estimated area is 15 million hectares.

Facultative wheat

ME7: Favorable, irrigated, moderately cold (0 - 5°C coolest month) environment

Breeding objectives are yield potential and resistances to stripe rust, leaf rust, and powdery mildew. A representative location is Zhenzhou, Henan (China).

ME8: High rainfall (> 500 mm), moderately cold (0 - 5°C coolest month) environment

Major diseases are stripe rust, powdery mildew, leaf rust, and eye spot. Representative locations are Temuco (Chile) and Corvallis (Oregon).

ME9: Semi-arid, low rainfall, moderately cold (0 - 5°C coolest month) environment

Drought tolerance and resistance to stripe rust and bunts are requirements. Representative locations are Diyarbakir (Turkey) and Vernon (Texas).

Winter wheat

ME10: Favorable, irrigated, severely cold (-10 - 0°C coolest month) environment

High yield potential and resistances to stripe rust, leaf rust, and powdery mildew are requirements. Beijing (China) is a representative location.

ME11: High rainfall (> 500 mm), severely cold (-10 - 0°C coolest month) environment

Major diseases are leaf rust, stripe rust, powdery mildew, and eye spot. Representative locations are Odessa (Ukraine) and Krasnodar (Russia).

ME12: Semi-arid, low rainfall, severely cold (-10 - 0°C coolest month) environment

Drought tolerance and resistance to the bunts are needed. Ankara (Turkey) and Kansas (USA) are representative locations.

Nomenclature of Breeding Materials

Coding

All genetic materials within the Bread Wheat Program have been assigned a standardized alpha-numeric code of 7 or 8 spaces to easily identify the germplasm flow.

The first two or three letters indicate the breeding nursery, segregating generation or yield trial stage. Also the three letters or letter/number combinations may designate the country from which the germplasm was received. Some examples are given below:

- CBS: Crossing Block Spring Wheat
- CBW: Crossing Block Winter Wheat
- ON: Observation Nursery
- F1, F2, F3, etc.: Filial Breeding Generation
- F1T: F1 Top Cross (= three-way cross)
- AL: Advanced Lines bulked in F7 or F8
- PC: Small plot (*Parcela Chica* in Spanish) of advanced lines bulked in F7 or F8, that have entered unreplicated, first-time preliminary yield trials (PYT)
- EAL: Elite Advanced Lines that have been promoted based on PYT performance
- EPC: An Elite PC of elite advanced lines have entered replicated yield trials (YT), following acceptable performance in the PYTs and EALs
- IND: Material from India

The second group of three characters in the internal Bread Wheat Program coding system defines the intended target mega-environment: ME1, ME2, etc.

| Mega-environment | Classifier | Int. Nurseries and Trials |
|-----------------------------|-------------------|----------------------------------|
| Spring Wheat: | | |
| ME1: Favorable Environment | FE | IBWSN ¹ ESWYT |
| Heat | HT | HTWYT |
| ME2: High Rainfall | HR | HRWSN HRWYT |
| ME3: Acid Soil | AS | ASWSN |
| ME4: Semi-Arid | SA | SAWSN SAWYT |
| ME5: Tropical Environment | TE | WAWSN |
| ME6: High Latitude | HL | (special) |
| Facultative Wheat: | | |
| ME7: Favorable Environment | FE | FAWWON |
| ME8: High Rainfall | HR | FAWWON |
| ME9: Semi-Arid | SA | FAWWON |
| Winter Wheat: | | |
| ME10: Favorable Environment | FE | FAWWON |
| ME11: High Rainfall | HR | FAWWON |
| ME12: Semi-Arid | SA | FAWWON |

¹ See explanation of nursery abbreviations on the following page.

International Nursery and Yield Trial abbreviations

- IBWSN: International Bread Wheat Screening Nursery
- ESWYT: Elite Spring Wheat Yield Trial
- HTWYT: High Temperature Wheat Yield Trial
- HRWSN: High Rainfall Wheat Screening Nursery
- HRWYT: High Rainfall Wheat Yield Trial
- ASWSN: Acid Soil Wheat Screening Nursery
- SAWSN: Semi-Arid Wheat Screening Nursery
- SAWYT: Semi-Arid Wheat Yield Trial
- WAWSN: Warmer Areas Wheat Screening Nursery
- FAWWON: Facultative/Winter Observation Nursery (distributed from CIMMYT Turkey)
- FAWYT: Facultative and Winter Wheat Yield Trial (to be terminated)

Classifiers

In some cases, the last two or three spaces in the Bread wheat Program coding system may provide a "classifier" code, which more specifically identifies the breeding aim within an ME. Classifiers may be used for nurseries, segregating populations and advanced lines. Some classifiers describe the specific biotic or abiotic stress being addressed, highlight the objective of the breeding effort, or identify the specific methodology used. The major ones are listed below:

- AT: Agronomic type
- BYD: BYDV
- DW: BW x DW crosses
- DD: Double dwarf
- DH: Doubled haploid
- DN: *Diuraphis noxia*
- HF: Hessian fly
- HS: *Helminthosporium sativum*
- HT: Heat tolerant

- IQ: Industrial quality
- KB: Karnal bunt
- KWT: Kernel weight
- NU: Nitrogen utilization
- PU: Phosphorus utilization
- SC: Scab (*Fusarium* spp.)
- SL: Salinity
- ST: *Septoria tritici*
- SW: Spring x winter wheat crosses
- SY: Synthetics
- TCL: BW x triticale crosses
- TS: Tan spot
- TWT: Test weight
- WC: Weed competition
- WF: Winter/facultative
- WG: White (amber) grain
- WX: Wide Crosses
- YC: Yield components
- YLD: Yield
- YR: Yellow (stripe) rust

Some nurseries have been developed using a shuttle breeding approach with a relevant NARS, and have been assembled to represent traits for a special target area. These, therefore, have been assigned a unique country or region classifier code:

- BR: Brazil/CIMMYT
- CH: Chengdu/CIMMYT (China)
- EC: Ecuador/CIMMYT
- PA: Paraguay/CIMMYT
- YZ: Yangtze/CIMMYT (China)

Examples of full nursery names

Basic materials

Mega-environment:

| | | | | |
|-----|-----|-----|-----|-----|
| ME1 | ME2 | ME3 | ME4 | ME5 |
|-----|-----|-----|-----|-----|

Nursery name:

| | | | | |
|----------|----------|----------|----------|----------|
| CBSME1FE | CBSME2HR | CBSME2AS | CBSME4SA | CBSME5TE |
|----------|----------|----------|----------|----------|

Segregating generations

| ME1 | ME2 | ME3 | ME4 | ME5 |
|----------|----------|----------|----------|---------|
| F1ME1FE | F1ME2HR | F1TME3AS | F1ME4SA | F1ME5TE |
| F1TME1HT | F2ME2EC | F2ME3BR | F1TME4DW | F2ME5PA |
| F2ME1CH | F3ME2WC | F3ME3PU | F2ME4HF | |
| F3ME1KB | F4ME2ST | F4ME3TS | | |
| F4ME1WG | F5ME2BYD | | | |
| F5ME1IQ | F6ME2DH | | | |
| F6ME1SL | | | | |
| F7ME1WX | | | | |

Yield Trials and associated nurseries

| ME1 | ME2 | ME3 | ME4 | ME5 |
|----------|----------|----------|---------|---------|
| ALME1FE | ALME2HR | ALME3AS | ALME4SA | ALME5TE |
| PCME1NU | PCME2YZ | PCME3BR | PCME4HF | PCME5HS |
| PYTME1HT | PYTME2SC | PYTME3HS | | |
| EALME1DW | EALME2SY | | | |
| EPCME1KB | | | | |
| YTME1SQ | | | | |

Pedigree Format

A standardized recording system is used for crosses made in the Bread Wheat Program. If parent A is pollinated with parent B and the F1 is pollinated with parent C, its pedigree would be designated as A/B//C. Subsequent crosses with parental materials D, E, F, and G used as males are indicated using a number in the following fashion:

A/B//C/3/D/4/E/5/F/6/G

The female is designated by listing it first (on the left) followed by the pollen parent (on the right). Thus, A is the female parent and B the pollen parent in the first cross. The line A/B is the female and C the male parent in cross two, etc. Thus, if subsequent parents (C, D, E, F, and G) would have been crossed alternately as female and then as male, rather than always as a male as in the first example, that cross would have been denoted as follows:

G/6/E/4/C//A/B/3/D/5/F

Backcrosses are designated with an asterisk (*) and a number indicating the dosage of the recurrent parent. The asterisk and the number are placed next to the crossing symbol that divides the recurrent and donor parents. The following are examples involving backcrosses:

- A is the recurrent parent: A*2/B
- B is the recurrent parent: A/3*B
- A/B is the recurrent parent: A/B*4//C/D
- C/D is the recurrent parent: A/B//5*C/D

Selection History Codes

Every F1, segregating line or advanced line in the program is assigned a so-called “breeder’s cross ID” (BCID) and a selection history. This history records the process of selection, which describes where and how the selection was made and the stage or generation of selection.

Each BCID begins with a letter designation of the cross origin (e.g. CM), followed by an indication of the kind of cross (e.g. SS = spring x spring wheat), the abbreviation of the year when the cross was made (e.g. 97 = 1997), and of the location (e.g. Y = Yaqui Valley) and finally a sequential number (e.g. 01001). After this BCID, there follows the selection history: the numbers identify the individual plant selected and the letter indicates the location where selection took place.

The zero-letter combinations (e.g. 0Y, 0M, etc.) are reserved for populations harvested in bulk in that generation. A zero followed by a number (e.g. 05., 010..) indicates the modified bulk selection method, in which a certain number (in the examples: 5 or 10) selected spikes are bulk harvested. The following codes indicate Mexican locations of selection (maximum code length is three spaces):

- B: El Batan
- M: Toluca
- Y: Yaqui (full irrigation)
- SY: Semi-arid Yaqui (reduced irrigation)
- HY: Heat Yaqui (heat, late planting)
- KBY: Karnal Bunt Yaqui
- PR: Poza Rica
- PZ: Patzcuaro
- SJ: Sierra de Jalisco

Selection history location codes for other countries have been determined by the cooperators in those countries.

Examples of selection histories used by the Bread Wheat Program are presented below:

| Type of cross | Breeder's cross ID (BCID) | Selection history (by generation) | | | | | | |
|---------------|---------------------------|-----------------------------------|-----|------|-------|-------|----|----|
| | | F1(Top) | F2 | F3 | F4 | F5 | F6 | F7 |
| A/B | CMSS91Y1001 | — | 12Y | 010M | 010SY | 010PZ | 1Y | 0M |
| A/B//C | CMSS89M0003 | 050Y | 10M | 05PR | 010B | 010HY | 1M | 0Y |

For more detailed information regarding crosses, selection histories and pedigree abbreviations, see the following CIMMYT publications:

1. B. Skovmand, R. Villareal, M. van Ginkel, S. Rajaram, and G. Ortiz-Ferrara. 1997. *Semidwarf Bread Wheats: Names, Parentages, Pedigrees, and Origins*. Includes diskette.
2. M.M. Kohli and B. Skovmand. 1997. *Wheat Varieties of South America: Names, Parentage, Pedigrees, and Origins*. Includes diskette.

Description of Major Breeding and Screening Locations in Mexico

Spring wheat winter cycle

Ciudad Obregon

Cd. Obregon is located at 27.5°N, 40 masl, in the state of Sonora. It is a dry, irrigated, low-altitude site. Yields are high, in the order of 8-9 t/ha in experimental plots and 4-7 t/ha in farmers' fields.

This is one of the two most important breeding and screening sites for the CIMMYT Bread Wheat Program. About 60 ha are annually planted to Bread Wheat Program breeding materials. Leaf rust and stem rust are major diseases, in addition to Karnal bunt. Breeding nurseries are sown during the later half of November and harvested in late April early May.

This location represents ME1 when managed optimally. Reduced irrigation and late planting simulate aspects of ME4 and ME5, respectively.

Poza Rica

Poza Rica is located at 20.5°N, 60 masl, in the state of Veracruz. It is a hot, humid, low-altitude site. Materials are screened for heat and *Helminthosporium sativum* resistance. The Bread Wheat Program plants about 1 ha.

The site represents aspects of ME5. Breeding materials are sown in late November/early December and screened during March.

Spring wheat summer cycle

Toluca

Toluca is located at 19°N, 2640 masl, west of Mexico City in the state of Mexico. This temperate, high rainfall, high altitude site is the most important summer cycle location for the CIMMYT Bread Wheat Program. The major part of the breeding program including all segregating materials is sown here during the summer, totaling about 30 ha.

It is a high rainfall environment with good disease expression, especially of stripe rust, *Septoria tritici*, and *Fusarium nivale*. Highest yields realized in experimental plots are in the order of 7-8 t/ha. Spring breeding materials are sown in May and harvested during October.

This site represents ME2 for spring wheat, when planted in May, and ME7 (FE) and ME8 (HR) for facultative wheats, when planted in November. Vernalization is sufficient for winter wheats to initiate flowering. Relatively short days compared to those at greater latitudes, result in some winter/facultative germplasm maturing late due to their photoperiod sensitivity.

El Batán

El Batán is located at 19°N, 2249 masl. This is the administrative center of the CIMMYT Wheat Program, situated to the north-east of Mexico City in the state of Mexico. Irrigation is available during periods of erratic rainfall.

Due to land limitations (5 ha) plantings are usually restricted to the crossing block ALs, PCs, EALs, EPCs, ONs, multiplications of selected advanced materials, and special studies. Leaf rust develops in epidemic proportions. Stripe rust occurs at irregular frequencies. Sowing commences in June and materials are harvested in October.

El Batán may represent ME2 and/or ME4, depending on water availability.

Materials intended for final multiplication in Mexicali before being internationally distributed in nurseries or trials are first increased in El Batan under the strictest protection against diseases, using fungicides.

Patzcuaro

Patzcuaro is located at 19°N, 2400 masl, to the west of Toluca in the state of Michoacan. This rainfed site is used to screen and select for the septorias, head scab and acid soil tolerance. 1-2 ha is planted.

The site represents ME2/ME3.

El Tigre

El Tigre is located at 21°N, 2300 masl. At this site, south of Guadalajara in the state of Jalisco, and to the west of Mexico City, ME2 materials are evaluated for diseases, such as *Septoria* spp., *Fusarium* spp. and leaf rust.

Winter/facultative wheat winter cycle

Toluca

Winter materials are sown in November using irrigation on about 8 ha at the Toluca station, at the start of the dry winter season. In May/July the rainy season starts. Harvest is in July. The winter/facultative breeding centers on developing materials to support the spring bread wheat breeding effort. Spring x winter wheat crosses are made here. These crosses contribute specific characters to the spring wheat gene pool and provide extended diversity.

Also improved germplasm is selected and developed, targeted towards the winter/facultative regions of China.

A regular stress is BYDV. Leaf and stripe rust develop in some years. Drought conditions can be induced by withholding irrigation in the early part of the crop cycle.

CIMMYT has a joint Winter/Facultative Program with the Turkish National Program, based in Ankara, Turkey. The latter program carries the main responsibility within the CIMMYT Wheat Program structure for developing improved germplasm for most winter/facultative areas in the developing world. They make winter x winter wheat crosses.

Breeding Methods and Germplasm Flow

The crossing blocks

The Crossing Blocks (CBs) are collections of elite breeding source materials arranged by mega-environment (ME). In order to facilitate crossing operations, the CBs are sown on four or five different dates, ten days apart. The largest CBs are the spring CBSs. In the Toluca winter cycle, also a winter CBW is assembled and planted.

Spring crossing block

The production of high yielding, widely adapted, stable and “durably” resistant spring wheat germplasm is the primary consideration of the Bread Wheat Program. For this reason, the spring Crossing Block (CBS) is the largest and most diversified of the two CBs. Germplasm has been grouped according to ME. The specific breeding objectives for each ME were outlined above. Within each ME, materials are sub-grouped based on their country of origin or specific character expression. CBS entries include the major varieties released in different targeted countries, elite CIMMYT and other germplasm identified from international and national testing, and advanced lines exhibiting desirable expression of one specific trait or group of traits, including those made available by the Pathology, Wide Cross, and other sections within the Wheat Program.

Genotypes from each section of the CBS carry genes specific to their defined ME. For example, ME1 genotypes carry genes or combinations of genes coding for one or more of the following: high yield potential, lodging tolerance (dwarfing genes *Rht1*, *Rht2*, and/or *Rht8*), improved industrial quality, durable resistance to the rusts or Karnal bunt, tolerance to saline soils, and resistance to aphids or powdery mildew. There are five CBSs arranged by ME. These are:

- CBS for favorable environments (ME1FE),
- CBS for the high rainfall areas (ME2HR; containing a ME3AS section),
- CBS for semi-arid areas (ME4SA),
- CBS for the warmer areas (ME5TE),
- CBS for the high latitude areas (ME6HL).

Considerable genetic diversity enters the breeding system in the form of introductions from most collaborating countries. From 2000-4000 entries are received annually from our collaborators. In addition, the CIMMYT Wide Cross Section within the Genetic Resources Subprogram provides unique gene combinations for inclusion in the breeding program. Once introduced, these materials are classified according to ME with regard to agronomic

type, disease resistance, and adaptability, and considered for crossing. On average 25% of the CB entries are replaced every crop cycle.

Winter/facultative crossing block

A winter/facultative crossing block (CBW) is sown at Toluca in November. The CBW is a collection of the best advanced lines and varieties from breeding programs around the world. Institutions like the Oregon State University (OSU) and other US university programs, the CIMMYT/Turkey program and Chinese Academies of Agricultural Sciences have contributed significantly to this infusion of germplasm. About 2000-4000 entries are introduced annually. The CBW is used primarily as a means of introducing variability into the spring bread wheat gene pool.

CIMMYT/Turkey is involved in the production of winter/facultative types in collaboration with OSU, the Turkish NARS, and the International Center for Agricultural Research in the Dry Areas (ICARDA), which are sent out to NARSs as the FAWWON. CIMMYT base-produced advanced lines are also shared with CIMMYT/Turkey. CIMMYT/Mexico distributes an international winter/facultative Yield Trial, called FAWYT, but this yield trial will soon be terminated. Materials generated by the winter/facultative program in Mexico will in the future be distributed through our Outreach colleagues based in Turkey.

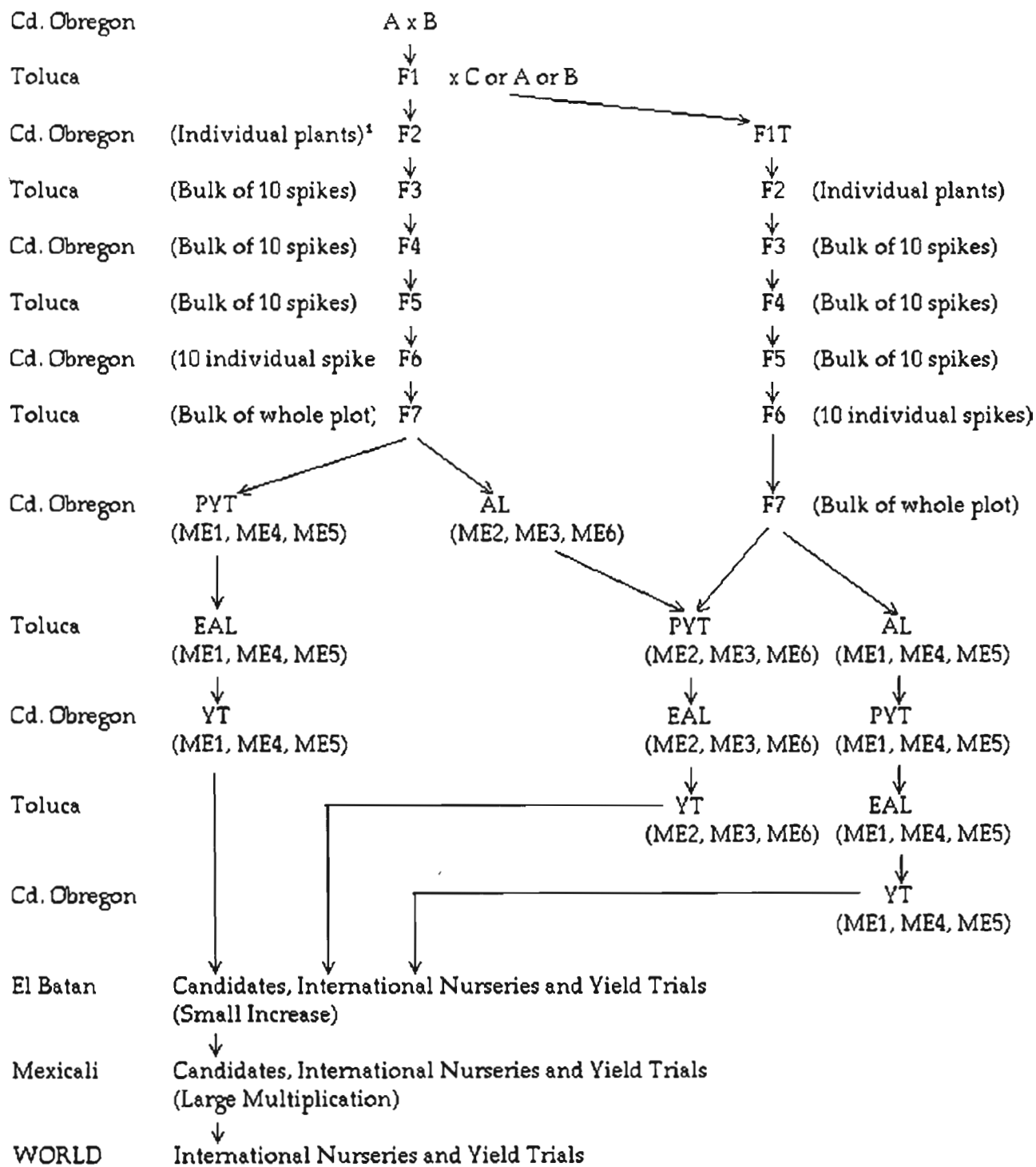
F1 and segregating populations

Crosses are directed toward specific MEs and the resulting nurseries labeled accordingly (see Nomenclature Section). Mostly introduced materials are used as females in their original crosses, in order to possibly expand the genetic base of CIMMYT bread wheat cytoplasm. Outstanding F1 populations are also either top- or backcrossed. Top- (or three-way) crosses are used to extend the variability. (Limited) backcrosses are carried out to stabilize variability as the genetic distance between parents becomes greater, and are proving very effective in expanding adaptation and performance.

As a rule, 4-5 spikes are emasculated for simple crosses and 5-7 for top- or limited backcrosses. Once a cross has been made and classified, it is selected in a shuttle between Toluca and Cd. Obregon, involving certain generations under the stresses specific to its targeted ME. However, as all elite CIMMYT advanced material is tested over a wide range of environments both in Mexico and internationally, some materials may also in the process enter different ME selection streams, as additional adaptation becomes apparent.

The following diagram is a hypothetical representation of germplasm flow, starting out from parental selection and resulting in replicated yield testing and final nursery distribution, according to the standardized abbreviations described in the Nomenclature Section:

Diagram of Germplasm Flow (For full description see text)



¹ Method of selection

These are by no means rigid procedures that are adhered to under all circumstances. Considerable flexibility exists within the system, allowing material to be channeled in different directions as the need arises.

In the early 1980s, the pedigree selection method was exchanged for a combination of pedigree and bulk breeding, named modified pedigree-bulk method, which operates as follows.

F1: A simple cross is made. About 2500-3500 simple crosses are made per cycle.

F1Top: About one third of the most outstanding F1's are top-crossed to a one or more third parents, or a (limited) backcross is made to the adapted parent. Per cycle about 1500-2500 top and limited backcrosses are made. In the first segregating generation of such crosses, only some negative selection is practiced. Samples from all remaining plants are promoted to the F2.

F2: The F2 populations exist of about 1500-2000 plants per cross, which are space-planted. Both simple, top and (limited) backcrosses are represented. Independent of the target ME an epidemic is created of the prevalent diseases, either in Cd. Obregon or Toluca. The poorest F2 crosses (10-15%) are completely discarded.

Within the better F2 populations, the best plants are selected by the breeders and experienced research assistants during 3-5 rounds of selection, based on good agronomic type, "durable" disease resistance, synchronous tillering, desired spike type, good fertility, and appropriate height and maturity. These plants are harvested and threshed on an individual basis, and the seed is visually observed for grainfilling characteristics, boldness, lack of diseases and yellow berry, and other markings. About 50% of the entries is thus discarded.

F3: The seed from individually selected F2 plants is planted as a double (Toluca) or triple (Cd. Obregon) row of 2m, at a normal seeding rate (80-100 kg/ha). The advantage of this planting method is that plants can develop as they would in farmers' fields with few tillers and in close proximity to their neighbors.

All materials except those targeted for ME4, are planted under optimum conditions. ME4 F3 lines, when in Cd. Obregon, are planted under drought stress.

The best lines are selected by the breeders, based on agronomic type, fertility, lodging tolerance, "durable" disease resistance, and expected yielding ability, and somewhat for phenotypic uniformity. Within the best lines 10 good spikes are harvested by the breeders and the experienced research assistants, and threshed in bulk. The advantage of this two-phase selection process is that the breeders can personally carry out all the between-line

selection phase. Seed selection follows. This generates the bulked seed for the next generation.

F4, F5, F6: The methodology detailed in the F3 is repeated. The number of lines retained decreases considerably from F3 till F6. In the fully pedigree method, numbers increase greatly, making it increasingly difficult for breeders themselves to personally select all the desired individual plants. During modified pedigree-bulk selection the selection intensity increases, as additive gene complexes express themselves more clearly.

In the F6, the selected 10 spikes are individually threshed. Due to low seed amounts per entry, no seed selection is practiced.

In the case of ME4 targeted materials the F3-F6 generations are alternated between sufficient rainfall (Toluca) and drought stress (Cd. Obregon; reduced irrigation). In this fashion drought tolerance and performance under drought are combined with responsiveness to increased moisture availability and yield potential.

F7: The head to row planting allows thousands of entries to be planted in a small area. Again disease epidemics are created. The best uniform lines are selected and harvested in bulk. Seed selection follows. These entries are promoted to preliminary yield trials (PYT) or Advanced Lines (AL), depending on the ME. Because the lines are bulked in the F7, some residual heterozygosity is retained. This provides an opportunity for cooperators receiving CIMMYT's International Nurseries and Yield Trials to carry out some reselection under their own conditions even within lines.

In Mexico, segregating generations targeted for specific MEs may occasionally be sown outside the regular Obregon/Toluca shuttle. In some instances, yield trials may also be conducted in the early segregating generations depending on the nature of the material.

Advanced lines and yield trials

AL: The newly bulked Advanced Lines are exposed to observation for agronomic type and disease resistance. Several major industrial quality characteristics are determined (grain hardness, grain protein, SDS sedimentation values) based on Cd. Obregon seed. The bottom group is generally discarded based on minimum quality requirements, but entries outstanding for key traits are retained even if they have poor quality.

PYT: The best AL entries are promoted to unreplicated Preliminary Yield Trials (PYTs), including one or two repeated checks, and planted/analyzed according to specific statistical designs to eliminate the bottom end of the yield distribution. PYTs targeted for ME1, ME4, and ME5 are carried out in Cd. Obregon. Lines targeted for ME2, ME3, and ME6 are grown in unreplicated PYTs in Toluca. Thus the target environment is somewhat represented during the yield trial phase.

The trials are either planted on beds (per entry: 2 beds (80cm wide/3-5m long), with 3 rows/bed,) or in irrigation units called “melgas” (*melga* is “irrigation basin” in Spanish) with 16 plots/melga. In melgas every entry is sown as an eight-row plot of 3.5-5 m long.

At the same time PCs (for *parcela chica*, “small plot” in Spanish) with the same entries as in the PYTs are separately grown in an area where rust and/or Karnal bunt is artificially inoculated. The PCs provide disease resistance data. In addition the PCs form small seed multiplication plots, where roguing can be carried out, and thus provide the seed for the subsequent cycle.

During the summer cycle in Central Mexico, PCs may be sown in many different sites, including Patzcuaro and El Tigre, for disease and adaptation evaluation.

The entries are keenly scrutinized for lodging tolerance in the large PYT plots. Based on absolute and relative yield, agronomic type, disease resistance, and additional industrial quality tests including alveograms (based on Cd. Obregon seed) the best lines are promoted to an EAL.

EAL: When grown as Elite Advanced Lines, the materials are exposed to disease epidemics and also selected for quality traits, if in Cd. Obregon.

YT: The best EAL entries enter replicated Yield Trials. As with the PYTs the materials are grown under representative relevant environmental conditions. Three times replicated alpha-lattice designs are used. The trials are spatially analyzed.

The seed is fully quality tested, including baking trials. The best entries are selected as Candidates for the International Nurseries and Yield Trials for international distribution.

Space permitting, an (un)replicated trial is sown in another (simulated) mega-environment to gauge the performance of materials outside their targeted ME. Although genotypes are developed for an designated/targeted ME, based on their parents and enforced through their subsequent selection history, they may cross MEs.

International Nurseries and Yield Trials

Candidate International Nurseries: During the first multiplication phase the selected lines are increased in El Batan, where special care is taken to produce clean seed. The entries are treated with fungicides during their development.

During the second multiplication phase the lines are grown out in Mexicali, in north-western Mexico, a high-yielding Karnal bunt free location. At the same time the entries are again yield-tested in Cd. Obregon, or Toluca, depending on their target environment. The

latter is done to identify more precisely key outstanding lines for direct introduction into the crossing blocks and special promotion with NARSSs.

International Nurseries and Yield Trials: Finally, adapted materials are distributed internationally by the International Nursery section within the the Wheat Program.

Shuttle breeding efforts outside Mexico

Some segregating material is selected in other countries by CIMMYT staff and/or cooperators and returned to the Bread Wheat Program. The most important of these international shuttles are listed below:

- CIMMYT/Brazil (Acid soils)
- CIMMYT/China (*Fusarium* spp.)
- CIMMYT/Ecuador (Stripe rust)
- CIMMYT/Guatemala (*Septoria tritici*, BYDV, and *Fusarium* head scab)
- CIMMYT/Mexico, La Paz (Salinity)
- CIMMYT/Turkey (Winter and facultative wheat)
- CIMMYT/OSU (USA) (Winter and facultative wheat)

Interaction with Other CIMMYT Wheat Program Sections

Pathology interface

In collaboration with CIMMYT pathologists, all segregating populations are exposed to artificial and natural disease epidemics. The most important diseases for each ME are listed in the following table.

| Mega-environment | Major pathogens (in order of importance) |
|------------------|---|
| ME1 | <i>Puccinia recondita</i> , <i>P. graminis</i> , <i>P. striiformis</i> , <i>Erysiphe graminis</i> , <i>Tilletia indica</i> |
| ME2 | <i>P. striiformis</i> , <i>Septoria tritici</i> , <i>P. recondita</i> , BYDV, <i>Fusarium graminearum</i> , <i>Xanthomonas campestris</i> pv. <i>translucens</i> , <i>H. tritici-repentis</i> |
| ME3 | <i>P. recondita</i> , <i>P. graminis</i> , <i>S. tritici</i> , <i>S. nodorum</i> , <i>E. graminis</i> , <i>F. graminearum</i> , <i>Xanthomonas campestris</i> pv. <i>translucens</i> |
| ME4 | <i>P. recondita</i> |
| ME5 | <i>P. recondita</i> , <i>H. sativum</i> , <i>F. graminearum</i> , <i>Sclerotium rolfsii</i> , <i>P. graminis</i> |
| ME6 | <i>P. recondita</i> , <i>H. tritici-repentis</i> , <i>F. graminearum</i> |
| ME7 | <i>E. graminis</i> , <i>P. striiformis</i> , <i>P. recondita</i> , BYDV |
| ME8 | <i>E. graminis</i> , <i>P. striiformis</i> , <i>P. recondita</i> , eye spot, BYDV, bunts |
| ME9 | Bunts |
| ME10 | <i>E. graminis</i> , <i>P. striiformis</i> , <i>P. recondita</i> , BYDV |
| ME11 | <i>E. graminis</i> , <i>P. striiformis</i> , <i>P. recondita</i> , BYDV |
| ME12 | Bunts, BYDV, eye spot |

The most important diseases for the major breeding/screening environments in Mexico are described below.

Cd. Obregon

Inoculation of stem rust (*Puccinia graminis*) and leaf rust (*P. recondita*) by spray applications of susceptible border-mixtures ensures adequate infection of the entire targeted fields. Rust inoculation is carried out in the latter part of January.

Genotypes targeted for environments experiencing KB are inoculated with Karnal bunt (*Tilletia indica*) at the boot stage and subjected to thrice daily overhead watering with a sprinkler system during flowering to optimize conditions for infection and disease spread. Loose smut (*Ustilago tritici*) and bacterial blight may occur either naturally or artificially.

Toluca

Spray applications of susceptible border-mixtures provide stripe rust (*P. striiformis*) and leaf rust infection. Dispersal of infected straw at the tillering stage initiates epidemics of *Septoria tritici* and *Fusarium nivale*. Individual spikes of selected entries are inoculated with *Fusarium graminearum* (200,000 spores/L) to create head scab disease.

Although the above diseases are artificially inoculated, they also occur naturally. Bacterial and BYDV infections are induced in selected populations and occur naturally in many.

El Batan

This site is well suited for the development of leaf rust on an annual basis. Occasionally stripe rust occurs. Russian wheat aphid (*Diuraphis noxia*) is endemic in the region.

Poza Rica

Materials are screened specifically for spot blotch (*Helminthosporium sativum*) and heat resistance. Infections occur naturally in the form of heavy epidemics.

The following table summarizes the major diseases targeted for each breeding/screening location in Mexico.

| Location | Major diseases/insects for selection |
|-----------------|---|
| Cd. Obregon | <i>Puccinia recondita</i> , <i>P. graminis</i> , <i>Tilletia indica</i> , (<i>Ustilago tritici</i>) |
| El Batan | <i>P. recondita</i> , <i>P. graminis</i> , <i>Xanthomonas campestris</i> pv. <i>translucens</i> , BYDV, <i>Diuraphis noxia</i> , (<i>Ustilago tritici</i>) |
| El Tigre | <i>S. tritici</i> , <i>S. nodorum</i> , <i>Fusarium graminearum</i> , and <i>P. recondita</i> |
| Patzcuaro | <i>F. graminearum</i> , <i>S. tritici</i> and <i>S. nodorum</i> |
| Poza Rica | <i>Helminthosporium sativum</i> , <i>P. recondita</i> |
| Toluca | <i>P. striiformis</i> , <i>P. recondita</i> , <i>S. tritici</i> , <i>F. graminearum</i> , <i>F. nivale</i> , <i>X. campestris</i> pv. <i>translucens</i> , and BYDV |

Quality interface

The Industrial Quality Section evaluates the industrial quality of parents, selected segregating populations and advanced lines. The Bread Wheat Program aims at producing high yielding, broadly adapted resistant germplasm for a range of quality characteristics. This is important as quality requirements among different countries vary from medium and strong types for the production of leavened pan-type breads, to medium but extensible dough for unleavened, flat and steamed breads, to weak dough for cookie and cake production. Also, noodle quality is desired in some countries.

While much of the quality assessment is based on advanced materials and lines from international nurseries, increasing emphasis is being given to identifying better quality types among parental stocks. Electrophoretic techniques allow the identification of specific loci coding for the high molecular weight glutenin sub-units. These bands can now be traced and combined more effectively. Sedimentation tests for gluten quality using small grain samples are fast and effective and are used to screen materials.

To determine pre-harvest sprouting tolerance advanced lines considered for ME2 and ME3 are planted at Toluca in late January, when the major frost risk has passed. They are allowed to ripen during the peak rainy season. Materials are then screened visually for sprouting tolerance. Selected lines are sent to the laboratory and tested for alpha-amylase activity (this enzyme is activated at germination and is involved in the process of starch degradation). Tolerant lines will have low enzymatic activity under rainfall free conditions with a slow rate of change under increasing rainfall.

Physiology interface

The application of physiological tools is in its infancy. Presently collaborative research centers on the following topics: raising yield potential, identifying physiological tools useful in abiotic stress (heat) breeding, determining the basis of lodging tolerance, and describing the fundamentals of within population (both homogeneous and heterogeneous) competitive forces.

International Nurseries interface

The role of international testing as distribution and data collection mechanisms has been dealt with briefly in preceding sections. The primary role of the International Nursery section is to efficiently distribute germplasm internationally that has been developed by the Bread Wheat Program. International nurseries such as the IBWSN serve as a vehicle for the dissemination of improved and genetically diverse bread wheat germplasm. The materials can be used in national wheat crossing programs, or tested for direct release to farmers. The return of data to CIMMYT is of secondary importance.

International Yield Trials such as the ESWYT serve both a germplasm distribution function and that of a research tool. The Bread Wheat Program very much encourages data to be collected by collaborators on these Yield Trials and to return them to CIMMYT. These data may include many different traits; yield, yield components, development data such as flowering and maturity dates, response to diseases and abiotic stresses such as drought, heat or soil acidity, plus miscellaneous data such as nematode resistance, chapati-making quality or leaf rust genes.

The collected data from International Screening Nurseries and Yield Trials are used extensively within the breeding program to help define and fine-tune objectives and direct

crosses for particular MEs. The handling of International Nurseries and Yield Trials is the responsibility of the International Nursery Section and can be divided into four major activities:

- Formulation and targeting of nurseries, in conjunction with CIMMYT breeders and NARS clients.
- Nursery preparation and distribution. Each nursery consists of a set of cultivars and lines and focuses on the specific requirements of individual MEs.
- Collation and analysis of returned data (IWIS).
- Distribution of information and reports.

Nursery preparation involves the chemical treatment, packaging, and distribution of healthy, disease-free seed grouped into mega-environment-oriented Screening Nurseries and Yield Trials. Seed is cleaned and treated with fungicide and insecticide prior to distribution to avoid the introduction of foreign pests and diseases. The system is computerized to facilitate the production of nursery lists.

Data returned by cooperators are analyzed with the help of the International Wheat Information System (IWIS) that was developed as a computerized database system to store, view, and query international nursery data. The program allows instant viewing of data regarding specific lines, locations, and nurseries. It is presently being modified to be used in the Bread Wheat Program and to allow faster application of data to the breeding process.

Presently reports and diskettes are produced using data collected at many sites and made available to cooperators. The accuracy and completeness of the reports depends heavily on the cooperation of staff in the NARSs. In the future we hope to provide access to IWIS and its data to all collaborators via the Internet.

Training interface

The In-service Training Program coordinates closely with the Bread Wheat Program. Trainees with a primary focus on bread wheat spend most of their practical time, which constitutes about 50% of the total training period, in the Bread Wheat Program.

In addition the Bread Wheat Program sometimes provides the opportunity, depending on availability, to a well experienced person from a NARS to spend 6 to 12 months in the Program, as a Mid-Career Fellow. In that position emphasis is not just on learning new germplasm, but primarily on how to manage a large breeding program, including how to set the required objectives, provide leadership to the staff/team, utilize the available resources efficiently, and achieve the objectives.

For additional information, please contact one of the three Bread Wheat Program breeders.

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(as of January 1998)

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