CIMMYT

DURUM WHEATS:

CHALLENGES AND OPPORTUNITIES

Ciudad Obregon, Mexico, March 23-25, 1992

S. Rajaram
E.E. Saari
G.P. Hettel
Editors

International Maize and Wheat Improvement Center
CIMMYT

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Wheat Special Report No. 9
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International Maize and Wheat Improvement Center
(CIMMYT)

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On the cover: Durum wheats on CIANO Station, Ciudad Obregon, Mexico.
Photo by G.P. Hettel.

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PREFACE

The importance of durum wheat as a major basic food is well established for most of countries of North and East Africa and the Near and Middle East. It is also important in the Asian Subcontinent and the Andean Region of South America as well as a major crop in Canada, the United States, Argentina, Chile, and several countries of southern and eastern Europe.

Twenty-six years ago when CIMMYT's durum wheat improvement program was established, major goals were to incorporate dwarfing genes, photoperiod insensitivity, enhanced spike fertility, and better disease resistance. These goals have all been accomplished.

With the transfer of a major dwarfing gene from bread wheat to durum wheat, the resulting semidwarf durum wheats heralded significant yield advances over the tall durums and laid the foundation for a systematic breeding approach that diversified adaptation and other traits. The yield potential of the semidwarf durum wheats has risen gradually over the last 20 years and during the same period there have been significant increases in biomass, harvest index, and 1000 grain weight. Durum wheat breeding efforts have been expanded through CIMMYT's collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA) in Aleppo, Syria.

In the midst of this spectacular yield advance and improved quality traits, we felt that to further expand the adaptability of durum wheat, there was a need to integrate the knowledge currently available in the areas of pathology, physiology, and biometry. To achieve this, we invited durum wheat workers from around the world to come to Ciudad Obregon, Mexico, for a three-day international workshop, March 23-25, 1992. Participants came from Latin America, the USA, Canada, Italy, Ethiopia, India, and Australia.

Selected papers presented during the workshop and included in this Special Report provide updated information on the crop, which we believe will be useful to durum wheat workers worldwide. Applicable discussion notes were taken by G.P. Hettel and are included after the various presentations. For convenience, paper abstracts are included in a separate section beginning on page 180.

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BREEDING DURUM WHEAT AT CIMMYT

O. Abdalla, J.A. Dieseth, and R.P. Singh
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Introduction

Durum wheat, *Triticum turgidum* var. *durum*, is cultivated on approximately 17 million hectares worldwide. This represents only 8% of the world's total wheat area (CIMMYT 1991). However, the importance of durum wheat (DW) stems from the fact that its production is concentrated in localized areas in developing countries where it is the main staple food and covers a greater portion of total wheat area (Table 1). Durum wheat production is concentrated in the Middle East, North Africa, the Asian Subcontinent, and Mediterranean Europe. Other production areas include parts of Ethiopia, Argentina, Chile, and the Andean region of South America as well as Mexico, the United States, and Canada.

Table 1. Durum wheat as percent of all wheat production in selected countries.

Developing countries	% durum of all wheat	Developed countries:	% durum of all wheat
Turkey	15-20	Canada	17
Morocco	50	USA	6
Algeria	75	Former-USSR	3
Tunisia	75	France	5
Ethiopia	60-70	Italy	50

Durum wheat productivity in developing countries is generally low. This may be attributed to the fact that the crop is grown under low inputs in semi-arid regions and other marginal areas characterized by sharp annual fluctuations in cropping conditions. Under favorable environments where moisture and other resources are not limiting, higher yield levels, approaching or surpassing bread wheat, are obtained.

The efforts of CIMMYT's Durum Wheat Section have led to remarkable improvement in DW productivity. In this presentation, CIMMYT's objectives and breeding methodology are outlined. Achievements and progress in increased yield potential, drought tolerance and improved grain quality are presented. Current and future challenges in DW improvement are discussed.

Durum Breeding at CIMMYT

At CIMMYT, intensive improvement of DW has been conducted for little more than two decades. The main goal of the CIMMYT's Durum Section is to assist developing countries in increasing DW productivity by supplying high yielding, widely adapted, disease resistant germplasm with good end-use quality characteristics. To achieve these objectives, CIMMYT directs its breeding efforts towards three main mega-environments (MEs). An ME is defined as a broad area with similar biotic and abiotic stresses, cropping system requirements and consumer preferences. The DW MEs are:

- Irrigated environments that include the Gangetic, Sind, and Nile Valleys; central Chile; and northwestern Mexico. The main production constraints in this ME are the rust pathogens, mainly leaf and stem rust, and occasionally salinity.

- High rainfall environments that include areas with greater than 500 mm annual precipitation, e.g., the Andean region, Mediterranean Coast, and East Africa. The primary diseases of concern in this ME are the rusts, septoria blotch, and powdery mildew.

- Semi-arid environments with drought stress that include locations receiving less than 500 mm annual precipitation, e.g., Middle East, North Africa, Southern Cone (Argentina), and Central India. In addition to drought stress, diseases such as rust and insect pests (Hessian fly and sawfly) are the main constraints to DW production.

The success of the CIMMYT Durum Section may be attributed to its breeding philosophy and methodology. Figure 1 outlines the breeding methodology and depicts the generation flow from crossing through to delivery of germplasm to national programs. The main components of the breeding methodology can be summarized:

- A directed and broad-based crossing program involving selected parents that are adapted to a specific ME or breeding objective category.

- Shuttle breeding of segregating populations between contrasting climatic conditions and differing complexes of diseases and insects. The material is generally shuttled between Cd. Obregon (Sonora State) in northwestern Mexico and Toluca and El Batan (Mexico State) in Central Mexico. Other screening sites in Mexico include Huamantla (Tlaxacala State) and Patzcuaro (Michoacan State).

- Multilocation testing through CIMMYT's international nursery network. Under such testing, germplasm is exposed to diverse disease virulence and variable agro-climatic conditions.

Through this dynamic breeding program, CIMMYT has been able to provide developing countries with high yielding, management-responsive and input-efficient germplasm.

Table 2. Distribution of CIMMYT durum wheat germplasm.

Segregating populations:	F_2 (SxS) Bulk F_2 (SxW) Bulk
Screening nurseries:	International Durum Screening Nursery (IDSN)--Optium Environments IDSN--Dryland Environments IDSN--High Rainfall Environments
Yield trials:	Elite Durum Yield Trial (EDYT) International Durum Yield Nursery (IDYN)

Such basic germplasm has been utilized and released as varieties in many parts of the world. Table 2 lists the main nurseries distributed by CIMMYT's DW Section.

Achievements and Progress

Yield potential and stability

The achievements made in increasing DW yield potential are reflected in the series of varieties released in Mexico from the 1950s to date. Figure 2 shows yield potential, biomass, and harvest index of the varieties released over the years in Mexico. Yields have increased from 4 t/ha (Barrigon Yaqui) to 9.6 t/ha (Aconchi 89). The percent yield increase of high yielding cultivars (HYVs) over the variety 'Mexicali 75' in optimum environment DW yield trials is presented in Figure 3. For the 1973-1990 period, the observed yield increases represent an increment of about 1% per year.

Grain yield improvements were based on increased grain number per m^2 due to more grains per spikelet (Waddington et al. 1987). Progressive increases in DW yield potential have been associated with increased biomass as well as improved harvest index (Figure 2). Further yield advances, however, are expected by increasing harvest index from its current levels.

Mean yield of the top five CIMMYTs durums in each site of the 19th Elite Durum Yield Trial (EDYT) is expressed as a percentage of the local check yield (Figure 4). Local checks represent site-specific adaptations. With the exception of only seven locations out of 44, the top five CIMMYT durums yielded more than the locally adapted checks. These results indicate that CIMMYT has been successful in providing national programs with high yielding germplasm with potential of release as varieties. In Figure 5, the yield response of 'Yavaros 79' is regressed over site mean yields across the 48 locations of the 17th EDYT. At most sites, the yield of 'Yavaros 79' was higher than the location mean yield. This shows that 'Yavaros 79' combines high yield potential and stability and as a consequence wide adaptation, a feature common in many CIMMYT DW advanced lines. Such features have led to the release of CIMMYT germplasm as varieties in many developing countries. Table 3 shows the area planted to the most popular CIMMYT durums during 1990-91.

Table 3. Area planted to popular CIMMYT durum wheat crosses, 1990-91.

Cross	Year Released	Area (000 ha)	Main Countries
Frigate	1983	480	Syria, Algeria
Cisne	1971	460	Morocco, Turkey
Bittern	1979	400	Morocco, Turkey

Source: CIMMYT Economics Program.

Drought tolerance

Semi-arid conditions prevail in 70% of the durum wheat producing areas (CIMMYT 1991). Drought stress is extremely variable and unpredictable (Cantrell 1987). In the Middle East and North Africa, terminal drought stress is common and often is combined with cold temperature stress in high elevation areas or terminal heat stress in certain pockets (ME4A). In contrast, early drought is experienced in South America, e.g., Argentina (ME4B). In South East Asia, e.g., Central and Southern India, the crop is raised under residual soil moisture and prevailing hot temperatures extenuate drought stress (ME4C) (CIMMYT 1989).

Breeding work for this ME is conducted in collaboration with the International Center for Agricultural Research in the Dry Areas (ICARDA). CIMMYT's present methodology to identify drought-tolerant germplasm involves selection under reduced irrigation in the Yaqui Valley of northwestern Mexico and alternating with a summer generation in the sandy soil, drought-prone site of Huamantla in central Mexico.

Drought tolerance/resistance is a complex interaction of morphological and physiological factors. Routine, rapid, and reliable screening methods have yet to be developed. At CIMMYT, yield per se under dry conditions is the main selection criterion for DW advanced lines. In segregating populations, the important characters considered during selection include the following:

- Delayed leaf senescence;
- Tiller variability;
- Low spike sterility;
- Grain plumpness;
- High test weight; and
- High yield.

In addition to multilocation testing in hot spot semi-arid areas in West Asia and North Africa (WANA), line source or gradient irrigation system, as described by Hanks et al. 1976, is utilized to identify yield stability under varying moisture stress conditions. Figure 6 shows the yield performance of four DW lines under variable moisture regimes in line source irrigation system. Cultivars Chen'S'/Altar84 and Altar84/Aos'S' exhibited higher yields than environmental mean yields across all moisture regimes. This suggests that these genotypes have high yield potential and drought tolerance and hence their input-responsive and input-efficient performance. Cultivar 'Focha' exhibited high yield under favorable environment, but did poorly under moisture stress. In contrast, cultivar Chen'S'/Poc'S' yielded well under moisture stress, but was not responsive to improved production conditions.

Despite the difficulties of breeding for semi-arid conditions, notable progress has been made. Table 4 shows the performance of advanced durum lines compared to the drought-tolerant line Omrabi 5. Under reduced irrigation (a total of 200 mm), yields as high as 2.8 t/ha were obtained, representing a 17% increase over the dryland check.

Disease resistance

One of the major limitations to increased durum wheat cultivation has been unsatisfactory levels of disease resistance. The major diseases of common occurrence in durum growing areas are stem rust (*Puccinia graminis*), leaf rust (*P. recondita*), stripe rust (*P. striiformis*), septoria blotch (caused by *Septoria tritici* and *S. nodorum*), head scab (*Fusarium graminearum*), tan spot (*Helminthosporium tritici-repentis*), powdery

Table 4. Outstanding lines under reduced irrigation, CIANO, 1989-90.

Genotype	Yield t/ha	 % of Omrabi 5
QFN/KILL	2.783	117
WIZZA	2.883	117
STN'S'/GOTE'S'	2.535	107

Table 5. Distribution of diseases and insect pests on durum wheat by ME.

Disease/ Insect	Irrigated (ME1)	Mega-environment High Rainfall (ME2)	Semi-Arid (ME4)
Rusts:			
Stem	X	X	
Leaf	X	X	
Stripe	X	X	X
Powdery mildew		X	
Septoria blotch		X	
Tan spot		X	
Head scab		X	
Bunts			X
Sawfly			X
Hessian fly			X

mildew (*Erysiphe graminis*), and bunts (*Tilletia* spp.). In addition, Hessian fly and sawfly are serious insect pests on durum wheat in North Africa and the Middle East. Table 5 shows the distribution of the major diseases and insect pests of durum wheat based on the production MEs.

The multiple resistance approach for the major pathogens in a given ME has been adopted. In this strategy, lines directed towards a specific ME should compile many resistance genes for the multiple diseases present in the target environment.

Artificial field inoculation with virulent cultures is routinely practiced in CIMMYT's plots. In addition, many disease hot spots in Mexico are utilized in screening for disease resistance (Table 6). It is evident that, while the virulence of some diseases (e.g., leaf rust) is quite broad in Mexico, it doesn't completely represent the spectrum found in all durum wheat growing areas worldwide. Hence, international multilocation testing is a vital part of building disease resistance. Through such screening, advance lines are exposed to various pathogen populations.

Table 6. Mexican locations for disease screening.

Locations	Leaf rust	Stem rust	Stripe rust	Septoria	Fusarium
Obregon/CIANO	X	X	-	-	-
El Batan	X	X	X	-	-
Toluca	X	X	X	X	X
Patzcuaro	-	-	-	X	X

Another CIMMYT approach to build up genetic resistance is the establishment of specific shuttle programs with certain disease hot spots outside of Mexico that have known diverse and virulent populations. Following this strategy, a collaborative shuttle program with Ethiopia was established in 1984 to broaden the genetic resistance variability for stem rust in CIMMYT durum wheats.

Identified sources of resistance from international screening as well as landraces and known resistance sources from the CIMMYT Wheat Germplasm Bank are utilized in the crossing program. Interspecific and intergeneric crosses are also made to transfer resistance to durum wheats. For example, an attempt is currently underway to transfer resistance to head scab from Chinese bread wheats and Russian wheat aphid resistance from *T. dicoccum*.

Progress has been made in improving the level of disease resistance in CIMMYT durum wheats. Achievements in improving stem and leaf rust resistance are described below:

Stem rust resistance--Table 7 shows the stem rust reaction of some CIMMYT DW lines in the 17th IDSN. 'Boohai', the major DW variety in Ethiopia, exhibited low stem rust infection with a 5.0 ACI (average coefficient of infection) compared to the Mexican varieties 'Mexicali 75', 'Yavaros 79', and 'Altar 84'. However, four other CIMMYT durums displayed much better resistance than 'Boohai' with an observed ACI range of from 0.0 to 3.8. These results indicate that some CIMMYT DW lines have adequate stem rust resistance.

Table 7. Stem rust resistance of top performing advanced lines compared to earlier varieties in the 17th IDSN (4 locations).

Variety or Cross	ACI
Ajaia	0.0
CHEN/TEZ	0.3
HUI/YAV	2.5
Fillo	3.8
Boohai (Tolerant check)	5.0
Altar 84	10.0
Yavaros 79	11.3
Mexicali 75	15.3

Genetic analysis of some CIMMYT durums (Singh et al. 1992) has indicated the presence of five genes in various combinations in the seedling stage. Two of these are suspected to be *Sr9e* and *Sr12*, which confer immunity and moderate adult plant resistance, respectively, in Mexico. Only one of the other three seedling genes was effective in the adult plant stage. All these genes appear to be ineffective in Ethiopia. Genetic diversity is being enhanced by incorporating *Sr2* from 'Iumillo', *Sr2*, and *Sr13* from Khapli emmer and other unknown resistance genes from wheats identified to be resistant in Ethiopia and North Dakota.

Leaf rust resistance--Unpublished results of Singh et al. have indicated the presence of various seedling-effective genes to certain Mexican pathotypes of *Puccinia recondita* f.sp. *tritici*. However, when pathotype BBB/BN, considered to be a durum pathotype, is used in the test, most of these genes are ineffective. The adult plant resistance of most durums to the above pathotype appears to be based on the interaction of 2 or 3 additive genes. These genes could be derived from 'Iumillo' because crosses of CIMMYT durums with 'Iumillo' failed to segregate. Genotypes, such as 'Altar 84', which possibly carry 3 additive genes display very low rust severity in Mexico and elsewhere. Singh et al. (unpublished) believe that this combination of additive genes not only confers very effective resistance, but also is of a durable nature. 'Altar 84' displayed very low ACIs in IDSN data (Table 8). When only one or two of the above additive genes are present, a slow rusting response is observed.

Table 8. Leaf rust resistance of top performing advanced lines compared to earlier varieties in the 17th IDSN (13 locations).

Variety or Cross	ACI
CBY/RUFO//LARU	0.5
CARC/AUK	0.6
CHEN/ALTAR 84	0.6
Golondrino	0.7
Altar 84	1.0
Carc	1.1
Yavaros 79	11.5
Mexicali 75	29.9

Improved grain quality

Durum grain is used to prepare various products in different parts of the world. Table 9 lists the major products from durum wheats and their quality requirements. Durum quality parameters include: 1) kernel vitreousness, 2) kernel size, 3) pigment concentration, 4) protein content, and 5) gluten strength.

Higher quality standards are usually required for the industrial products made from semolina such as spaghetti, macaroni, and other pastas. CIMMYT is responding to the increasing demand for good quality durums by applying heavy selection pressure for quality factors. Segregating populations, both at F2 and F5, are subjected to seed screening for appearance, plumpness, color, and yellow berry. Subsequently, the selected lines are evaluated in the quality laboratory for protein content, pigment concentration, and gluten strength. Advanced lines and progenitors for the crossing block are subjected

Table 9. Durum use and quality requirements in different parts of the world.

Country/region	Use	Requirement
North Africa, Europe, America, Australia	Pasta	Medium to strong gluten, high yellow pigment
North Africa	Couscous	Medium to strong gluten, high yellow pigment
Middle East	Unleavened bread	Medium to strong gluten
Near and Middle East	Bulgur	Hard grain, yellow pigment
Andean Region	Mote	Hard grain

to more extensive testing including for semolina yield, pigment content, and spaghetti processing qualities. The ultimate goal is to simultaneously increase yield and improve grain quality.

Table 10 lists the quality characteristics of some advanced CIMMYT lines. Our goal is to produce lines with better quality than those listed. Figure 7 shows the distribution of gluten strength in the 20th and 24th IDSNs. The 24th IDSN had a lower number of lines with weak gluten strength and a higher number of lines with medium and strong gluten strength compared to the 20th IDSN. These results indicate that, in recent years,

Table 10. Improved quality characteristics of CIMMYT durum wheat advanced lines compared to earlier varieties.

	Protein (%)	Sedimentation (cc)[a]	Yellow pigment (ppm)
New advanced lines			
CARC/AUK	11.8	12.0	9.3
SULA/WLS/DWL5023	11.9	12.5	8.2
CHEN/Altar 84	12.0	14.5	7.6
Earlier varieties			
Altar 84	11.2	11.5	6.9
Yavaros 79	10.7	12.0	7.4

[a] Gluten quality characteristic.
Note: Higher values correspond to higher quality.

CIMMYT has produced and distributed a greater number of lines with superior quality to national programs. This trend will continue in the future as quality is expected to be an important consideration with increased productivity and self-sufficiency in developing countries.

Current and Future Challenges

The yield gap

Under optimum environments where production is not limited by moisture and fertilization, research has demonstrated that durum wheat has a high yield potential (9.6 t/ha). Realization of such a potential in farmers' fields will substantially increase total production. However, on-farm research in northwestern Mexico shows that a yield gap of 27% exists between on-farm trials and experimental station trials. This large gap exists despite the fact that the trials were conducted on fields of progressive farmers. Compared with the region's average production of 5 t/ha, the gap is even greater (48%). In less favorable environments, the yield gap is expected to be even greater.

Thus, to realize the on-farm yield potential of improved varieties, appropriate production technologies are needed. In this respect, the role of crop management research and agricultural extension cannot be underestimated.

Marginal and nontraditional areas

With increasing demand for food from traditional wheat growing areas, agricultural production is extending to marginal areas. In nontraditional areas, tremendous efforts are under way to grow wheat to meet local demands. Acceptable production levels have been achieved in some areas and industrial quality is expected to be a major demand in the future.

Many constraints limit production in marginal and nontraditional areas. These include incidence of disease, insects, drought, acid soils, salinity, soil infertility, and sharp annual fluctuations in cropping conditions. Breeding for such areas emphasizes yield stability and dependability. Genetic variability for resistance or tolerance to the stresses encountered in these environments will be needed. Sources for this variability include interspecific and/or intergeneric donors. In addition, new biotechnological approaches will be utilized. Thus, in the future, techniques of alien transfer will expand in addition to the utilization of new biotechnological approaches as a tool for traditional breeding.

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Discussion Notes

Acevedo: You should expand the use of the line source technique as it relates to multi-location testing.
Abdalla: The line source is a good test of drought tolerance per se.

Elias: You concentrate on gluten strength since it is associated with quality, but what about protein and semolina extraction?
Abdalla: We look at these traits in advanced lines only.
Peña: Actually, we put a lot of pressure at the segregating stages for semolina extraction.

Kohli: Have you identified durum lines for acid soils?
Abdalla: The CIMMYT Wide Crosses Section has just recently begun looking at alien material that may be a source of tolerance.

Fischer: The role of durums has become much more important as it relates to triticale improvement and the exciting work involving the creation of synthetic hexaploids through crossing durums with *Triticum tauschii.*

Abdalla: We generally select for multiple disease resistance in the early generations.
Hamblin: Your selection methodology, I think, is a good example of specific adaptation over wide adaptation. Could you amplify a bit on broad vs. specific?
Abdalla: How broad is broad? It depends on where one makes the cut off.

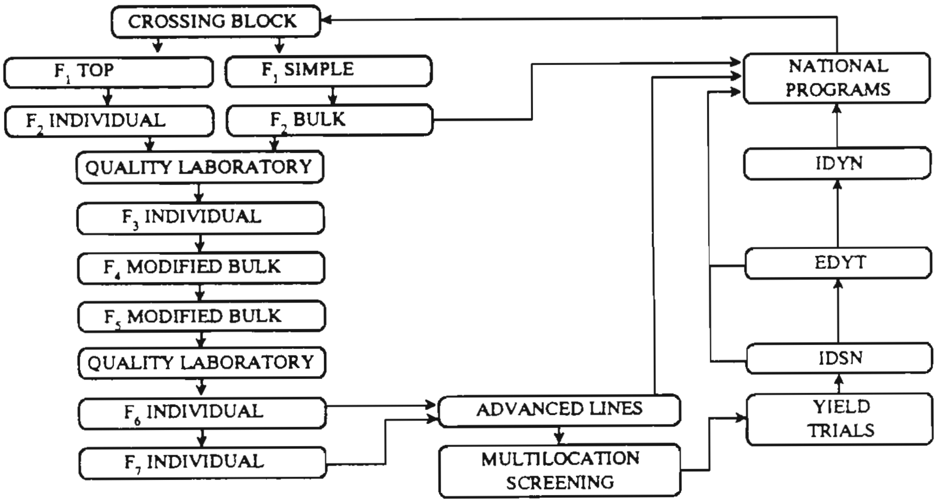


Figure 1. Durum wheat breeding methodology at CIMMYT.

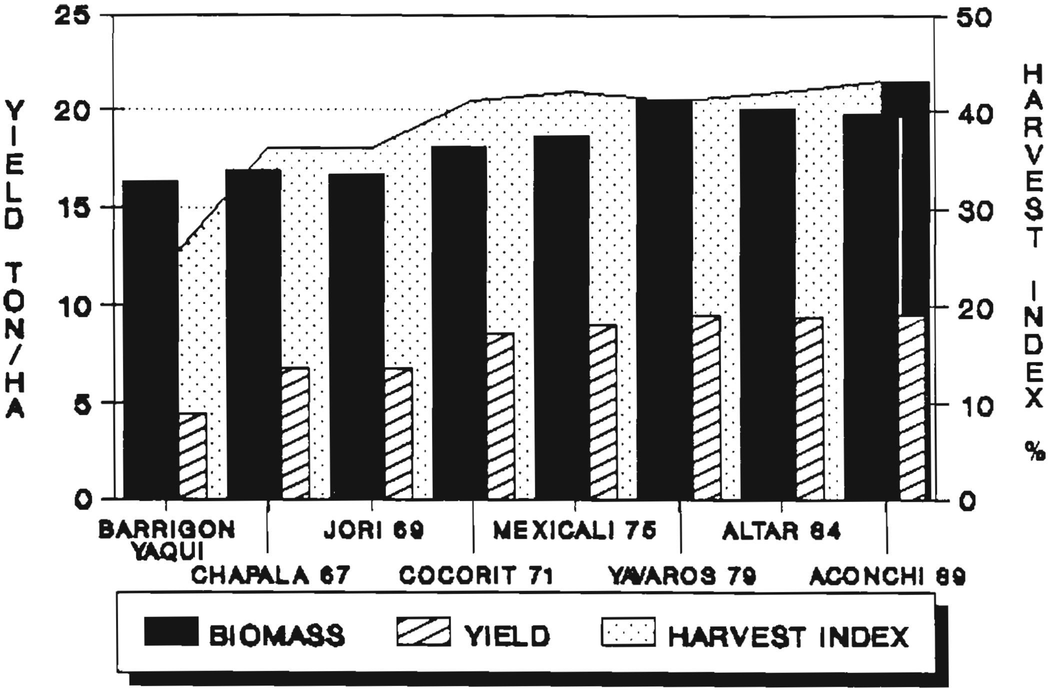


Figure 2. Durum wheat yield potential in optimum environments.

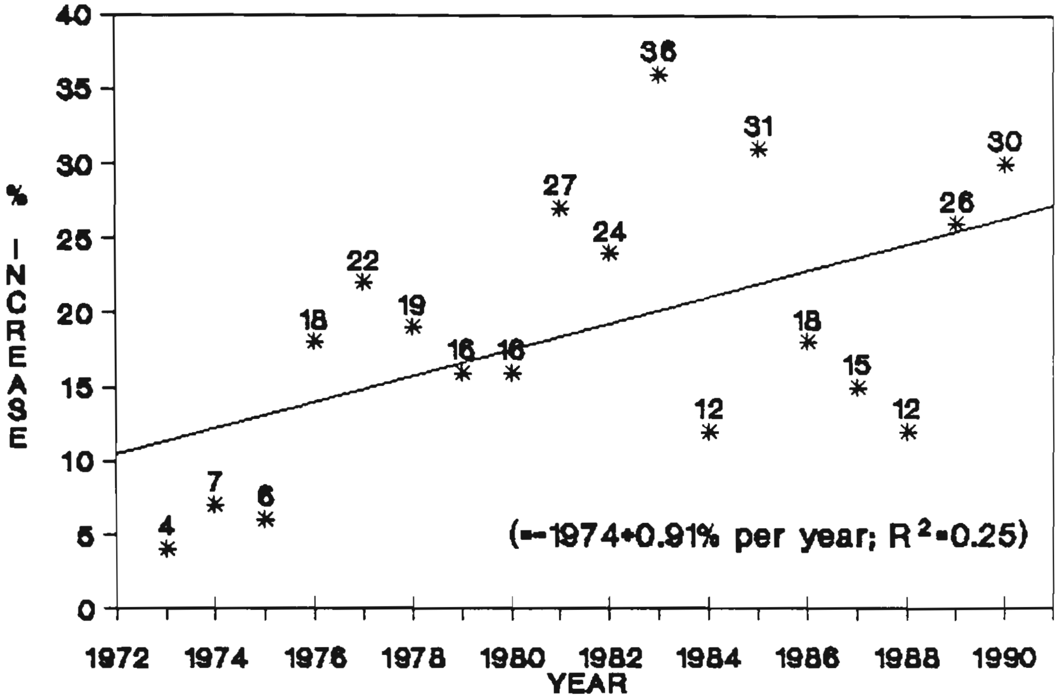


Figure 3. Yield increase of HYV durum wheats over Mexi75.

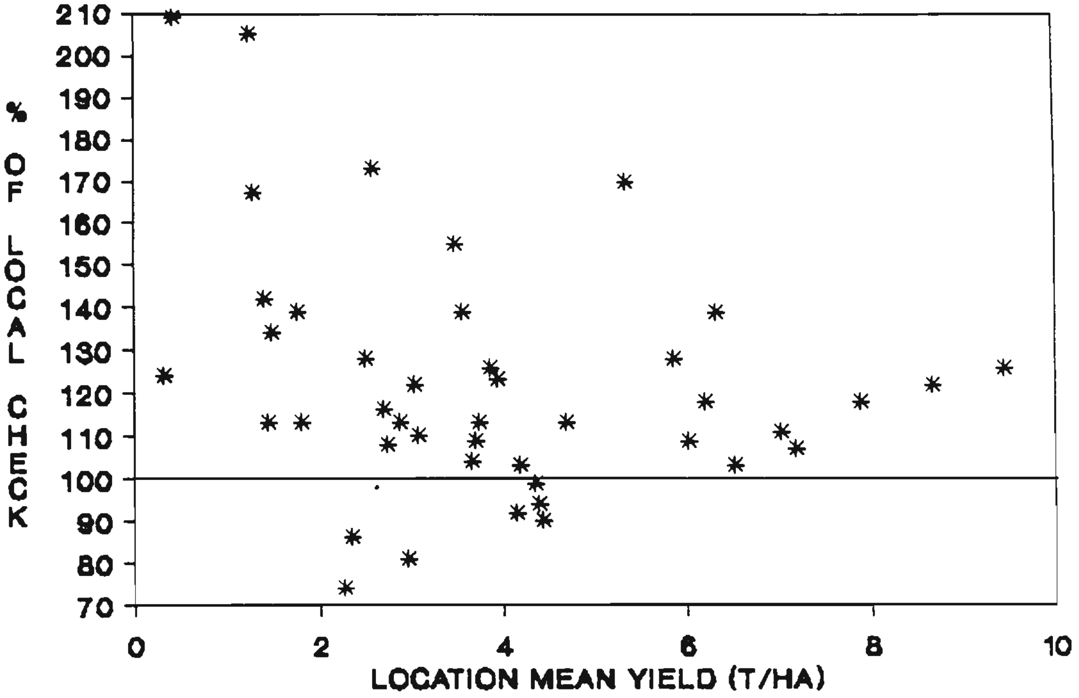


Figure 4. Mean performance of the top five CIMMYT durum wheats in the 19th EDYT.

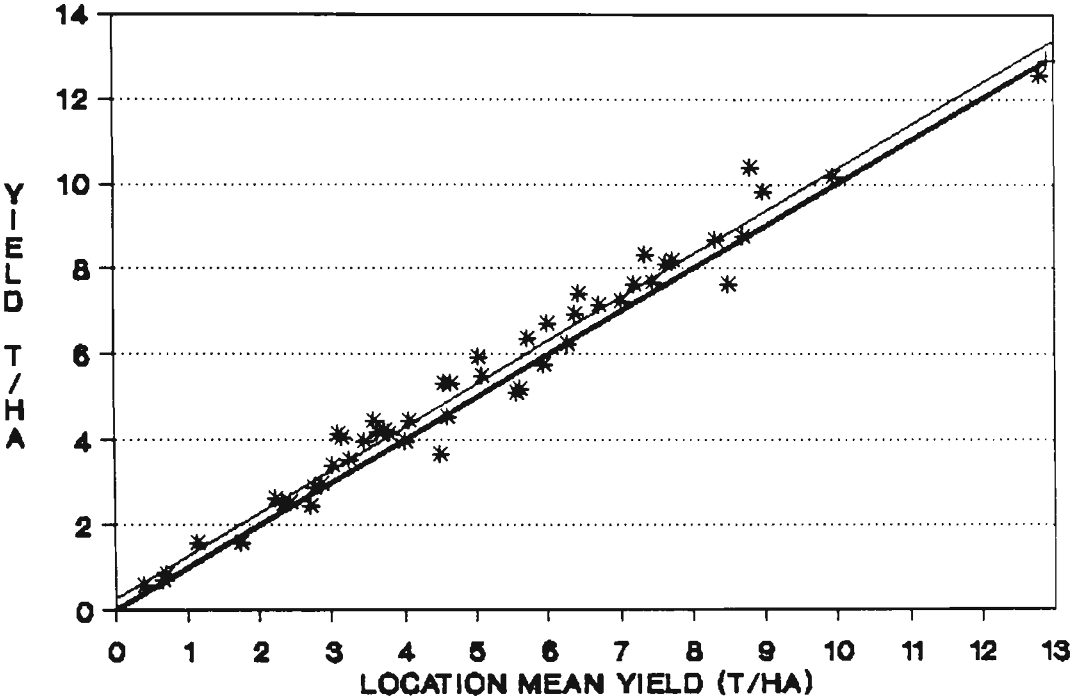
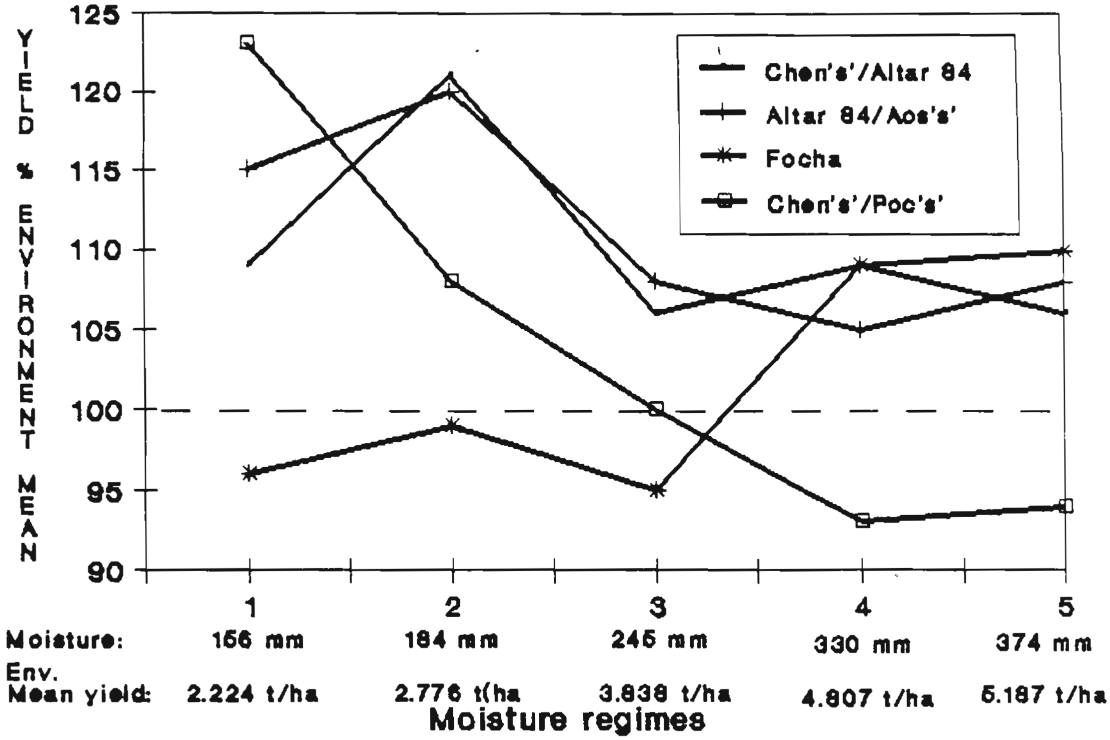


Figure 5. Performance of YAV79 across locations in the 17th EDYT.



Source: CIMMYT Agronomy Section, 1989. Line Source Studies

Figure 6. Yield stability of CIMMYT durum wheats across variable moisture regimes.

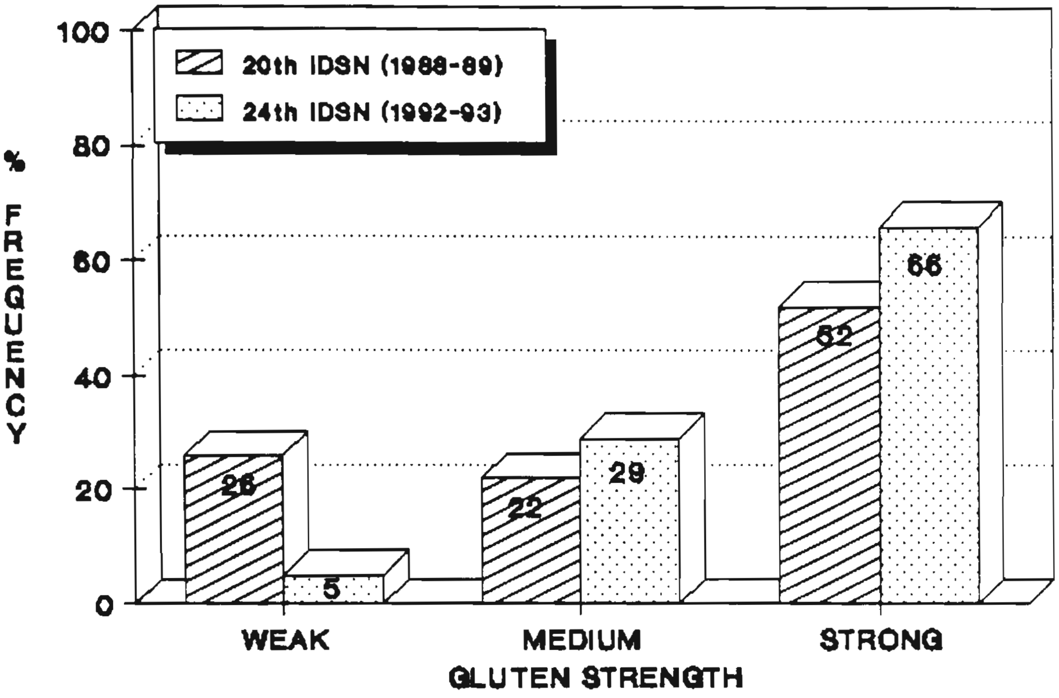


Figure 7. Distribution of gluten strength in the 20th and 24th IDSNs.

DURUM WHEAT BREEDING FOR MEDITERRANEAN DRYLANDS OF NORTH AFRICA AND WEST ASIA

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Introduction

Durum wheat (*Triticum turgidum*, var L. *durum*) covers 10% of the total wheat area in the world. About 50% of this area is in the developing countries. In these countries, durum wheat occupies approximately 11 million hectares of which 80% is found in the Mediterranean region of West Asia and North Africa (WANA) (Table 1). Rainfall and temperature regimes in the Mediterranean drylands show large and unpredictable fluctuations from year to year. Drought and extreme thermal stresses (cold and heat) affect durum wheat growth at various development stages. In the same growing season and at the same or different growth stages, both drought and cold or drought and heat can occur. In addition, several diseases, insects, and viruses can attack durum wheat in the WANA region.

As for the use of durum wheat grain in the human diet, it is included in most dishes and food products consumed in the WANA region. Traditional products made from durum wheat grain are local breads, burghul, frike, couscous, and pasta. Consumption is very high ranging from 150 to 200 kg/person per year. Durum wheat consumption is highest in the rural areas.

Table 1. Area and average grain yield for durum wheat grown in Mediterranean North Africa and West Asia.

Moisture regime	Area (1000 ha)	%	Grain yield (t/ha)
Usually under some stress	35000	41	0.63
Frequently under stress	24000	27	0.98
Sometime under stress	25000	29	1.23
Rarely under stress	500	3	2.12

Agro-Ecological Zones of Durum Wheat in the WANA Region

In the WANA region, drought may occur alone or in combination with each of the extreme thermal stresses at various stages of crop development. Furthermore, even when the crop is grown in an "optimum moisture environment," occasional periods of stress due to lack of moisture or to temperature extremes may occur during the growing season. Use of irrigation in this region is limited and in many areas nonexistent. Therefore, the genetic manipulation of plants to improve the productivity and stability of durum wheat through improvement to abiotic stress resistance is still the only possible and practical solution. Complete crop loss can sometimes occur because of frost damage at anthesis or sorocco (hot and dry winds) damage during anthesis and grain filling periods.

Temperature extremes, i.e., cold, frost, and heat, can affect grain yield directly but also aggravate the effect of drought.

Lack of moisture remains the most dominant feature of dryland in the WANA region. The erratic nature of precipitation adds to the hazard of limited rainfall, and makes it more challenging to develop cultivars adapted to these types of environmental conditions. In addition to these stresses, durum wheat yields in the WANA region are reduced by biotic stresses and poor crop management and weed control.

Long-term averages for precipitation, evapotranspiration, minimum and maximum temperatures, and frequency and extent of diseases and insect damage in the main durum wheat growing areas of the WANA region have been analyzed. Four major agro-ecological zones have been determined in terms of prevailing abiotic and biotic stresses with the aim to develop specific germplasm with the required genes of resistance for the environmental constraints in each agro-ecological zone.

Low rainfall (below 350 mm) and low winter temperatures
This zone covers approximately 40% (3.5 million ha) of the total area sown with durum wheat in the WANA region. The major abiotic production constraints are:

- Drought,
- Winterkill and frost at anthesis, and
- Terminal stress (drought and heat).

The site-to-site and year-to-year variabilities within this environment are very large. This agro-ecological zone is also endemic to the following biotic stresses:

- Yellow (stripe) rust (*Puccinia striiformis*),
- Common bunt (*Tilletia foetida* and *T. caries*),
- Wheat stem sawfly (*Cephus pigmaeus*), and
- Sunni pest (*Eurygaster integricens*).

Wheat stem sawfly and sunni pests usually cause crop damage in the dry seasons, while yellow rust and common bunt dominate during the wet ones. This environment is found in the continental and high altitude areas of Morocco, Algeria, Syria, Turkey, and Iraq.

Low rainfall (below 350 mm) and mild winter temperatures
This zone covers approximately 2.5 million ha or 25% of the land cultivated with durum wheat in the WANA region. It is mainly in the coastal and southern latitude areas of North Africa.

The major abiotic stresses in this zone are:

- Drought and
- Terminal stress (heat and drought).

The biotic stresses are:

- *Septoria tritici*,
- Tan spot (*Helminthosporium tritici-repentis*) ,
- Leaf rust (*Puccinia recondita*),
- Hessian fly (*Mayetiola destructor*), and
- Dryland root and foot rots.

Hessian fly and dryland root and foot rots usually occur in the dry seasons, while leaf rust and *Septoria tritici* are more common in the wetter ones.

Moderate rainfall (350-600 mm) and low winter temperatures
This zone covers 1.5 million ha, i.e., 17% of the total durum wheat growing area in the region. It includes such areas as north Morocco, northeastern Algeria and Syria, and the southwestern parts of Turkey. The biotic stresses are the major constraints in this zone. However, spells of cold, frost, and sorocco can occur and affect durum wheat yields. The biotic constraints in these areas are:

- Yellow rust,
- *S. tritici*,
- Tan spot,
- Leaf rust, and
- Sunni pest.

Moderate rainfall (350-600 mm) and mild winter
Around 1 million ha are grown in this zone that are mainly found in North Africa and southwestern Turkey. In addition to climatic fluctuation, diseases and insects are the major constraints. Most of the biotic stresses prevailing in the WANA region are present in this zone.

The area under full irrigation is small and confined to Egypt, Saudi Arabia, and some parts of Syria and Iraq. However, full and supplementary irrigation schemes are increasing in most durum wheat growing countries of WANA.

Breeding Methodology

Although most food crops in the world are frequently affected by environmental stresses, few breeding programs are working on the development of abiotic stress-tolerant germplasm. Most breeding programs are targeted to favorable environments where high levels of yield can be achieved. In WANA, drought or moisture deficit is the most dominant stress factor limiting production in durum wheat. Drought incidence usually varies largely from site to site and from season to season. Even in the favorable rainfall environments where an annual average yield of 4 t/ha is usually harvested, drought alone or in combination with thermal stresses can occur and sometimes reduce grain yields below 1 t/ha. As the durum wheat growing environments in WANA are mainly located in areas with alternating stressed and favorable conditions, the joint CIMMYT/ICARDA Durum Wheat Project at Aleppo, Syria has developed a strategy that aims at breeding improved germplasm with abiotic stress resistance and responsiveness to improved conditions as follows:

- Resistance to abiotic and biotic stresses,
- Less environmental sensitivity to inter- and intra-seasonal fluctuations,
- Responsiveness to improved conditions when the seasons are favorable.

Our research work has shown (Nachit and Ketata 1986, Nachit et al. 1988, Nachit, 1988) that selection efficiency is greatest when selection is made:

- In the environment in which the varieties will be commercially grown,
- For combining resistance to abiotic stresses with yield potential, and
- For adaptation to variable environmental conditions.

The basis of our breeding work is to select durum wheat populations and advanced lines with resistance to abiotic and biotic stress and to test for yield stability and productivity under Mediterranean dryland conditions. The cornerstone of this strategy is the introgression of resistance genes from landraces and wild relatives to cultivated durums and the utilization of contrasting and representing environments in the Mediterranean dryland.

Utilization of landraces and wheat relatives
Mediterranean landraces have been found to possess desirable traits lacking in other materials, such as resistance to drought and cold, early plant vigor, long peduncle, and high tillering. Our results on the use of durum wheat landraces in the hybridization program show that substantial progress can be achieved in developing improved cultivars for dry areas.

Besides landraces, wheat relatives (e.g., *Triticum dicoccoides*, *T. monococcum*, *Aegilops* spp., etc.) can provide valuable sources for widening the genetic base of durum wheat (Figure 1) and for improvement of important economic traits including stress tolerance.

Optimum utilization of testing sites
Four sites are extensively used during the various phases of selection in segregating populations and advanced lines. These sites are:

- Tel Hadya (35^{o}N) with an annual average rainfall of 342 mm, cold winters, and moderate terminal stress conditions.
- Breda (35^{o}N) with an annual average rainfall of 278 mm, cold winter, and severe terminal stress.
- Lattakia (35^{o}N) with an annual average rainfall of 784 mm, mild winters, and severe disease pressure.
- Terbol (32^{o}N) with an annual average rainfall of 550 mm and high input conditions.

Realizing that an important part of our work, particularly in the early stage, has to be done on the research station, we have developed a stress screening technique using simulated environments at one site (Nachit 1983, Nachit and Ketata 1986). The technique is based on growing the same germplasm using staggered sowing dates (early, normal, late, and summer) at one site. The germplasm is thus exposed to different stresses according to date of sowing (cold, drought, and heat).

Thus at Tel Hadya station durum wheat germplasm is grown under four environmental conditions:

- Early sowing (mid-October) with supplemental irrigation (450 mm including rainfall) to simulate a crop cycle with long duration and favorable growing conditions.

- Normal date of sowing under dryland conditions representing Mediterranean continental dryland conditions.

- Late sowing (late March/early April) to simulate a short growing season.

- Summer sowing (early July/mid-October) to test for high temperature conditions during all crop growth stages.

The early sowing conditions subject durum wheat plants to cold damage (winterkill) during tillering to frost during anthesis and to attacks of yellow rust and *S. tritici*. Whereas late sowing conditions subject durum wheat plant to terminal heat and drought stresses, particularly during grain filling. Late sowing conditions increase the attacks by aphids, BYDV, and Hessian fly. Whereas summer sowing conditions subject durum wheat plant to extremes high temperatures and sorocco.

Breda station provides a dry site with cold winters and high natural infestation of wheat stem sawfly. Whereas Lattakia is a high-rainfall site used to test for resistance to diseases under natural and artificial infestation, particularly *S. tritici* and BYDV. Further, Terbol is used during the winter season to test yield potential and during the summer to screen for resistance to heat and stem and leaf rusts.

Thus, the testing sites/environments provide two interacting selection gradients for rainfall and temperature regimes. This double selection gradient also encompasses the main abiotic and biotic stresses that prevail in the four major agro-ecological zones.

Selection procedures

Before developing a selection procedure for abiotic stresses, it is crucial to determine the frequency of occurrence of a particular stress and its timing in relation to crop development in each agro-ecological zone. In our selection approach, all early segregating populations are subjected to the stresses in the above-mentioned environments with the aim of identifying the populations that do particularly well in certain environments and are not sensitive to the stresses of other environments.

The pedigree method of selection is used to select individual plants from the populations that were selected across sites/environments, whereas the bulk method is more extensively used to select among populations during winter and summer cycles. This method presents the double advantage of testing more crosses at several sites/environments. The promising bulked segregating populations are shared with NARSs and tested in several agro-ecological zones of the WANA region. With this selection procedure, it is possible to identify at early stages the populations that combine productivity and stability with tolerance to biotic and abiotic stresses and are heterogeneous for a number of important characteristics in the populations reaching the advanced testing stage.

Results of our selection work under contrasting environments show that genotypes that do well under favorable conditions do not necessarily do so under less favorable conditions. It may be difficult to select for genotypes with high yield potential in dryland environments, but it is far more difficult to select for moisture stress tolerance under high input environments. However, it appears that selection only under extreme environmental conditions (too favorable or too dry) is not an efficient way to identify cultivars for Mediterranean dryland (Figure 2). Mediterranean drylands are characterized by a high year-to-year variability and an unpredictable alternation between favorable and less favorable seasons (Nachit 1989). Breeding cultivars, which combine yielding ability with stress tolerance and yield stability, are therefore prerequisite to the Mediterranean drylands (Nachit 1989).

Stress-associated traits

Plant characterization is another tool we use to improve our breeding work (Nachit and Jarrah 1986). We have found that earliness, fertile tillering, spike fertility, peduncle length, and early plant vigor are associated with higher grain yield under drought conditions. Most of our improved lines show desirable values for these traits (Nachit 1988). The analytical approach is likely to be more useful for areas with severe moisture stress. It relies on the plants' different adaptive mechanisms in a stress environment, with the possibility that breeding and selection for these adaptations will contribute to growth and yield under stress (Acevedo 1986). Under Mediterranean dryland conditions, fertile tillering ability is by far the most potent predictor of durum wheat grain yield under moisture-stressed conditions. The trait contribution estimates have shown that fertile tillering can account for more than 30% of the total variability in grain yield, whereas spike fertility and earliness account for 5.3 and 4.1% of the total variability in grain yield, respectively.

Multilocation testing

Although the delimitation of agro-ecological zones in the WANA region decreases the GxE interaction, it does not necessarily eliminate it because the year-to-year and site-to-site variations within a zone can still be very important and make it imperative to look for cultivars possessing an acceptable degree of consistency of superior performance (commonly called stability) across a series of environments within an agro-ecological zone (Figure 3).

The cultivars' performance then reflects interaction of genetic and environmental factors. The relative performance of genotypes or crosses may vary in different environments, in which case the genotypes are said to interact with the environments. Results from this project as well as other work show the overwhelming evidence of GxE interactions. For an efficient breeding program in a given region of interest, it is important to know the causes and the nature of GxE interactions. The multilocation testing provides the data for assessing the consistency of relative cultivar performance. It also enables the identification of cultivars combining desirable traits such as resistance to various diseases and insects and tolerance to drought, cold, and heat. These cultivars provide good sources of parental material for the hybridization program.

Breeding for Abiotic Stress Tolerance

Drought tolerance breeding

For the drier zones, emphasis is placed on resistance to drought, heat, winterkill, and frost at anthesis stage and to pathogens and insects specific to dry areas (e.g., root rot, common bunt, wheat stem sawfly, and Hessian fly). Genetic stocks have been developed with combined resistance to drought and cold (winterkill). The number of advanced lines possessing consistent and high yields is steadily increasing as reflected by an increased number of lines outyielding the national checks in regional yield trials (Figure 4). From these lines, several cultivars were released in several countries in the WANA region. Examples of cultivars suitable for the drier zones in various countries include Korifla, Belikh2, Omrabi crosses, and Sebou.

The progress achieved in drought resistance breeding can be shown in the example of Omrabi 17. This line is a cross between a Middle East landrace (Haurani) and a CIMMYT high yielding variety (Jori C69). Because of its high performance under stress and favorable conditions, it was included in the farmers' field verification trials of the low and high rainfall areas of Syria (Figure 5) and Lebanon (Figure 6). As for the thermal conditions, Omrabi 17 is adapted to low-rainfall areas with continental climates. By contrast, Korifla (released under the name of Cham 3 in Syria and Petra in Jordan) is adapted to dry areas with mild winters. These results confirm earlier findings in which yield and stress resistance can be successfully combined (Nachit and Ouassou 1988).

Breeding for tolerance to cold and frost

In the continental Mediterranean dryland and high altitude areas of WANA, durum wheats are often damaged by cold at the vegetative stage and/or frost at anthesis. The cold and frost incidence increases with higher latitude and altitude.

Cold damage reduces dry matter production and spikes per unit area, whereas frost damage is displayed through impaired spike fertility. In the continental Mediterranean drylands, 44.12% of the total grain yield variability is explained by the number of fertile tillers. Because of subjecting early segregating populations to cold and frost, most of the advanced lines show desirable values for cold resistance.

Breeding for resistance to heat and terminal stresses

The high temperatures during the grain filling period cause crop damage through premature desiccation, kernel shrivelling, and reduction of grain yields. Intermittent high temperatures during the growing season also increase water stress. This phenomenon is found in areas of southern latitudes and of mild winters. Durum wheat grown on light textured soils and/or not fallowed land is particularly prone to moisture and high temperature stress.

The testing techniques for heat and premature desiccation stresses are conducted as follows. Heat screening is carried out under summer sowing conditions at the Terbol and Tel Hadya stations where maximum temperatures are above 30°C and minimum temperatures do not go below 20°C during the vegetative stage of plant development. Late sowing conditions at Tel Hadya simulate stresses caused by high evapotranspiration demand and premature desiccation. The temperature rises from mid-April onward, causing high evapotranspiration and is normally coinciding with a rapid decrease of rainfall.

Field screening for heat and premature desiccation resistance is made difficult because of uncontrollable temperatures and confounding effects of other stresses, particularly drought. However, if the objective is to develop cultivars for a target environment where drought and heat often occur simultaneously, the confounding effects need not be emphasized. This technique has been used now for the last decade and the results are rewarding, as evidenced by the performance in warm areas (Nile Valley and Arabian Peninsula) of durum wheat lines identified through heat and premature desiccation screening (Figure 7).

Breeding for Biotic Stress Resistance

Disease resistance

Among the many diseases affecting durum wheat in the areas with cold winters are: yellow rust, loose smut (*Ustilago tritici*), common bunt, while in other agro-ecological zones with mild winters, the important diseases are *Septoria tritici*, leaf rust, stem rust (*Puccinia graminis*), barley yellow dwarf virus (BYDV), root rot (*Fusarium* and *Choliobolus* spp.), and powdery mildew (*Erysiphe graminis*).

The most economical and practical way to avoid losses by diseases is through the incorporation of disease resistance. This holds particularly true for the marginal areas with low-input agriculture. However, changes in crop management practices may have a dramatic effect on the development of diseases, for example, early sowing, often recommended by agronomists, favors the development of foliar diseases, particularly yellow rust and *S. tritici*; while late sowing can increase attacks by leaf rust, stem rust, or Hessian fly; and monoculture and minimum tillage increase the inoculum potential of diseases that reside on crop over summer.

The selection for resistance exploits indigenous races of pathogens to create artificial inoculum. Multilocation resistance screening and testing in "hot spots" are also made to detect other races of diseases. The screening of advanced generations and materials in Mexico for leaf and stem rusts plays an important role to identify broad resistance to these diseases. Increased resistance is achieved for yellow rust, stem rust, and leaf rust, and *S. tritici* (Figure 8), common bunt, and BYDV. The resistance genes for the different diseases are incorporated into durum wheat genotypes carrying resistance to drought, cold, and heat. Most of the advanced genotypes included in the regional nurseries and trials are combining the biotic and abiotic resistance.

Insect resistance

Wheat production in the rainfed areas of the WANA region is beset by many insects that annually account for yield losses of 5 to 14%. However, in some areas the losses are higher, e.g., in Morocco the Hessian fly caused about 80% crop loss in the dry areas. Hessian fly, wheat stem sawfly, and sunni pests are primarily pests of the rainfed areas. Aphids are primarily a problem in the Nile Valley region, although any wheat grown under irrigation or in high to moderate rainfall areas may also be heavily infested.

Most of the advanced lines of durum wheat exhibit medium to high resistance to the wheat stem sawfly under natural infestation. Resistance to the wheat stem sawfly is apparently not restricted to stem solidness. However, several durum wheat landraces from Morocco were found to possess solid stems and are now used in the crossing program for wheat stem sawfly resistance. Incorporation of resistance to the wheat stem sawfly from different sources and with different resistance mechanisms are combined to develop stable resistance. Screening for resistance to aphids and Hessian fly is carried out jointly with the national programs of Egypt and Morocco.

Breeding for Improved Grain Quality

The WANA region has a large variety of foods made from durum wheat grain. Identification and incorporation of desirable quality parameters for the different end products into improved germplasm are given high priority in the joint CIMMYT/ ICARDA Durum Wheat Project. The most used quality test parameters are protein content (%), vitreousness, sedimentation test (SDS), carotene content, grain size, and the gliadin 45-band. The most important durum wheat end products are summarized in Table 2.

Table 2. Food products made of durum wheat in the WANA Region.

Product	Consumption (%)
Two-layered flat bread	20.0
Single-layered flat bread	10.0
Raised breads	20.0
Burghul	14.5
Pasta	12.0
Couscous	14.0
Frike	5.0
Other foods	4.5

Crosses are made to increase industrial and nutritional qualities of the stress tolerant germplasm. WANA landraces are the best sources for local end products, while the *T. dicoccoides* are used to increase grain protein content. The technique for vitreousness screening by using zero-nitrogen and irrigation (Nachit and Asbati 1988) is now generating promising results. This technique discriminates better between genotypes quality traits and enables a better selection of genotypes with high grain quality.

Varietal Releases in the WANA Region

Cooperators have identified outstanding lines from the regional trials sent by the joint CIMMYT/ICARDA program for possible release by testing them in field verification trials. Table 3 lists examples of varieties released or tested on a large scale in the drier zones in various countries.

Table 3. Varieties recently released or tested on a large scale in the WANA region.

Variety	Cross	Pedigree	ME	Countries
Korifla	DS15/Geier	CD 523-3Y-1Y-2M-0Y-0AP	4A	Syria, Algeria, Jordan
Belikh 2	Cr/Stk	L92-6AP-1AP-1AP-0AP	6B	Lebanon, Syria
Omrabi 6	Jori c69/Hau	LO589-4L-2AP-2AP-0AP	4A	Syria, Jordan, Morocco, Tunisia, Algeria
Sebou	Cr/*T. polonicum*	ICD79-7L-3AP-5AP-0AP	4A	Morocco, Lebanon
Kabir 1	Ovi/Cp//Fg	LO38-4AP-2AP-2AP-0AP	7D	Algeria, Turkey
Brachoua	Fg/3/Gs/Tc60//Stk	CD 26701-0AP-1AP-0AP	4A	Jordan, Libya, Morocco
Tensift 1	Rabi/Fg//GdoVZ 579/3/Bit	CD 26109-0AP-2TR-1AP-1AP-1AP-0SH	4A	Morocco
Marjawi	Can 2109//Jo/AA /3/S15/Cr	CD 10535-D-1M-1Y-1M-2Y-0M-0AP	4A	Libya
Waha	Plc/Ruff//Gta/Rtte	CM 17904-B-3M-1Y-1Y-0SK-0AP	4A	Syria, Cyprus, Jordan, Lebanon, Algeria, Saudi Arabia
Sabil 1	Ibis/Fg//Cando	ICD79-1437-25AP-1AP-0AP	4A	Morocco, Tunisia, Saudi Arabia, Kuwait

Conclusion

Since it is improbable that more land can be put under cultivation, the production increase has to come from improved technologies, including development of suitable varieties, better cultural practices, and weed control. Results from experimental stations and on-farm research trials and large-scale testing in several countries of the WANA region point to the possibility of doubling the current yield levels.

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Discussion Notes

Nachit: Durum breeding for the Mediterranean drylands is a recent phenomenon, but national programs are already producing results.

van Ginkel: What is your view of the environment that should be used for selecting durum wheats for drought tolerance?
Nachit: Selecting in only one (irrigated such as in Obregon) or the other (dry conditions) is not good. The germplasm should be exposed to both environments.
Elias: The key is: what are the parameters used to determine what makes a dry area dry.

Singh: Omrabi 17 is a good example of wide adaptation.
Nachit: Yes, I don't like to crossover within ME4--we want to have wide adaptation.

Fischer: If durums are being pushed into the dry regions, is they competing with barley?
Hamblin: There is no competition because different end-users are involved; barley is an animal feed. Also, there's an open market for barley whereas there are controls for wheat.
Nachit: I don't think that durum wheat is moving to the dry areas, instead, durum wheat--and barley--are moving to the wet areas. I disagree with Byerlee's estimations; the ICARDA Economics Department is seeing a different trend. We need to collect more data before we draw conclusions on this.

Braun: Isn't the population now use to bread wheat products?
Fischer: There is no subsidized durum wheat available for the WANA region.
Nachit: There is a big demand for durum wheats and the products derived from them.
Elias: The average bread wheat and durum wheat yields are statistically the same. Durum wheat is grown because of the traditional products consumed in the region.

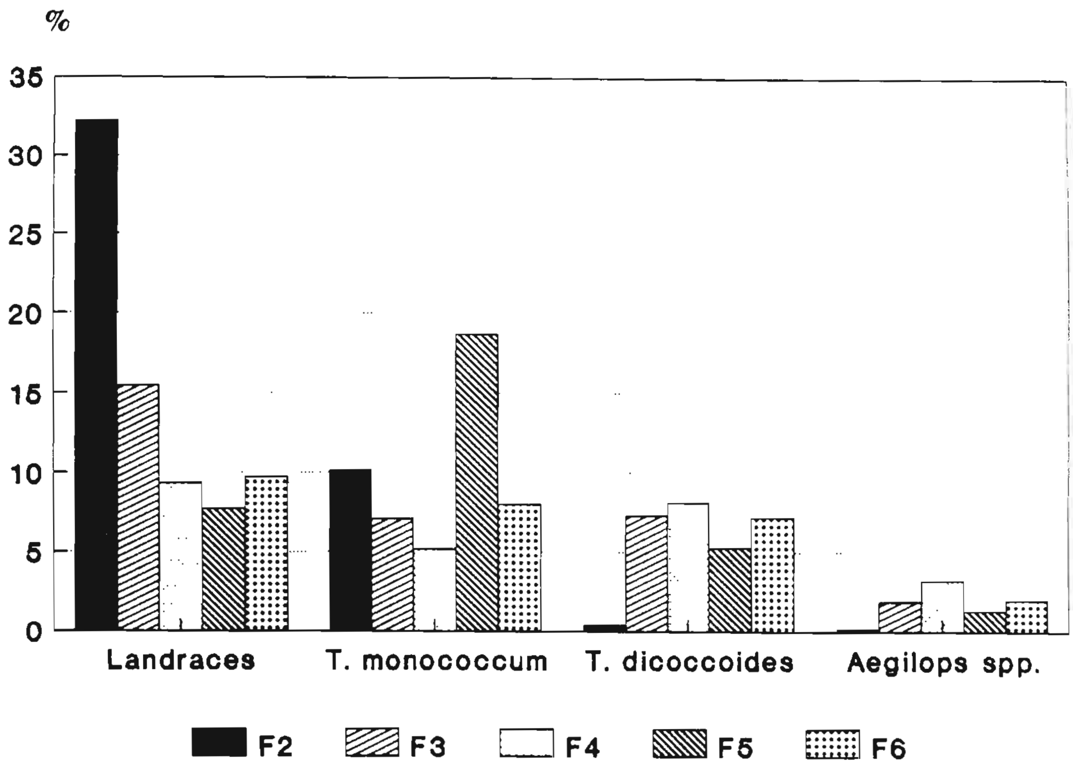

Figure 1. Type of crosses (%) in segregating populations.

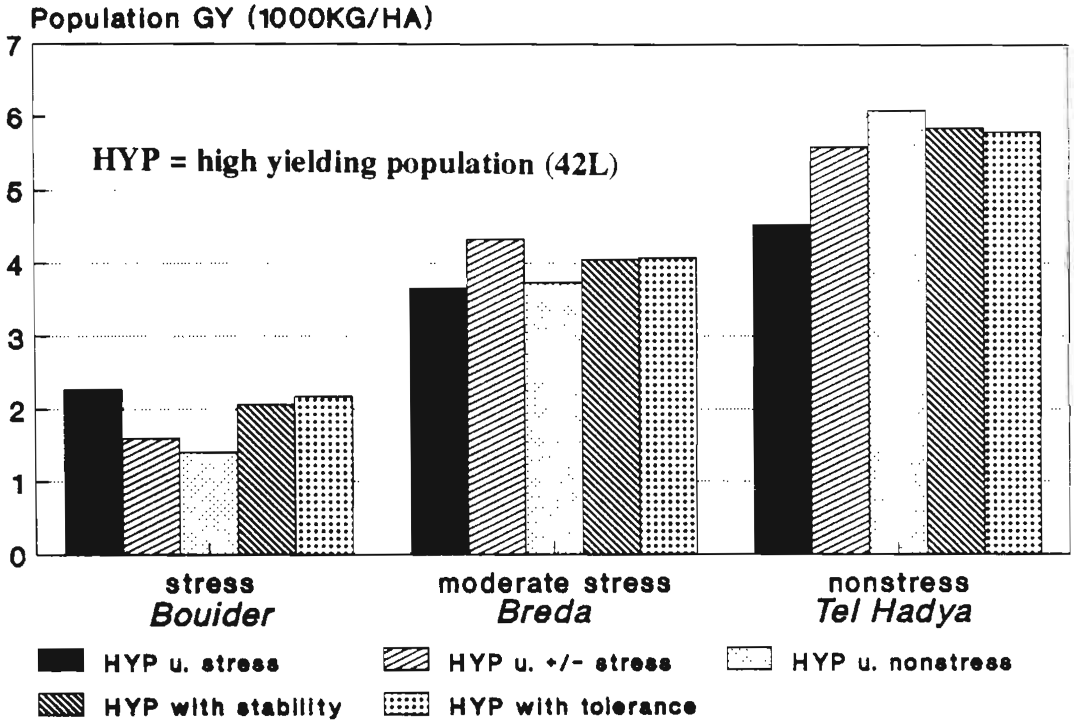

Figure 2. Yield and drought resistance.

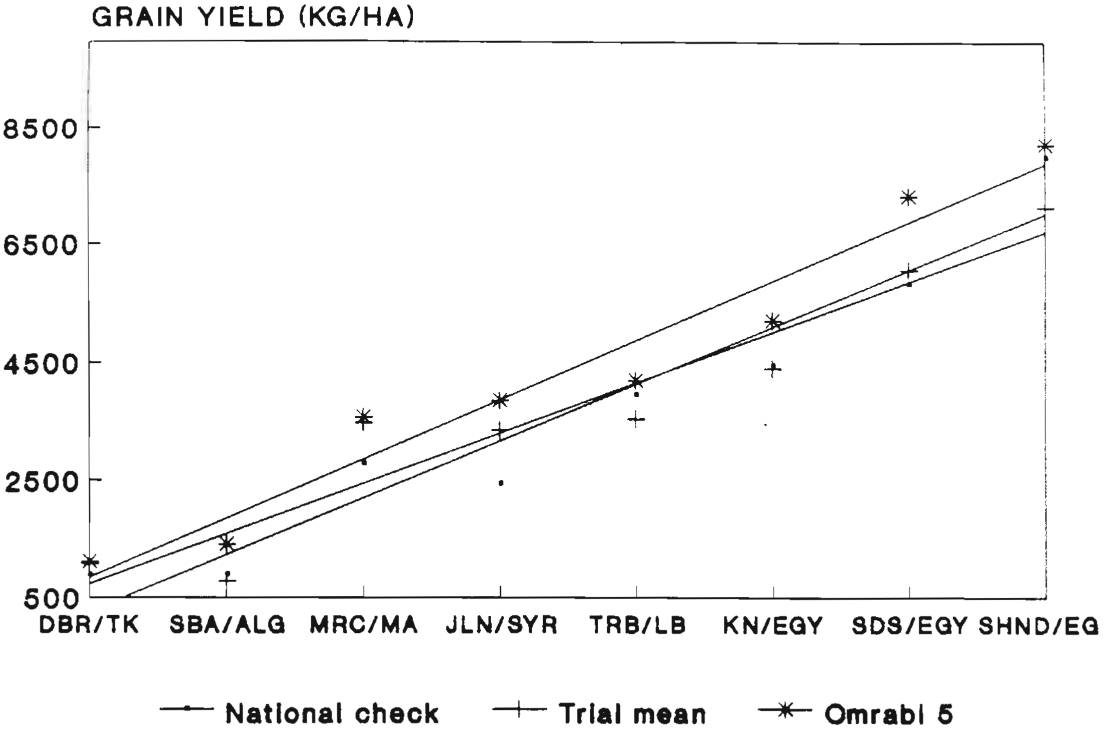

Figure 3. Yield of Omrabi 5 across environments in the WANA region.

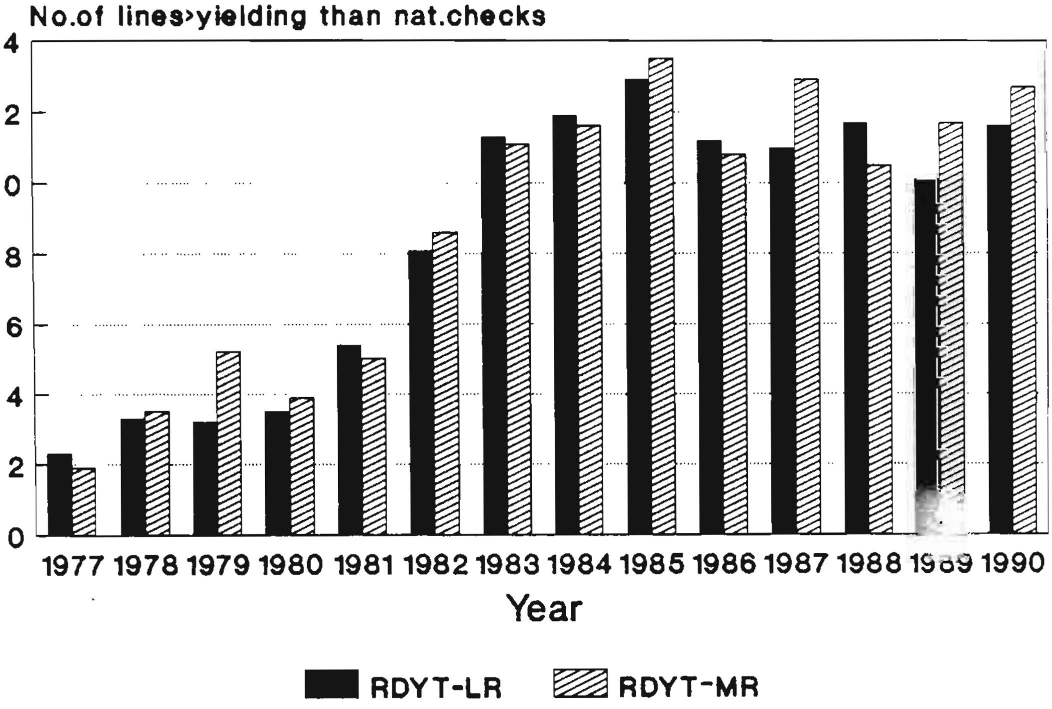

Figure 4. Performance of regional yield trials.

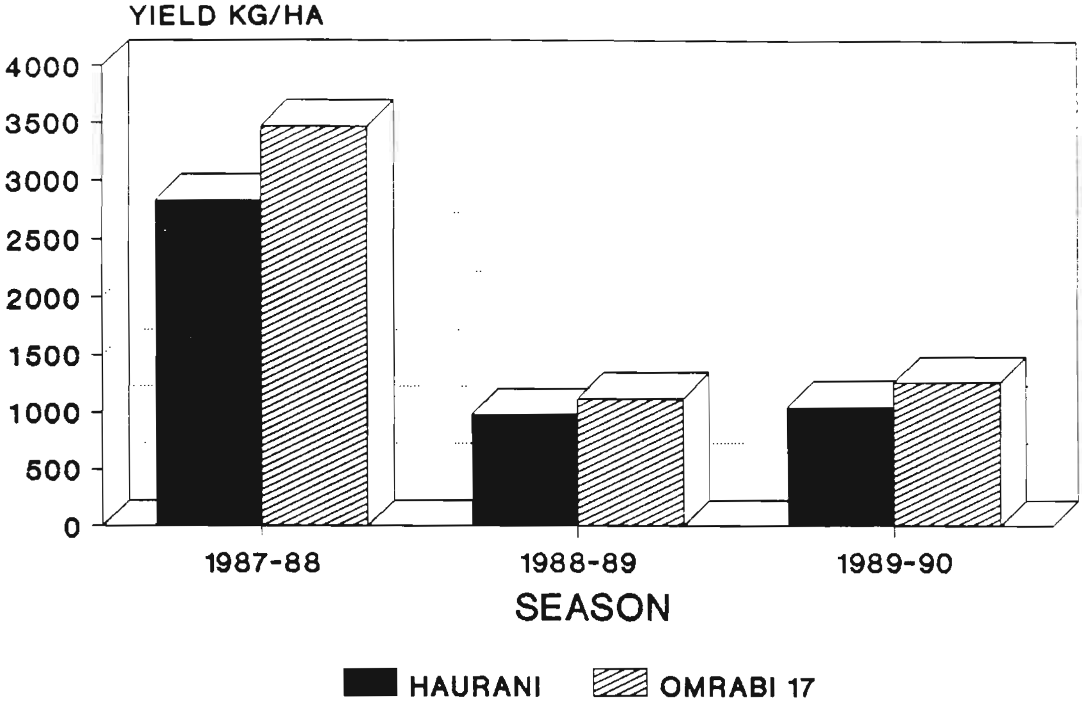

Figure 5. Yield of Omrabi 17 under dryland conditions in on-farm trials in Syria.

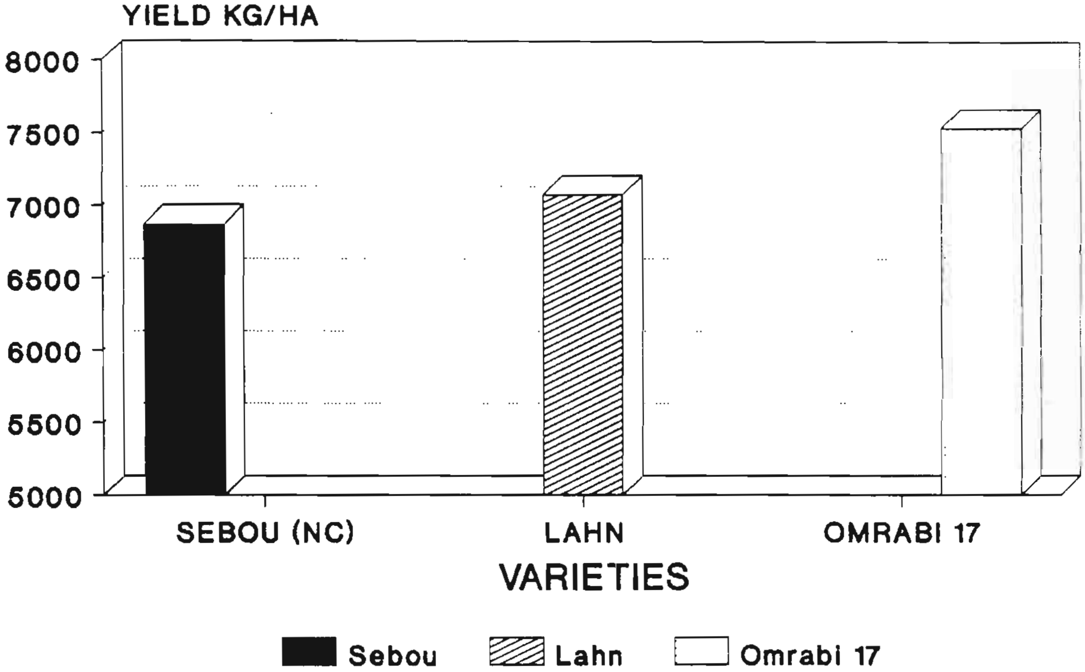

Figure 6. Yield of Omrabi 17 under high input conditions (600 mm) in the Bekaa Valley, 1990-91.

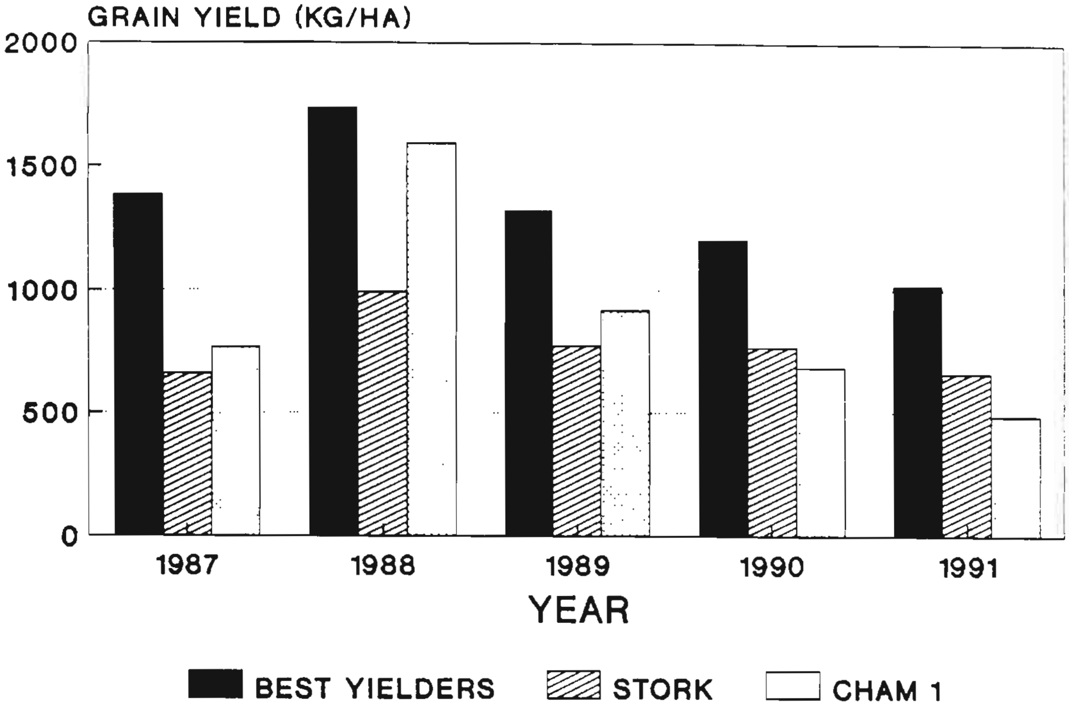

Figure 7. Yields of drought resistant lines under terminal stress.

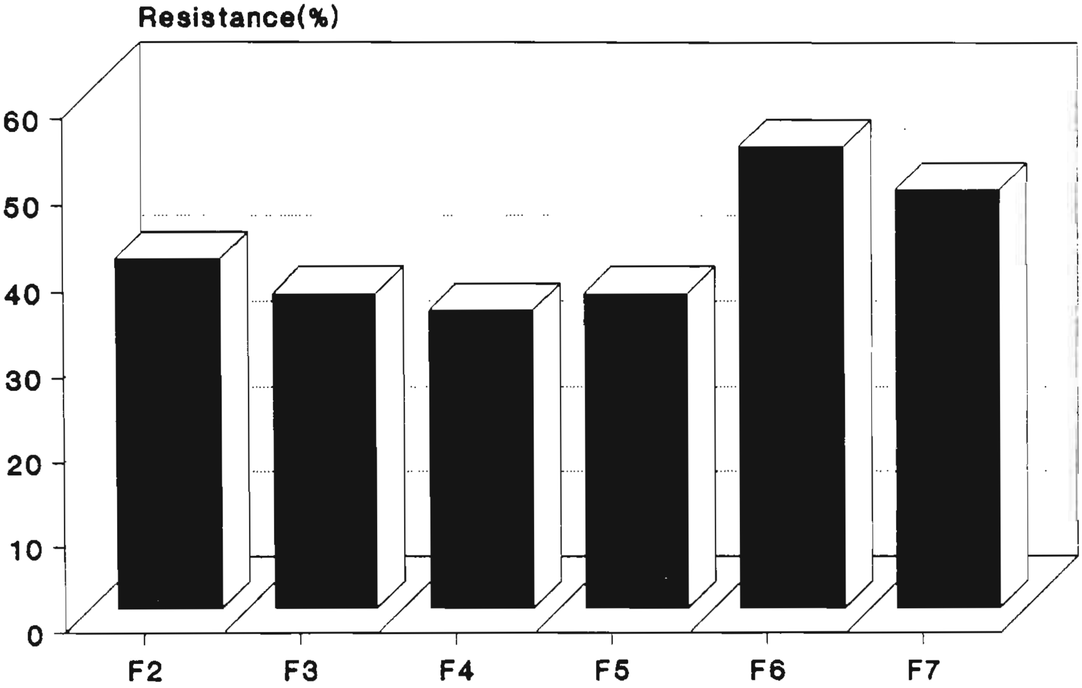

Figure 8. Multiple disease resistance in segregating populations.

IMPACT OF DURUM WHEAT BREEDING IN DEVELOPING COUNTRIES: A DILEMMA FOR THE FUTURE

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Note: Paper presented by R.A. Fischer

Durum Wheat in the Developing World

No reliable global statistics on durum wheat are available, but from various sources we can gain a general picture of durum wheat production. Durum wheat is grown on a total of about 17 million hectares in the world, producing about 26 million tons (Mt) annually (International Wheat Council 1987). In developing countries, some 7-8 million ha of durums are grown, but because of lower yields, only about 35% of global production is grown in developing countries. Previous estimates place durum wheat area at 12 million ha in developing countries (Srivastava 1984), but this appears to be a considerable overestimate. The latest IWC publication (Jan. 1992) states 1989-1992 durum production averaged 30 Mt with 14 Mt from the Soviet Union and developing countries. This suggests an area of closer to 9-10 million ha for developing countries. Presently, about 5% of wheat production in developing countries is from durums. However, durums generally receive a price premium (averaging 15% in international markets), which increases their share of the total value of wheat production. In addition, the developing world imports another 3 Mt of durum wheat annually (over half of which is imported by Algeria).

Overall, area and production of durums have expanded more slowly than for bread wheats. In fact, there is probably a long-term tendency for the total area under durums to decrease. For example, 50 years ago over half of the black soil area of Central and Southern India was sown to durums (Howell 1909), but durums now occupy only an estimated 22% of the wheat area in this region (Byerlee 1992). Further evidence will be presented later that this downward trend in durum wheat area is likely to continue, because of substitution of durum by bread wheats in consumption patterns.

Durum wheat area is largely concentrated in regions of low rainfall (Table 1). However, because of the low yields in these regions, about half of all durum wheat is produced in higher rainfall or irrigated areas. The great bulk of durum wheat area in developing countries is grown in West Asia and North Africa (WANA) between the 300 and 450 mm annual rainfall isohyets (Srivastava 1984). Another 1.0-1.5 million ha are grown under hot, dry conditions in Central and Southern India in what is termed mega-environment 4C. Finally, some area of durum wheat is scattered under varying environments in Ethiopia, Mexico, Argentina, and Peru. These data exclude the durum wheat area of 1.5-2.0 million ha in the former Soviet Union, which may soon fall under CIMMYT's mandate. Nearly half of this durum wheat is produced in Kazakhstan.

Release and Adoption of Improved Varieties

Released durum varieties

The CIMMYT database on varietal releases indicates that some 135 durum wheat varieties have been released by developing countries since 1965, nearly all of them spring durums. The bulk of these releases have occurred in the WANA region (Table 2). From 1965 when the first semidwarf durum variety was released in Mexico, the proportion of releases that are semidwarfs has increased rapidly, so that by the 1980s almost all releases were semidwarfs (Figure 1). This reflects the steadily increasing use of CIMMYT germplasm in varietal releases. By the 1980s, over 70% of releases were directly from CIMMYT crosses, and another 10% of releases carried CIMMYT germplasm with one or more of the parents being CIMMYT lines. Most of the remaining varieties were released for Central and Southern India, where improved tall varieties have been developed by the Indian national program (see below).

By far, the most popular CIMMYT crosses have been Bittern, Stork, Cisne, Albatross, and Frigate, which together account for 36 of the 85 releases from CIMMYT crosses in the 1966-90 period (Table 3). However, there is often a considerable time lag between the release of a variety outside of Mexico and its first release in Mexico (Table 3).

The above data, of course, only include varietal releases in developing countries. Durum varieties containing CIMMYT germplasm, or based directly on CIMMYT crosses, have also been widely released in developed countries, including the USA, Spain, Italy, and Australia. Because CIMMYT's mandate is specifically to work with developing countries, our database does not include releases in developed countries.

Adoption of improved varieties

An estimated 4 million ha of durum wheat area are now sown to improved varieties. This represents just over half of the estimated 7.5 million ha of durum wheat in the developing world. Of the 4 million ha sown to improved varieties, some 2.5 are sown to varieties derived from CIMMYT (or CIMMYT/ICARDA) crosses. The most widely grown crosses have been Cisne, Frigate, and Bittern that each cover more than 0.5 million ha (Table 3). Another 0.35 million ha of durum wheat, mostly in India, are sown to varieties with a CIMMYT parent. Although adoption of improved durum varieties still lags that of bread wheats in every region (Table 4), the data at hand suggest considerable progress in the short space of 25 years in which CIMMYT has had an active durum wheat breeding program.

Nonetheless, a closer examination of the adoption of improved durum varieties shows that adoption has been uneven (Tables 5 and 6). The highest adoption rate has been in Latin America followed by WANA. Adoption in Asia (largely India) and in sub-Saharan Africa has been minimal. In general, adoption has taken place in irrigated and higher rainfall environments, and most of the durum area in these environments is now sown to semidwarfs (Table 7). By contrast, only about one-third of dryland durum area is sown to semidwarfs. This is despite the fact that a considerable proportion of the released varieties have been targeted to dryland areas (Figure 2).

This is seen most clearly for India where semidwarfs have generally performed poorly under dryland conditions. Only one semidwarf has been released for rainfed conditions in India, whereas nearly all the releases for irrigated conditions (Table 8) have been semidwarfs, and most of the irrigated durum area has been planted to these varieties compared to only 10% of the dryland durum area that is planted to improved varieties (nearly all tall varieties) released since 1966.

Impacts of Improved Varieties on Yield and Quality

Gains in yield potential

The release of semidwarf varieties has had a spectacular effect on yield potential in spring durums. This has been well documented in northwestern Mexico where, under irrigated conditions, yield potential of durums released since 1965 has increased by an annual rate of 1.7-2.5% per year (Figure 3--Waddington et al. 1987, Sayre et al. pers. comm.), considerably faster than the equivalent progress in bread wheats. Likewise, yield potential of durums released for irrigated areas in northwest India has increased by 1.4% per annum, since the first improved durum variety (Raj 911) for irrigated areas was released in 1974 (calculated from data provided by K.B.L. Jain). Part of the reason for these rapid yield gains has been success in overcoming sterility in the first generation of semidwarfs.

In dryland areas, gains in yield potential have generally been much smaller and in many cases, negligible. The most comprehensive evidence comes from India (mega-environment 4C, with production on residual moisture) where no gains in yield potential of durum varieties released for dryland Central and Southern India have been recorded over the past 25 years (Figure 4). The situation in dryland areas of WANA (mega-environment 4A with production on growing season moisture) is probably somewhat better, but to date, comprehensive data from dryland areas on yield of varieties of different vintages are unavailable from that region. These differences in rates of gain in yield by environment undoubtedly explain the contrasting adoption rates experienced in each environment.

Gains in quality

Quality is probably a more important factor in varietal acceptance for durums than in bread wheats. In many areas, and especially in dry areas, high quality durums are grown as a speciality crop that is marketed at a price premium. In Central and Southern India, this premium may be is as much as twice the price for bread wheats.

For irrigated durums, rapid progress has been made in transforming the first varieties, which generally had low quality for pasta making, to varieties released in the 1980s, which easily meet international market standards for pasta (Figure 5). Indeed, Mexican varieties provide the basis for the production of durums in western USA--quality durum wheat produced under irrigation for export--southern California and Arizona. There are also examples of durums for dryland areas which have been quite successful because of their high quality for local foods. In Gujrat, India, the variety GW 1 released in 1980 has been fairly widely accepted by farmers under the harsh dryland conditions of that state. Although this variety provided little yield advantage over the previously grown variety, A206 released in 1954, it commanded a price premium for its high quality grain (Byerlee 1992). Likewise, acceptance of improved durums by small farmers in Ethiopia was in part because of quality characteristics of these varieties (for local food preparations (Negatu et al. 1992). This suggests that, for durum wheat, breeders may have to pay as much attention to quality for the various food preparations as to yields (Varughese 1975).

Considerations for the Future

The data presented above on impacts of durum wheat breeding clearly point to considerable success, both by CIMMYT and our national program collaborators, in developing and diffusing improved varieties in many countries of the developing world. Despite a late start, the release and adoption of improved durums, and especially semidwarfs, now rival those of spring bread wheats. Nonetheless, the gains have been uneven, with the largest impacts clearly occurring in the irrigated and well watered areas.

In closing, I want to raise two issues that are important in mapping our strategy for the future: 1) the dominance of CIMMYT crosses in varietal releases and 2) the appropriate emphasis in the future on developing durum varieties for favorable versus unfavorable environments.

Dominance of CIMMYT crosses

As in the case of spring bread wheats, CIMMYT is clearly the main supplier of improved germplasm for durum wheat in the developing world. However, there is an important distinction. For spring bread wheats, large national programs tend to use our materials as parents in their crossing programs, with crosses generally occurring between CIMMYT lines and locally developed materials. In the case of durums, however, CIMMYT germplasm is generally released directly, and only in India is it widely used as a parent in local crossing programs. In the 1980s, 70% of the released durum varieties were derived directly from CIMMYT crosses, and only six varieties were released from national program crosses with a CIMMYT parent. This excludes some varieties released from third country crosses, such as the variety, Gerardo, developed in Italy with one CIMMYT parent, and subsequently released in a number of developing countries. This presumably reflects the fact that few national programs have sufficient resources to run a full crossing program for durum wheats.

This implies that CIMMYT germplasm is largely being used as a finished product. Hence to be successful, we will have to pay particular attention to those characteristics that are important to farmers, including grain and straw quality. The varietal characteristics desired by farmers vary according to local farmers' circumstances. Hence we should consider in-depth studies of the type conducted in Ethiopia (Negatu et al. 1992), on the uses and preferences of farmers for durum wheats in selected durum-growing regions, in order to have a clear sense of the characteristics we should be emphasizing. In the Ethiopian study, it is clear (Table 9) that the semidwarf durums grown by farmers are very acceptable in terms of grain and straw quality, but that their adaptation would be realized by more emphasis on biotic and abiotic stresses (although the improved durums had better disease resistance than the local varieties that they replaced). We also need to be concerned about ensuring sufficient genetic diversity in our program, given that we are the major "gene mixers" for spring durums.

Priority to well watered vs. dryland areas?

An important dilemma for our future strategy is the extent to which we should emphasize durum wheats for well watered or dryland regions in the future. There are two important considerations in making this decision.

Future of durum wheats in dry areas--In general, there is a long-term tendency for the area of durum wheat to decline relative to that of bread wheat. This, in part, reflects the spread of irrigation and the availability at an earlier date of semidwarf bread wheat varieties, as in India. It also reflects the much faster growth of consumption of bread wheats, promoted by urbanization (see the example of Tunisia in Figure 6 where consumption of durum wheat in large cities is less than half of that in rural areas). In some countries, government policies have also promoted this substitution through consumer subsidies on bread wheat at the expense of durums (e.g., as in Morocco). However, there is a tendency for the remaining area of durums to be concentrated in the driest zones. For example, the proportion of the national durum area that occurs in the drier Central Zone of Tunisia has increased from 23% in the 1960s to 36% in the 1980s.

Negative spillover effects on dryland producers--An unintended effect of success in breeding high-quality durum wheats for favored areas is the possible negative price effects for dryland producers. In general, durum wheat producers have received a considerable and increasing price premium over bread wheats. This dilemma is most apparent in India. As irrigation and semidwarf bread wheats have spread over the past 25 years, durum wheat production was reduced to the driest and hottest environments. The reduction in durum wheat supply meant that producers in these environments were able to command a growing price premium for durum wheats, which increased from 25% in the 1960s to 50% percent in the 1980s (Byerlee 1992). However, since 1975, India has established a wheat breeding program for irrigated durums (Figure 7), which by 1990 had released nine varieties. These varieties are being steadily adopted--for example in the irrigated Punjab--and the supply of good quality durums from irrigated areas now competes with durum production in dryland areas. The consequences for the price premium on durums has not been analyzed but it is logical that dryland producers of durum wheats are now worse off than they would have been in the absence of an irrigated durum wheat program.

Taken together, the evidence suggests that the case for expanding resources to durum wheats is not strong, given their long-term downward decline in area relative to bread wheats. However, given the considerable and growing proportion of the durum area that is grown under dryland conditions and the availability of suitable bread wheats for the wetter areas, I would argue that most of CIMMYT's efforts in durum wheats in the future should be targeted at the drier areas. In fact, our effort on dryland durum wheats could constitute the bulk of our total effort in breeding for dryland areas, since it seems clear that in the case of bread wheats, the highest payoffs will come from concentrating on mega-environment 1.

In formulating our strategy for the future, we should ensure that we have the best information available. In particular, we need to update our mega-environment database and analyze shifting trends in the environments in which durum wheat is grown. Secondly, we need to understand the preferences and experiences of small farmers in dry areas for improved varieties of durum wheats. Recent work initiated by CIMMYT and ICARDA to analyze adoption patterns in dry areas of Tunisia and Morocco is an important start in this direction.

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Discussion Notes

Varughese: In durums, CIMMYT-ICARDA lines dominate compared to bread wheat. National programs do not have their own durum wheat programs--a reflection of their weakness.

Fischer: Byerlee does not mention if the national programs should be strengthened. Should they be?
Rajaram: Look at the Indian Durum Program in Central and Southern India--semidwarfs are not necessarily needed.
Fischer: That is a good point; we don't necessarily have to think semidwarfs for that part of the world.

Nachit: Durum wheat is coming back into the highlands of Morocco, so the trend into 1991 is not what is stated by Byerlee.
Fischer: If you think trends are changing, keep us informed.

Table 1. Distribution of durum wheat area and production by mega-environment, 1980.[a]

Mega-environment	Area (000ha)	Production (000t)	Yield (t/ha)	Percent of Area	Percent of Production
ME1 Irrigated	376	1082	2.9	3.6	7.9
ME2 High rainfall	2370	4629	2.0	23.0	33,6
ME4A Dryland winter rainfall	4703	4408	0.9	45.6	32.0
ME4C Dryland residual moisture	1500	1200	0.8	14.5	8.7
ME6C Winter wheat-high rainfall	165	765	4.6	1.6	5.6
ME6D Winter wheat-dryland	1210	1694	1.4	11.7	12.3
	10324	13778	1.3	100	100
Total dryland (ME4A, 4C, 6D)	7413	7302	1.0	71.8	53.0

[a] The data reported here appear to be overestimates of durum wheat area and production. This is in part because the data are for the late 1970s, and, in part, because durum area in some countries, especially Turkey and India, was overestimated.

Source: CIMMYT mega-environment database.

Table 2. Number of durum wheat varieties released in developing countries by period and region, 1966-1990.[a]

Region	1965-69	1970-79	1980-90	Total
Sub-Saharan Africa	2	3 (1)	2 (1)	7 (2)
WANA	6	36 (24)	38 (26)	80 (50)
Asia	4	9 (4)	8 (4)	21 (8)
Latin America	2 (2)	8 (8)	17 (15)	27 (25)
Total	14 (2)	56 (37)	65 (46)	135 (85)

[a] Numbers in parentheses are CIMMYT or CIMMYT/ICARDA crosses.

Table 3. Popular CIMMYT and CIMMYT/ICARDA durum crosses.

Cross	Name of variety released in Mexico	Year released in Mexico	Average year released other countries	Total number of releases	Area 1990 (000 ha)
Bittern	Yavaros	1979	1985	10	576
Stork	Mexicali	1975	1981	9	74
Cisne	Cocorit	1971	1974	8	674
Albatros	Jori	1969	1974	6	277
Frigate		na	na	5	560
Gallareta	Altar	1984	_	2	85
Others				45	262
Total				85	2508

na = Not released in Mexico.

Table 4. Percent of area under durums and adoption of semidwarf varieties by region 1990.

Region	Percent wheat area in durums	Percent durum area sown to semidwarfs	Percent spring bread wheat area sown to semidwarfs
Subsaharan Africa	39	18	62
WANA	23	51	72
Asia	3	28	89
Latin America	2	65	82
Developing countries	8	46	85

Table 5. Percent of durum wheat area sown to varieties classified by origin, 1990.

			Non-CIMMYT		
Semidwarfs	**CIMMYT cross**	**CIMMYT parent**	**Released since 1966**	**Released prior to to 1966**	**Total**
		(Percent of area)			
Subsaharan Africa	11	0	7	82	100
WANA	46	1	20	33	100
Asia	0	28	0	72	100
Latin America	65	-	0	35	100
All developing countries	39	5	9	41	100

Source: CIMMYT Wheat Variety Database.

Table 6. Composition of durum wheat area planted to varieties released since 1966.

	Percent of area under recent releases				Percent area planted to releases since 1966
	CIMMYT cross	**CIMMYT parent**	**Non-CIMMYT**	**Total**	
Subsaharan Africa	60	0	40	100	18
WANA	70	2	28	100	67
Asia	0	100	0	100	28
Latin America	100	0	0	100	65
All LDCs	66	8	26	100	59

Table 7. Percentage of wheat area under semidwarfs by moisture regime, 1990.

Wheat type	Well-watered[a]	Dryland[a]
Spring bread	99	62
Spring durum	87	33
Winter bread	94	9
Winter durum	100	0

[a] Based on ecological niche recommended for each variety.

Table 8. Composition of durum wheat releases in India, 1960-90.

	Percent for		
	Irrigated	Dryland	Total
1960-69	0	100	100
1970-79	50	50	100
1980-89	63	37	100
All	39	61	100
Origin of durum wheat releases in India, 1960-90			
Percent releases from:			
CIMMYT cross	78	0	32
CIMMYT parent	22	14	14
Non-CIMMYT	0	86	55
	100	100	100
Percent semidwarf	88	14	41
Percent successful	57	49	52

Table 9. Index of farmers' rating of semidwarfs durums and tall bread wheats for several characteristics, Central Ethiopia, 1991.

	Semidwarf durums			Tall bread wheats	
Type of characteristic[a]	Boohai	Cocorit	Gerardo	Enkoy	Israel
Yield	2.4	2.6	2.4	2.5	2.7
Straw characteristics	2.4	2.2	2.4	1.9	2.5
Resistance to abiotic stress	1.8	2.0	2.0	2.1	2.3
Resistance to biotic stress	1.9	2.2	2.1	2.0	2.6
Grain type	2.5	2.5	2.4	1.6	2.2
Food quality	2.6	2.6	2.6	1.6	2.4
Storage and marketability	2.3	1.9	2.0	1.6	2.2

[a] The index for each type of characteristic is a composite of farmers' rating of several characteristics. For example for food quality, farmers rated each variety for five local foods.

Source: Data provided by Wilfred Mwangi.

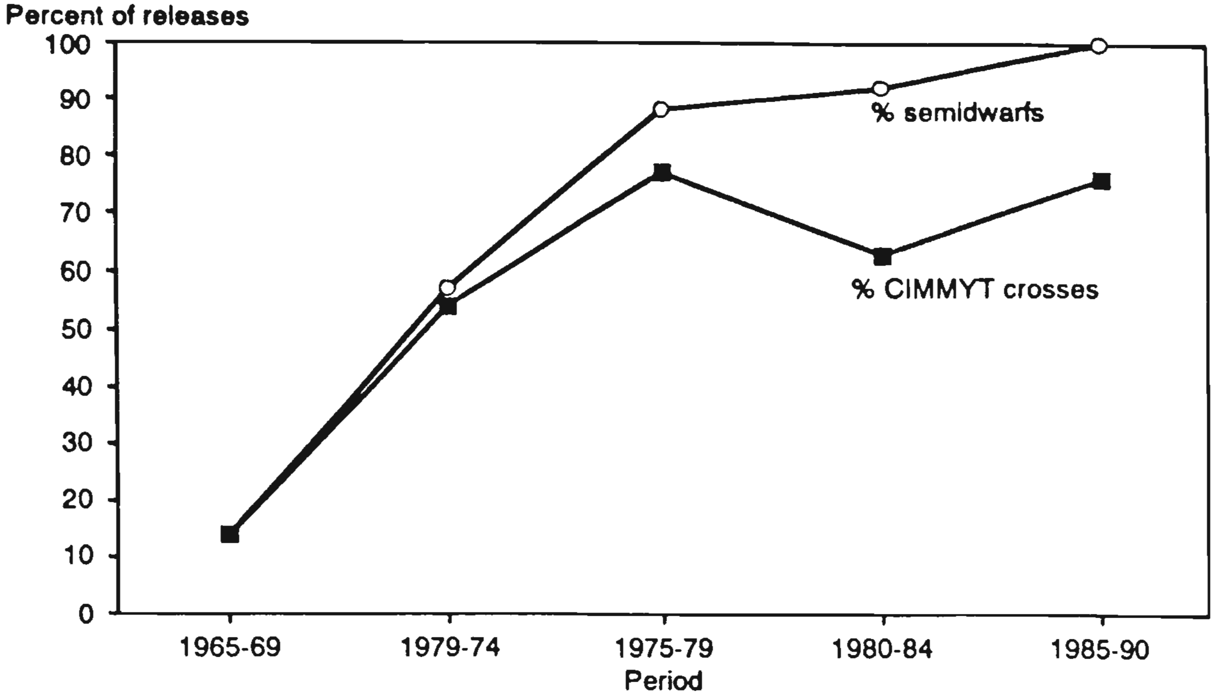

Figure 1. Percent of durum releases in developing countries as semidwarfs and percent from CIMMYT crosses, 1965-90

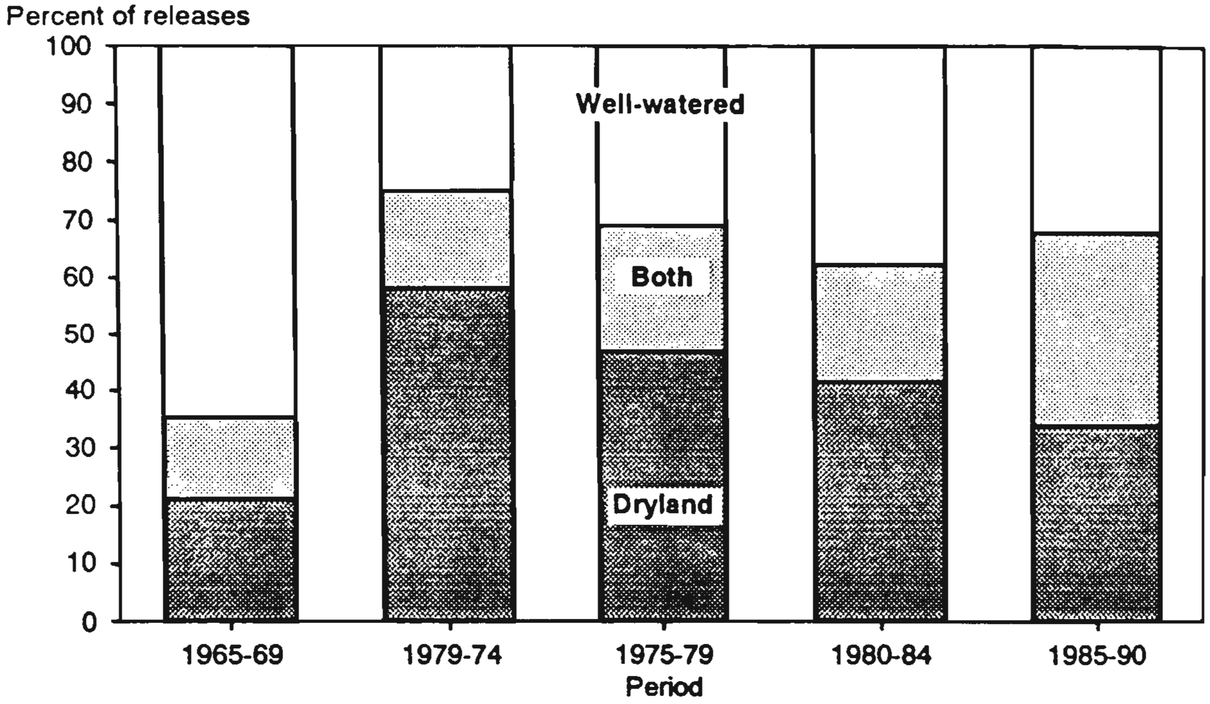

Figure 2. Ecological niche of released durums by period, 1965-90

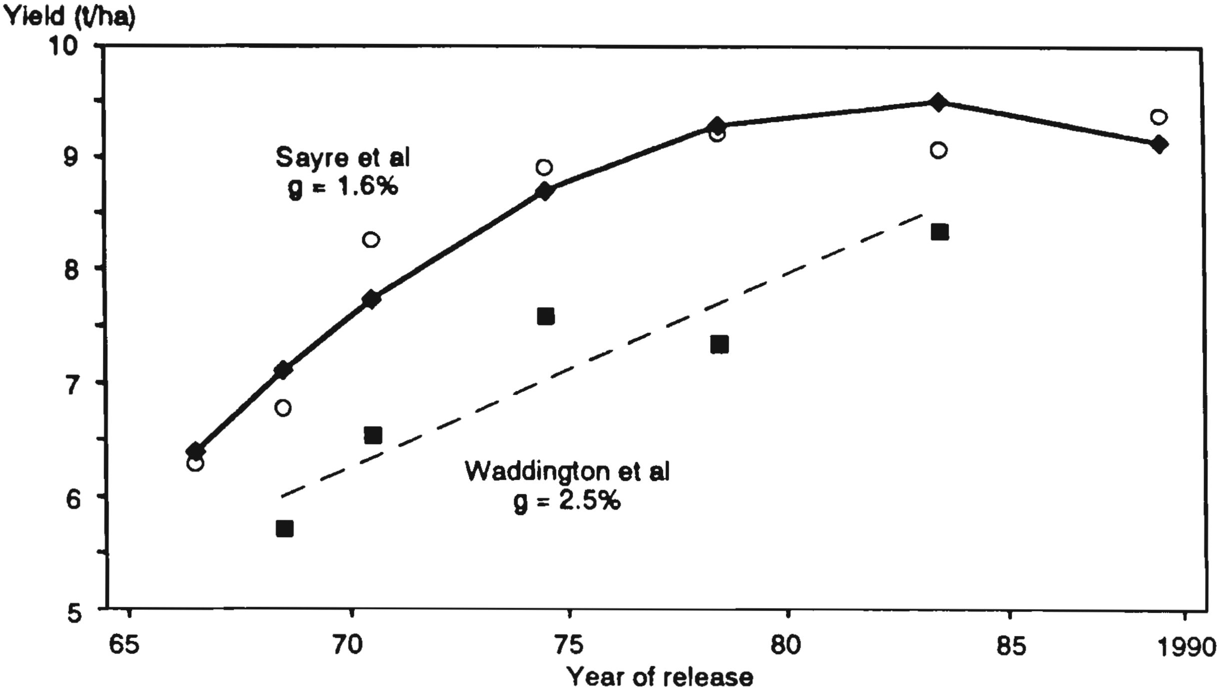

Figure 3. Yield potential of durum varieties, Mexico, 1967-89.

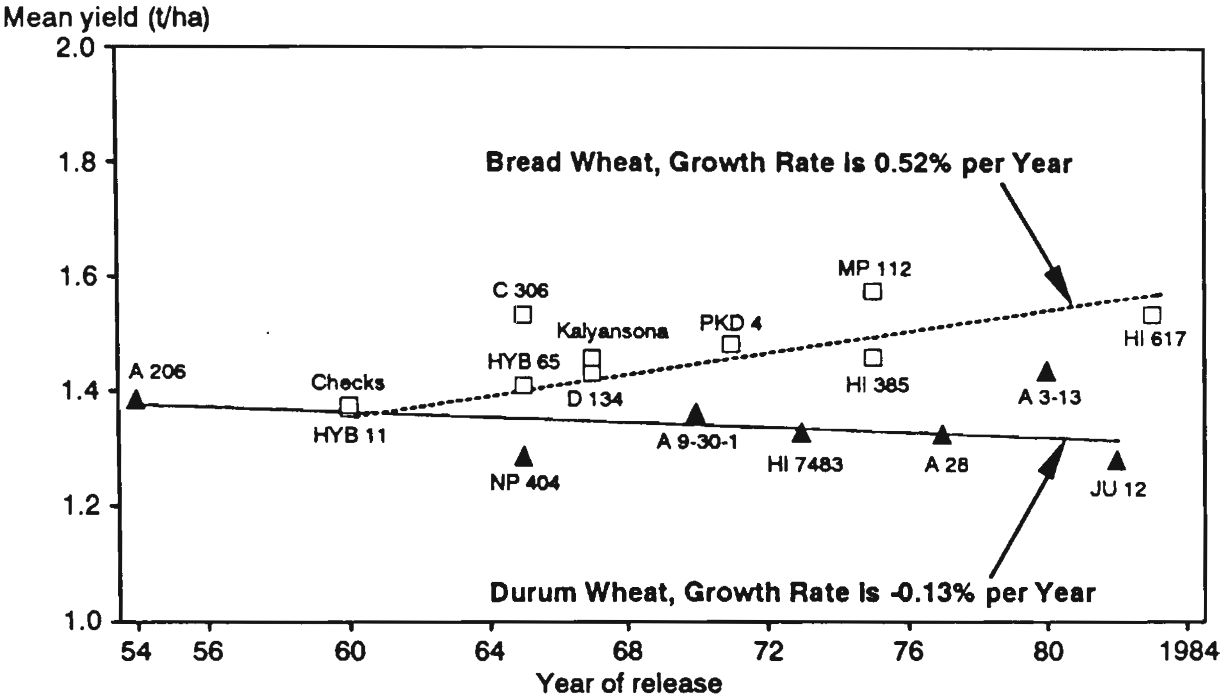

Figure 4. Yield gains in bread and durum wheat varietes released for the Central Zone, India: rainfed, timely sown condition, 1954-83.
Source: K. B. L. Jain.

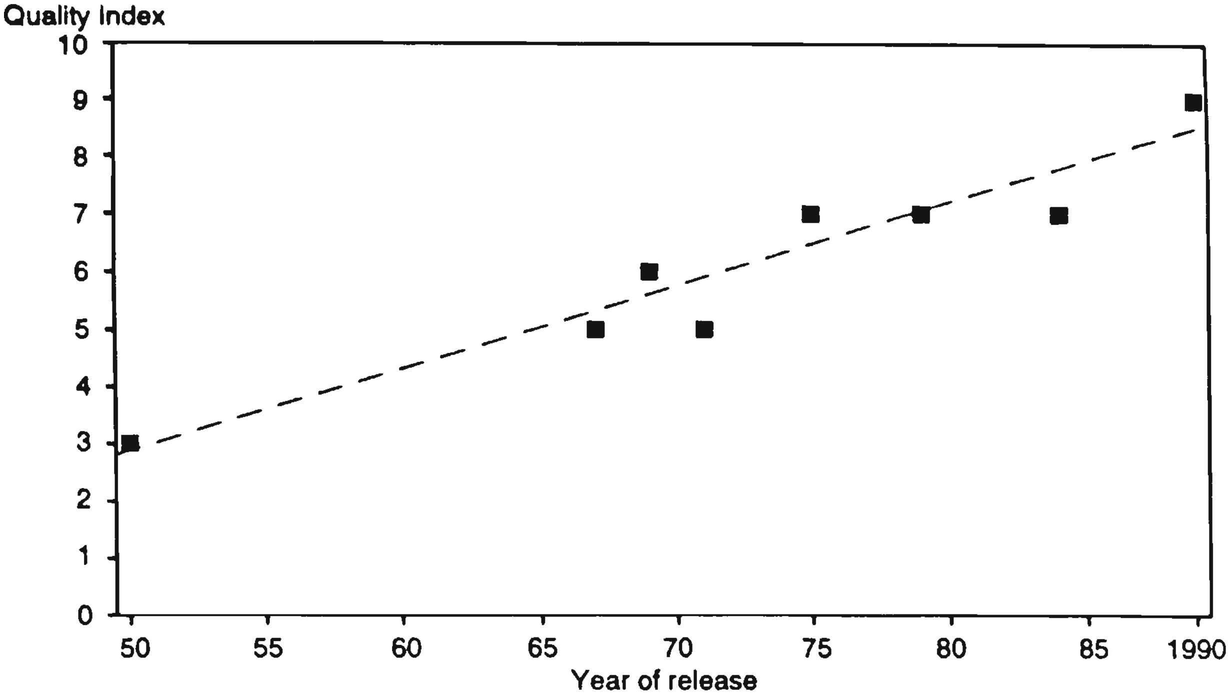

Figure 5. Quality Index for durum wheat varietes Mexico, 1950-89.
Source: A. Amaya & J. Peña (pers. com.). Based on yellow pigment (ppm) and SDS-sedimentation (mR). Maximum quality score is 10.

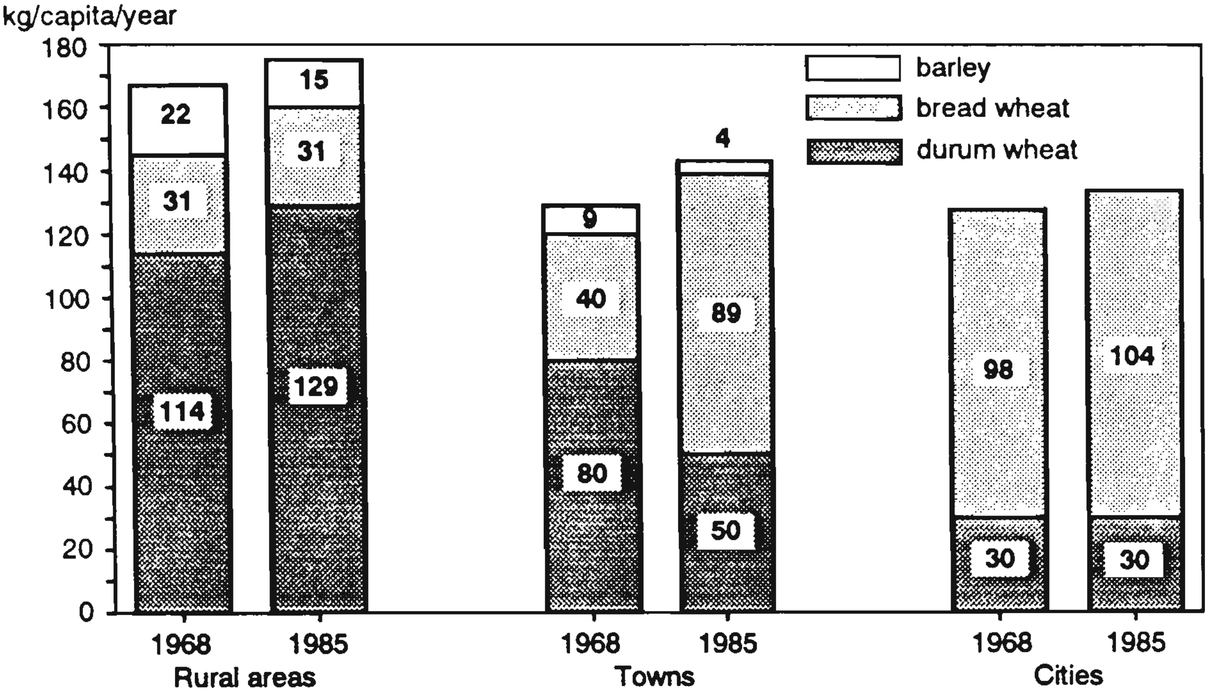

Figure 6. Changes in cereal food consumption patterns in Tunisia, 1968-85.
Source: Perisse and Kamoun (1987), and Johnson et al. (1983).

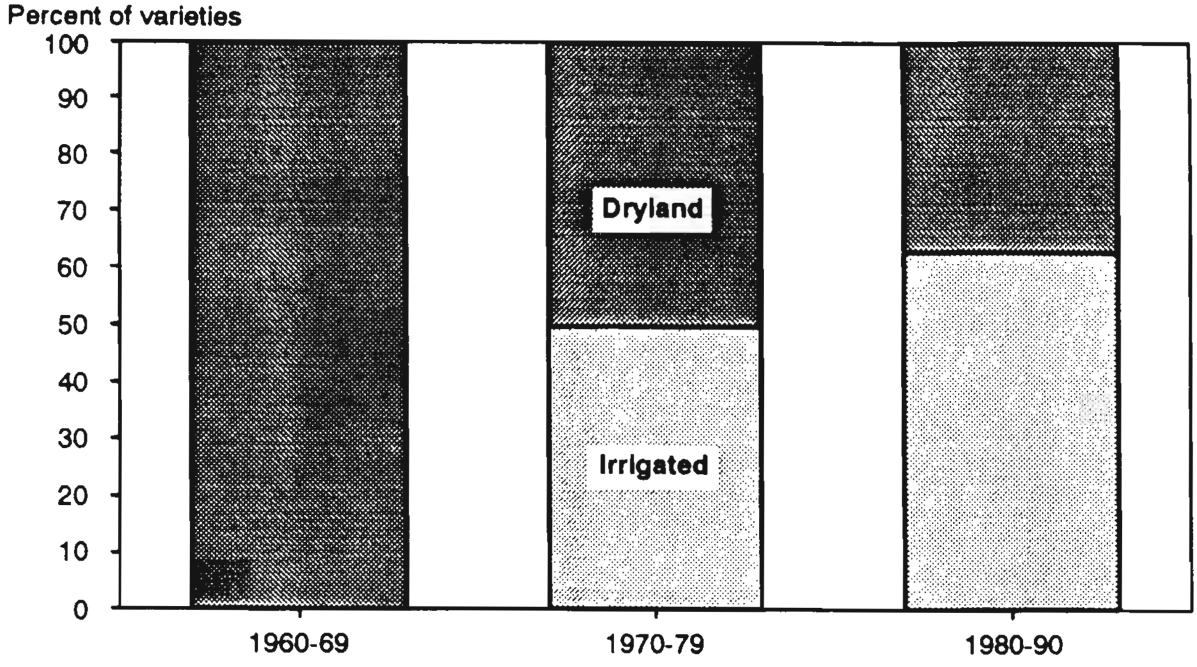

Figure 7. Composition of durum variety releases in India, 1960-90.
Source: K.B.L. Jain.

Annex A.

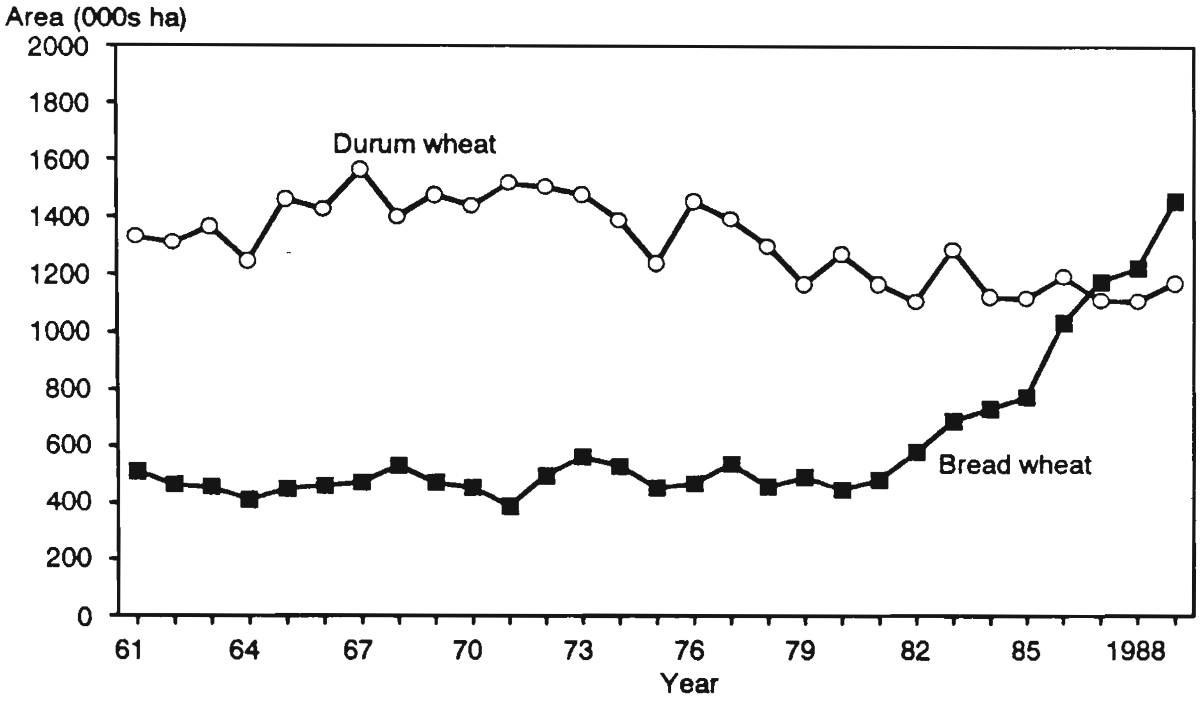

Figure 1. Area of durum and bread wheat, Morocco, 1961-89.

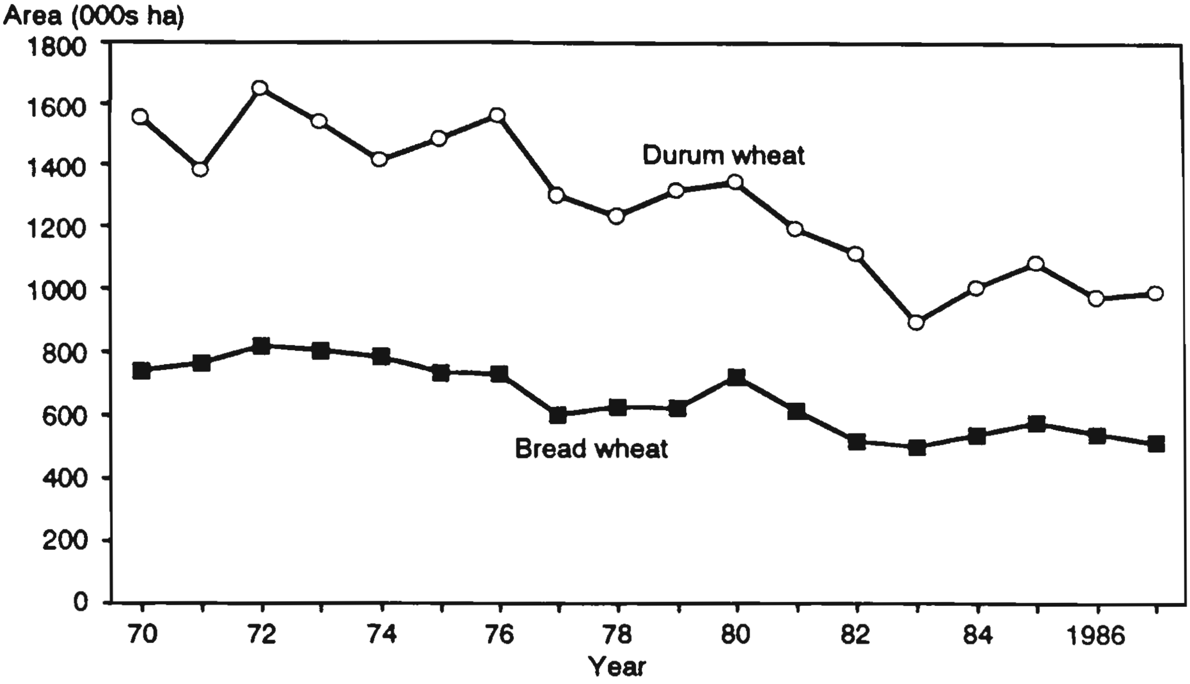

Figure 2. Area of durum and bread wheat, Algeria, 1970-87.

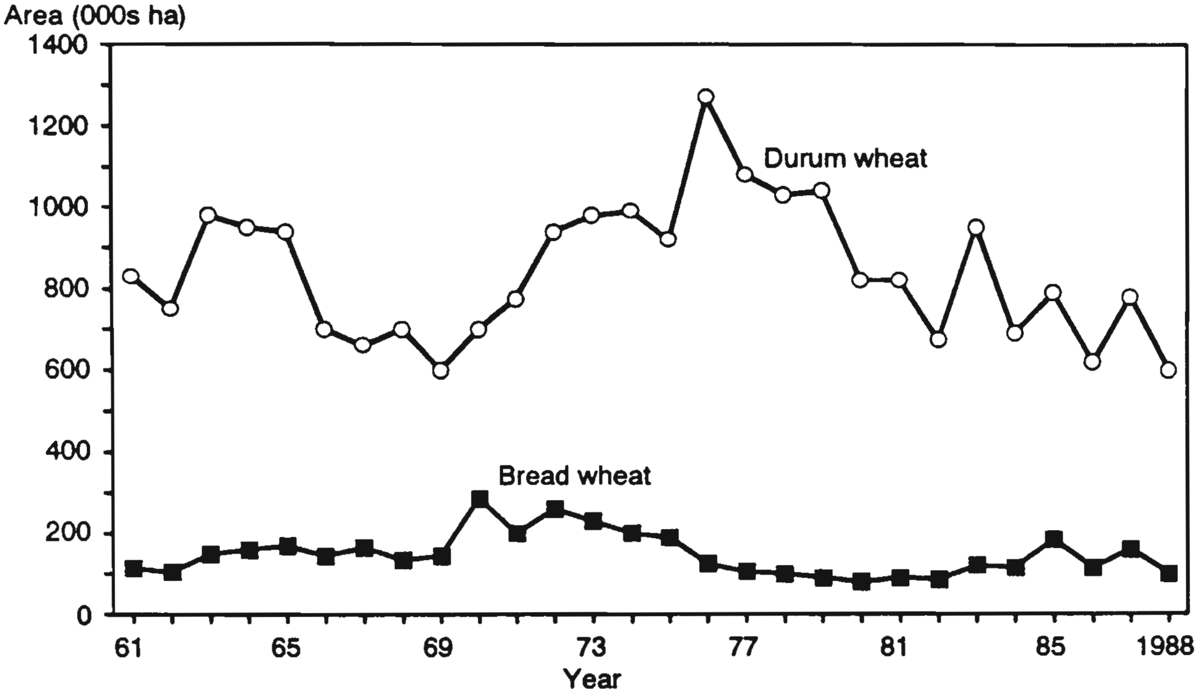

Figure 3. Area of durum and bread wheat, Tunisia, 1961-88.

Annex B.

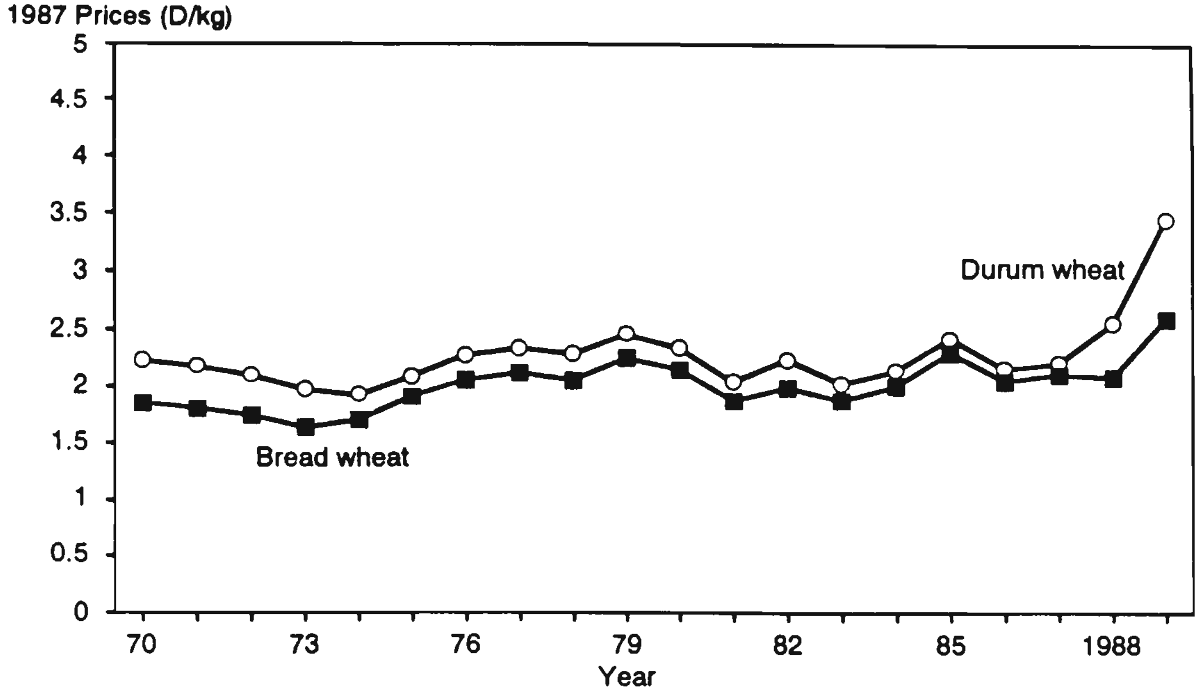

Figure 1. Real producer price of wheat, Algeria, 1970-89.

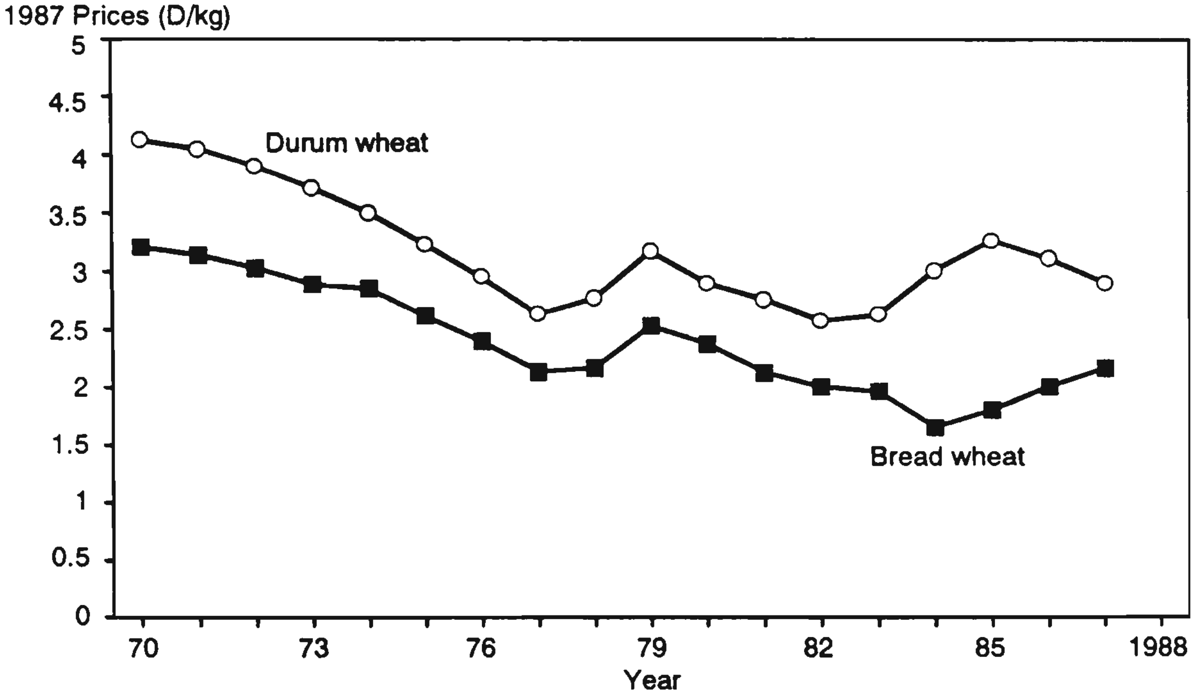

Figure 2. Real consumer price of wheat, Algeria, 1970-87.

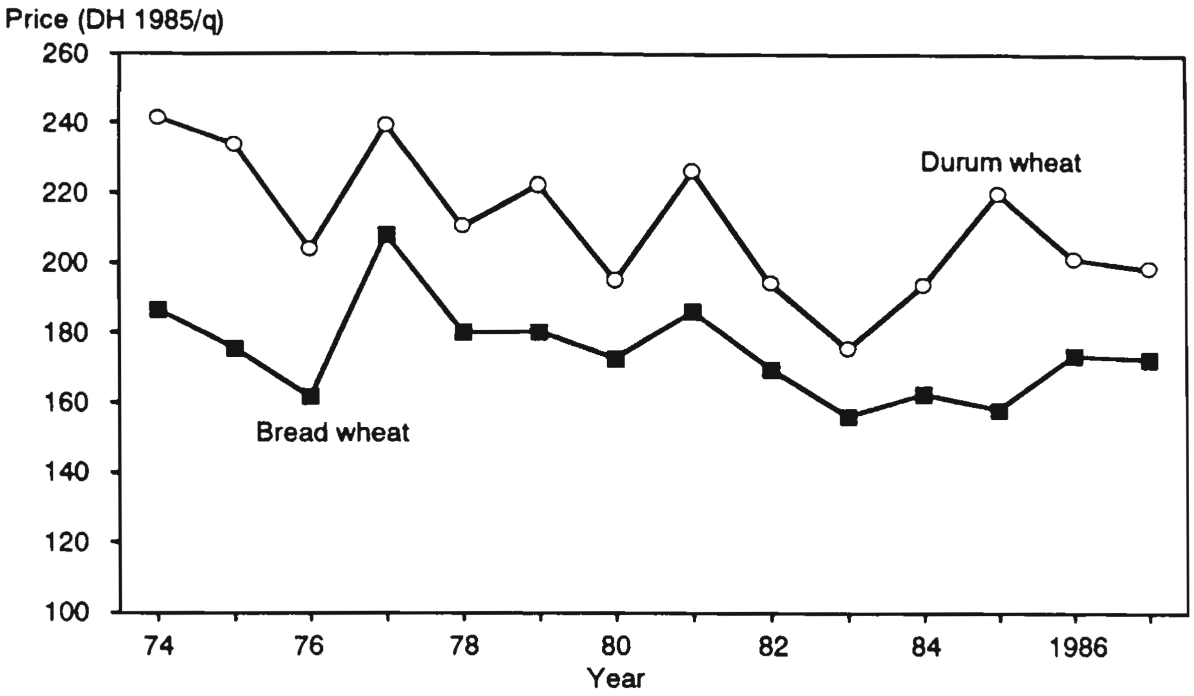

Figure 3. Market price to producers for bread and durum wheat in Morocco, 1974-87.

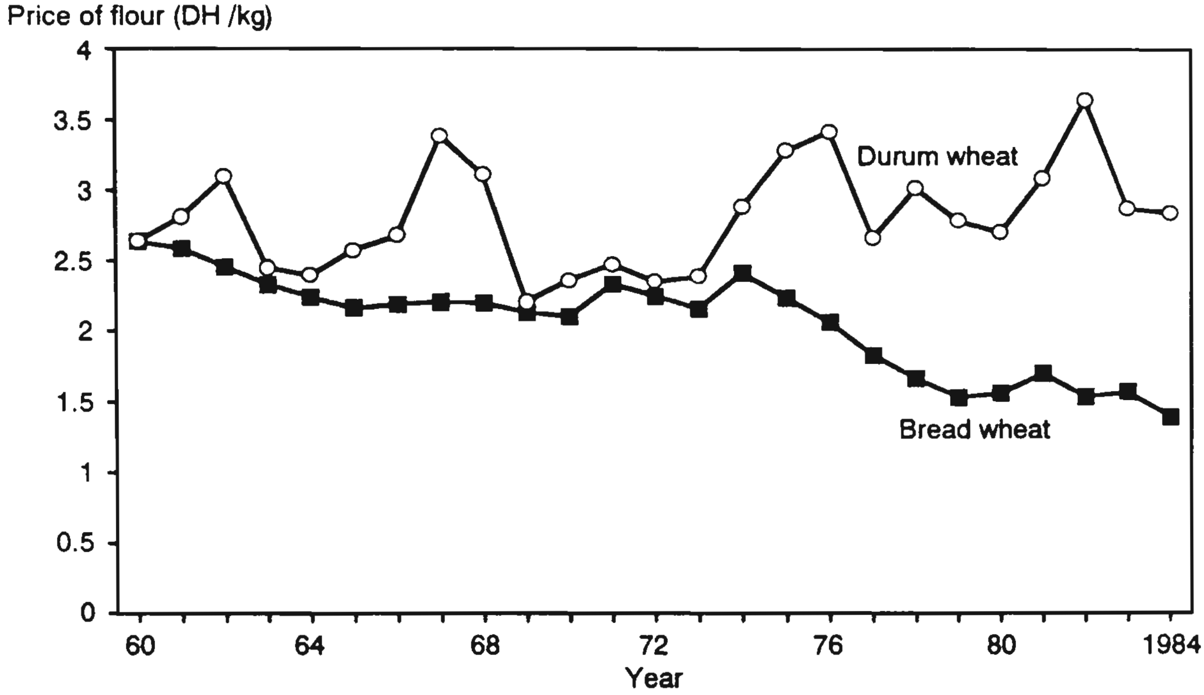

Figure 4. Consumer prices of bread and durum wheat in Morocco, 1960-84.

DURUM WHEAT BREEDING IN INDIA

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Although durum or macaroni wheat (*Triticum turgidum* var. *durum*) is the second important wheat species in India, it only accounts for around 8% of the country's total wheat area. Traditionally, durum wheat has been cultivated, to varying degrees, from Punjab in the north to Karnatka in the south and Gujarat in the west to Bengal in the east. It has also been cultivated in isolated pockets of the hilly tracts of Himachal Pradesh (H.P.). However, high susceptibility to stripe rust (*Puccinia striiformis*) followed by leaf rust (*P. recondita*), resulted in total elimination of durum wheats in several parts of the country and a marked decrease in durum area in peninsular and central India.

Rainfed durum cultivation is now confined to the peninsular and central states of Maharashtra, Karnatka, Madhya Pradesh (M.P.), Gujarat, and Rajasthan. Usually sown in October or early November, the durum wheat crop grows during the dry winter season on conserved moisture from the monsoon rains. The soils are characterized by typical shallow to deep Vertisols. Maturity occurs in January-February in the peninsular region and extends up to April in central India, U.P., and northern region of the country. The durum crop is exposed to high temperatures at both the tillering and grain filling stages and poses a problem if genotypes do not have the ability to tiller and set seed well under hot conditions. Irrigated durum cultivation is also common in the peninsular states of Andhra Pradesh (A.P.), Karnatka, and Maharashtra. Irrigated durums also occupy substantial areas in M.P., Gujarat, and Rajasthan and the Bundelkhand region of Uttar Pradesh (U.P.). Irrigated cultivation has expanded markedly in recent years, particularly in the northern states of Punjab and Haryana in response to the Karnal bunt (*Tilletia indica*) problem.

Durums are mainly used in preparing semolina known as dalia, unleavened bread (chapati), and various sweet and salty preparations, which are better cooked due to the granular structure and nonsticky character. Indian durums are also suitable for manufacturing macaroni, spaghetti, and noodles.

Traditional Durum Wheat Varieties

Prior to durum wheat improvement efforts, typical durum varieties of the Malwa region were medium to late in maturity and tall in height and they had nonpubescent glumes and white or brown grains that tended to mottle under low fertility. In U.P. and adjoining areas of M.P., highly drought resistant durum varieties known as Kathia were cultivated, which had a tendency to withstand moisture stress due to their extensive root systems.

In Karnatka and Adhra Pradesh, local red durums were popular for use in the preparation of upma. These durums were of medium height, medium to late in maturity and had brown glumes.

Durums of early maturity with medium height, smooth glumes, red or amber bold grains were grown in dry areas of extreme western Gujarat. They proved their worth as good yielders with wide adaptability.

In Bengal, Gangajalli durum types with late maturity, pubescent glumes, and bold amber grains were cultivated. In Punjab as well, tall, late-maturing durums with pubescent glumes and bold, hard grains were grown.

In general, it can be said that because durum wheats have been grown in various agro-climatic regions of the country, the various genotypes possess a wide genetic diversity. Some of the old types are still popular with farmers for their excellent grain quality and good yield under abiotic stresses.

Durum Wheat Improvement

Durum wheat improvement work in India started during the first decade after independence and was confined mainly to the isolation of pure lines from the locally grown mixtures found in the farmers' fields. Resulting varieties included Punjab T1 and T2 in Punjab, Bansi 168 (Motia), Bansi 202, Bansi 224 (Gulab), P.W. 3 (Bansi selection), A.O. 13, A.O. 88, and A.O. 90 from the old central provinces; selections like Ujjain 1, Ujjain 9, EK 2, EK 6, EK 9, and N 111 were developed in central India. In Gujarat, A 206 and R 264 were very popular selections derived from mixtures in farmers' fields in the Bhal Tract. A 206 had wide adaptability throughout India and is still grown in Gujarat, but due to its susceptibility to the rusts, it has lost its popularity elsewhere.

Varieties K 2, K 19-3, and K 21, obtained from Kathia in the Pundelkhand region of U.P., were good yielders and grew well in the typically black soils that crack upon drying.

These indigenous Indian varieties were highly susceptible to the rusts. Whenever a rust epidemic occurred, total losses of the wheat crop--particularly the durums--were common. So breeding programs aimed at incorporating rust resistance along with other desirable traits were undertaken in the major durum wheat states. In the 1950s, local selections with good agronomic types were crossed with rust-resistant wheats such as Gaza, which had good resistance to the then prevalent races of stem and leaf rusts. More than a dozen varieties resulted, such as N 59, NI 200, and NI 146 in Maharashtra; Amrut, Bijaga Yellow, and Bijaga Red in Karnatka; NP 404, NP 412, Hyb 32, Hyb 34, and Meghdoot in M.P., NP 401 in U.P.; and A-9-30-1 in Gujarat.

However, the above-mentioned varieties succumbed as more virulent biotypes of the rust pathogens appeared. So rust-resistant donors such as E 4724 (Canada), G4-48 (Egypt), E 43459, St 464 (Ethiopia), E 2025 (Arabia), and Nurshit (Israel) and Stewart 163, Ward, Wells, Parana 66, and Durum No. 24 from Mexico were used heavily in durum improvement programs of the major research stations. Interspecific crosses involving, *T. dicoccum*, *T. carthlicum*, *T. polonicum*, and *T. timopheevi*, resulted in the rust-resistant varieties MACA 9, Vijay, and Jairaj.

But these varieties did not raise productivity and they were not responsive to higher levels of fertilizer and changes in agricultural practices that had accompanied the intensive cropping systems initiated in the 1960s. So, efforts were begun to develop high yielding durum wheats that were input-responsive as well as resistant to a range of fungal diseases that attacked durum wheat.

Through crosses between Indian and exotic wheats--mostly those from CIMMYT in Mexico--high yield potential, good grain quality, and reasonable resistance to important diseases were incorporated into the new semidwarf plant types. Resulting durum wheat varieties, such as DWL 5023, PBW 34, and PDW 215, have done well in the irrigated conditions of the Northern Plain Zone.

Ten durum varieties are currently recommended for commercial cultivation in India (Table 1).

Table 1. Recommended durum wheat varieties for India.

Variety	Parentage	Recommended production conditions
North Plain Zone		
DWL 5023	Cr'S'/Ld 'S'//Gr 'S'	Timely sown, irrigated, good fertility
PBW 34.	D. Dwarf/15 Cr'S'	Timely sown, irrigated, high fertility
PDW 215	DWL 5031/DWL 5002	Timely sown, irrigated, high fertility
Central Zone		
Raj 911	Selection from Mexican Line V 229	Timely sown, irrigated, high fertility
HD 4530		Timely sown, irrigated, good fertility
Jairaj		Timely sown, irrigated, good fertility
JU 12	HDM 22550-3/JA 3-3-1	Timely sown, low fertility, rainfed
Raj 1555	Cocorit/Raj 911	Timely sown, good fertility
Peninsular Zone		
Malvika (HD4502)	Pi-'8'/2TC//Z-B-W	High fertility, timely sown, irrigated
MACS 1967	Gulab/CPAN 1471	Timely sown, low fertility, rainfed

Most of these improved semidwarf genotypes have high yield potential and a high degree of rust resistance when grown under good soil and water management conditions. Some of the varieties have been successfully cultivated in the Northern Plain Zone where productivity is much higher compared to the Central and Peninsular Zones. This has opened possibilities for a durum export market. Durum wheat cultivation in the north is also helping to curb the Karnal bunt dilemma, which is much more of a problem with bread wheat (*Triticum aestivum*).

Presently, the average durum yield in advanced yield trials in the Northern Plain Zone is 4.68 t/ha (PBW 34), which is comparable to bread wheat (4.85 t/ha for HD 2329. However, in the Central and Peninsular Zones, absence of high yielding durum varieties poses a challenge for breeders, especially for the irrigated tracts in these zones.

Immediate steps should be taken to develop durum varieties that are as productive as bread wheat varieties for these important zones.

Future Programs

Rainfed durum wheat cultivation is declining and already is negligible in Central India. However, durum cultivation should continue in Karnatka and Gujarat where these wheats have specific adaptability. Irrigated or partially irrigated durum wheats continue to gain importance in all parts of the country.

As already alluded to, durum wheats are grown over a wide range of agroclimatic conditions in India. The main aim of durum wheat breeders will be to continue developing new varieties that are stable, high yielding, rust resistant, and of high grain quality. Other diseases such as powdery mildew, alternaria, septoria, barley mosaic virus, loose smut, and Karnal bunt will receive due attention.

It has been observed that genotypes with relatively shorter heights and an erect leaf habit tend to yield more under the high input conditions of the Northern Plain Zone. This may be attributable to the lower leaves intercepting more sunlight, which allows them to contribute more actively to photosynthesis. Erect foliage also allows a higher plant population, which enables the genotype to reach its yield potential at high fertility. On the other hand, in the Central and Peninsular Zones where limited moisture and lower fertility in farmers' fields reduce plant growth and leaf area drastically, genotypes with drooping, broad leaves can cover the ground faster, intercept more sunlight, and compete better with weeds than erect-leaf types. Presently, the aim is to develop better plant types in durums by making use of both erect- and drooping-leaf types for the conditions under which they are better suited.

Similarly, for the Northern Plain Zone, emphasis will be placed on incorporating resistance to leaf and stripe rusts, while stem rust resistance will be the goal in central and peninsular India. Many genetic stocks that exhibit immunity or resistance to all three rusts or one or two of them have been identified. Breeders are using off-season nurseries at Wellington and Lahaul Valley, situated in extreme southern and northern India, respectively, to screen for rust resistance. Such shuttle breeding will also provide means to eliminate photosensitive material and obtain genotypes with wider adaptability.

Karnal bunt is widespread in the Northern Plain Zone. Field resistance to this seedborne fungus in most durums appears to be due to their distinctive head types. But it has been found that with artificial inoculation, most varieties and lines exhibit susceptibility. It will be vitally important to combine physiological KB resistance as well since derivatives of crosses between the Norin 10 semidwarfs and wild relatives are producing promising selections, but with head types very similar to those of KB-susceptible bread wheats.

During selection and reselection of breeding materials derived from the Norin 10 semidwarfs during the last 20 years, sterility problems in the spikelets have been overcome. Breeders are attempting to raise yields in durums by increasing the number of spikelets per spike, but so far the approach has not been as successful as with bread wheat. Efforts will be intensified to identify genotypes that have longer spikes with more spikelets and utilizing them to develop more productive durums.

Quality traits that will require more emphasis in the future include bold grains, low yellow berry incidence, semolina recovery, and B-carotene content.

In recent years, attempts have been made to identify durum genotypes that can tolerate high temperatures prevailing at both sowing and grain filling in the Peninsular and Central Zones, particularly under irrigated conditions. Continued work on this aspect is of vital importance in these zones because, in the coming years, canal development and other irrigation projects will compel traditional durum wheat farmers to adopt genotypes that are suitable for irrigated conditions.

Although the problem of narrow adaptability has been nearly eliminated, there is still scope for developing more productive durum wheats with wider adaptability, especially for the Central and Peninsular Zones.

A wide range of herbicides with negligible effects on durum genotypes are available, but there will be a continuing need to eliminate susceptibility to the widely used chemicals. However, this aspect is not receiving adequate attention and may pose a challenge where, due to marketing/supply/availability constraints, a farmer's choice of herbicide may be restricted.

While breeders continue their relentless struggle to further raise and stabilize durum yields, the immediate task of everyone concerned with durum wheat production is to assist farmers in reaping full benefits from its cultivation by using currently available technology in the country.

Discussion Notes

Fischer: Rainfed durum areas in India are decreasing. Do you agree with Byerlee's figure of 1.5 million hectares of rainfed wheat or is the area lower than that?
Mathur: I don't have the data to know one way or the other.

Vivar: If you plan to export durum wheat, do you have the grain quality for the international market?
Mathur: Yes, very much so.

PRODUCTION CONSTRAINTS OF DURUM WHEAT IN ETHIOPIA AND USE OF ETHIOPIAN DURUM WHEAT LANDRACE VARIETIES IN BREEDING

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Introduction

Durum or macaroni wheat (*Triticum turgidum* var. *durum*) is indigenous to Ethiopia and it has been under cultivation since ancient times. Ethiopia is considered to be the center of genetic diversity for the crop (Tesfaye and Getachew 1991). Durum wheat production is concentrated in the central and northwestern parts of the country (Figure 1). It is primarily produced by the peasant sector under rainfed conditions at altitudes between 1800 and 2800 meters above sea level (Tesfaye 1987b).

Accurate statistics on area and production of durum wheat in the country are difficult to obtain since they are lumped together with bread wheat. Of 700,000 hectares currently under production, it is estimated that 60% is planted to durum wheat (Getachew et al. 1992). According to some reports, prior to 1954 Ethiopia was an exporter of durum wheat grain and flour (Pinto 1971). However, consumer demand presently far exceeds domestic production area and the country is even importing pasta products. The durum areas in Ethiopia have been declining in recent years due to formidable competition from tef (*Ergrostis tef*), a staple cereal in the country. Tef fetches a higher price than any other cereal in the country. In addition to the escalating price of the grain, tef straw also provides additional income to farmers since it is highly valued as a cattle feed and as reinforcement material for plastering house walls with mud. Consequently, traditional durum areas are being planted to more tef than ever before.

Ethiopians consume durum wheat as leavened bread, common bread, macaroni, spaghetti, biscuits, pastries, and in various indigenous food preparations. The straw is mainly used for cattle feed and as fuel at times of scarcity (Tesfaye and Getachew 1991).

Production Constraints

Although, in general, the national average yield of wheat in Ethiopia has increased to 1.29 t/ha over the last few years (CIMMYT 1991), the rise comes mostly from bread wheat produced in the Arsi and Bale regions. Almost all of the bread wheat varieties grown in the two regions are improved and high yielding with an average yield over 1.5 t/ha. Essential inputs, such as improved seeds and fertilizers, are available to farmers since state farms are located in these regions.

Although some durums are high yielding and improved varieties have been released and distributed to farmers, the area under improved varieties is very small (Tesfaye 1987b). Furthermore, the national average yield is also low, less than 1.0 t/ha. Some of the major factors limiting yield of durum wheat in Ethiopia are indicated below.

Current production practices

The heavy black soils (Vertisols) on which durum wheat is traditionally planted are characterized by cracking when dry and waterlogging during the rainy season, which forces farmers to delay planting. As a result, plant stands are poor and crop yields are

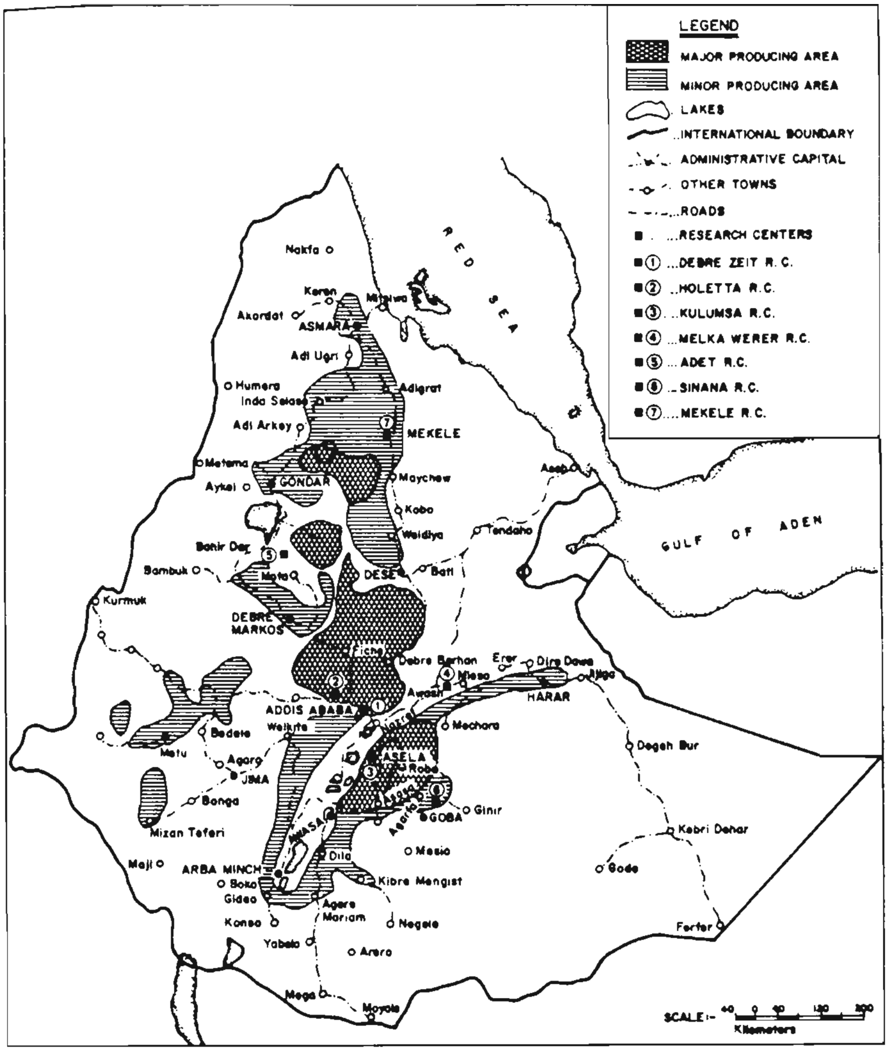

Figure 1. Major and minor wheat production areas in Ethiopia and major cooperating centers for wheat research. Source: Land Use Planning and Regulatory Dept., DOA.

reduced by moisture stress and cracking soils, which induce root lodging and premature drying (Tesfaye 1987b). Farmers do not use surface or subsurface drainage implements.

Sowing dates range from mid-July on well drained soils to middle or late August on waterlogged soils. However, under waterlogged soil conditions at Cheffe Donsa, it has been shown that yield can be improved by using optimum date of planting and fertilizer without benefit of an improved variety (Table 1). The optimum time of planting for durum wheat in the area is between mid-July and early August.

Imported fertilizer in Ethiopia is expensive and limited in supply and hence farmers tend to use it on higher cash-fetching cereals such as tef and not on durum wheat. Most durum wheat farmers do not weed their wheat crops. Those that do usually weed later than recommended because of overlapping activities. Herbicide use is minimal (Hailu et al. 1991).

Varieties

In Ethiopia, durum wheat is cultivated under a wide range of agro-ecological conditions where crop requirements and disease development vary to a high degree and environmental conditions in areas, even within short distances of each other, are different. This calls for the development of widely adapted varieties or those that are suitable to specific agro-ecological zones.

Unfortunately, efforts to obtain high yielding, widely adapted varieties have so far been rather discouraging (Negasa 1986). On the other hand, the development of specific varieties for specific areas, practical as it may seem, is also difficult to implement. The few research stations in the country there are do not cover all of the major durum wheat growing areas. As a result, improved durum varieties released so far serve only limited areas. In addition, since the varieties require high inputs such as fertilizers to give better yield than the local cultivars, most durum wheat farmers continue to use unimproved local cultivars until such time better varieties and fertilizers are available. However, it should be recognized that the local cultivars have location-specific adaptabilities as well, despite their adaptive capacity to survive unfavorable conditions in a specific area. They also have weak straw that is prone to lodging. Above all, they lack satisfactory resistance to leaf rust and tend to be rather low yielding (Tesfaye 1991).

Soil fertility

Soils in the durum wheat growing regions of the country are deficient in one or more of the major elements. As a result, yields are low and continue to be low unless farmers follow proper soil management practices.

As shown in Table 2, yields of durum wheat can be increased substantially with fertilizer application regardless of the varieties. Fertilizer studies on Vertisols show that durum wheat responds best to a combination of nitrogen and phosphorus fertilizer applications (Tesfaye 1987a). However, as mentioned earlier, fertilizer is generally unavailable.

Diseases and pests

Fungal diseases cause a considerable yield loss in durum wheat, among these, leaf rust (*Puccinia recondita*), stem rust (*P. graminis tritici*), and stripe rust (*P. striiformis*), are the most important. Problem diseases in some areas (Tesfaye 1991) include Septoria leaf blotch (*Septoria tritici*), glume blotch (*S. nodorum*), leaf spot (*Helminthosporium* spp.), bunt or stinking smut (*Tilletia foetida* or *T. caries*), scab or root rot (*Fusarium* spp.), powdery mildew (*Erysiphe graminis*), and bacterial stripe (*Xanthomonas translucens*).

The Russian wheat aphid (*Diuraphis noxia*) commonly attacks durum wheat causing crop losses of up to 100% on late-planted local cultivars (Hailu et al. 1991, Tesfaye 1991). Grasshopper damage also occurs frequently in some parts of the country when no heavy rainfall occurs immediately after seed emergence.

Low prices

Low fixed prices are an important constraint. Until a year ago, farmers were forced to sell a large portion of their wheat to the Government at a fixed, official price that was nearly three times lower than the local market. This, in addition to reducing farm income, discourages the use of inputs such as fertilizer and improved seeds (Hailu 1991).

Table 1. Average grain yields of durum wheat varieties grown on different dates with and without fertilizer at Cheffe Donsa during the 1983-85 crop seasons.

Sowing Date	Variety	Yield (kg/ha) With fertilizer	Yield (kg/ha) Without fertlizer
July 4-5	Ld357	586	679
	Cit71	428	402
	DZ04-118(CK)	1026	704
July 13	Ld357	1188	801
	Cit71	951	610
	DZ04-118(CK)	1176	778
July 22-26	Ld357	1273	810
	Cit71	976	747
	DZ04-118(CK)	1361	1049
August 2-6	Ld357	1365	708
	Cit71	970	665
	DZ04-118(CK)	1044	627
August 12-16	Ld357	798	438
	Cit71	728	544
	DZ-04-118	884	614

Use of Landrace Varieties in Breeding

Nearly all of the durum wheat varieties grown in Ethiopia are landraces with location-specific adaptation. They consist of mixtures of different genetic lines that vary in botanical forms and agronomic characters. The high level of diversity in these landraces allows a vast scope for selection. The genotypes exhibit diversity in spike form and density, awn condition (awnless, short, and long), and awn and kernel color (amber, brown, and violet). They also vary in height and maturity. Other distinguishing characteristics include hairy or waxy leaves, hairy or glabrous glumes, and pigmentation in glumes, awns, and kernels (Tesfaye 1991, Tesfaye et al. 1991a).

Plant breeders in the other parts of the world have found some highly desirable characters for breeding purposes from a relatively small amount of Ethiopian durum germplasm in world collections. Abebe (1990) reported that these include stem rust resistance, long coleoptiles, short stems, early flowering, low pH and drought tolerance, ability to yield in poor soils and management conditions, and high contents of protein and other basic amino acids. Ethiopian durums are also reported to have resistance to powdery mildew, glume blotch (Negasa 1986), and Hessian fly (*Mayetiola destructor*) (Amri 1990, Mass et al.).

Although the value of the Ethiopian durums has been well documented, very limited activities have been carried out to utilize this indigenous germplasm in local durum improvement. Prior to 1986, only six strains from local landraces (A10, R18, P20, H23, Arendeto, and Marou) and two selections from crosses between landraces and an introduction (A10 X Mindum and R18 X Mindum) had been released to farmers (Tesfaye and Getachew 1991).

Table 2. Average grain yields (kg/ha) for 11 varieties of durum wheat grown with and without fertilizer at three locations (Debre Zeit, Akak and Cheffe Donsa) during 1981-83 crop seasons.

Variety	With fertilizer	Without fertilizer	% increase due to fertilizer
Ld 357	2210	460	51
Cit 71/Condeall II	2220	1430	55
CD3862-1GS-6BS-1GS-0DZ	1880	1290	46
Gerardo	1880	1010	86
Yemen/Cit'S'//PLC'S' /3/Tagnroy B.B	2150	1240	73
Boohai	1930	1290	50
CD 3862-1Bs-1DZ 4DZ-0DZ	2360	1590	50
Mexi'S'//Chap/21563/3/ Pg'S'	1930	1280	51
CD 3862-1BS-2GS-1BS-0DZ	2080	1270	64
Enkoy (BW check)	2820	1480	90
DZ-04-118 (Local check)	2210	1240	78
Mean	2150	1330	62

The Debre Zeit Research Center is the coordinator for the Durum Wheat Improvement Program. One of the major reasons why indigenous germplasm has not been effectively utilized in the national program is that the material has not been adequately evaluated. The few collections that were tried when the wheat program was started were found to be extremely susceptible to leaf and stem rusts and produced very low yields under Debre Zeit conditions, a "hot spot" for the two diseases. Consequently, more attention was given to introductions mostly due to the influence of the "Green Revolution". In spite of this, some high yielding, improved durum varieties derived from landraces have been released to farmers. Unfortunately, requirements for technical inputs, a lack of wide adaptation, and susceptibility to some of the major diseases have restricted expansion of these varieties in the country. Therefore, breeders need to take a new look back at the indigenous durum landraces.

Since the establishment of the Plant Genetic Resources Center/Ethiopia, there has been ample opportunity to evaluate most of the indigenous wheat collections under Debre Zeit conditions. Lines that have some breeding values, except for yield, have been identified and are being used in the national program. Due to the extreme susceptibility of most of the landraces to leaf and stem rusts and accompanying very low yields at Debre Zeit, selection for yield has been rather difficult.

The yield potential of the indigenous durums was not ascertained until the late 1970s when in the nationwide Research/Extension Durum Wheat Adaptation Trial. The local durum wheat cultivars used as checks for comparison outyielded the so-called high yielding introduced varieties at many locations under low-input conditions traditionally practiced by the farmers (no fertilizer, no weeding). In general, this indicated that the local cultivars grown by the farmers were specific in adaptation and since they consisted of mixtures of genetic lines with different yielding capacity, disease reaction, etc, it was felt that the chance of identifying superior lines would be greater if the local durum wheat collections were evaluated at or near their original collection sites.

As a result, a joint program between Debre Zeit Agricultural Research Center of Alemaya University and the Swedish Agency for Research Cooperation with Developing Countries (SAREC) has been in operation since 1985. One of the specific objectives of the study was to develop high yielding landrace selections from populations collected at specific locations by evaluating them at their respective original collection sites. Good examples of this are the durum wheat collections from the Bichena and Cheffe Donsa areas of Ethiopia where they are now being tested for yield performance at their respective collection sites. Performance trials at these locations in the past have shown the local check cultivars to be superior in yield to the introduced varieties. The selections are now in the final stages of yield testing. At the end of the study, it is expected that landrace selections with higher yield than the original populations will be identified for immediate release to farmers and/or as parents in future breeding efforts.

Since modern high yielding, introduced varieties are mostly unadapted to low-input farming, new germplasm possessing the adaptive capacity of the landrace selections and the high yield potential of the introduced varieties are being developed through one or two backcrossings to the landrace parent. The modified bulk method is being used and the material is now in the F_4 generation. After the F_5 generation, comparisons will be made to determine whether selections from single crosses or one or two backcrosses are more useful.

Lately, the landraces have been found to have good resistance to stripe rust at Meraro, a "hot spot" for the disease. Of some 475 durum genotypes composed of landraces, introductions, and Debre Zeit crosses, 25 genotypes have been identified as being resistant to both leaf and head infections among which 22 were landraces (Getachew et al. 1992). It is anticipated that some of the resistant strains will serve as donors of genetic material in the development of varieties for the highland areas.

Bacterial stripe is a disease that is mostly prevalent on wheat varieties of Mexican origin. Since most of the Ethiopian durum wheat landraces are almost immune to the disease, the utilization of the indigenous material in a cross may automatically take care of the control of the disease.

Conclusions

Rainfall is not a major limiting factor to production in most of the durum wheat growing areas of Ethiopia. However, to increase production of durum wheat in the country, among other factors, the following should be considered:

- The drainage condition of Vertisols on which the major portion of the durum wheat in country is grown must be improved. In this regard, the Vertisol Project, which is a collaborative effort between the International Livestock Center for Africa (ILCA), the Institute of Agricultural Research (IAR), and the Alemaya University of Agriculture (AUA) is a step in the right direction.

- Fertilizers, herbicides, and seeds of improved varieties should be made available in adequate supplies to the farmers.

- There should be a free-marketing Government policy that allows farmers to sell their produce when and wherever they wish.

- At present, pasta products for local consumption are manufactured from mixtures of durum wheat, bread wheat, and maize, which for the most part are of low quality. Even then, due to scarcities, imports are made to supplement the local demand. If production of durum wheat in the country is to increase, the price of the grain must be made attractive to farmers so they will produce more. Then, the local industries will be able to manufacture more good quality products, thereby saving the scarce foreign exchange which otherwise is spent in importation.

The Ethiopian durum landraces are the results of many years of natural selection under the varying environmental conditions of Ethiopia. The genetic variability in these landraces has a tremendous potential which if properly exploited, could be a vital and a very useful source of germplasm not only for the country but also for the rest of the world. The evaluation of this germplasm resource is the key to its utilization in breeding programs and, more effort is needed along this line.

The adaptive capacity of the landraces must he exploited to the best advantage in increasing yields through the identification of superior and adapted lines. Efforts to explore the potential of the landraces with regards to adaptation and resistance to stress must be strengthened.

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Discussion Notes

Ortiz: What is the grain quality of these durum wheats?
Tesfaye: Quite variable. We have so many other problems that we have not had an opportunity to select for grain quality.

Varughese: I would think it would be possible to control the diseases at Debre Zeit in order to select for yield.

Hamblin: Do you test the landraces as populations or as lines?
Tesfaye: As lines.

Sayre: When is waterlogging a problem?
Tesfaye: At tillering, 3 weeks after planting.

Saari: Does tef have any anerobic properties?
Tesfaye: Yes, it does in these soils.

Vivar: Have you looked at legumes for rotating with durum wheat?
Tesfaye: Durums do very well after legumes, but farmers prefer growing tef because of the better market price.

van Ginkel: Did the reconstituted landraces outyield the original landraces in their location of origin?
Tesfaye: Yes, they did.

Saari: Have you found landraces that have high or moderate stem rust resistance?
Tesfaye: They have a little bit.

Fischer: How useful has CIMMYT material been to you?
Tesfaye: National yield trials show a confused picture--up one year and down the next.

van Ginkel: Are you going to specific or wide adaptation?
Tesfaye: Trying both ways. With the landraces, we are trying to develop material for the locations the landraces were collected in.

Sayre: How do you differentiate biotic vs abiotic effects in terms of talking about adaptation?
Tesfaye: It depends on location as to whether we concentrate on diseases or abiotic stresses.

BREEDING FOR GRAIN YIELD AND QUALITY OF DURUM WHEAT IN AUSTRALIA

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Australian Durum Wheat Industry

Australian durum wheat production is small by comparison with that for bread wheat (i.e., 0.5% of total). Since the mid-1970s, durum wheat production has increased rapidly from about 8000 tons annually to 80,000 tons in 1992.

All durum grain is currently processed by domestic semolina mills and most of the milled product is made into pasta for sale within Australia. The sale of wheat within the country is completely deregulated, consequently farmers sell their grain directly to mills and negotiate the prices, quantity, and quality with mills.

The Australian durum pasta industry has experienced a rapid and substantial change from bread wheat-based pasta to durum wheat. Virtually all domestic pasta is manufactured from durum semolina, even the inexpensive generic brands. Increasing sales of imported high quality durum-based Italian pasta forced the domestic industry to change to durum to compete with these imports. Recently, 87% of the growth in the pasta market was taken by high quality durum products. The growth of imports appears to have plateaued at a 21% market share. Australian consumers clearly demand higher quality pasta at a reasonable price. In order to supply this demand, domestic pasta makers and mills have invested tens of millions of dollars in new high technology semolina mills and pasta plants. Because Australian production costs are now comparable with those overseas, Australian manufacturers are endeavoring to secure sizeable export markets for finished products.

Australian pasta consumption is low (2.7 kg per person per annum) when compared with that in Western nations of similar ethnic composition (USA, 9 kg; Canada, 4 kg), thus there appears to be significant potential for growth in the domestic market. The present annual growth rate of 5% is one the of highest for grocery items in Australia. Pasta is seen as a healthy and convenient source of complex carbohydrates.

Industry Organizations

During the period of rapid growth, all sectors of the industry recognized the need to form a consultative Durum Industry Council. This body, composed of representatives from grain growers, all millers and pasta makers, the Australian Wheat Board, and New South Wales (NSW) Agriculture (advisory, research, and administration) meets every 6 months to plan grain production, and lobby the government for policy changes (e.g., anti-dumping laws) and provides a forum for the exchange of ideas, information, and feedback to the breeding program, growers, and others.

The durum growers have formed an association to give themselves a collective voice when negotiating with mills and the Council.

Grain Production

Most durum wheat is grown in northwestern New South Wales with smaller amounts in southern Queensland (Darling Downs, Western Downs), southwestern New South Wales (irrigated sites on the Lachlan, Murray and Darling Valleys), and southeastern South Australia. The principal physical determinants of location are soil type and rainfall.

Soils

The most common types are deep, alkaline (calcareous--pH 7-8.5), self-mulching (high montmorillonite clay content), highly fertile (in virgin state--adequate N, P, K, Zn), and high moisture holding capacity. Fertilizer applications of N, P, and Zn are now required to ensure good quality, high protein grain (No. 1 grade ≥ 13.0% grain protein; No 2 ≥ 11.5%).

Rainfall

The annual average rainfall is about 500 mm, being summer-dominant in the north and winter-dominant in the south. The rainfall amount and distribution are highly variable within and between seasons. Most durum wheat is produced on rainfed areas.

Sowing time

The optimum sowing time is from mid-May to mid-June. Earlier times predispose the crop to frost damage of floral parts near anthesis, while later times expose the crop to high summer temperature and yield reducing moisture stresses.

Durum Breeding

A small and continuous program has been conducted since 1948 by NSW Agriculture. Released cultivars include Dural 1955, Duramba 1970, Durati 1977, Kamilaroi 1982, and Yallaroi 1988. Kamilaroi and Yallaroi now completely dominate production with Yallaroi occupying about 70% of the area.

Breeding objectives

Agronomic

- Height: semidwarf 75-85 cm.
- Maturity: early (quick), 150 days, to senescence no vernalization requirement, minimum photoperiod sensitivity.
- Straw strength: stout with minimum lodging.
- Threshing: free, no grain shelling.

Awns: preferred, reputed drought tolerance, inhibit damage by kangaroos and feral pigs.

- Grain yield: increase > Kamilaroi/Yallaroi.
- Drought tolerance: high level of osmoregulation.
- Zinc nutrition: select nonsensitive lines on heavy black earths pH 8-8.5.
- Seedling vigor: vigorous establishment.

Disease resistance

- Exploit multiple specific and/or durable resistances.
- Stem rust: seedling reaction ≤ 2, adult-plants immune.
- Leaf rust: adequate adult-plant resistance.
- Stripe rust: adult-plant reaction type ≤ 3 (Line scale) retained.
- Black point: reduce incidence to maximum 2% of grain (main causal agent is *Alternaria alternata*).
- Flag smut: immunity.
- Stinking bunt: immunity.

- Yellow leaf spot: lines 3 or lower desired (Rating scale 0-9 on tillering plants in field nursery).
- Crown rot (*Fusarium graminearum*) not under satisfactory control.

Herbicide sensitivity

- Pre-release lines tested with recommended herbicides (X1 and X3 approved rates).
- Specific emphasis on wild oat herbicides as durums are more sensitive than bread wheats to this group of chemicals.
- These tests provide information to growers.
- Sensitivity is not used as a selection criterion.

Grain characters

- Type: vitreous, bright clear amber.
- Size: 1000 kernel weight > 45 g desired.
- Preharvest sprouting resistance: > Kamilaroi; around 5 days to 50% germination in ear; resistance equivalent to seed dormancy.
- Hardness: pearlograph hardness units; > 150 units.
- Protein content: around 12.5-13% on fertile sites.

Semolina quality

- Mill yield: semolina yield ≥ Kamilaroi/Yallaroi.
- Color: semolina Yallaroi--1) lutein (yellow) ≥ Yallaroi and 2) brown minimize < Yallaroi.

Dough rheology

- Strong, stable dough as given by Yallaroi.
- 'Gliadin 45', LMW glutenin 2, and HMW glutenin 6+8 types preferred.
- Testing: 1) SDS-PAGE on parents, 2) mixograph on F3 lines, 3) farinograph on advanced lines.

Protein content

- > 12% in semolina when grown on high protein sites.

Pasta making

- Small (1.5 kg semolina) batch process.
- Process equipment: 1) experimental vacuum extruder for spaghetti, 2) programmable (T^{o} and RH%) dehumidifier.
- Simulate commercial process both high and low temperature drying.

Pasta quality

- Dry product: 1) checking 0-10 visual, 2) color--LAB reflectance.
- Cooked product: 1) optimum cooking time, 2) cooked in steady boiling water ($NaHCO_3$, NaCl added), 3) post-cooking tests--swelling-wet/dry diameter, starch content of cooking solution, water uptake of pasta, surface texture 0-10 visual, Instron bite test, Instron stickiness, color--LAB reflectance, number of deformed pieces.

Commercial trial

A commercial semolina mill processes all pre-release lines. Twenty tons of high quality grain are milled into top grade semolina then sent to selected pasta makers. Milling and pasta making performance is compared with commercial materials of similar quality. Commercial recommendation is considered carefully prior to a release decision.

Breeding procedure

Modified pedigree method

Includes early generation testing for agronomic, disease resistance, and basic quality factors.

Parents

Detailed information on as many aspects as possible.

Crossing

- Enlarge genetic diversity.
- Eliminate complementary defects.
- Around 50 crosses per season.

Handling of generations

- F_1: grown out in a summer glasshouse
- F_2: large single plant nurseries, 20,000 plants per season. Select for general plant appearance, height, maturity, rust reactions, head fertility, grain color, and size.
- F_3: large single-plant progeny row nurseries, 1500 entries. Select for uniformity in height, maturity, disease reaction, and zinc reaction and for quality related to protein content, dough strength, and color.
- F_4: preliminary yield trials--1) 50 entries, two reps, three sites; 2) agronomic--disease resistance; 3) quality--protein content, hardness, 1000 kernel weight, semolina mill yield, farinograph dough strength, color (yellow/brown), pasta tests on selected lines.
- F_5 and F_6: advance yield trials--1) 20 entries, four reps, 10 sites; 2) tests as at F_4; 3) field trials in Queensland/South Australia.
- Pre-release: Breeders Mother seed (F_7) increased prior to despatch to foundation seed growers. Foundation seed is made available to commercial growers after formal release by the Minister of Agriculture.

Field Experiment Design

Advanced statistical designs for field experiments are used to improve the resolution of yield differences. These designs are classified under nearest-neighbor or spatial analysis designs, which can estimate environmental variation (fertility gradients, etc.) either within replications (i.e., across a row of plots) or in both directions (i.e., two dimensional designs--rows and columns) and remove the variation from the treatment (variety) effects. Experience over the past 5 years indicates a significant improvement in the discrimination of grain yield differences, which has led to a sizeable increase in the yield (around 15%) of advanced lines because better lines can be identified more accurately. The simpler nearest-neighbor designs (one-dimensional, SAFE layouts) are available for operators on standard PC computers.

International Cooperators

National and international breeders both agree that there should be an expansion of international cooperation in durum wheat development that embraces developed and developing nations. Such cooperation will offer an expanded resource base (personnel, germplasm, etc.), access to some external funding, a greater range of genetically diverse materials and associated data, which should lead to a better rate of improvement when compared with a group of independent national programs.

The funding of national programs is becoming increasingly more difficult to maintain in real terms, consequently breeding progress could remain static or diminish if more international cooperation/exchange does not occur. Clearly, national programs must and will continue, but their international content will increase. National programs will devote more effort to commercially sensitive issues, e.g., aspects of quality, while the international cooperation could cover grain yield, environmental adaptation (e.g., drought tolerance, trace element nutrition), disease/pest resistance and certain quality attributes (e.g., protein content, sprouting resistance).

Discussion Notes

Ortiz: How important is straw quality?
Hare: The only concern is that it is stout enough to hold up the head.
Fischer: Sheep do not eat the straw.

Peña: Does the grain size affect semolina yield?
Hare: It can.

Vivar: What are the prices of locally produced durum products compared to those that are imported?
Hare: Local products are very competitive.

Nachit: Is Septoria a problem?
Hare: Only some in the south; there is no Septoria in the north.

Fischer: How are you using osmotic adjustment in your breeding program?
Hare: Have recently found a variety that has the adjustment gene. We are currently trying to find an RFLP marker for the gene, which we believe is on chromosome 7A.

FACULTATIVE AND WINTER DURUM WHEAT BREEDING IN WEST ASIA AND NORTH AFRICA (WANA)

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Objectives

The primary breeding objectives for facultative and winter durum wheat improvement reflect the WANA (West Asia and North Africa) environments in which their production is intended--cold winters, hot dry summers. Therefore, of primary importance is winter (i.e., cold) hardiness to allow survival of autumn-sown crops, followed by a targeted maturity to avoid late occurring frosts during anthesis while providing early physiological maturity to allow avoidance of hot, dry, desiccating summer conditions.

Of the three principal grain yield components, tillering plasticity influences environmental yield responsiveness most because of growth opportunities that may occur during the autumn and early spring. Head size is often limited due to the rapid transition between vegetative and reproductive phases induced by temperature and photoperiod changes. Kernel size tends to be the least responsive of this triumvirate, however, large kernel size is the primary consumer-demand quality trait.

Vernal recovery potential should be addressed in its relationship with vernalization requirements and cold tolerance. Spring x winter introgression has been utilized, however, identifying suitable "winter" parents and transgressive winter segregants is a problem. Biotic production constraints and end-use industrial quality objectives have been considered of tertiary importance in most winter durum breeding programs. Resistances to stem and stripe rusts and Zabrus and sunni pest are potential breeding objectives that need to be addressed. Pasta rheological properties have been minor breeding objectives due to primarily local consumption.

WANA National Programs

Turkey

Recent estimates indicate that approximately 8.6 million hectares of wheat are grown in Turkey, of which 1.0 million are durums. Historically, displacement of durum acreage to bread wheat production has occurred with the introduction of improved bread wheat cultivars, thereby relegating durums to more marginal production environments. Durum wheats are grown in three principal areas in Turkey: coastal areas (15%), the central Anatolian Plateau (50%), and southeastern Turkey (35%).

- Turkish Aegean and Mediterranean coastal environments are characterized by relatively high annual rainfall (500-800 mm) with mild winters during the November-June cropping cycle. Biotic constraints include stripe, leaf, and stem rust, *Septoria tritici*, powdery mildew, and sawfly. Spring durum cultivars predominate in these environments.

- The central plateau cropping cycle (October-July) is characterized by cold winters and warm summers with 350-450 mm annual precipitation. The principal biotic constraints included stripe and stem rusts and loose smut. Lack of winter cold hardiness is the primary production constraint in currently available germplasm. Contemporary endemic germplasm tends to be tall, late-maturing, disease-susceptible, and cold-temperature sensitive. Facultative or winter durum wheat cultivars released for production in this environment include: 'Berkman 469', Kunduru 1149' (1967), 'Cakmak 79', 'Tunca 79', and Kiziltan 91'.

- Durum production areas in southeastern Turkey are characterized by cold winters and hot, dry summers with an annual precipitation of 300-550 mm. Both spring and facultative/winter varieties occur in this region, however, currently spring types predominate. Late maturity and Zabrus and sunni pest are the major production constraints. Current cultivars include 'Dicle I' (='Cocorit 71'), and 'Gediz I' (=CD27534).

Commonwealth of Independent States

Winter durum wheats were first introduced into the Black Sea region of Georgia in the 1800s, but lack of winter hardiness prevented adoption. Active breeding efforts were initiated in the late 1940s in Odessa, Ukraine, and Krasnodar, Russia. Initial activities focused on improvement of winter hardiness (the primary production constraint) via interspecific *T. aestivum* x durum crosses. The effect of parental cytoplasm on winter hardiness indicated that maternal aestivum preserved, or improved, expression of this trait. The winter durum cultivars 'Michurinka', and 'Novomichurinka' (1961) resulted from this effort in Odessa. Intra- specific (durum x durum) crossing at Odessa resulted in release of 'Odessdaya-Yubileynaya' (1972), a cultivar which has served as the parental foundation for winter durum efforts in Romania, Bulgaria, Hungary, and Nebraska.

Balkan countries

The combined area represented by winter durum production in Romania, Bulgaria, and Hungary is estimated to be less than 15,000 ha. Production limitations included *Fusarium* spp. and BYDV, and pricing versus quality standards.

Area and varietal releases include:

Romania	**Bulgaria**	**Hungary**
3500 ha	?	5000 ha
'Topaz' (1977)	'Zagorka'	'GK-Basa'
'Rodur' (1984)	'Lozen'	'GK-Minaret'
	'Cirpan'	'GK-Pannodur'

Discussion Notes

Keser: Disease problems in winter wheats are not that much of a problem in Turkey except for stem rust where we can't grow short types.
Braun: The tall varieties are more susceptible to disease because they come from the landraces.

Fischer: Where are you getting your winter wheat germplasm?
Keser: We use North Dakota (USA) lines.
Fischer: What material from Odessa?
Keser: We can't use very much.

van Ginkel: Do you make spring x winter crosses and why do you grow winter durums in Turkey at all?
Keser: Yes to the first question; We grow them for their end products, flat breads and bulghur.

Braun: Bread wheat does not have a yield advantage; however, if the agronomy changes, bread wheat could replace durum wheat in the transitional zone.

Fischer: What is the breakdown of durum wheats grown in high and low rainfall areas?
Keser: > 500 mm, 20% and < 500 mm, 80%.

Peña: Is Turkey still exporting durum wheat to the Eastern Block countries?
Keser: Not very much.

Payne: More winter durums are moving into the traditional spring areas not the winter areas. The D genome is why winter durums are not true winter wheats.

Hamblin: There is a state farm in the middle of Turkey that has grown wheat and barley on a large scale and a 30-year data set shows barley outyielding wheat.

Fischer: Are D/A substitutions available?
Payne: Yes, but we don't know what chromosomes we want. Cambridge data show the vernalization genes and winterhardiness genes are separate systems.

Fischer: How much area is devoted to winter durums in the ex-Soviet Union?
Murgonov: Less than 100,000 ha.
Fischer: It is interesting that 100 years ago that Russia grew 100% spring wheats, now it is nearly 40% winter wheats.

UTILIZATION OF GENETIC RESOURCES IN DURUM WHEAT IMPROVEMENT

B. Skovmand and G. Varughese
CIMMYT Wheat Program

Introduction

One of CIMMYT's major objectives is increasing farm-level productivity while safeguarding against genetic vulnerability. The preservation, evaluation, documentation, enhancement, and easy availability of genetic resources are central to those ends.

Modern durum wheat cultivars are an assembly of genes or gene combinations pyramided over the last century by breeders using, in most cases, well adapted cultivars of their region. The advance of international agriculture has enormously expanded the availability of germplasm with wide adaptation and from more sources, thus significantly changing patterns of cultivar distribution. To build on this base for further improvements in yield potential and to sustain that potential, introgression of additional variability found in genetic resources is necessary.

This variability is available from the different collections of durum wheat, which is now in existence in different parts of the world. The CIGAR wheat collections found in CIMMYT and ICARDA are part of this worldwide system.

Policies and Philosophy

The CIMMYT Wheat Collection defines genetic resources in the widest sense, consistent with Frankel (1977) and the FAO Commission on Plant Genetic Resources (FAO 1983) as follows:

- Advanced cultivars in current use,
- Obsolete cultivars,
- Landrace cultivars,
- Wild and weedy relatives of wheat,
- Special genetic and cytogenetic stocks, and
- Elite and advanced breeding lines.

The CIMMYT wheat collection presently consists of almost 100,000 accessions (Table 1), of which the 14,835 accessions of *T. durum*, *T. dicoccon*, and *T. carthlicum* have direct application to durum improvement. Approximately 34% of the durum accessions are landrace cultivars; another 36% are CIMMYT-derived advanced lines that have entered the international nursery system, while the remaining 30% are released cultivars and genetic stocks.

CIMMYT signed an agreement with ICARDA in 1988 to share the base collection responsibility for wheat genetic resources. Under this agreement, ICARDA has the base collection responsibility for tetraploid wheat and the wild relatives while CIMMYT is responsible for hexaploid wheat and triticale. Active collections are not involved in this agreement and each center preserves the genetic resources necessary to support the breeding programs.

Table 1. Number of accessions contained in the CIMMYT Wheat Bank by species as of January 1992.

Crop	No. of Accessions
Bread Wheat (*Triticum aestivum*)	52,839
Durum Wheat (*T. durum*)	14,835
Triticale (X *Triticosecale*)	13,268
Barley (*Hordeum vulgare*)	7,991
Rye (*Secale cereale*)	194
Emmer (*T. dicoccon*)	1,258
T. cartlicum	129
Primitive wheats	3,236
Wild relatives (*Triticum* spp.)	2,984
Total	99,734

Evaluation

The CIMMYT Genetic Resources Subprogram, as a rule, does not undertake evaluations except on request of the CIMMYT breeding sections or national breeding programs.

Seed multiplication and seed rejuvenation are important functions of the conservation program and during this phase certain evaluations can be accomplished. We now do this in a screenhouse at El Batan rather than in the field. This offers the advantages of producing better seed and evaluating accessions in the absence of the common wheat diseases and other problems that occur with field plantings.

Durum Section requests

The CIMMYT Durum Wheat Section has requested that the Bank evaluate material for the characters listed in Table 2. Evaluation of some of these traits has been performed on a subset of material, which was planted in the screenhouse because of low germination. The low germination was due to the location where the subset was re-generated, so these accessions can be considered as a random sample.

Table 2. Characters requested for evaluation by the Durum Section.

Physiological characters	**Stresses**
Earliness	Heat tolerance
Dwarfing	Septoria resistance
Biomass*	Russian wheat aphid
Morphological characters	**Quality characters**
Leaf length and width	Kernel size*
Peduncle ejaculation	Protein content*
Spike length	
Number of spikelets*	

* Not yet completed.

Results
Table 3 presents mean, range, and number of accessions evaluated for days to anthesis, leaf length and with, spike length, peduncle ejaculation, and height. This evaluation compared these traits for 398 improved accessions with 770 unimproved durum accessions.

Table 3. Average score and range for Bank durum accessions that compare improved and unimproved durums.

Character	Type	Mean	Range	Number
Anthesis	Improved	98	67-161	398
	Unimproved	118	70-165	770
Leaf length	Improved	30	20-48	398
	Unimproved	33	20-55	770
Leaf width	Improved	2.1	1.5-3.1	398
	Unimproved	2.1	1.4-5.0	770
Spike length	Improved	8.1	1.7-16.7	398
	Unimproved	8.8	2.0-18.7	770
Peduncle ejaculation	Improved	18.7	5.0-42.7	398
	Unimproved	16.0	3.7-43.0	770
Height	Improved	110	65-190	398
	Unimproved	145	90-235	770

An unfortunate problem occurred during the first re-generation in the screenhouse, which is located on land that had been planted to maize for 25 years. A severe attack of *Pythium* spp. was encountered, probably aggravated by the drip-irrigation system employed. The frequency distribution of *Pythium* scores for improved and unimproved accessions recorded during the re-generation showed no significant differences between the scores for this disease, which is not considered important in wheat production.

Evaluation for resistance to the Russian wheat aphid, *Diuraphis noxia* (Kurdjumov), has been carried out separately in the field, utilizing methods developed by Robinson et al. (1992). This evaluation showed that no resistances were found in improved and unimproved durum wheats. However, in evaluation of 182 *T. dicoccon* Schank accessions, 24 accessions were found to be highly resistant (Robinson and Skovmand 1992).

Evaluation conclusions
This exercise demonstrated that evaluations of only unimproved germplasm may be misleading. The ranges recorded for these materials were not essentially different. For

earliness and height, there might be some different sources among the unimproved germplasm that might be useful in durum wheat improvement.

The *Pythium* scores are interesting in the sense that the frequency of reactions was not different between improved and unimproved germplasm, demonstrating that evaluation should be done first in improved material when encountering new problems. Obviously, for *Pythium* spp., there has been no loss of resistance during wheat improvement.

By contrast, improved durum wheats have no resistance to Russian wheat aphid, but emmer wheats from the area where the RWA originated have a high frequency of resistance (Robinson and Skovmand 1992).

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Discussion Notes

Abdalla: Have done any heat tolerance screening?
Skovmand: We've tested the dicoccons in the Bank--about half did not flower. Indian dicoccons do have a certain level of heat tolerance.

Mamluk: Don't underestimate pythium occurrence at the seedling stage when conditions are moist.
Saari: I agree. The disease is underestimated. It is found quite often in Oklahoma.

DURUM WHEAT IN SOUTH AMERICA

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Introduction

Crop diversification and sustainability are becoming important key words with scientists and administrators of South American national programs. The new realities imposed by the political desire to form a "community market" (MERCOSUR) by the Southern Cone countries are challenging agricultural technology and farmers alike to demonstrate a comparative advantage in the region's production system.

One of most critical questions that faces the region's countries, which have a large proportion of their economy based on agriculture, is "what real alternative is there for the winter season other than bread wheat?" It is in this context that there is renewed interest in durum wheat along with barley, oats, rapeseed, and sunflower.

Argentina, Bolivia, Chile, and Peru produce sufficient quantities of durum wheat to satisfy their domestic demand. Brazil, which consumes many pasta products, either imports them directly or makes them from the bread wheat like many other countries. However, there is room for market expansion and each of these five countries has a durum wheat breeding program waiting for a break.

In order to understand their needs and potential, this paper deals with each country individually.

Argentina

Argentine farmers have grown durum wheat for more than 50 years. At its peak during 1969-70, the country produced more than 750,000 tons (Figure 1). The crop grown primarily in rotation with potatoes in the southeastern part of Buenos Aires Province was an alternative to the prevailing cattle-crop system, which was in place because short-cycle bread wheat varieties were not then available.

The successful adoption of tall, short-cycle durum varieties with high pasta quality was responsible for developing a significant export market to Europe, especially Italy. However, two severe scab epidemics caused by ***Fusarium graminearum*** in 1976-77 and 1977-78 and the simultaneous appearance of short-cycle bread wheats precipitated the decline of durum area in Argentina. The introduction of the high yielding, semidwarf durums from Mexico in the mid-1970s (Table 1) may have further added a variable quality consideration to local production. The crisis became very severe during 1983-84 and 1984-85 when the new high yielding durum varieties (having received little fertilization) fell below commercial quality standards, which discouraged further production. Although new varieties with high quality have been released recently, the present Argentine production of approximately 60,000 MT barely meets domestic demand in most years. During 1991, Argentina imported approximately 15,000 MT of durum wheat. This domestic shortfall, coupled with renewed interest in regional and global export markets, has allowed three breeding programs to continue their durum wheat activities.

Table 1. Percent break down of tall and semidwarf durum wheat varieties in central Buenos Aires Province.

Varieties	Crop Year 1977/78	1979/80	1981/82	1983/84	1989/90
Tall	82	75	27	19	0
Semidwarf	18	25	73	81	100

Source: Barrow Experimental Station Survey.

Durum breeding programs

Genetic improvement of durum wheats dates back to the 1930s at Barrow Experimental Station at Tres Arroyos and later by a private breeding establishment, Jose Buck S.A., at La Dulce, Necochea. Recently, the National Research Institute (INTA) is concentrating its durum efforts at Tres Arroyos and in the semi-arid southwestern part of Buenos Aires Province at Bordenave.

Breeding requirements

Argentine farmers need durum germplasm that has:

- A longer cycle (over 180 days) for the southwestern region.
- Adaptation to semi-arid conditions.
- Resistance to diseases, especially septoria leaf spot, fusarium head blight, and leaf and stem rusts for the southeastern region.
- High industrial quality, especially with high semolina yield, low stickiness, and resistance to over cooking of the industrial product.

Results achieved

Since 1983-84, three new varieties have been released that combine high yield potential of the semidwarfs with the desired quality characteristics of the older varieties. Disease susceptibility of the newer varieties is pushing the crop to relatively drier areas of the southwest and Table 2 shows the generally lower yield potential of this region. The possibilities of increasing yield in this area are being explored through the use of longer cycle and better adapted germplasm. However, for some time in the future, the durum area is likely to remain in southeastern Buenos Aires Province and disease resistance is a key element in the breeding program.

In order to maintain the easy commercialization of durum products, new quality regulations were imposed in 1988 that conform to the Italian export market. This has not only curtailed the release of new varieties, but has also seriously narrowed the genetic variability present in the breeding programs. While these quality standards need to be re-analyzed, based on the new market orientations of Argentina, it has been possible to identify a group of new lines from the regional testing program (Table 3).

Future potential

At present, virtually all durum produced in Argentina is sold based on contracts between the farmers and the millers, who normally pay between 15 and 25% more than for bread wheat. The market also pays a premium for all grain having more than 11% protein content and more than 50% vitreous kernels.

Table 2. Performance of new durum varieties in three ecological regions of Buenos Aires Province.

Region	Variety[a]	Yield (kg/ha)	Protein (%)	Farinograph Value NE (Energy Level)
Southeast	1	4130	11.7	44.1
	2	4370	12.0	45.0
	3	4710	10.9	41.3
	Average	4403	11.5	43.5
South central	1	3120	14.2	51.7
	2	3170	15.0	53.5
	3	3270	14.3	50.4
	Average	3187	14.5	51.9
Southwest	1	2420	12.4	53.5
	2	2380	12.9	54.5
	3	2520	11.9	48.4
	Average	2440	12.4	52.1

[a] 1 = Bonaerense Valverde; 2 = Bonaerense Quilaco; 3 = Buck Cristal.
Source: Carlos Jensen and Ma. Laura Seghezzo, Barrow Experimental Station, Tres Arroyos.

Table 3. Agronomic characteristics of selected lines of durum wheat at La Dulce, Necochea, 1991.

Advanced line	Yield (kg/ha)	Test weight (kg/hl)	TKW (g)
GOTTE'S' CD54202	4912	82.0	52.0
MO'S'/YAV CD52723	4850	82.9	58.0
TROB/4/FGO/CIT//BBAL /3/DUT/BBAL 12723	4778	83.5	52.0
VERONA 12718	4680	80.8	41.0
BONAERENSE VALVERDE (CHECK)	4532	81.3	51.0
BUCK CRISTAL (CHECK)	4530	83.1	60.0

Source: Carlos Favoretti, Jose Buck, S.A., 1991.

Considering the expansion of the international market, Argentina can reasonably share a part of it, provided it can develop some long-term, stable production policies. The domestic market does show some tendencies of relative increase, but it will depend a lot on internal economic conditions to create a demand for expensive durum semolina products.

Given this scenario, Argentina has tremendous potential to increase durum production, but will be limited by export market openings and the stable quality product it will need to produce.

Chile

All durums grown in Chile are spring-type semidwarfs. Back in the mid-1960s and early 1970s, Chile had one of the most dynamic, industry-supported durum wheat programs. However, this program suffered a serious set back caused by the free market policies of the mid-1970s coupled with subsidized production and easy credit availability from outside. By the mid-1980s, the policies were again being changed and the incorporation of the price-band structure renewed interest in the country's wheat production. Millers' with renewed interest in local production possibilities helped support the research and durum production in Chile is again increasing (Figure 2). All durum production is used for commercial pasta products.

Most durums are grown in the irrigated, central Metropolitan Region and adjacent Regions V and VI (Table 4). Average yields are very high and the best farmers harvest over 8 t/ha. On the other hand, a smaller portion of the durum area is also grown under rainfed conditions in the coastal areas of Regions IV and VII. Although the crop has been tried farther south and some effort to develop winter durums was conducted at INIA's experimental station in Temuco, the success has been limited.

Durum breeding programs

Genetic improvement of durum wheats started with selection from old landraces probably brought over during colonial times. Efforts of the Ministry of Agriculture and SNA (National Agricultural Society) to introduce Italian varieties during the 1930s and later were the next step. Several varieties were released by the Ministry during the late 1950s as a result of the first crossing program among the introduced materials. With the creation of INIA in early 1960s, this program was taken over from the Ministry and is based at La Platina Experimental Station in Santiago.

Table 4. Durum wheat production by region in Chile, 1990.

Region	Area (000 ha)	Production (000 MT)	Yield (kg/ha)
III-IV	0.61	1.88	3120
V	3.85	18.94	4920
VI	4.95	24.60	4970
VII	1.53	4.08	2680
Metro	8.58	47.96	5590
Total	19.52	97.46	-

The SNA breeding effort, although modest, continues to work with the durums at Graneros, just south of Santiago. The third program that started working with the durum wheats is at the Catholic University at Pirque, Santiago. As mentioned earlier, INIA also started a winter durum program based in the south at Temuco, but it is being modified to develop facultative durums for the rainfed coastal region.

Breeding requirements

Considering that most durums in Chile are under irrigation, Mexican germplasm adapts and yields very well. However, the program requires germplasm with:

- Stable resistance to leaf, stem, and stripe rusts.
- Resistant to septoria leaf blotch for the marine-terraces of the coastal region.
- Resistance to barley yellow dwarf virus (BYDV) and powdery mildew.
- High quality characters such as grain type, semolina yield, protein percentage, quantity and quality of gluten, sedimentation, and mixograph values.

Results achieved

The dynamism of the durum breeding effort in Chile has been primarily responsible for the release of new high yielding varieties as soon as the commercial environment turned favorable (Table 5). Besides high yield, the newer varieties also demonstrated a wide adaptation to the different durum regions (Table 6).

New germplasm with high yield potential is constantly being identified from the local crosses as well as from the introduced materials (Table 7).

Disease resistance, especially leaf rust resistance, has been more difficult to stabilize. The breakdown of leaf rust resistance in the new varieties has been a serious problem in recent years. In spite of the very severe leaf rust infection at La Platina during the 1991

Table 5. Yield potential of four durum varieties used as checks in regional yield experiments, 1989-90.

Variety	Average yield (kg/ha)[a] 1989	1990
AROMO INIA	4830	6320
LICAN INIA	5770	8220
CHAGUAL INIA	5390	7440
CHONTA INIA	5546	6750
MILLALEU INIA (Bread Wheat)	5530	6900

[a] Yield is average of five locations.
Source: Wheat Program INIA, La Platina.

Table 6. Yield potential (kg/ha) of four durum varieties at various locations across Chile, 1990.

Location	Aromo INIA	Lican INIA	Chagual INIA	Chonta INIA	Millaleu INIA
OVALLE	5960	6500	5330	6070	5470
LA PLATINA	7570	8050	7900	7230	6010
SAN FERNANDO	6190	8430	8240	6870	7570
HIDANGO	5720	9760	8370	7140	7550
TALCA	6150	8370	7370	7240	7170
AVERAGE	6320	8220	7440	6900	6750
CHILLAN	5010	6310	4380	6180	4310
TEMUCO	4130	8610	4440	5140	3630

Source: Wheat Program INIA, La Platina.

Table 7. Advanced lines showing high yield potential (kg/ha) in regional durum yield tests during 1989-90.

Line	1989	1990
EIP/S15//CL'S'/3/YAV'S' /5/....PLC'S'/CR'S'/ RABI'S'/3/CIT/4/KIF	5870	8040
YAVAROS'S'	5560	7760
YAV'S'/TEZ'S'	5580	7870
GOVZ394//SBA81/PLC'S'		7760
ALTAR84/AOS'S'		8020

Source: Wheat Program, INIA, La Platina.

cycle, a number of advanced lines included in the regional test and 23rd International Durum Screening Nursery (IDSN) demonstrated a high level of resistance. From the crosses shown in Table 8, it can be seen that both Altar 84 and Sterna have been two good sources of leaf rust resistance.

Table 8. Selected advanced durum lines showing resistance to leaf rust at La Platina, 1991.

Cross	Selection history	Leaf rust
CHEN'S'/ALTAR	CD57005-7Y-14M-3Y-1M-0Y	TR
CHEN'S'/ALTAR	CD57005-7Y-16M-2Y-1M-0Y	TR
FUUT//HORA/JORI	CD64322-2B-1Y-5M-0Y	TR
AUK/GOO'S'	CD60773-2Y-1M-2Y-4M-0Y	TR
CHTO'S'/ARA'S'//SRN	CD74825-C-5M-1Y-0M-2YRC	TR
SRN//HUI'S'/SOMO'S'/3/...	CD85656-0M-2YRC-501M-0REC	0
CALI'S'/CHUN 18//ALTAR	CD83744-B-6M-0YRC-0M-17B	10MR

Utilization of key disease sites has been critical for the selection of germplasm resistant to stem rust, stripe rust, septoria leaf blotch, and powdery mildew in the segregating populations. The advanced germplasm in the yield trials demonstrates a fair degree of resistance to these diseases.

The program analyzes around 10,000 individual plants for quality from the segregating populations and advanced lines every year. Based on quality tests, over 50% of the materials derived from the local crosses are forwarded to the next generation. Only about 25% of the introduced germplasm meets this standard. The characters being considered for selection are lack of yellow berry, protein content (>10%), micro-sedimentation SDS value (>6), wet gluten content (>30), high yellow pigmentation, and excellent gluten strength (Table 9).

There is widespread yellow berry problem in Chile. However, depending on the weather, fair selection for low yellow berry is possible at La Platina and other localities.

Table 9. Advanced durum lines selected for their quality characteristics, 1990. All have strong gluten strength.

Line	Test Wt. (kg/hl)	Protein (%)	Sediment SDS (0-5 g)	Wet glutgen (%)	Color	Yellow berry (%)
DIVER'S'	80.6	10.6	7.0	31.8	Y	0
FRIG'S'/CANDO	82.6	12.5	6.6	36.3	Y	0
TEZ/YAV//HUI	84.2	11.8	7.0	31.5	Y	0
GTA/DUR	84.4	11.3	11.2	31.2	Y	0
STN//HUI/SOMO	85.1	11.2	5.2	34.7	Y	1
Checks						
AROMO INIA	84.6	9.9	5.0	30.3	PY	1
CHONTA INIA	84.8	10.9	6.4	33.8	Y	1

Y = yellow; PY = pale yellow.
Source: Wheat Program, INIA, La Platina.

Potential for increase in durums

In the past, Chile has maintained a policy of producing enough wheat to meet its domestic market. Considering its separation from the main continent by the Andean Cordillera mountains, Chile has high transportation costs. However, given the excellent yield potential that the climate permits and the industrial infrastructure already present, Chile has potential for an export market of finished pasta products. This will become even more viable once the region unites economically. In case such an opportunity arises, Chileans are putting extra effort into the development of high quality durum varieties. With the support from the milling industry and probably some contracts with the farmers, the durum area in Chile may continue to increase.

Brazil

There is no commercial production of durum wheats in Brazil and most of the pasta products are either imported or made from bread wheat internally. However, there is some interest on the part of research workers in Paraná and São Paulo to introduce durum cultivation.

Breeding programs involved

The Agronomic Institute of Campinas (IAC) is by far the leader in identifying germplasm for the irrigated conditions of the northern São Paulo region. Most germplasm is selected from the international nurseries received from CIMMYT and other sources. Similar selection has also been started by Agronomic Institute of Paraná (IAPAR) and the Cooperative Organization of Paraná (OCEPAR) for the rainfed and aluminum-free soils of the Paraná State.

Germplasm requirements

Considering that many Brazilian soils are acidic in nature and carry varying degrees of aluminum toxicity, there is hardly any variability for this character in the durum germplasm. Durums being tested under irrigated or dryland conditions are highly susceptible to leaf spot and tan spot diseases. Again little variability has been identified against these diseases. Under rainfed conditions of Paraná, durums are highly susceptible to fusarium head blight (*Fusarium graminearum*) and bacterial stripe (*Xanthomonas campestris* pv. *undulosa*). Even though durum is yet being grown in the country, millers interested in durum production are already asking for quality, which will be critical for any potential growth. Since all production is likely to be industrialized, the characters are very similar to those of Argentina and Chile.

Selection results

The best durum lines selected by IAC include Mexican lines such as: GALLARETA, CD22344, GUILLEMONT, and CM14646, which are yielding between 5 and 6 t/ha under pivot-irrigation systems in northern São Paulo. These yields are comparable to the those of the best bread wheats.

Potential

Brazil consumes between 15 and 20% of its wheat needs in pasta products. The potential production needed to meet this demand would be over 1 million tons annually. However, considering the 10 to 15% premium millers have to pay for durum, it may not happen shortly.

Dr. Carlos Camargo of IAC thinks it is possible to cover some 40,000 ha of irrigated land immediately with durums. He is in contact with the industrial sector, which is testing four of IAC advanced selections before official releases can be made.

Peru

Durums were introduced into Peru during colonial times and all production is limited to the Andean Highlands. The geographic division of the area in the highlands is approximately 45% in the north, 40% in the center, and 15% in the south. Until about a decade ago, Peru seeded approximately 40-50% of its total wheat area (approximately 100,000 ha) to durum wheats. However, with the release of Gavilan, a high yielding and disease resistant bread wheat variety, a large share of the durum area is now being planted to bread wheat. At present, between 20,000 and 25,000 ha are grown to durums.

Germplasm requirements

Farmers need durum wheats that have:

- Shorter (about 120-130 days) and intermediate cycles (150-170). The old cultivars have a 210- to 230-day cycle.

- Resistance to stripe and stem rust, septoria leaf blotch, snow mold, and bacterial stripe.

- Reduced height.

Durum breeding program

Most of the early durum effort concentrated on selecting landraces introduced during colonial times and gave rise to varieties such as Barba Negra, Barba Blanca, Barba Azul, Candeal, and Estaquilla. However, through the efforts of the newly formed National Research Institute (INIAA) based at Lima and Cusco, a new variety, TARAY85, has been released, which is adapted to the Andean Highlands as well as the coastal region. In the highlands, it has replaced several old cultivars, but its spread is quite slow. Considering the degraded nature of the soils in the Andes and lack of fertilization, the yields generally range between 800 and 1000 kg/ha. In a good year (with plenty of rainfall but no disease pressure), yields of 1500 kg/ha are possible. Under irrigated conditions, a maximum yield of 6100 kg/ha has been obtained.

Future production and consumption trends

All of the durum production in Peru is used for local consumption as mote, a whole grain that is pre-cooked and pearled with lime, or as pearled wheat, which is used to make local soup and meat dishes.

The durum area could go return to 50,000 ha if new varieties with disease resistance, high yield potential, and quality characteristics (large grains that are hard and vitreous) can be identified and promoted. Recently, there is some interest in the use of durums in industrial pasta products and for the first time approximately 30,000 MT of durums are being imported from the USA and Canada.

Bolivia

All durum production in Bolivia is a concentrated in the inter-Andean Valleys covering approximately 40% of its wheat area or 30,000 ha. The inter-Andean Valleys comprising of Cochabamba, Chuquisaca, Potosi, and Tarija departmental regions lie between 2000 and 3400 meters above sea level. The average temperature of the region fluctuates between 18 and 25°C and average rainfall between 300 and 450 mm during the year. As with Peru, the soils are quite degraded and cultivation methods are still traditional (animal traction, broadcast seeding, hand harvesting, and threshing by a pair of bullocks or horses). The entire wheat crop is seeded under rainfed conditions in December and harvested in May or June. Virtually all of the durum area (95%) is seeded with the old landrace varieties selected from the colonial collections forming a subsistence farming system for families that use durums for home consumption.

Germplasm requirements

Bolivian farmers need germplasm that has:

- High yielding and semidwarf traits with a 140- to 150-day crop cycle and in some cases even shorter (110-120 days).
- Resistance to stripe and stem rusts and septoria leaf spot.
- Resistance to drought in semi-arid areas.
- Quality characters for traditional food products such as mote. There is also certain demand for industrialized pasta products, which will require different quality considerations. Large vitreous grains are considered an important character.

Durum breeding program

Farmers made early selections of durums from landraces. The Ministry of Agriculture in the 1960s and 1970s made little effort to replace this material with newer varieties as they did with bread wheats. During the last decade, the National Research Program (IBTA) based at Cochabamba has released three varieties from the Mexican germplasm (SACABA 81, San Martin 85, and Cliceño 85), but these have had limited spread and success. Farmers' average yield during the past 5 years has been around 750 kg/ha due to the use of old susceptible varieties, weeds, and lack of fertilization. Aggressive seed multiplication and distribution programs for the newer varieties have also been lacking.

IBTA, working primarily with the introduced materials from CIMMYT, has started a local selection and testing program. CIMMYT has also sent some early segregating material derived from specific crosses with Bolivian landraces for selection in the highlands. Some local crosses have also been attempted. Based on last few year's selection, a regional elite test has been formed to identify superior lines.

Table 10. Selected advanced lines from international nurseries that are adapted to Bolivian conditions.

Cross	Selection History	Yield (kg/ha)
ALTAR84/ALD'S'	CD68153-15Y-1M-1Y-0M	3166
CHEN/ALTAR	CD57005-1Y-5B-4Y-1M-0Y	3155
ALTAR/AOS	CD67124-1Y-503M-0Y	2834
CHEN/ALTAR	CD57005-7Y-14M-3Y-1M-0Y	3464
CHEN/ALTAR	CD57005-2M-2Y-4M-2Y-0M	2914
CHEN/AUK	CD61042-5M-7M-1M-0Y	2863
SACABA 81	Local check	2803

Several advanced lines have been selected from international durum nurseries. Several performed well during 1991 (Table 10). All of the lines in the Table 10 are resistant to both stripe and stem rust as well as septoria leaf blotch. Since 1991 was a fairly dry year, the performance of these lines needs to be watched carefully. Most of these lines have an average grain size that may be unacceptable in the traditional market. Quality information of some of these lines will also be helpful.

Potential for durum production

Durum wheat is an important part of the traditional staple diet of the highland Bolivians. The replacement of the old landrace varieties and extension of the area will depend a lot on the new germplasm available and aggressive seed multiplication and distribution programs. Farmers are interested in disease resistant, high yielding varieties with large vitreous kernels. Some of these factors will be remedied by the local selections from the segregating populations. However, germplasm variability including crosses with local landraces probably needs to be further exploited.

Conclusions

There are strong indications that the expansion of durum area in South America has been primarily limited by diseases (the three rusts, septoria leaf blotch, and fusarium head blight). Quality characteristics such as large vitreous grains, lack of yellow berry, high protein, gluten content and strength, and pigmentation are important as well. While most countries have selection and breeding programs of varying abilities, the amount of genetic variability available for the required characters is not forthcoming rapidly. Any future expansion of durum area in a given country or the region as a whole will depend on germplasm availability in the future. While fluid commercialization and pricing policies will always remain a critical factor, the region shows signs of growth possibilities based on regional economic cooperation.

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Discussion Notes

Fischer: Where do the durum wheats fit in Bolivia?
Kohli: In the same areas as the bread wheats.

Mamluk: What about smuts and Karnal bunt?
Kohli: Bunts have been reported, but to date they present no commercial problem.

Elias: Why is no one interested in sedimentation tests in Argentina?
Kohli: I don't understand it either. We have a list of about 20 characters for overcooking, but we find few lines that have these traits.

Fischer: We do not need a new challenge of introducing durums into Brazil's acid soils.
Kohli: However, there is interest throughout Paraná in the aluminum-free soils.

Varughese: What is the advantage of growing durum wheats in southern Argentina?
Kohli: No disease problems and not much difference in yield compared to bread wheats.

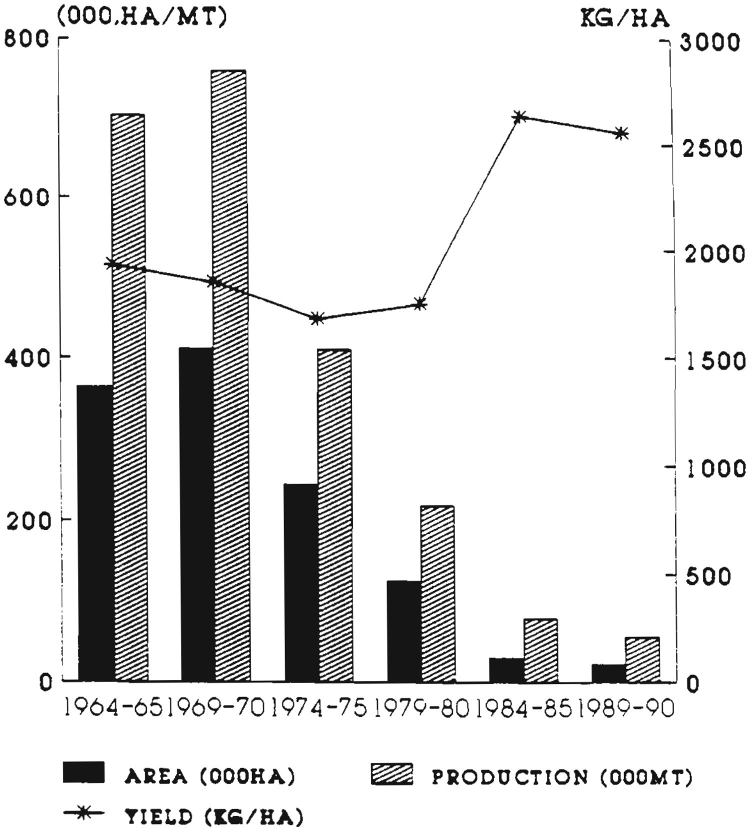

Figure 1. Durum wheats in Argentina. Source: National Seed Board, Agentina.

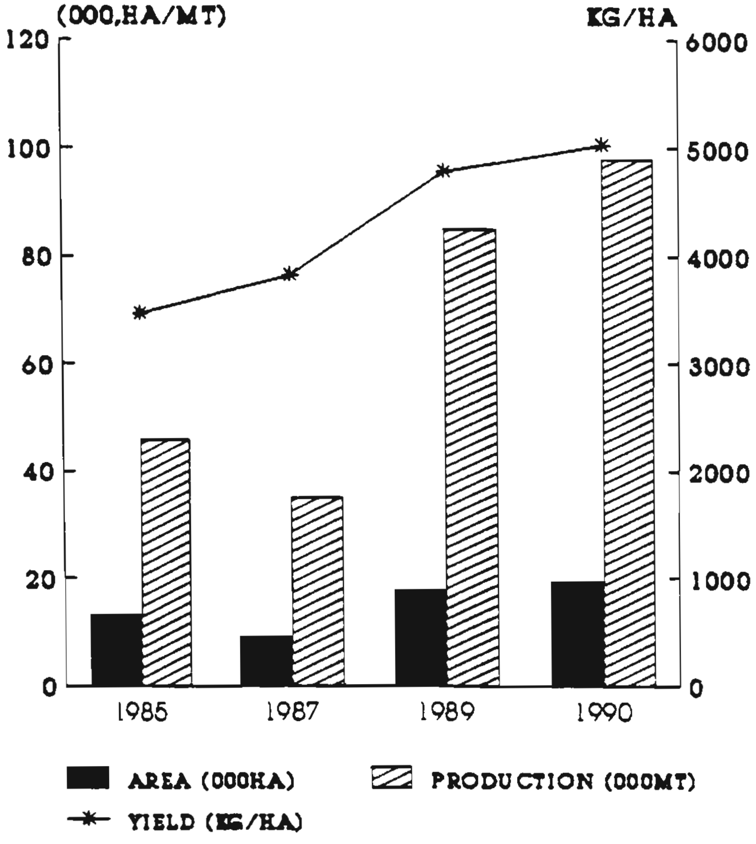

Figure 2. Durum wheats in Chile. Source: INIA, Chile.

STEM RUST AND LEAF RUST RESISTANCE IN DURUM WHEATS

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Introduction

Durum wheat, *Triticum turgidum* var. *durum*, is widely grown in southern Europe, southern and western Asian, and northern African countries. Elsewhere, durum wheat is grown in small areas of Chile, Peru, the United States, Canada, and the former USSR. In recent years, significant durum cultivation has occurred in Mexico due primarily to its better resistance to Karnal bunt (*Tilletia indica*). Durum wheat is generally grown in the winter except in the more northern and southern latitudes. The primary use of durum grain is in pasta making, but other products are also made from durum flour in North Africa and Asia. Durum wheat consists of the A and B genomes. These genomes are generally thought to be similar to the A and B genomes in hexaploid bread wheat (*T. aestivum*).

Stem Rust (*Puccinia graminis* f.sp. *tritici*)

Genes for stem rust resistance have been located on many chromosomes (Table 1). Of the stem rust resistance genes on the A and B genomes, only *Sr2, 9, 11, 12, 13, 14, 17, 36, 37* and *40* have been derived from tetraploid wheats (Table 2). *Sr9* and *11* have also been isolated from bread wheats and *Sr2* and *17* from emmer (*T. dicoccum*). The *Sr9* locus is interesting as it has a number of alleles. The alleles and their sources are *Sr9a*, Red Egyptian, a bread wheat; *Sr9b*, a number of Kenyan bread wheats; *Sr9c*, not assigned; *Sr9d*, from Yaroslav emmer and some durum wheats; *Sr9e*, many durum wheats and emmer; *Sr9f*, from Chinese Spring a bread wheat that is unusually compatible in crosses; and *Sr9g*, from Iumillo and other durum wheats and in bread wheats derived from Thatcher. Whether the *Sr9* locus occurs in both bread and durum wheats is unclear. *Sr11* was from the bread wheat Lee, probably through Gaza; however, in durum wheat lines (furnished by N.D. Williams) a line postulated to have *Sr11* was obtained from the durum Beladi 116. *Sr12* was isolated from Thatcher, the gene being inherited from its durum parent Iumillo. *Sr13* and the closely linked *dp-2* were isolated from durums. *Sr13* and *14* were initially from Khapstein, a Khapli emmer derivative. Lines with a gene postulated

Table 1. Genome locations of genes that provide resistance (*Sr*) to stem rust in bread wheat.

Chromosome	Genome A	Genome B	Genome D
1	None	14,31	18,33
2	21,32, 34,38	9,11,16,19, 20,23,28,32, 34,36,39,40	6,U
3	27,35	2,12	24
4	37	7,Tmp	None
5	None	None	30
6	8,13,26	11	5,29
7	15,22	17	25

Underlined genes are from tetraploid *Triticum* spp.

Table 2. Sources of wheat stem rust resistance genes.

Source	Genome	Genes for stem rust resistance
Triticum aestivum	ABD	5,6,7,8,9a, 9b,9f,11?,15, 16,18,19,20,23, 28,29,30
Triticum turgidum	AB	2,9d,9e,9g,11?, 12, 13, 14, 17
Triticum dicoccum	AB	2,9d,9e,17
Triticum monococcum	A	21,22,35
Triticum timopheevi	AG	36,37,40
Triticum speltoides	D	32,39
Triticum tauschii	D	33
Triticum comosa	U	34
Triticum ventricosum	DUn	38
Secale cereale	R	27,31
Agropyron elongatum		24,25,26

to be *Sr13* were also isolated from St464 (lines furnished by N.D. Williams). *Dp-2* was isolated from Golden Ball and postulated in Medea Ap9 and seems to be present in many durum cultivars. *Sr14* is postulated to be in a few durums. *Sr17* was from Yaroslav emmer and through the line Hope it has been spread to bread wheat worldwide.

A number of stem rust genes have been isolated from *T. monococcum* L., *Sr21*, *22*, and *35*. They are all more effective in the diploid than in the derived tetraploid and hexaploid lines. To our knowledge, these genes do not occur in durum wheats. *Sr36*, *Sr37*, and *Tt-3* were derived from *T. timopheevi* (A and G genomes) and were transferred to the 2B, 4A, and an unknown location, respectively. It is unknown if their origin was the A or G genome. The genes on A and B genomes seem to be similar in reaction to those isolated from the D genome. Most are more effective in the tetraploid than in hexaploid wheats. Most stem rust resistance genes have been effective through the plants' life cycle. *Sr2* is the lone exception and it was isolated from Yaroslav emmer. In the group of genes isolated from durum wheat, both *Sr12* and *17* are generally considered to be recessive. None of the other numbered *Sr* genes are known to be recessive. Bolat recently isolated recessive resistance genes from Mindum, Spelmar, and Entrelargo de Montijo durums. Each cultivar has a recessive gene for resistance and Entrelargo de Montijo has three to five recessive resistance genes. Thus, recessive resistance genes may be more common in durum wheats.

In summary, it seems that we know little about the stem rust resistance existing in durum wheat. In recent years, there has been little effort expended in looking at stem rust resistance. One of the missing links is a durum wheat susceptible to all races; Marroccos 9623, Glossy Hugenot, and perhaps Local Red are possibilities. A set of disomic substitution lines exist in a Langdon type background, but Langdon is resistant to many of the cultures on a worldwide basis.

Virulence of *Puccinia graminis* f.sp. *tritici* to the durum cultivars has not been a real concern in many countries as many cultivars are resistant. The only major epidemics that we found reference to were the 1953-54 ones in the Northern Plains of North America, although stem rust has been reported on durum wheat worldwide. Huerta-Espino (1992) recently looked at virulence of cultures from many countries where durum wheats are grown (Table 3).

Although only a few isolates were evaluated, it is interesting that *Sr9g* and *17* were susceptible to all isolates from durum wheat. The virulence to *Sr8b*, *9e*, *15* and *21*, all of which are in the A and B genomes, was higher among the durum wheat isolates than the bread wheat isolates. In North America, where both the United States and Canada conduct virulence surveys, the most common races since the 1930s have been race 56 (Pgt-MCC), various forms of race 15 (currently Pgt-TPM), and now Pgt-QCC, a race that primarily attacks barley. Race 56 was avirulent to *Sr2*, *9a*, *9b*, *9d*, *9e*, *11*, *12*, *13*, *14*, *17*, and therefore to most durums, while Race 15-B of recent years was avirulent to only *Sr2*, *9a*, *9b*, and *13*, and was virulent to durums with *Sr9d* and/or *9e*.

To summarize, assessing virulence to durums on a worldwide basis is difficult due to the low number of isolates available, which must indicate either the lack of rust or a lack of interest on this crop. The epidemics of 1953-54 indicate that stem rust can and does cause significant losses in durum wheat. However, note the high frequency of virulence to the resistance genes derived from durums, *Sr9e*, *9g*, and *17*. Also there seems to be a lower frequency of virulence to *Sr5*, *7b*, and *28* in durum than bread wheat isolates.

Leaf Rust (*Puccinia recondita* f.sp. *tritici*)

Leaf rust resistance genes have also been found on most chromosomes of wheat (Table 4). It is interesting to note that most of the loci were on the B and D genomes. None of these genes were isolated directly from *T. turgidum* (Table 5). Thus, in spite of the durums (A and B) and *T. monococcum* (A) generally being reported as resistant to leaf rust, they have not been a source of resistance genes. As with stem rust, a leaf rust susceptible cultivar is needed in genetic studies of resistance. The cultivars used were Berkmen, Glossy Hugenot, and Local Red. Local Red from the Indian Subcontinent seems to offer the most potential, however, it is not well adapted in many conditions. When crosses have been made to transfer leaf rust resistance from durum to bread wheat,

Table 3. Percent virulence in *Puccinia graminis* f.sp. *tritici* to selected *Sr* genes with isolates from durum and bread wheat in the international virulence survey.

	Percentage of the isolates virulent to *Sr*															
Host	5	6	7b	8a	8b	9b	9e	9g	10	11	15	17	21	28	30	36
DW[a]	33	53	36	6	81	39	78	100	42	39	97	100	100	36	28	17
BW[b]	74	69	83	42	64	69	20	96	74	42	93	94	80	88	52	32

[a] Thirty-six isolates evaluated.
[b] Five hundred and eighteen isolates evaluated.
Underlined genes are from tetraploid species.

the resistance is seldom expressed. A study of leaf rust resistance in durum wheat was done recently by Knott where resistance genes were found in durum cultivars. The resistance was studied by crossing the resistant cultivar with RL 6089 a selection from an Ethiopian durum collection. In our tests, these durum lines are better at differentiating isolates of leaf rust from bread wheat than those from durum wheat. In the case of rust resistance from durum wheat, the resistance gene isolated by Knott often lacked the resistance of the source cultivar.

Virulence in *Puccinia recondita* f.sp. *tritici* to durum wheats has not been considered a major problem in the United States and Canada. Most studies of virulence to durum wheat involved tests to determine the potential value of the durum resistance for improving bread wheat cultivars. No durum cultivars have ever been included in any of

Table 4. Genome location of genes that provide resistance (*Lr*) to *Puccinia recondita* f.sp. *tritici* in *Triticum aestivum*.

Chromosome	Genome A	Genome B	Genome D
1	10	26,33	21,40,41
2	11,17,37,38	13,16,23,35	2,15,22,39
3	None	27	24,32
4	12,25,31	28,30	None
5	None	18	1
6	None	3,9,36	None
7	20	14	19,29,34

Underlined genes are from tetraploid *Triticum* spp.

Table 5. Sources of wheat leaf rust resistance genes.

Source	Genome	Genes for leaf rust resistance
Triticum aestivum	ABD	1,2,3,10,11,12,13,14b,15,16,17,18,20,22b,27,30,31,33,34
T. turgidum	AB	14a,23
T. tauschii	D	21,22a,32,39,40,41
T. ventricosum	DUn	37
T. speltoides	S	28,35,36
Agropyron elongatum		19,24,29
A. intermedium		38
Secale cereale	R	25,26
T. umbellulatum	U	9

Table 6. Percent virulence of *Puccinia recondita* f.sp. *tritici* to selected *Lr* genes with isolates from durum and bread wheat in the international virulence survey.

	Percent virulence to Thatcher backcross lines with *Lr*																
Host	Tc[a]	1	2a	2c	3	9	16	24	26	3ka	11	17	30	10	18	21	23[b]
DW[c]	48	22	11	18	40	0	15	1	10	12	4	15	6	73	20	4	48
BW[d]	100	59	27	39	64	3	16	2	30	30	23	29	15	75	22	5	45

[a] The bread wheat cultivar Thatcher was used as a background host for the resistance genes.
[b] From a tetraploid species.
[c] One thousand and thirty-three isolates evaluated.
[d] Two hundred and one isolates evaluated.

the sets of differential host cultivars. In a recent international virulence survey of P. *recondita* f.sp. *tritici*, considerable differences were found between virulence of isolates collected from durum and bread wheats (Table 6).

Differences exist and virulence to Thatcher (*Lr22b*) was much lower in the population isolated from durum wheat as was the virulence frequency to *Lr1*, *2c*, *3*, and *26*. A slightly higher percent of virulence existed in the durum wheat population (virulent to Thatcher) to *Lr23*, a gene derived from durum wheat and used in both durum and bread wheat germplasm. The general conclusion is that isolates from durum wheat are less virulent to bread wheats than isolates from durum wheats. However, the isolates from bread wheat are less likely to be virulent to durum wheats. In preliminary studies, we selected bread wheat cultivars that were generally susceptible to leaf rust from bread wheat, Thatcher, Morocco, Little Club, Baart, and Cheyenne; and durum wheat cultivars that were generally susceptible to leaf rust isolated from durum wheat, Local Red, Arendeto, Kubanka, RL 6089, and Karkov. Although variation occurred between isolates, the rusts from bread wheats were usually virulent to all the bread wheats, while the durum cultivars responded as differential hosts. The reverse was true for the isolates from durum wheat.

It was evident that the isolates from durum wheat were generally avirulent and had little variation in virulence patterns when evaluated with bread wheat lines and cultivars. These isolates were often virulent to many durum cultivars and lines and many virulence patterns were found. Thus, little is currently learned by inoculating bread wheat with isolates from durum wheats. Isolates from durum wheats that appear to be avirulent on bread wheat and without variation in virulence can be quite variable when inoculated on durum wheats. In Turkey, durum wheat and bread wheat were the most similar while in Mexico race Prt BBBM was the most common race from durum wheat while TCLH was the most common race from bread wheat (Table 7). Thus, isolates from durum wheat were virulent to *Lr10* and *23*, while isolates from bread wheat were virulent to *Lr1*, *2a*, *2c*, *3*, *3ka*, *18*, *23*, and *26*. In Ethiopia, 164 of 211 isolates from durum wheat were avirulent to Thatcher. Thus, before progress can be made in understanding leaf rust

Table 7. Inter-country variation in virulence to leaf rust differentials for isolates obtained from durum (D) and bread (B) wheat rust populations from 1987 through 1990.

Country	Number of isolates	Wheat type[a]	Percentage of leaf rust isolates virulent to *Lr* gene																
			Tc	1	2a	2c	3	9	16	24	26	3ka	11	17	30	10	18	21	23
Chile	67	B	100	98	3	3	25	0	0	7	94	23	79	0	0	94	1	0	83
Chile	49	D	100	0	0	0	0	0	0	0	0	0	0	0	0	69	0	0	20
Ethiopia	92	B	100	17	3	19	94	1	31	0	5	12	1	41	5	90	19	2	47
Ethiopia	164	D	–[b]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ethiopia	46	D	100	24	15	34	69	0	28	0	13	13	4	39	2	74	34	11	43
Israel	40	B	100	100	10	10	100	0	40	0	0	22	5	15	22	97	5	0	70
Israel	25	D	100	68	0	4	68	0	24	0	0	20	16	4	20	96	0	8	56
Italy	76	B	100	10	5	60	85	1	23	0	21	23	2	26	20	85	21	14	12
Italy	20	D	100	0	0	0	0	0	0	0	0	0	0	0	0	80	25	0	80
Kenya	23	B	100	60	39	48	87	0	17	0	0	48	4	17	4	100	4	0	65
Kenya	4	D	100	50	50	50	100	0	0	0	0	50	0	0	0	100	0	0	50
Mexico	36	B	100	100	91	91	97	0	0	0	94	100	19	3	5	11	88	0	88
Mexico	17	D	100	0	0	0	0	0	0	0	0	0	0	0	0	100	29	0	100
Morocco	20	B	100	80	45	45	95	0	5	0	5	5	0	20	0	95	0	0	25
Morocco	16	D	100	25	12	25	56	0	37	0	12	6	6	31	0	50	0	0	31
Morocco	18	D	–[b]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Turkey	61	B	100	32	24	32	83	3	34	6	34	55	11	27	46	64	44	9	41
Turkey	24	D	100	41	37	54	75	0	25	8	70	41	4	29	29	37	58	4	50

[a] B = bread wheat, D = durum wheat.
[b] Could not test due to avirulence to Thatcher background of the differential lines.

resistance in durum wheats, a susceptible line is needed and a differential host set representative of the resistance present in durum cultivars must be selected. Then work can be started on the genetics of resistance in durum wheats.

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Discussion Notes

van Ginkel: Does *Sr2* have the same expression in bread wheat as in durum wheat?
Roelfs: The expression is probably better in durum wheat.

Payne: Since *Sr* genes in durum wheat tend to be recessive, how should the breeding scheme differ in durum wheat compared to bread wheat?
Roelfs: You can't do anything with the F_1s--wait for the F_2; normally this is not too critical.

Kohli: What should the strategy be for durum wheat breeders?
Roelfs: I need to know more about what is going on. I can't say with my current set of differentials.

DURUM WHEAT DISEASES IN WEST ASIA AND NORTH AFRICA (WANA)

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Introduction

Durum wheat diseases in the countries of West Asia and North Africa (WANA region) are more or less the same as those of bread wheat, except for some peculiarities in the agro-climatic areas where each wheat type is grown and some specific interaction between host and pathogen, e.g., host-preference.

Durum wheat, for instance, will be affected by septoria tritici blotch and powdery mildew, if planted in areas with adequate rainfall. These are two typical diseases of bread wheat in these areas.

Field observations indicated that bread wheat in Morocco is more severely attacked by septoria tritici blotch than durum wheat and this situation is reversed in Syria. Field and green house tests show that, in both durum and bread wheat, disease development is greatest when the source of the inoculum is their own species of wheat; a typical host-preference phenomenon (46). Another example of host-preference in septoria is evident in the Durum Germplasm Pool for Sources of Resistance to Septoria, developed at the Center (30). The average score of the lines in this pool ranged from 4 to 6, on a 0-9 scale from multilocation screening in WANA. However, all lines in this pool were completely immune to the disease in field tests in California and only a few lines, 3 of 19, showed light susceptibility in seedling tests. The isolates used in both tests were local ones and it can be assumed that the septoria pathogen population in California is more adapted to bread wheat than to durum wheat.

Another example of host-preference is the stripe (yellow) rust epidemic of 1988 in Syria and Lebanon. This epidemic affected solely the bread wheat cultivars. In contrast, the leaf rust epidemic of 1991 affected mainly the durum wheat cultivars in both countries.

Still another example of the host-preference phenomenon is the common bunt disease of wheat. The two causal agents, *Tilletia foetida* and *T. caries*, showed preference for the host plant; while *T. caries* attacks durum wheat and bread wheat at the same level in a nonpreference way, *T. foetida* attacks bread wheat with much more preference (41,43).

Except in the case of common bunt, where two pathogens are involved in one disease, the difference in the level of attack by a disease on durum wheat versus bread wheat can be related primarily to the degree of susceptibility of the cultivars and secondly to the pathogen, its adaptation to one or other wheat genotype, and to its prevailing biotype.

The examples above may explain the difficulty in distinguishing between durum wheat diseases and those of bread wheat.

Wheat Diseases in the WANA region

Table 1 gives an overview of wheat diseases in WANA. The references cited are by no means complete, but represent those mentioned in documents currently available. Diseases encountered by the author in WANA (42) are also included. As a rule,

Table 1. Wheat diseases in countries of West Asia and North Africa, the WANA region.

Disease	Country
Smuts	
Common bunt (*Tilletia foetida* and *T. caries*)	Pakistan (24,45), Egypt (3,31) Iran (42), Morocco (10), Turkey (23,50,61), Syria (40), Lebanon (33,53,60), Jordan (38)
Dwarf bunt (*Tilletia controversa*)	Turkey (26,49,50), Iran (26,44), Iraq (26,59)
Loose smut[a] (*Ustilago tritici*)	Pakistan (24), Egypt (14), Iran (42), Libya (42), Turkey (50), Morocco (10), Syria (41), Lebanon (33,53,60), Jordan (38), Libya (42)
Flag smut (*Urocystis agropyri*)	Pakistan (24,32), Egypt (2,22), Turkey (50), Tunisia (25), Syria (41), Jordan (38)
Rusts	
Stripe rust (*Puccinia striiformis*)	Turkey (16), Egypt (5,58) Pakistan (34), Tunisia (25), Iran (12,13), Lebanon (33,53,60), Syria (41), Jordan (38), Yemen (42)
Leaf rust (*P. recondita*)	Pakistan (27,51,52), Egypt (18,19,21,48,58), Syria (41), Lebanon (53), Sudan (42), Yemen (42), Morocco (10)
Stem rust (*P. graminis*)	Pakistan (28), Egypt (1,4,18,19,47,58), Syria (40), Lebanon (33,53,60), Sudan (42), Yemen (42)
Helminthosporium	
Tan spot (*Pyrenophora trichostoma*)	Turkey (42), Tunisia (42), Iran (42), Morocco (10), Libya (42)
Septoria	
Septoria tritici blotch (*Mycosphaerella graminicola*)	Pakistan (24), Tunisia (20,25) Syria (41), Algeria (42), Lebanon (33,53), Morocco (10,54)
Septoria nodorum blotch (*Leptosphaeria nodorum*)	Syria (41), Morocco (10), Lebanon (53), Jordan (38)

Table 1. Continued.

Disease	Country
Mildews	
Powdery mildew (*Erysiphe graminis*)	Syria (41), Algeria (42), Lebanon (33,53,60), Tunisia (42), Jordan (38,42), Morocco (42), Libya (42)
Downy mildew (*Sclerophthora macrospora*)	Syria (41)
Fusarium	
Foot and root rot (*Fusarium* spp.)	Syria (41), Tunisia (42), Cyprus (42), Morocco (42)
Head scab (*Fusarium* spp.)	Pakistan (42)
Bacteria	
Bacterial leaf streak (*Xanthomonas campestris* pv. *translucens*)	Pakistan (8), Libya (42), Turkey (42), Syria (41), Yemen (42)
Basal glume rot (*Pseudomonas syringae* pv. *atrofaciens*)	Syria (41)
Bacterial leaf blight (*Pseudomonas syringae* pv. *syringae*)	Syria (11)
Viruses	
Barley stripe mosaic virus (BSMV)[a]	Syria (36), Lebanon (33,36), Jordan (36)
Barley yellow dwarf virus (BYDV)	Syria (37), Tunisia (37), Jordan (37), Algeria (37), Morocco (37)
Nematodes	
Seed gall nematode[a] (*Anguina tritici*)	Pakistan (24,56), Turkey (61), Iraq (57), Syria (41,55), Jordan (7,38,56)
Cyst nematode (*Heterodera* spp.)	Pakistan (56), Morocco (9,56), Cyprus (56), Libya (56), Syria (55,56), Tunisia (56)
Root-knot nematode (*Meloidogyne* sp.)	Syria (55), Egypt (17)
Root-lesion nematode (*Pratylenchus* sp.)	Syria (55), Morocco (9), Jordan (7)

[a] Exclusively seedborne.

references that cite all previous references from a country, as in Mamluk et al. (38,41), have been used.

Among the four smuts, loose smut [*Ustilago tritici* (Pers.) Rostr.] and common bunt [*Tilletia foetida* (Wall.) Liro. and *T. caries* (DC) Tul.] are the most widely spread diseases of wheat in WANA. It is assumed that "..modern-high yielding cultivars, might have less bunt resistance than the land varieties used previously" (26). Many of the old cultivars possessed excellent resistance to smut diseases. The cultivar Tosson, which was grown extensively in Egypt, is resistant to common bunt (3) and loose smut (14). In Syria, the once widely grown cultivar, Senatore Cappelli (known in North Africa as Jenah Khatifa) possesses excellent resistance to common bunt (39). Also the famous durum wheat landrace from Syria and Jordan "Haurani" has reasonable resistance to common bunt. Flag smut [*Urocystis agropyri* (Preuss) Schroet.] has been reported from Pakistan (26,32), Turkey (50), Syria (41), Jordan (38), Egypt (2,22), and Tunisia (25). Dwarf bunt (*T. controversa* Kuehn) has been reported from Turkey (26,49,50), Iran (26,50), and Iraq (26, 59). Karnal bunt (*T. indica* Mirat) has not been found in Syria (15,41) as previously reported by Lambat et al. (35) and Zillinsky (62).

All three rusts are present in the majority of WANA countries and it is difficult to say which rust is more important and in which country or sub-region. However, stripe rust [*Puccinia striiformis* West.] is the prevalent rust in West Asia (12,13,16,33,34,38,41,53, 60) and Yemen (42), while leaf rust (*P. recondita* Rob. ex Desm.) and stem rust (*P. graminis* Pers.) are more prevalent in Egypt and Sudan (1,4,18,19,21,42,48,58). Stripe rust in Egypt occurs every 4 to 5 years; in Yemen, due to the cultivation of wheat in two cycles, the disease is present throughout the year. Stripe rust is the predominant rust in Turkey, and leaf rust in North Africa (10,42). In Sudan, leaf rust and stem rust occur only in the New Halfa area and in no other cultivated area.

Among the Helminthosporium diseases, tan spot [*Pyrenophora trichostoma* (Fr.) Fckl.] is restricted in its spread to Iran (42), Turkey (42), Libya (42), Tunisia (42), and Morocco (10).

Septoria tritici blotch [*Mycosphaerella graminicola* (Fuckel) Sand.] is reported from Pakistan (24), Syria (41), and Lebanon (33,53) and occurs in endemic forms in Tunisia (20,25), Algeria (42), and Morocco (10,54). However, the disease is becoming more and more important in the irrigated areas of West Asia, like Syria. Septoria nodorum blotch (*Leptosphaeria nodorum* Mull.), though reported from four countries in the Region (10,38,41,53), is not as frequently reported as septoria tritici blotch.

Powdery mildew (*Erysiphe graminis* DC. ex Merat) is prevalent in the wetter areas of WANA, mainly in North Africa (42), and downy mildew [*Sclerophthora macrospora* (Sacc.) T.S. et N.] has been reported, to date, only from Syria (41).

The foot and root rots of wheat are gaining more and more importance in WANA (41,42). The causal agents, *Fusarium* spp., in some cases associated with *Cochliobolous* sp., are involved in other diseases, like seedling blight and black point. Root rot is a major disease problem in Morocco and Tunisia, especially in years of drought. It seems that the problem is complex, involving physiological stress. Wheat cultivars with no tolerance to drought are mostly affected by the disease. Foot and root rot caused by *F. graminearum* Schwabe and *F. culmorum* (W.G.Sm.) Sacc. became of significant importance on wheat, barley, and triticale in Cyprus, due to the continued cultivation (monoculture) of the three crops. The same might well happen in other countries of the Region, with the trend to reducing crop rotation or eliminating fallow. Head scab

(*Fusarium* spp.) is reported from Pakistan (42), but information on the presence of the disease in other countries is lacking.

The bacterial leaf streak on wheat (*Xanthomonas campestris* pv. *translucens* Dowson) is reported from Pakistan (8), Turkey (42), and recently, in 1991, from Yemen (42). The disease is widespread in the relatively high rainfall and irrigated areas of Syria (41) and Libya (42). The basal glume rot [*Pseudomonas syringae* pv. *artofaciens* (McCull) Stevens] and the bacterial leaf blight [*P. syringae* pv. *syringae* (Elliot) Young, Dye & Wilie] have been reported from Syria (41,42). In general, the importance of these bacterial diseases is underestimated.

Among the viruses, the seedborne barley stripe mosaic virus is reported from Lebanon, Syria, and Jordan (33,36), but seems to be present in most countries of WANA. Barley yellow dwarf virus (BYDV) is spread across the Region. This virus reoccurred widely in Egypt in the past two seasons, 1998/90 and 1990/91.

The seed gall nematode [*Anguina tritici* (Steinb) Chit.] is reported from Pakistan (24,56), Turkey (61), Iraq (57), Syria (41,55), and Jordan (7,38,56). However, its spread and incidence are negligible. Cyst nematodes (*Heterodera* spp.), root-knot nematodes (*Meloidogyne* spp.) and the root lesion nematodes (*Pratylenchus* sp.) are reported from several countries in the Region (7,9,17,55,56), but their importance as wheat pathogens is not yet quantified in most countries.

A wheat disease problem has evolved in the newly developed irrigated areas in WANA. These are at some distance from the old traditional areas such as those in the desert of Fazzan in Libya or close to the old traditional cultivation areas, such as those on the Euphrates River in Syria. Pivot system or dam irrigation provide excellent conditions for disease development in these dry areas. However, many of the prevailing diseases are seedborne, such as loose smut, septoria blotch, and bacterial leaf streak (41,42).

Major Durum Wheat Diseases in WANA and Control Measures

Out of the myriad diseases mentioned above, it is quite difficult to distinguish the major diseases of durum wheat and those that should receive research priority. ICARDA considers three factors in the determination of priority: the form of occurrence of a disease in the region and sub-regions, endemic or epidemic; the losses caused by a disease and how much research priority is given by national programs, and regional and international organizations to a disease in a particular country (40). However, research priorities are not fixed, but change as knowledge of pathogens and diseases improves. The development of cultivated land in the steppe makes a disease such as septoria blotch a high research priority for dry areas, where it was not one before. Also, the problem of foot and root rots, created by the continuous cultivation of cereals, becomes a high priority. All these changes should be considered when reallocating research priorities at ICARDA.

Table 2 illustrates the allocation of research priorities for durum wheat diseases in the different climatological zones and subregions of WANA and shows the major diseases with high research priority. These include the three rusts (leaf, stem, and stripe), septoria tritici blotch, common bunt, BYD, and powdery mildew.

Considering the availability of any disease control measure to farmers in WANA, the use of host plant resistance remains the most applicable control measure. It is unlikely that fungicides will be used in the short-term to control diseases, such as rusts, septoria blotch, and powdery mildew. Only chemical seed-treatment for the control of seedborne

Table 2. Priorities of durum wheat diseases over different climatological zones.

Disease	North Africa LRF	North Africa MRF	North Africa ARF	West Asia LRF	West Asia MRF	West Asia ARF	Nile Valley	High Elv.
Stripe rust	-	+	+	-	+++	+++	-	+++
Leaf rust	+	++	+++	-	+	++	+++	-
Stem rust	+	+	+++	-	-	+	+++	-
Septoria blotch	+	++	+++	-	-	+++	-	-
Powdery mildew	+	++	+++	-	-	+	+	+
BYD	+	+++	+++	-	-	+	+	-
Root rot	++	++	++	-	-	-	-	-
Tan spot	-	+	+	-	-	-	-	++
Common bunt	++	++	++	+++	+++	-	-	+++
Loose smut	+	+	++	-	-	++	++	+
Flag smut	-	-	-	-	-	+	-	-
Dwarf bunt	-	-	-	-	-	-	-	++
Bact. streak	-	-	-	-	-	+	-	-

LRF = Low rainfall.
MRF = Moderate rainfall.
ARF = Adequate rainfall.

+ to +++ = lowest to highest priority; - = not important.

diseases is used and farmers are encouraged to sow certified and treated seed. However, many farmers in WANA still use their own seed, which is in most cases untreated (26).

Screening for resistance to diseases is the tool used to upgrade the resistance levels in the germplasm developed by the breeders at ICARDA and national programs.

Methodology for Screening for Resistance to Major Durum Wheat Diseases

All breeding material at ICARDA undergoes, in one way or another, at least two screenings for the major diseases: leaf, stem and stripe rusts, septoria blotch, common bunt, and BYD. The screening is done at the Center's Principal Station, Tel Hadya, the substation at Lattakia/Syria, and the substation at Terbol/Lebanon. Data on powdery mildew are obtained from the multilocation screening system.

Crossing blocks, segregating populations, preliminary yield trials (= Preliminary Disease Nursery, PDN), and advanced material (Key Location Disease Nursery, KLDN) are screened annually for the three rusts and septoria blotch. Crossing block and advanced material are additionally screened for common bunt and BYD.

Material in the advanced stage is also exposed to different diseases and biotypes of the pathogens when tested through the multilocation screening system. Several "hot-spot" locations in WANA constitute the multilocation screening system. Main "hot spot" locations for durum wheat diseases in the past three years, 1989-1991, were: two for stripe rust, T. Hadya/Syria and Terbol/Lebanon; eight for leaf rust, T. Hadya and Lattakia/Syria, Terbol (summer cycle), Elvas/Portugal, Guelma/Algeria, Marchouch/Morocco, and Sakha and Sids/Egypt; six for stem rust, T. Hadya, Terbol (summer cycle), Marchouch and Tessout/Morocco, and Sakha and Sids; five for septoria tritici blotch, T. Hadya and Lattakia, Beja/Tunisia, Marchouch and Elvas; two for powdery mildew, Terbol and Deir Alla/Jordan; and one each for common bunt and barley yellow dwarf virus, T. Hadya.

The disease inoculum used in each screening site represents the prevailing biotypes of the pathogen in the respective country. In Syria and Lebanon, disease inoculum is renewed every year. Inoculum of septoria blotch is adjusted to the ratio 1:1 from bread wheat and durum wheat. The common bunt inoculum is adjusted to have the two pathogens, mixed to the ratio 1:1.

Screening for common bunt resistance follows a different scheme. In the first year, the material is screened in the Common Bunt Nursery I using a bulk of isolates collected in Syria. Lines performing well in this screening will be retested for a second year, also with Syrian bulk isolates. Lines performing well in the second year of testing will be tested in the Common Bunt Nursery II against 8-10 different isolates from WANA: SY01 from Syria; TR02, TR03, and TR12 from Turkey; LE04 from Lebanon; TN05 from Tunisia; IR06 and IR11 from Iran, PK07 from Pakistan; and MA08 from Morocco. They represent the high-altitude areas (IR06, TR03, and PK07), the medium-high areas and areas with cold continental climates (SY01, TR02, and LE04) and the semicontinental areas (TN05, MA08); whereas TR12 represents a mild coastal climate, Izmir.

Parallel to the screening work, monitoring of pathogen races is done wherever disease nurseries are planted at the Principal Station and substations. However, virulence analysis of rust pathogens from the Region is done with the support of IPO/Wageningen, Netherlands, for stripe rust, of ENMP/Elvas, Portugal for leaf rust, and of ARC/Giza, Egypt for leaf rust and stem rust. The 1991 initiation of the "Network on Leaf and Stem Rusts of Wheat in the Nile Valley Countries" will better link and coordinate work on virulences and monitor pattern changes of the two rusts in these countries.

Germplasm resistant to a disease, selected through screening and multilocation testing is included in a "Special Purpose Disease Nursery", to be retested for 2-3 years in different locations. During this retesting, the material is selected for acceptable agronomic traits and for reasonable resistance to nontargeted disease. In the third phase, lines with resistance to a disease are pooled together in the so-called "Germplasm Pools for Sources of Resistance", increased and distributed to national programs and other collaborators. These pools are the end-products of the screening work carried out at ICARDA.

Achievements

Screening for disease resistance

The resistance of advanced durum wheat germplasm to major diseases--Disease data from multilocation screening on the advanced yield trials (KLDN-90) are presented in Table 3. There were 104, 70, 49, 32, 23, and 11 resistant entries for stem rust, stripe rust, common bunt, BYD, septoria blotch, and leaf rust, respectively. For the combination stripe rust and common bunt, 13 lines showed resistance (nos. 19, 27, 38, 55, 66, 121, 133, 136, 164, 215, 223, 231, and 236 of the DKL-90); whereas for septoria and BYD, eight lines were resistant, (DKL-90 nos. 21, 22, 23, 24, 71, 72, 97, and 99). Three lines, entries number 11, 26, and 121 (DKL-90), showed resistance to all three rusts. One entry (named Brachoua, number 121, cross: Fg/3/Gs/Tc 60//Stk), which showed combined

Table 3. Number and percentage durum wheat lines[a] resistant[b] to one or more major diseases (KDNL-90).

Disease	Resistant lines number	%
Stem rust	104	48
Stripe rust	70	32
Common bunt	49	23
BYD	32	15
Septoria blotch	23	11
Leaf rust	11	5
Stripe rust and common bunt	13	6
Septoria blotch and BYD	8	4
Stripe, leaf, and stem rusts	3	1
Stripe, leaf, and stem rusts and common bunt	1	0.5

[a] Total number tested 216, checks excluded.

[b] Selection criteria: CI 0.2 for stripe rust, ACI 2.0 for leaf rust and stem rust, 0-5 score on a 0-9 scale for septoria tritici blotch and BYD, 0-15% head infection for common bunt.

resistance to stripe rust, leaf rust, stem rust, and common bunt, is among the most promising lines in Farmers' Fields Verification Trials. Its score against septoria blotch in several locations is relatively high (score 8) and it has a moderate resistance (score 6) to BYD, both scores on a 0-9 scale.

The performance of durum wheat germplasm in the special purpose disease nurseries (1990/91)--Table 4 represents the performance of the durum wheat material included in the "Special Purpose Disease Nurseries" for the season 1990/91. Every line in a disease nursery has undergone at least a two years of screening. The highest percentage of resistant entries, 64%, is present in the Durum Septoria Nursery, followed by 58% resistant entries in the Stripe Rust Nursery. Also, a high percentage of resistant lines were found in the Repeat Testing Bunt Nursery (43%) and the Stem Rust Nursery (41%). The lowest percentage of resistant lines (7%) is in the Leaf Rust Nursery. In both germplasms, it is obvious that the level of leaf rust resistance is low. It can be assumed that in the leaf rust epidemic of 1991, new virulences affected the resistance present in the durum germplasm.

Durum wheat germplasm pools for sources of resistance--Two germplasm pools for sources of resistance to stripe rust, and septoria tritici blotch were assembled from our screening and multilocation testing. In the years 1989 and 1990, 29 sets each of stripe rust and septoria pools were furnished to national programs and other collaborators.

The Germplasm Pool for Sources of Resistance to Stripe Rust (Table 5) includes 26 lines screened over 3 years in Syria, Lebanon and Portugal (29). The performance of these lines ranged from 0 to 10MR. Most of the lines in this pool also performed well in

Table 4. The performance[a] of durum wheat germplasm in the special purpose disease nurseries, season 1990/91.

Nursery	Number of Entries Tested	Resistant	%
Septoria (DST)	36	23	64
Stripe Rust (DYR)	117	67	58
Repeat Testing Bunt (RTB)	28	12	43
Stem Rust (DSR)	59	24	41
Leaf Rust (DLR)	41	3	7

[a] Performance: 0-5 score for septoria blotch, 0-4 ACI for rusts, 0-15% head infection.

seedling tests carried out at IPO/Wageningen, using 10 different isolates from WANA. One particular line, Waha = Cham 1, released in 1984 and planted on a large scale in several countries of WANA, still maintains its excellent resistance to stripe rust. Currently, this cultivar occupies 25%, about 300,000 ha, of the wheat acreage in Syria.

The Germplasm Pool for Sources of Resistance to septoria tritici blotch includes 19 lines (30). The performance of these lines over 4 years ranged from 0 to 6 in field testing in Syria, Tunisia, and Portugal (Table 6). Their performance in seedling tests was also acceptable. All lines in this pool have good resistance to the nontargeted disease, stripe rust, which did not exceed 20MR. Some lines combine earliness, septoria resistance, and high yield potential. Lahn, e.g., a cross between Schearwater and Bittern made in Mexico and selected from the F_2 in Syria, showed an increased yield of 16% as compared with Gezira 17, local check, and 4% as compared with Cham 1. Lahn is a strong candidate for release in Syria.

A new pool for sources of resistance to common bunt in durum wheat germplasm is under multiplication. The advanced screening for resistance to the disease was carried out from 1984 to 1991 in the Common Bunt Nursery II using 8 or 10 different isolates from the Region. This screening resulted in 31 durum wheat lines/cultivars with sources of resistance to the disease. The performance of these lines against the most virulent isolate, SY01, was relatively poor; however, the overall (average) performance against all isolates was good, i.e., not exceeding 10.6% head infection in all years of testing. Eight cultivars (AA/Br.., S. Cappelli, Fa/Cando, Cit/Godvz, W-2057, Haurani, Stork, and Syrica) underwent a second year of testing. The best performing cultivars in the years 1984 and 1985 were S. Cappelli, W-2057, Cit/Gdovz 579, Fa/Cando, Haurani, and Stork with 0.0, 0.6, 0.7, 0.9, 1.9, and 2.0% head infection, respectively. In 1986 and 1987, the best performing line was Oronte with 2.1% head infection, whereas during the 1988-91 period, the best performing line was the cross AA/BR//...with 0.4% head infection. Lines in this pool have also been screened for rust during the testing years and the majority, 18 out of 31, have good resistance to the disease, not exceeding 10MR. S.Cappelli, an old cultivar, which used to be planted in Syria on a large scale, has since 1986 been introduced in all common bunt nurseries as a resistance check. Except in 1988, where this cultivar had 20% head infection, its performance did not exceed the 10% head infection in the five years of testing. The consistency of resistance of this cultivar suggests a kind of durable resistance.

Table 5. The performance[a] of selected durum wheat lines to stripe rust, *Puccinia striiformis* (DYRGP 87).

	Year and Screening Site[b]									
	1984			1985	1986			1987		
Variety or Cross	SYR	LEB	POR	IPO[c]	SYR	LEB	POR	SYR	LEB	POR
Pen	0	-	-	10	0	1R	0	5R	1R	10MR
Gr/S.Cp//St46/3/ Cr/4/Gta	1MS	-	0	10	1	0	1MS	5R	1R	0
Rabi/31810/Snipe /3/Balcarceno Inta	0	-	0	10	1	0	0	1R	1R	10MR
BD 2014/Rabi	2MS	-	0	9	1	0	1MS	1R	5R	1R
Fg/Ato	10MR	5MS	0	-	5	1R	0	10MR	5MR	1R
Zeroud	0	0	1R	-	5	1R	0	5R	1R	5R
Ovi/Cp//Cando	0	5MR	0	-	1	1R	0	1R	1MR	0
Ruff//Jo/ Cr/3/F9/3	1R	1MR	0	-	5	0	0	5R	1R	5R
Gta/Stk//Snipe	-	0	0	-	5	0	0	1R	1R	1R
Can 2101/Magh// Stk//3/Wlls/65150	1MS	1MR	1R	-	5	5MR	0	10MR	5MR	-
D.dwarf S15/Cr/3/ Plc/Gv//Jord 119	1R	0	0	-	5	5MR	0	10MR	1R	0
Ato//S15/Cr	0	1R	0	-	5	1R	0	5R	1R	0
Ato/Gta	0	1MR	0	-	5	0	0	5MR	1R	1R
AA/Br//V1658/Cr /3/Shwa/4/Swan	1MS	1MS	0	-	5	3MR	1MS	10MR	10MS	1R
Frigate	10MS	1MS	0	-	1	0	0	1R	1R	0
Phibirol.82	1R	0	10MR	-	5	1R	0	5MR	1R	0
Plc/Ruff//Gta/ D6715/3/Shwa	0	1MR	0	-	1	3MR	0	5R	5MR	0
Cit/GdoVZ79	1R	5MS	0	-	5	1MR	0	10MR	5MR	0
Stil/Bit	5MR	5MS	1MS	-	1	1R	5MR	5MR	1MR	0

Table 5. Continued

Variety or Cross	1984 SYR	1984 LEB	1984 POR	1985 IPO[c]	1986 SYR	1986 LEB	1986 POR	1987 SYR	1987 LEB	1987 POR
Trob	10MR	5MS	0	-	5	1R	0	10MR	5MR	1R
D.dwarf S15//Cr/Stk	5MS	5MR	0	-	5	1R	0	5MR	1MS	20R
GroVZ385/Gs/4/ D.dwarfS15//T.dic. V.Vern//G11/3/Plc	-	-	-	-	5	1R	0	5R	1R	0
Lds Mut/teal	-	-	-	10	1	1R	0	1R	1R	0
Syrica	-	-	-	10	1	1R	0	1R	1R	0
Waha (Cham 1)	-	-	-	10	1	0	1MS	5MR	1R	0
Gr/Boy	-	-	-	9	5	5MR	0	1R	5MR	-

Year and Screening Site[b]

[a] Performance: % severity/reaction type.

[b] Screening site: SYR = T. Hadya/Syria; LEB = Terbol/Lebanon; POR = Elvas/Portugal.

[c] Number of isolates to which the line was resistant at IPO/Wageningen; seedling test using 10 isolates (3 Syria, 2 Pakistan, and one each from India, Turkey, Italy, Tunisia, and Kenya).

Table 6. **The performance of selected durum wheat lines to septoria tritici blotch, *Mycosphaerella graminicola* and stripe rust, *Puccinia striiformis* (DSTGP 87).**

Variety or Cross	Mean score[a]				Seedling test[b]		Stripe rust[c]
	1984	1985	1986	1987	Necrosis	pycnidia	
	4[d]	2	4	3			
Shwa/Bit	3	6	4	6	4	+	20MR
Shwa/Bit	4	5	4	-	5	+	tR
Shwa/Goo	4	4	4	-	6	++	5MR
Fg/Rabi	5	3	3	5	7	+	tMR
PI 298547	3	4	4	4	7	+	5R
(ACC 3040*Lang)Leeds	2	6	4	5	6	+	tR
Pin/Gre//Cit/Fg	-	4	4	6	6	+	tR
Pin/ Gre//Cit/Fg	-	4	3	5	6	+	00
Pin/Gre//Cit/Fg	3	5	6	-	7	++	5MR
Badri//Gta/Fg	6	5	4	-	5	+	10MR
Berillo	6	4	6	-	7	+	00
Grosby	5	6	4	-	8	++	00
Br/ZB/4/Gll/3/ BYE*2/Tc//213W	3	6	5	-	7	+	00
Memo/Goo	-	6	4	5	6	+	10MR
Uveyik126/61-130// Kohak2916/Lds/3/Ibis	0	6	5	-	6	++	5MR
D/T/3/D 21563/AA//Fg	6	4	3	6	6	+	25MR
Cr/4/21563/61-130// Lds/5/Cameltooth/6/Gs/ Cr//Shwa	1	6	5	-	6	+	5MR
MT/S1K//Ch67/21563/3/Waha	4	6	5	-	8	+	5MR
P9/3/GU//T.dic.v.vern/GU	4	6	4	6	6	+	10MR
Gezira 17 (Check)	-	8	6	7	7	+++	

[a] Scale 0-9.

[b] Necrosis (0-9) = mean score on 30 leaves 21 days after inoculation; Pycnidia formation: +light; ++ moderate; +++ abundant.

[c] Highest reading of severity and reaction type.

[d] Number of screening sites.

A new series of durum wheat germplasm pools for sources of resistance to the major diseases will be made available for the season 1992/93.

Studies on the host-pathogen system

Host preference in septoria tritici blotch--This study aimed at investigating the preference of septoria blotch pathogen, *M. graminicola*, for one or the other host, i.e., bread wheat verses durum wheat (46). Based on pycnidial formation as a tool for the measurement of disease development, a kind of host-preference has been demonstrated. Pycnidial formation of the pathogen in both durum and bread wheat was greatest when the source of the inoculum was their own species of wheat.

Partial spike infection as partial resistance to common bunt--The phenomenon of partial infection of wheat spikes by the common bunt pathogen is well established in nature and in artificially inoculated nurseries. If proven to be heritable and thus a kind of partial resistance, this characteristic would offer an alternative for breeding for resistance to common bunt. Work on this phenomenon started in the 1989/90 season. Preliminary results showed that progenies of healthy seeds from partially infected spikes segregate in spikes with all kernels healthy (30%), in spikes with all kernels infected (13%), in spikes with partial infection (19%), and in spikes with total, as well as with partial, infection (38%). The results give an indication that the characteristic of spikes being partially infected is heritable. The heritability of this characteristic will be further studied.

The pathogenicity of septoria tritici blotch and common bunt on Aegilops *spp.*--Since the 1988/89 season, more than 710 accessions of 23 *Aegilops* species of the Center's collection have been under field testing for stripe rust, septoria blotch and common bunt. While a wide range of response to stripe rust was found in these collections, none of the tested entries showed any susceptibility to septoria blotch and common bunt. Greenhouse tests were conducted to confirm the septoria blotch immunity of the genus *Aegilops* found in the field. All check plants, cv Gezira 17 and Mexipak, showed an excellent disease development in the form of necrosis and pycnidial formation. Some of the *Aegilops* entries showed chlorosis, but only one entry of the species, *Ae. kotschyi*, showed typical necrosis with pycnidia. Work is continuing to further test other species of Aegilops.

In the previous screenings for common bunt, the routine inoculation method used for wheat was also used to inoculate the *Aegilops* spp. Due to the morphological differences of wheat and *Aegilops* seeds, it was essential to test the effectiveness of this method in order to confirm the immunity of these species to common bunt. In a field test, 10 *Aegilops* spp. (*biuncialis*, *caudata*, *columnaris*, *crassa*, *cylindrica*, *squarrosa*, *triaristata*, *triuncialis*, *ovata*, and *vavilovii*), along with the wheat cultivar Mexipak were used. Four different inoculation methods, plus the check (not inoculated) were tested. All *Aegilops* spp. in all inoculation methods remained healthy and uninfected by the common bunt.

All four inoculation methods yielded bunted spikes only in the wheat plants. The routine wheat inoculation method resulted in the highest (68%) head infection. It is evident that the inoculum method has no influence on the susceptibility/resistance of the *Aegilops* spp. to common bunt. It can be concluded that *Aegilops* spp. are an excellent source of resistance to common bunt of wheat.

Crop loss assessment--Crop loss assessment trials for stripe rust and septoria tritici blotch were started in the 1987/88 season. The objective of these trials is to determine the actual losses in each cultivar, since yield in wheat cultivars is affected differently even at the same level of disease infection. In the trials conducted at T. Hadya and Lattakia, the cultivars used are those under verification from the Collaborative Research and Training

Program with the Syrian national program. These cultivars are usually promising lines or candidates for release. Several of these cultivars have already been tested for 3 or 4 years. By using protectant chemical spray(s), the potential yield of each cultivar is estimated and compared with the treatment left unprotected, for best development of the disease after artificial inoculation. Data obtained from the past four seasons combined await final statistical analysis. One significant finding from last season is that durum wheat cultivar Omrabi 3, with an average stripe rust score of 12MS-S, lost 9.7% of its potential yield. Mexipak in previous tests showed a 29% yield loss with an infection of 73S (40).

Concluding Remarks

- Durum wheat diseases are the same as bread wheat diseases except for some peculiarities of the agroclimatic areas where they are grown and for the host-preference demonstrated by the pathogen.

- Major durum wheat diseases in WANA are stripe rust, leaf rust, stem rust, septoria tritici blotch, common bunt, BYD, and powdery mildew. Foot rot, root rot, and bacterial leaf streak are becoming more important.

- The level of resistance to the major diseases in the durum wheat germplasm can still be improved, especially that of leaf rust.

- Identification/postulation of resistant genes in the established germplasm pools for sources of resistance to diseases is essential. This will give a better understanding of the genetic basis used in the breeding program.

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Discussion Notes

Singh: For what diseases do you inoculate?
Mamluk: The three rusts, septoria blotch, and common bunt.

Gilchrist: Do you have *Septoria nodorum*?
Mamluk: *S. nodorum* can be important in Morocco, Syria, and Turkey--but *S. tritici* predominates.

Varughese: Do you find higher tolerance to Septoria in the local varieties?
Mamluk: Have not looked at Septoria, but we should.

van Ginkel: How important are foot and root rots? What are you doing about them?
Mamluk: Doing almost nothing. There is no crop rotation: wheat after wheat and barley after barley--that is why I mention it as a potential problem.

Leisle: What is the source of BYDV tolerance?
Mamluk: I don't know.
Lukas: BYDV in the Nile Valley is a result of changed cultural practices.
Mamluk: The aphid vectors have become resistant to pesticides.
Saari: The aphids came with irrigation, and then the BYD followed.

TAN SPOT OF DURUM WHEAT

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The Pathogen

Tan spot or yellow spot of wheat is caused by the ascomycetous fungus *Pyrenophora tritici-repentis* (Died.) Drechs. The anamorph or asexual form is *Drechslera tritici-repentis* (Died.) Shoemaker. This species has had a number of synonyms in the past. In addition to the current nomenclature, reports in the literature have used the generic names Pleospora and Helminthosporium. Other trivial names have included *tritici-vulgaris*, *trichostoma*, and *graminearum* f.sp. *tritici-repentis* (Hosford 1982). The morphologically closely related species *Pyrenophora teres* and *P. bromi* have not been found to infect durum or bread wheat and conidia are readily distinguishable.

Asci of *P. tritici-repentis* are borne within dark brown, globose pseudothecia that normally develop on infested wheat straw and leaf sheathes. Pseudothecia have a setose beak and are 400 to 500 µm in diameter. Ascospores are ovate, light brown, have three transverse septa and (usually) one longitudinal septum that divides one or both middle cells, and measure 18 to 28 by 45 to 70 µm (Shoemaker 1962).

Conidia are yellowish brown to olive in color, cylindrical, and multiseptate. They vary in number of constituent cells, so their length will range from about 45 to 255 µm. Width is a relatively uniform 14 to 18 µm. The apical cell is hemispheric and the basal cell is shaped like a snake's head. Germination can occur from any cell. Conidiophores are yellowish brown, erect, septate, 50 to 250 µm long, and often have a scar on the rounded proximal end (Shoemaker 1962). Conidia are formed under natural conditions on older leaf lesions and may also arise on the beaks of pseudothecia.

Tan spot can be positively identified by putting surface-sterilized sections of affected leaves into a moist chamber. Conidiation occurs only under a diurnal light cycle with conidiophores being produced during a light period and conidia during the subsequent dark period. Conidiation will occur over a fairly broad temperature range so no special incubation is required if room temperatures are moderate. Examination of the leaf tissue at about 40X after 3 to 4 days should resolve the causal agent. Pseudothecia may form after several weeks of incubation.

The Hosts

Tan spot affects durum and bread wheat crops on all wheat-producing continents. The greatest disease intensity usually develops in the Great Plains of North America and in wheat-growing provinces of eastern Australia. Average annual yield losses for all marketing classes of wheat fall between 5% and 15% in these areas. Prior to the 1970s, tan spot was considered to be a minor disease of wheat but this is no longer the case. In areas such as North Dakota, where durum cultivars resistant to wheat stem and leaf rusts are grown, tan spot has become the predominant disease problem.

Pyrenophora tritici-repentis also causes disease in grass species belonging to at least 23 different genera, including *Aegilops*, *Agropyron*, *Andropyron*, *Bromus*, *Bouteloua*, *Dactylis*, *Elymus*, *Festuca*, *Hordeum*, *Leymus*, *Panicum*, *Pascopyrum*, *Phalaris*, *Psathyrostachys*, *Schizachyrium*, *Secale*, *Stipa*, *Thinopyrum*, and *Triticum* (Krupinsky

1982, 1992). Typically, no species within these genera has been found to be immune to tan spot, but resistant accessions within species are customary (Alam and Gustafson 1988).

Host-Parasite Interactions

On leaves, *P. tritici-repentis* forms tan blotches, usually sharply delimited and having distinct dark brown infection sites. Lesions in some fungal isolate-plant accession combinations may be diffusely chlorotic rather than necrotic. Lesion spread tends to be limited by major veins in the leaf, giving many blotches a diamond to rectangular shape. Plant cells can be killed in advance of the spread of fungal hyphae and this necrosis is associated with the more typical tan spot symptom (Larez et al. 1986). *Pyrenophora tritici-repentis* produces a proteinaceous phytotoxin with a molecular weight of about 14 kD that is involved in pathogenicity (Ballance et al. 1989, Tomás et al. 1990). The toxin apparently disrupts the plasma membrane and the outer membranes of the mitochondria and chloroplast (Larez et al. 1986), but this mode of action should be confirmed by further study.

Symptoms on wheat leaves can be confused with septoria and spot blotch diseases. Septoria blotches typically take on a grayish color and black, conidiospore-bearing pycnidia are visible to the naked eye. The number of pycnidia and size of the lesion depend in part on resistance of the host. Compared to tan spot, spot blotch lesions are more rectangular, typically smaller and have a darker colored infection site.

Although *P. tritici-repentis* can cause yield reduction by reducing the amount of healthy leaf tissue, grain yields and quality can be reduced further by infection of the developing seed. *P. tritici-repentis* has been linked to a reddish discoloration of wheat seed called red smudge (Valder 1954), a symptom more distinct on kernels of durum than bread wheat. However, *P. tritici-repentis* apparently is capable of causing a number of different symptoms on seed. In a study of durum seed lots, *P. tritici-repentis* was primarily associated with red discoloration but also was isolated from a significant number of seed showing the black point symptom (Table 1). Black point previously had been linked to seed infection by *Cochliobolus* (*Helminthosporium*), *Fusarium*, and *Alternaria* spp. (Wiese 1987).

Table 1. Fungal isolations from surface-sterilized seed of *Triticum durum* cv. Sceptre showing various pathological discolorations.

	Symptom		
	Red	Black point	Green
Pyrenophora tritici-repentis	74	20	19
Cochliobolus sativus	6	45	57
Alternaria spp.	36	42	92
Fusarium spp.	1	4	5

Initial lesions on leaves of a durum crop arise from ascospores and/or conidia that are produced on infested residue, or other graminaceous hosts. Ascospores are thought to travel only a short distance, on the order of meters (Rees and Platz 1980), but conidia are airborne for longer distances (Wright and Sutton 1990). Periods of wet weather swell the pseudothecial tissue and cause liberation of ascospores. The ascospore infection phase of the tan spot epidemic is best characterized by a monomolecular (simple interest) model because the source of inoculum is finite and not replaced.

Secondary infections on upper leaves and the inflorescence are thought to be caused primarily by conidia (Wright and Sutton 1990). Conidia are formed when the lesion remains wet over at least one light and dark period. Spores become airborne typically around midday when free moisture evaporates. A repeating cycle of sporulation is possible so the disease increases exponentially (compound interest) under suitable environmental conditions. Since conidia can travel considerable distances, even fields without infested residue can suffer yield reductions from tan spot. The severity of infection on the flag leaf is thought to be a major determinant of yield reduction but early season injury can reduce yield as well (Rees and Platz 1983).

Severity of a tan spot epidemic depends on a number of factors that are dynamically interlinked. Certainly, the environment is a major factor. Since conidiospores need free water to germinate, wet periods provided by dew and rainfall are critical to disease progress. Conversely, tan spot lesion expansion and conidiation are halted by dry weather. Tan spot proceeds optimally under a wide temperature range of about 18 to 27°C (da Luz and Bergstrom 1986a). Severity also depends on factors inherent to the plant host. Susceptibility to tan spot varies with genotype but most, if not all, durum lines become increasingly susceptible with age (Hosford et al. 1991). Lower leaves of plants past anthesis can become severely diseased, even in moderately resistant lines. Finally, the fungus itself can vary in aggressiveness and the amount of airborne spora available for inoculum.

Disease Management

A number of options are available to the durum grower faced with the risk of a tan spot epidemic. Cultural and chemical controls and genetic resistance offer the most immediate payoff. Biological control offers some promise for the future.

Management practices that minimize the amount of infested wheat residue will decrease the source of primary inoculum and presumably delay the onset of a serious epidemic. Unfortunately, this option may be in conflict with other management goals such as soil conservation. An alternative approach that has been researched involves treating infested wheat straw with a biological antagonist or a chemical inhibitor to reduce or eliminate sporulation (Aharma et al. 1989, Pfender 1988).

Fungicide protection of a susceptible cultivar provides another option. The most cost-effective treatment may prove to be the use of a systemic fungicide applied to the seed prior to planting (da Luz and Bergstrom 1986b). Protection for 30 to 45 days may be enough to tilt the balance in the grower's favor, but this option is still in the experimental phase at this time. A systemic or protective fungicide treatment, applied at an early growth stage, i.e., EC 21-32 (Zadoks' scale), may reduce the epidemic's rate of progress enough to be economical, but again this is an experimental approach. The most reliable method of protecting a durum crop is to protect the flag leaf and the leaf below the flag. This is accomplished by fungicide application at flag leaf emergence, i.e., EC 37-39 (Zadoks' scale), and later stages if necessary. Yet to be reliably answered is the question of economic return from a fungicide application on a given crop. To answer this question, more information is needed about economic threshold levels at different growth stages.

Durum breeders may be able to incorporate genetic resistance, the most economical means of tan spot control. Transfer of a high level of resistance to tan spot from wheat types that are otherwise not agronomically suitable has been difficult because of the undesirable traits that are also transmitted.

Resistance to tan spot in durum wheat is thought to be quantitatively inherited, moderately heritable and linked to plant height (Elias et al. 1989). Quantitative inheritance has been reported in hexaploid wheat (Nagle et al. 1982), but in at least one line, Carifen 12, qualitative inheritance seems to be operative (Lee and Gough 1984). Rees and Platz (1989) concluded that resistance is incomplete due to changes in severity with leaf age and wetness period. Recent results by Lamari and Bernier (1989, 1991) and Lamari et al. (1991) have reopened the question of quantitative inheritance. By focusing on reaction type (necrotic and extensive chlorotic responses) on a specific leaf rather than on some measure of disease severity, they were able to demonstrate the interaction of fungal and plant genes. Results suggest an intricate series of systems involved in resistance. Incorporation of multiple copies of a "minor" resistance gene, perhaps one conferring protection against the phytotoxin of *P. tritici-repentis*, may be the key breeding objective.

Screening Durums

North Dakota State University has instituted a revised tan spot screening program for advanced durum lines. Evaluation begins in the greenhouse and continues in the elite lines and uniform regional field trials. Every durum line is evaluated many times before it is released as a public cultivar to ensure that its disease reaction is stable and at least moderately resistant.

Conidiospores for the greenhouse procedure are produced according to the method of Lamari and Bernier (1989). Typically, 1,500 propagules per plant are inoculated at the 2- or 3-leaf stage. We use a closed tower with a rotating bottom to inoculate plants evenly. Nonetheless, it is important that observations (plants) in the greenhouse be replicated due to variability. Plants are moved after inoculation to a chamber and subjected to mist from an ultrasonic humidifier on a timer. After 24 hours, plants are moved to the greenhouse, dried under a fan to assure wet period uniformity and subirrigated to avoid wetting the leaves further. Disease assessment takes place one week after inoculation.

Evaluation of genotype reaction uses a number of criteria to guarantee that all disease resistance mechanisms are accounted for as much as possible. The uppermost fully expanded leaf at the time of inoculation is assessed to control the leaf age effect (Hosford et al. 1991). The number of lesions per leaf is counted to evaluate for receptivity (infection efficiency). Next, the lengths of the three longest lesions are measured to evaluate for restriction of infection sites. Percent tan spot severity is estimated independently by two individuals for an assessment that combines the effects of the previous two criteria. Finally, the necrotic and chlorotic reactions as defined by Lamari and Bernier (1989) are noted.

With this system, durum lines susceptible to tan spot are identified quickly and can be discarded by the breeder. Durums that appear resistant are subjected to field evaluation in multiple locations and/or further greenhouse evaluation.

Durum screening for tan spot resistance in the near future will probably be based on new techniques being developed today. The possibility of using known concentrations of phytotoxin as a bioassay is being researched at North Dakota State University. Assessment of plant reaction at the cellular level to *P. tritici-repentis* or its toxin would remove work space limitations and permit rapid assessment of reaction. Efforts in these and other directions will pay off in a screening system that more reliably and efficiently rates resistance.

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Discussion Notes

Gilchrist: What checks do you use?
Francl: MD495 is the susceptible bread wheat check in our screening nursery. Generally, we do not include a resistant check. Reactions are similar in bread wheat and durum wheat.
Ortiz: We do not have a susceptible check in durum wheat and so we are forced to use a bread wheat.

Mamluk: I've seen tan spot in the Libyan desert and in Morocco. Why is the disease so widespread in different environments?
Francl: Its occurrence is dependent on leaf wetness--be it irrigation or rainfall. Temperature is not that important.

SEPTORIA DISEASES OF DURUM WHEAT

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Distribution and Environmental Conditions

In the Mediterranean area, the septoria diseases of wheat can be major problems if climatic conditions are favorable. Disease development is favored in high rainfall areas (700 mm and above). As a result in most years, septoria diseases are localized and seldom become epidemic throughout the entire region. Based on available literature and the experience of various CIMMYT breeders and pathologists, *Septoria tritici*, the causal agent of septoria leaf blotch, has been identified as a major problem in durum wheat growing areas (Figure 1).

In West Asia and North Africa (WANA), it is well established that *S. tritici* is the principal species involved. Severe epiphytotics of septoria leaf blotch have occurred in Morocco, Tunisia, and Turkey resulting in substantial wheat yield losses in certain regions of these countries (Saari 1973). Srivastava et al. (1986) reported that septoria leaf blotch is a major disease of durum wheat, particularly in North Africa.

Septoria leaf blotch is one of the major wheat diseases in northern Tunisia (Djerbi et al. 1974) where the January to April temperatures range from 9.3 to 16.5°C at Beja and from 11.3 to 15.4°C at Bizerte, accompanied by rainfall of from 500 to 700 mm. However, in certain years, climatic factors do not favor disease development (El Ahmed et al. 1984). During the last 20 years, disease occurrence was frequent, but not severe enough to cause serious grain losses.

In the Mediterranean environment of Western Australia, septoria leaf blotch can be especially severe on early-sown crops and on early maturing varieties (Rosielle 1972). Over the last 10 years, it has been a major disease on bread wheats. Durum wheats may represent a source of resistance to the septoria problem.

In Italy, the frequency of *S. tritici* and severity of its attacks are economically important (Forni and Zitelli 1979). Strong natural epidemics of *S. tritici* on durum wheat have been recorded in Italy in 1980, 1981, 1982, and 1988 (Pasquini et al. 1988).

Virulence Patterns of *Septoria tritici*

Leaf blotch isolates have been identified from different regions along with their relationship to durum wheat and bread wheat. Breeding for resistance to this fungus has increased resistance levels, but selection for resistance is often hampered by differences in observed resistance between locations and/or years. This may be due to different environmental conditions or to variability of the *S. tritici* population (Arama et al. 1988).

Eyal et al. (1973, 1985) studied the virulence patterns of 97 isolates of *Mycosphaerella graminicola* (the sexual state of the pathogen) from 22 countries using 35 bread and durum wheat and triticale cultivars in the seedling stage. Significant isolate x cultivar interactions indicated the existence of specific virulence genes among the isolates. These genes were used to determine virulence frequencies of *M. graminicola* and their geographic distribution. Virulence frequencies varied considerably among regions (South America, North America, Europe, Mediterranean, Africa, and Oceania--and even within countries. Mexico and Uruguay had the highest overall frequency of virulence factors.

Isolates secured from tetraploid wheats in Syria and Tunisia were more virulent on tetraploid cultivars than on hexaploid cultivars (Figures 2 and 3).

These results agree with those obtained by van Silfhout et al. (1989). They recorded significant isolate x cultivar interactions and their differences in geographic distribution. They also found indications of specificity in some durum and bread wheat isolates (Table 1). By contrast, van Ginkel (1986), using only *T. durum* cultivars and isolates collected from both *T. durum* and *T. aestivum*, did not find significant isolate x cultivar interactions.

Table 1. Percent pycnidial coverage on seedlings of *T. durum* cultivars after inoculation with five isolates of *S. tritici* collected from *T. aestivum* and *T. durum* cultivars.

	Isolate				
Cultivar	ARG86075[a]	TUR86022	ETH87014	TUR86023[a]	SYR87005[a]
Inbar	44	43	0	1	0
V447	39	42	17	20	0
Cakmak	2	20	0	1	0
T. aestivum[b]	0	0	10	18	29

[a] Collected from *T. durum*, Arama et al. (1988).
[b] Mean of 12 cultivars.

Further research on specificity is being done in The Netherlands to obtain more information on this important aspect. With the background of this information and the differences in geographic distribution of virulences of *M. graminicola* within regions and countries, we are developing strategies for germplasm and cultivar deployment for resistance to *M. graminicola*.

A special surveillance nursery consisting of resistant advanced lines from the CIMMYT durum wheat program was formed in 1991 and sent to key areas: Morocco, Algeria, Syria, Turkey, Ethiopia, Kenya, and Argentina. The material included was preselected under field conditions at Toluca (State of Mexico) and Patzcuaro (State of Michoacan, Mexico) under field conditions during three cycles (1987, 1988, and 1989). In Toluca, the material was artificially inoculated with a mixture of five isolates from bread wheat for the first 2 years and with a mixture of three isolates from durum wheat in the third year.

The selected material was multiplied and utilized in forming the surveillance nursery. Information from this nursery will be utilized by the breeding program to increase the level of resistance in the durum wheat. In addition, this information should be complemented by virulence analyses carried out in The Netherlands. This, however, will depend on the approval of the *S. tritici* Project's 3rd phase budget (The Netherlands, Tel Aviv University, and CIMMYT).

Resistance to *S. tritici*

Genetic resistance is the most economic way of disease control for field crops. Finding sources of resistance and incorporating them into improved cultivars are high priorities for most breeding programs. A number of studies report evaluation of *T. durum* for resistance to *S. tritici*, but with conflicting conclusions. For example, in Tunisia, 60 of 300 bread wheat lines and 17 of 262 durum wheat lines were found resistant to septoria leaf blotch (El Ahmed et al. 1984). This study concluded, as have others (Anonymous 1979-1982, Djerbi and Ghodbane 1975, ICARDA 1983), that bread wheat in general is more resistant to the disease than durum wheat. By contrast, Rosielle (1972) in Australia found durum wheat more resistant than bread wheat when he evaluated 5500 bread wheats and 2000 durum wheats under both a natural epidemic and artificial inoculation. The correlation coefficient between varietal scores for the natural epidemic and the artificial epidemic conditions was 0.63***. In all, 34 varieties of *T. aestivum* and 266 varieties of *T. durum* were classified as resistant. The resistance present in the accessions of *T. durum* was generally higher than that founded in *T. aestivum*. A large number of the accessions of *T. durum* was recorded as being immune to highly resistant, while only four accessions of *T. aestivum* were classified as equally resistant (Rosielle 1972). Luthra et al. (1938) also observed varieties of *T. durum* to be almost immune in the Punjab, India.

Many durum wheats (genomes AABB) and triticales (genomes AABBRR) were reported to be immune to *S. tritici* in California (Gul et al. 1975). Eyal (1981) reported a higher frequency of resistance among *T. durum* and triticale accessions than among accessions of *T. aestivum* when subjected to a highly virulent mixture of isolates of *S. tritici* in Israel. The durum wheat cultivar Zenati-Bouteille was resistant to all seven isolates, and the varieties Inbar and N 163 were susceptible only to two isolates originating from durum (Yechilevich-Auster 1983). Table 2 compares the *S. tritici* resistance of durum accessions found in the CIMMYT and ICARDA germplasm banks.

Table 2. A comparison of ICARDA and CIMMYT gene bank durum wheat populations and their response to *S. tritici* in Tunisia and Mexico, respectively.

Classification	No. of accessions	Percentage
ICARDA--Resistant	379	10.2
CIMMYT--Resistant	289	17.8
ICARDA--Intermediate	1349	36.6
CIMMYT--Intermediate	534	32.8
ICARDA--Susceptible	1952	53.2
CIMMYT--Susceptible	889	54.7

Some varieties of durum and bread wheats have been tested for *S. tritici* resistance in the field in Italy. The bread wheat Atlas 66 and durum wheat Joapar seemed to be the most resistant varieties to the disease (Forni and Zitelli 1979). In addition, Pasquini et al. (1988) reported that, in the heavy epidemics occurring in the 1980s, only the varieties Belfuggito, Filippo, and Giano showed moderate resistance. Among the introductions tested, Bittern's' and S.T. 464 (a Tunisian durum) showed less severe symptoms.

In the United States (Illinois), a number of varieties of *T. vulgare* and of *T. durum* were artificially inoculated at the seedling stage in the greenhouse in order to select varieties representing susceptible, intermediate, and resistant types. All varieties of *T. vulgare* tested were extremely susceptible. The varieties of *T. durum* ranged in reaction from susceptible to resistant, with a majority highly resistant, but not immune (Hilu and Beveois 1957). In Israel, Eyal (1980) and Eyal et al. (1983) screened wheat cultivars against locally available, but highly virulent isolates and observed that resistance was more common in winter bread wheats, durum wheats, and triticales than in spring bread wheats.

Some 2436 entries of bread wheat and 2253 entries of durum wheat (Table 3) in CIMMYT's Wheat Germplasm Bank were screened and classified during 1988 in Toluca (State of Mexico).

Table 3. Distribution of *Septoria tritici* disease score coefficients of durum wheats from different countries tested at Toluca, Mexico, in 1988.

	Coefficient range								
	4-10	11-20	21-30	31-40	41-50	51-60	61-70	71-81	Total
CANADA	1								1
JORDAN	2*	1*	1			1	1	1	4
SPAIN	1*		1			1	2	3	7
USA		1		2		1	5	2	10
ISRAEL		1				3	2	6	11
PORTUGAL		2*	2		3		1	8	14
TUNISIA		4	1	7	2	4	3	4	21
TURKEY	1		1	5	1	3	6	8	24
SYRIA		1	3	2	5	5	11	4	30
INDIA			1*		2		10	26	38
ALGERIA		1		6	1		33	1	41
EGYPT			1	2	1	1	5	33	43
ETHIOPIA		2*	1	1	4	5	19	44	74
ITALY	1	1	2	2	3	4	13	101	125
MEXICO	86	203	125	239	170	217	502	170	1626

* Landrace cultivars.

Figure 4 presents the frequency distribution for *S. tritici* reactions in each crop. Correlation analysis between the CM (CIMMYT Mexico cross) number and disease score showed more *S. tritici* resistance was available in CIMMYT bread and durum wheats than from other sources--with resistance being more frequent within the CIMMYT bread wheats.

Septoria tritici Resistance in other *Triticum* spp.

Beach (1919) reported that *S. tritici* failed to infect *T. dicoccum*, *T. durum*, and *T. polonicum*. Arsenijevic (1965) reported high resistance in *T. monococcum* and *T. timopheevi*. King et al. (1983) reported resistance in the same species as Arsenijevic *T. dicoccum* as well.

After three successive inoculations with *S. tritici* and *S. nodorum* at the seedling stage (three leaves at 10 to 14 days) of 6161 wheats species including *T. aestivum*, Roseille (1972) found 20 accessions other than *T. aestivum* to be very resistant (1.1 to 11.4% necrosis) compared with the susceptible check Fortuna (80% necrosis). Of the 20 resistant lines, nine *T. timopheevi* were mentioned as a potential sources of resistance to *S. tritici* and *S. nodorum*. Rosielle (1972) also observed high resistance in *T. dicoccum*, *T. carthlicum*, *T. polonicum*, *T. piramidale*, and 266 varieties of *T. durum*.

A study done by Brokenshire (1976), although limited in the number of wheat lines tested, indicated that the hexaploid wheats *T. aestivum*, *T. spelta*, and *T. compactum* were more resistant, except for the highly susceptible *T. dicoccum* selection, than the tetraploid species. *T. timopheevi* reported as highly resistant by Morales (1957), Arsenijevic (1965), and Brokenshire (1976) suggests immunity possibly conferred by the G genome.

Rosielle (1972) screened 7500 varieties, including 2000 durums, under artificial *S. tritici* field infection and found 48 varieties that demonstrated a certain degree of resistance. Older durum varieties Cappelli, Azizia, Garigliano, and Capeiti 8 were resistant and perhaps even immune.

Yechilevich-Auster et al. (1983) evaluated seedling resistance to seven isolates of *S. tritici* in populations and accessions of diploid and tetraploid wild *Triticum* species representing different genomes along with bread and durum wheat varieties. Of 22 *T. monococcum* and *T. boeoticum* lines (A genome) tested, only two were susceptible. Accessions of diploid wheats with the B and D genomes exhibited several pathogenicity patterns. Of 47 wild emmer (*T. turgidum dicoccoides*) lines, 25 were resistant to all seven *S. tritici* isolates, while the rest exhibited 14 identifiable pathogenicity patterns. The considerable genetic variation encountered within populations of the wild wheats (Table 4) indicates a large reservoir of genes for differential reactions. Populations of diploid and tetraploid wild wheats showed different interactive patterns regardless of species, genomes, and geographical sources. Interactive patterns were observed even in populations collected in arid habitats (*T. longissimum* and *T. turgidum dicoccides*) where infections by *S. tritici* are rare. Little information is available on the occurrence and magnitude of septoria leaf blotch epidemics in wild *Triticum* species in their natural habitats (Yechilevich-Auster et al. 1983).

Inheritance

From generation mean analyses for 65 durum crosses, van Ginkel and Scharen (1987) found that 88% of the variation was explained by models generally involving additive and dominant gene effects. Epistatic gene effects were of minimal importance. Additive gene effects were more important than dominant gene effects. The number of effective

Table 4. *Septoria tritici* resistance found in other *Triticum* species.

Triticum spp.	Author and year	Reaction
T. monococcum	Arsenijevic (1965)	Resistant
	Rosielle (1972)	Resistant
	Yechilevich-Auster et al. (1983)	Resistant (20/18R 2S)
T. timopheevi	Morales (1957)	H. Resistant
	Arsenijevic (1965)	Resistant
	Krupinsky et al. (1972)	Resistant
	Rosielle (1972)	Resistant
	Brokenshire (1976)	H. Resistant
T. dicoccoides	Rosielle (1972)	Resistant
	Yechilevich-Auter et al. (1983)	Resistant
T. dicoccum	Beach (1919)	Resistant
	Rosielle (1972)	Resistant
	Brokenshire (1976)	Resistant and Suscept.
T. polonicum	Beach (1919)	Resistant
	Rosielle (1972)	Resistant
T. carthlicum	Rosielle (1972)	Resistant
T. piramidale	Rosielle (1972)	Resistant
T. longissimum	Yechilevich-Auster et al. (1983)	Resistant

factors governing disease reaction was calculated for each cultivar, ranging from 1 to 68, with most of them being under 20. Transgressive segregation in many crosses indicates the presence of different factors in both parents. Broad-sense heritabilities were estimated for a large number of crosses and ranged from 0-78%, averaging 38%. These intermediate heritability values, coupled with the presence of additive effects and transgressive segregation, suggest that hybridization followed by selection could increase resistance levels in durum wheats (van Ginkel 1986, van Ginkel and Scharen 1987).

Van Ginkel and Scharen (1988) reported the results of analysis of variance for combining ability using the F_1 and F_2 generations from 45 crosses inoculated with eight *S. tritici* isolates. These analyses showed general combining ability to be the major component of variation; however, specific combining ability effects were significant in several crosses.

Van Ginkel and Scharen (1986) estimated that an average of seven genes were involved in the expression of resistance to septoria leaf blotch in 65 durum wheat crosses.

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Discussion Notes

Mamluk: Do you believe the sexual stage of *S. tritici* is not as important?
Gilchrist: That is what some believe.
Mamluk: I have heard that the sexual stage is important for survival of the disease. In T. Hayda 2 weeks ago we saw the first symptoms and I don't think that the teliospores caused the initial infection.
Gilchrist: We do not know where the sexual stage is present.
Mamluk: The sexual stage is all over the Mediterranean.
Gilchrist: I have not seen that published any place.

Singh: The sexual stage only reshuffles the genes--it does not create new virulences.

Saari: The sexual stage requires specific conditions, for example, it has to rain on the straw. The sexual stage would be disruptive to environmental fitness of the disease. With the sexual stage, we can isolate and demonstrate physiological specialization in the laboratory--mix two cultures and the resulting population will act differently either of the two cultures.

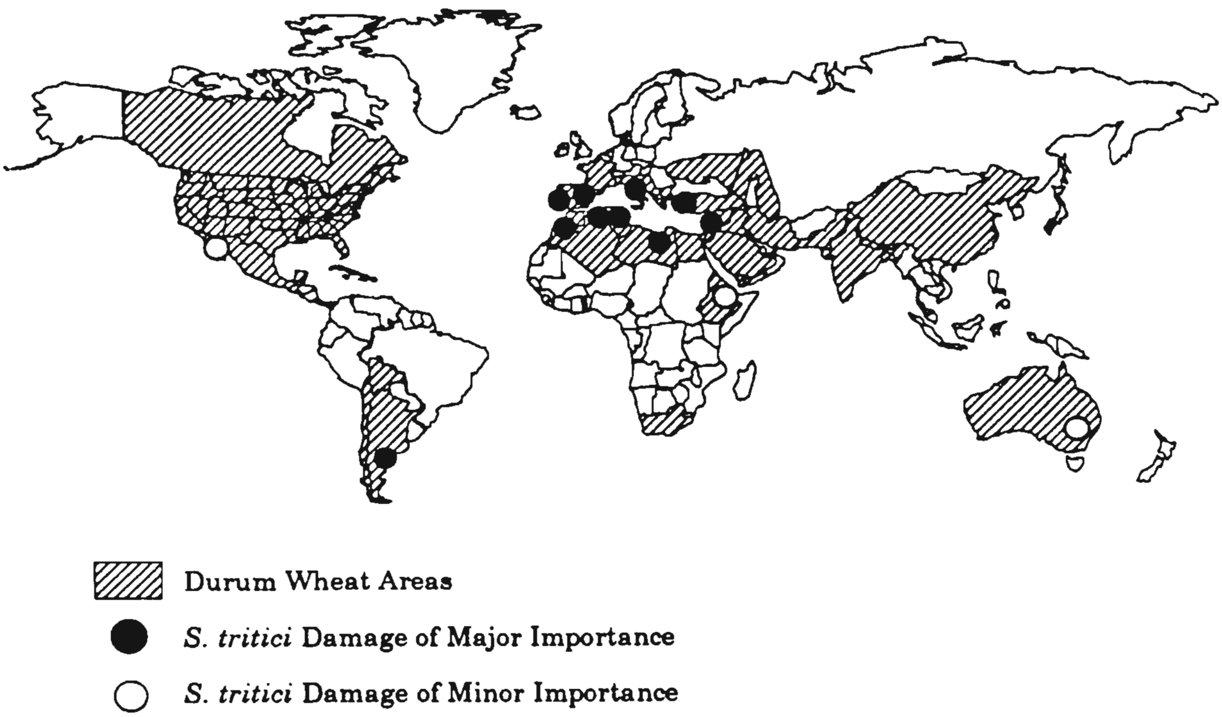

Figure 1. Areas of major and minor *S. tritici* damage on durum wheat worldwide.

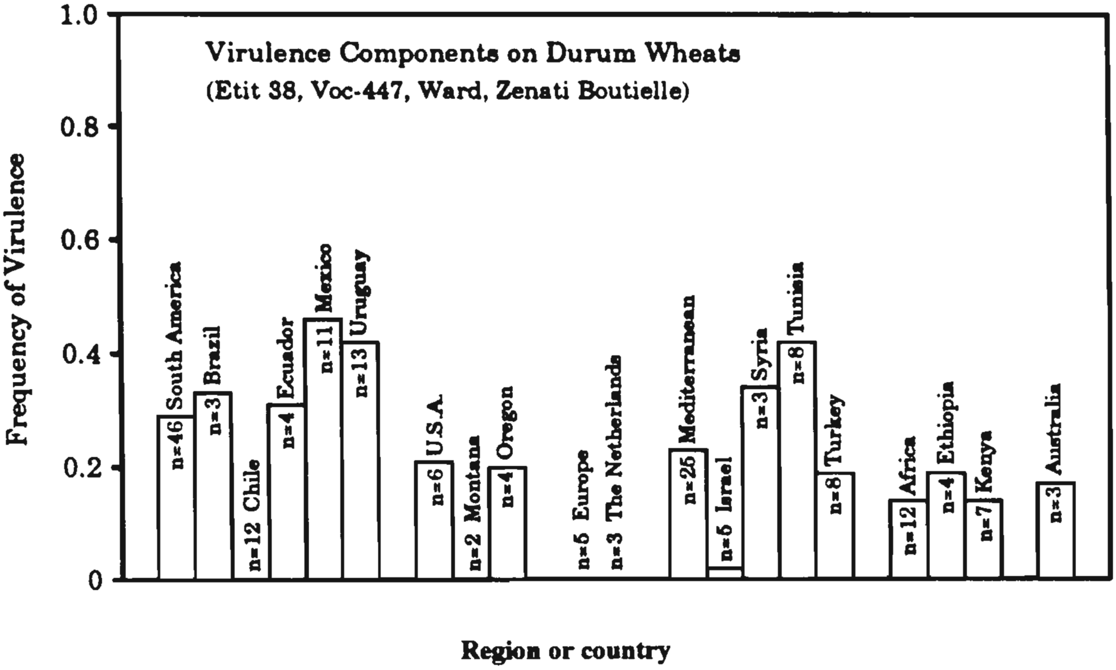

Figure 2. The frequency of hypothetical virulence factors (genes) of *Mycosphaerella graminicola* on tetraploid wheats; n = no. of *M. graminicola* isolates analzyed. Source: Eyal et al. (1985).

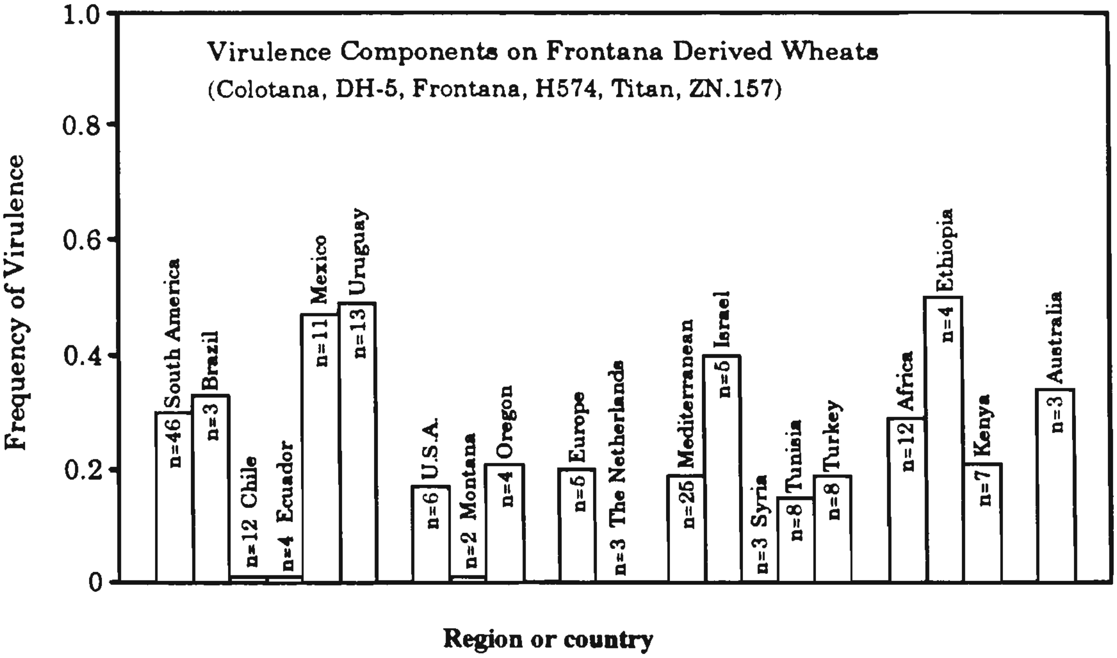

Figure 3. The frequency of hypothetical virulence factors (genes) of *Mycosphaerella graminicola* on Frontana-derived wheats; n = no. of *M. graminicola* isolates analyzed. Source: Eyal et al. (1985).

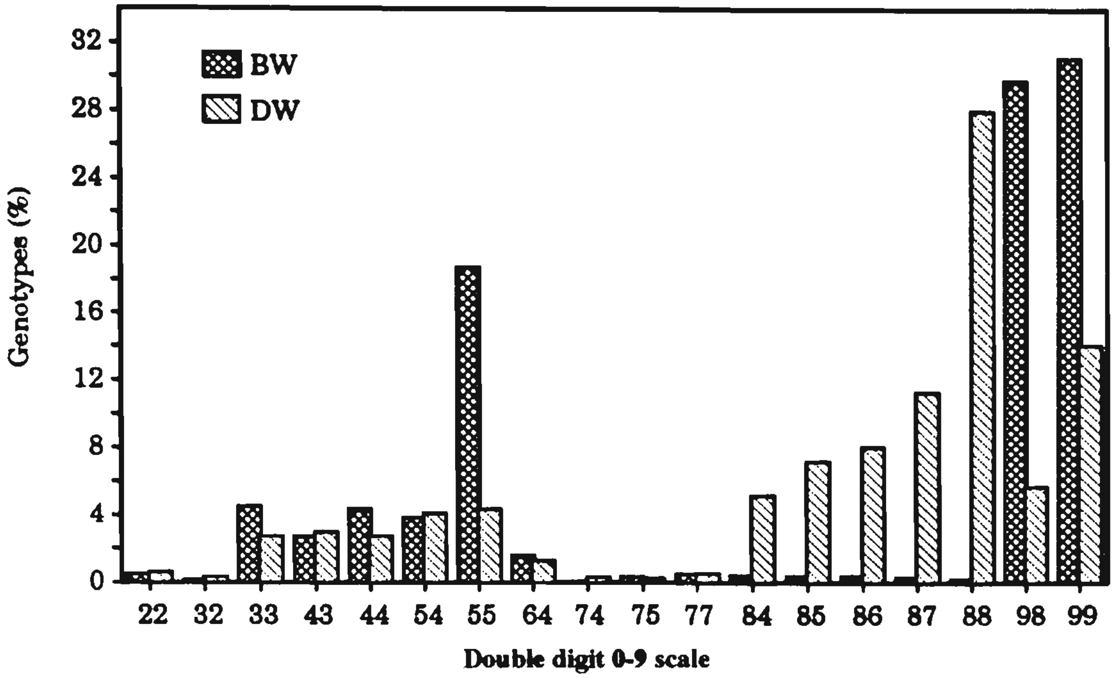

Figure 4. Frequency distribution for *S. tritici* in durum and bread wheats.

BREEDING DISEASE-RESISTANT DURUM WHEATS IN WESTERN CANADA

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Introduction

This paper focuses on efforts to develop durum wheat cultivars with adequate disease resistance for western Canada. For a number of diseases, our efforts are quite recent, and CIMMYT undoubtedly has more experience with some of these diseases than we do. However, some of our experiences may be of some value to CIMMYT.

Durum wheat is a crop of increasing importance in western Canada. Prior to 1980, the annual area of production fluctuated widely, depending on price and market opportunities. Over the last 10 years, however, we have seen a steady increase from 1.5 million hectares to a peak of 2.6 million hectares in 1989, and dropping off slightly to 2.1 million in 1991. This represents about 15% of the total wheat area in western Canada. Durum wheat is produced almost exclusively in the southern part of the Prairie Provinces, where average yields range from about 1.65 to 2.50 t/ha.

In western Canada, there are presently four significant breeding programs in durum wheat: Agriculture Canada at Swift current, SK and Winnipeg, MB, University of Saskatchewan, Saskatoon, and Saskatchewan Wheat Pool, a producer-owned grain marketing agency. The major disease problems occur in Manitoba and eastern Saskatchewan, where moisture levels are higher, and therefore the Winnipeg program is more heavily, but not exclusively, involved in breeding for disease resistance. The Research Station at Winnipeg was established in 1925 to solve the cereal disease problems, particularly rust. Our continuing philosophy is that where resistance is available and selection procedures are reasonably effective, incorporation of resistance into commercial cultivars is the desirable alternative, from both a long-term economic and an environmental standpoint.

Wheat Diseases in Western Canada

The diseases currently of interest and being addressed to various degrees include: stem rust, leaf rust, bunt, kernel smudge/blackpoint, loose smut, tanspot, fusarium head blight, septoria leaf spot, common root rot, wheat streak mosaic virus, and barley yellow dwarf virus.

Stem rust and leaf rust

Current cultivars have very good resistance to prevalent races of both stem rust (*Puccinia graminis* f.sp. *tritici*) and leaf rust (*P. recondita* f.sp. *tritici*). Genetic studies have shown that the cultivar Medora has three genes for resistance to stem rust races C10 and C17. These have been postulated to be *Sr9e*, *Sr13*, and a gene from Khapli. These genes are likely present in most of our cultivars since there is much common background. Little is known of the basis for leaf rust resistance in the Canadian durum wheat cultivars. It does appear that the resistance of Sceptre is more temperature-sensitive than that of other cultivars. All our breeding populations are screened under artificial field epidemics beginning in F_2. Seedling reactions to individual races are obtained from F_8 onward.

Bunt

Bunt (*Tilletia* spp.) is considered a disease of importance due to its potential impact on end-use and yield loss. We are fortunate to have very good resistance to prevalent races in our Canadian cultivars and breeding material. Genetics of this resistance is not known. Currently, we test all advanced lines under artificial inoculation to ensure that no susceptible lines are released.

Kernel smudge

Kernel smudge, caused by several organisms primarily *Alternaria*, is another disease we pay attention to because of its degrading effects. Current cultivars are mainly moderately resistant, but there is variation among our breeding materials. Visual selection based on natural infection is practiced in the F_2 through F_6 populations.

Loose smut

The Swift Current and Winnipeg programs have both put significant efforts toward developing cultivars resistant to loose smut (*Ustilogo tritici*). All current cultivars are highly susceptible to prevalent races. Resistance is being incorporated into several cultivars by backcrossing. The line DT 369, one resistant source being utilized, has recessive resistance. Other sources being used are Amarelejo, Orgaz, and VIR6815, which all have a single dominant gene for resistance to race T33. Unfortunately, the resistance these sources carry to several other races is due to other genes, and we find ourselves having to inoculate with several races. Because testing for loose smut reaction is a tedious, time-consuming task, it is one example of where we are attempting to find and exploit useful linkages to more readily identified traits to facilitate breeding efforts. Our focus has been on identifying linkages to specific proteins (gliadins, glutenins), which can be tested for by electrophoretic analyses or even monoclonal antibodies. The gene for resistance to race T33 appears to be very loosely linked to glutenin subunit 7; however, the linkage is likely not strong enough to be of practical value.

Close linkages with easily identified markers would be useful in breeding for other diseases such as tanspot, fusarium head blight, and septoria. In the future, use of RFLPs will also be explored.

Leaf-spotting and head diseases

With an increase in western Canada of continuous cropping and reduced tillage, we have seen an increased prevalence of leaf-spotting diseases (tanspot, septoria) and fusarium head blight. Therefore, we have recently given more attention to these in our breeding program.

Tanspot--Tanspot (*Drechslera tritici-repentis*) is of concern in durum wheat, not only with regard to potential yield loss, but also as the causal agent for pink smudge, an important degrading factor. Current cultivars are moderately susceptible to susceptible. A modified backcrossing program has been initiated using tetraploid sources 4B233 (Lebanon) and 4B1149 (CIMMYT), previously evaluated by Lamari and Bernier, University of Manitoba. We have also made some crosses to the resistant hexaploid cultivar, Salamouni (Lebanon). Earlier attempts to screen seedling populations in growth rooms were somewhat unsuccessful due to lack of clear cut differential reactions. Changing the inoculation technique slightly (i.e., 16-hour photoperiod during incubation) is resulting in very clear cut reactions. Recent data obtained on backcross and F_3 families of crosses with 4B1149 suggest that resistance is partially dominant and relatively simply inherited. The relationship between seedling and flag leaf reactions in these populations was very good. These materials will be subsequently field-evaluated.

Septoria--We are just beginning to direct specific attention to the septoria leaf-spotting diseases in durum wheat. Dr. Jeannie Gilbert, our leaf disease pathologist, is studying the relationship between leaf symptoms and yield loss, as measured by kernel weight reduction for *S. nodorum*. Her preliminary data suggest that leaf reactions do not always correlate with yield loss, and that kernel weight reduction may be a useful measure of resistance/tolerance. If further work confirms this, a possible strategy would be a bulk breeding program, using kernel reduction under an artificial epidemic as a selection criterion.

Fusarium--While the fusarium organism (*F. graminearum*) can be detected in head samples over a relatively wide area, it is of concern only in a small area of Manitoba during years of high rainfall. However, because of the concern regarding toxins, we feel some research, particularly in the durum and Canada Prairie Spring (CPS) wheats, is warranted. As found by other workers, the best sources of resistance we have are in the Chinese hexaploid wheats, particularly Nanjing 7840, Nang 8331, and Sumai#3. We have not found any useful level of resistance at the tetraploid level, even after screening approximately 900 lines from the Kyoto University germplasm collection. We have only limited information on genetics of resistance, and no knowledge of which genome carries resistance. We have nevertheless made hexaploid x durum wheat crosses to explore the possibility of transferring resistance. Recent evaluation of some breeding populations in growth rooms identified a number of resistant lines in crosses with CPS wheats. In the hexaploid x durum cross, we found one resistant line. However, it looks very much like a hexaploid wheat morphologically, and we suspect it will have some or all of the D-genome chromosomes. Thought is being given to utilize techniques to induce a translocation.

Other diseases

Diseases we are concerned about, but currently have very little specific breeding effort, are common root rot (*Helminthosporum sativum*), wheat streak mosaic virus (WSMV), and barley yellow dwarf virus (BYDV). We have initiated a small backcrossing program to incorporate resistance to the wheat curl mite (*Aceria tulipae*), a vector for WSMV, using a hexaploid line carrying resistance from an *Agropyron elongatum* chromosome-6A substitution. We do not anticipate undertaking any major breeding efforts on these diseases with our current available resources.

Discussion Notes

Payne: You mentioned an association between semidwarf wheats and fusarium susceptibility.
Leslie: We have that feeling. We are currently re-evaluating. I think it is morphological, not genetic.

Fischer: Durum wheats in Canada are in the dry areas. Why?
Leslie: Historically in the 1930s and 40s, durum wheat was grown mainly in Manitoba and not the dry areas. When stem rust came in the 1950s, durum wheat was then moved to the dry areas.

Elias: Can you estimate smut losses in Canada?
Leslie: Average level is a 2% yield reduction, some fields up to 10%.

Mamluk: Chemical seed treatment is not a problem with Canadian farmers, so why then is there a problem with common smut?

Leslie: Why do you think chemicals are not a problem in Canada? There is a problem getting farmers to treat seed especially with lower prices, not to mention the health hazard and some evidence that the pathogen is becoming resistant to the treatments.

Abdalla: Could you comment on quality standards?
Leslie: The variety Hercules sets the standard for pigment content (yellow), cooking quality, and gluten strength. Protein content is a primary focus because when we find high yielding lines, the protein content is often marginal.

Fischer: Is protein content important because the market insists upon it?
Leslie: There is an effect on quality if semolina protein drops below a certain level, but maintaining a certain level does have a lot to do with market demand.

KARNAL BUNT AND DURUM WHEAT

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CIMMYT Wheat Program

The most important objective of the Karnal Bunt (KB) Research Program at CIMMYT has been to identify sources of resistance to *Tilletia indica* that could be used in the wheat breeding sections to develop advanced lines for national programs, especially for those countries where KB is a problem.

Since the occurrence of the disease is erratic in the Yaqui Valley (where the CIMMYT Wheat Program operates during the Fall-Winter), we cannot rely on natural infection. Then, artificial inoculations during the boot stage are necessary to be able to evaluate and select resistant genotypes. The inoculation is done by injecting 1 ml of a sporidial suspension of 10,000/ml, using 10 spikes per experimental wheat line per sowing date. These tests are carried out once a year during the Fall-Winter cycle in the Yaqui Valley; for this reason, it is essential to obtain as much information as possible about the experimental germplasm. Therefore, experimental lines are sown on two dates during the first 2 years, then on three dates. After 2 years of tests, lines with less than 5% infection (based on the number of infected and healthy grains) are selected to form part of the Karnal Bunt Screening Nursery (KBSN), which is distributed to cooperators who request it.

Durum and triticale lines have shown to be more resistant to *T. indica* than bread wheats. For example, in 1987-88 the mean percent infections in the bread wheat, durum wheat, and triticales of the KBSN were 5.18, 1.24, and 0.9, respectively (Figure 1); in 1988-89, they were 3.19, 1.23, and 1.38. This brought up the consequent accumulation of a great number of durum and triticale lines within the resistant category (Figure 2). In 1987-88, it was decided to give more priority to the bread wheats; that year 178 bread wheats, 259 durums, and 327 triticales were screened. The following year, the number of bread wheats decreased to 74, primarily due to susceptibility; there were 92 durum wheat lines and 54 triticales. The number of durums and triticales has steadily been reduced and the bread wheats have increased.

It is important to point out that some durum lines have shown not to be in the resistant category (Table 1). For example, in 1988-89 under artificial inoculation of the 4th Mexican National Durum Wheat Trial (ENTDUR), line No. 3 (STIL'S'/YAV'S') had a mean percent infection of 12.39%; one of the CHEN'S'/ALTAR 84 lines (No. 10) had 14.62; and cultivar Mexicali 75 had 16.22%. While the susceptible bread wheat cultivar Opata M85 had a mean percent infection of 36.11.

To confirm their susceptibility, those durum lines were artificially inoculated during 1989-90. However, they showed a resistant reaction. This could be an indication that host specialization or preference by the fungus might occur on durum wheat, since the inoculum used did not come from durum but from bread wheat infected grains.

Durum wheat's resistance to *T. indica* and its high yields have important commercial implications. The Mexican quarantine against KB, initiated in 1987 (Anónimo 1987), establishes that bread wheat cultivars could not be grown for 3 years in fields where more than 2% infection levels (more than 500 infected grains/kg) were obtained. As a result of this, the area covered with durum wheat has increased. Cultivar Altar 84, the most cultivated durum wheat in northwestern Mexico, provides good yields and presents a genotype response of low KB infection to artificial and natural inoculation (two good reasons for farmers to prefer that cultivar). For example, during 1988-89 under artificial inoculation, it had 1.55% infection (Table 1) while the bread wheat cultivar Opata had 36.11%. Under natural conditions during the 1988-89 cycle (Table 2), 86.90% of the grain samples of Altar 84 evaluated in the Yaqui Valley were free of KB and only 13.10% presented infected grains within the category "low" (1-130 infected grains/kg equivalent up to 0.5%). Opata M85 had 85.70% of the samples with KB and 14.30 without. Levels of more than 3% infected grains (more than 750/kg) were present in 1.3% of the samples.

The extensive cultivation of Altar 84 (in 1991-92, this cultivar covered 26% of the area planted with wheat in the Yaqui Valley and 36% in the Mayo Valley) must be reviewed carefully, since it represents a serious potential problem if virulent forms of *T. indica* and other pathogens develop in those valleys.

Table 1. Results of Karnal bunt artificial inoculation of the 4th Mexican National Durum Wheat Trial (ENTDUR) in the Yaqui Valley during 1988-89[a].

Entry	Cross or Cultivar	KB % Infection[b]
1	CHUS'S'	2.27[c]
2	AIX'S'	5.20
3	STIL'S'/YAV'S'	12.39
4	SULA'S'	3.71
5	NUS'S'	9.73
6	P66.253/3/GTA'S'/TC60// MEXI'S'/4/SAPI'S'/MEXI75	3.42
7	CARC'S'/AUK'S'	5.13
8	CARC'S'/AUK'S'	2.04
9	CHEN'S'/ALTAR 84	0.43
10	CHEN'S'/ALTAR 84	14.62
11	CHEN'S'/ALTAR 84	4.88
12	CHEN'S'/ALTAR84	4.87
13	AJAIA'S'	2.55
14	FILLO'S'	2.36
15	HUI'S'/YAV'S'//FULI'S'/ALTAR84	2.69
16	STN'S'//HUI'S'/SOMO'S'	8.12
17	STN'S'//HUI'S'/SOMO'S'	6.93
18	SULA'S'//WLS/DWL5023	1.01
19	ALTAR84/AOS'S'	4.17
20	MEXI75 (DW)	16.22
21	YAV79 (DW)	1.76
22	ALTAR84 (DW)	1.55
23	OPATA (BW)	36.11
24	ERONGA (TCL)	3.75
25	LOCAL CHECK	----

[a] Ten spikes per line per sowing date were inoculated.

[b] Percent infection was calculated based on the number of infected and healthy grains.

[c] Numbers represent the mean percent infection of two dates.

Table 2. Percent of grain samples of cultivars Altar 84 and Opata M85 with and without Karnal bunt infection under natural conditions in the Yaqui Valley during the 1988-91 cycles.

Cultivar	Cycle	KB Free	With KB
Altar	88-89	86.90	13.10
	89-90	97.56	2.44
	90-91	83.90	16.10
Opata	88-89	14.30	85.70
	89-90	84.23	15.77
	90-91	41.10	58.90

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Anónimo. 1987. Cuarentena interior número 16 contra el carbón parcial del trigo. Secretaría de Agricultura y Recursos Hidráulicos. Diario Oficial, 12 de Marzo de 1987. Páginas 33-42, México.

Discussion Notes

Fuentes: 1991-92 should be a KB year because of the high rainfall in January-February and high number of teliospores in the soil.

Mamluk: Two observations: 1) No KB exists in Iraq and Lebanon; 2) As more durum wheats, they will become more KB-susceptible over time.
Fuentes: 1) There are two reports of KB in Iraq--we need to verify. There is no KB in Lebanon/Afghanistan; 2) What may happen is that we will start to see higher KB incidence in the next few years in durum wheat.

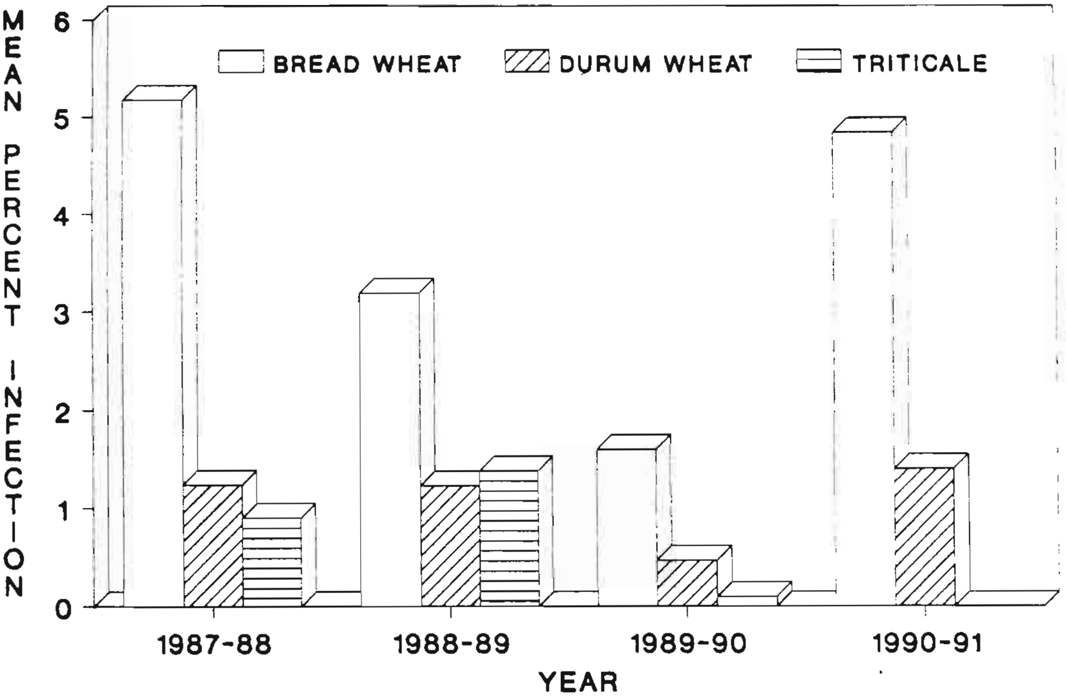

Figure 1. Mean percent infection resulting from artificial inoculation of the Karnal Bunt Screening Nursery in the Yaqui Valley, Sonora, 1987-91.

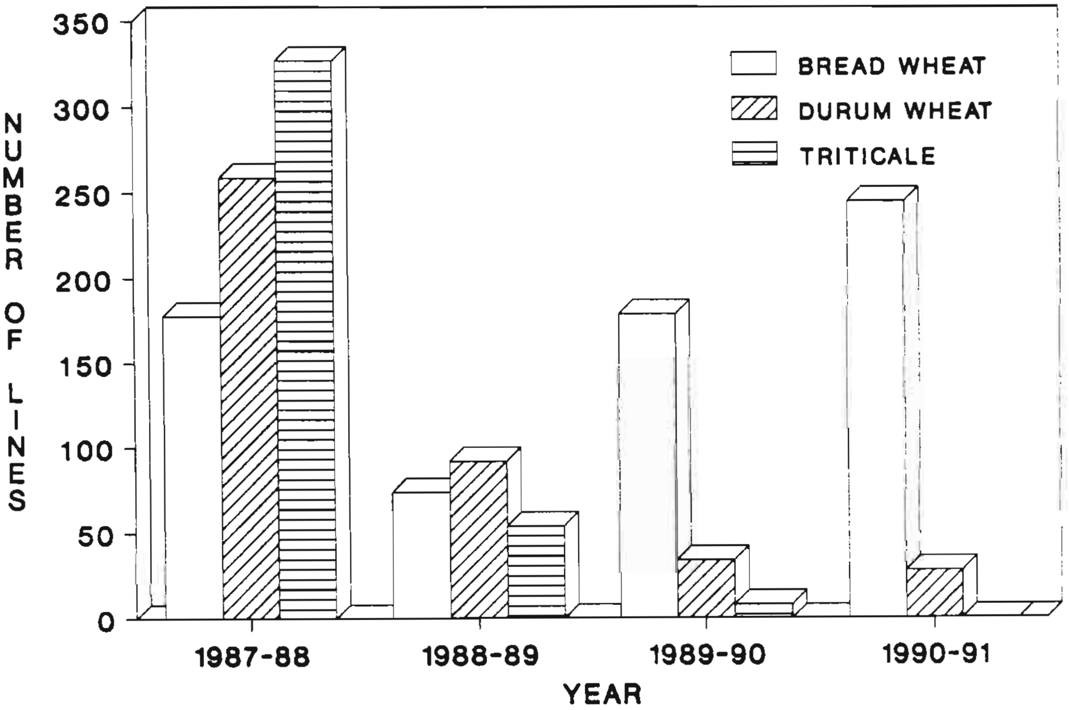

Figure 2. Number of lines artificially inoculated in the Karnal Bunt Screening Nursery in the Yaqui Valley, Sonora, 1987-91.

WHEATS FOR DRY ENVIRONMENTS

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Introduction

The improvement of drought tolerance is suggested as a desirable breeding objective in crops such as wheat (e.g., Keim and Kronstad 1979, Blum 1983). However, Roseille and Hamblin (1981) expressed doubt that the concept of breeding for drought tolerance has been seriously examined. Similarly, Baker (1987) emphasized the need to re-examine accepted definitions of terms such as efficiency, tolerance, adaptability, and stability in relation to cultivar performance.

Improvement of the yield of wheat in dry environments is usually approached directly by breeding for yield, but some workers have attempted to develop an understanding of the mechanisms contributing to yield in dry environments in anticipation that indirect selection for specific traits might improve progress. Marshall (1987) refers to these as the 'empirical' and the 'analytical' approaches. Implicit in the analytical approach is the idea that traits related to yield under drought can be identified and that indirect selection for these traits would be more efficient than direct selection for yield. However, few breeders have accepted these recommendations, principally because there is insufficient evidence to warrant such a course of action. Allard and Bradshaw (1964) went so far as to question whether understanding the biochemical, morphological, and physiological basis of genotype response to environment is of any value in breeding programs with the primary purpose of developing superior cultivars. Similarly, Marshall (1987) stated that empirical breeding is likely to continue to be very important.

It may seem to physiologists that breeders have a cynical view of the possibilities of using physiological selection criteria, but it must be understood that addition of further selection criteria will only be contemplated if they improve selection efficiency. Only solid evidence of the worth of selection for physiological or morphological traits will encourage their incorporation into practical breeding programs. The evidence required includes heritabilities of the traits, phenotypic and genotypic correlations with agronomic traits such as yield, and some indication of the complexity of genetic control.

Several workers have suggested the steps necessary to use the analytical approach for yield improvement in water-limiting environments (Zobel 1983, Clarke 1987), but there are few concrete examples of the success of this approach in the literature. Conversely, the empirical approach has contributed to increased yield in durum wheat in semiarid environments such as that at Swift Current. Using the cultivar Hercules (released 1969) as a base, we have increased yield in steps: Wakooma (1973) yields 14% more, Kyle (1984) yields 19% more, and DT618 (breeding line, 1991) yields 25% more.

The reasons for the apparent lack of success of the analytical approach are not immediately clear. Is it due to incomplete evaluation of traits or to the sheer size of the undertaking? It is worth looking critically at the physiological approach to breeding for improved yield in dry environments to see if there are any answers to these questions. Before doing so, however, I will briefly examine the concept of drought tolerance because it is fundamental to the discussion of breeding for dry environments.

The Concept of Drought Tolerance

Drought tolerance or resistance in native plant species is often defined as survival, but in crop species should be defined in terms of productivity (Passioura 1983). For example, definition of drought resistance as the ability of plants to grow satisfactorily when exposed to water deficits (May and Milthorpe 1962) has little direct applicability to either quantifying or breeding for the character in crop species. Fischer and Maurer (1978) suggested that quantification of drought tolerance should be based upon grain yield under dry conditions due to the lack of understanding of specific mechanisms of tolerance. Yield also happens to be the most important agronomic trait in breeding programs.

Relative yield performance of genotypes in drought-stressed and more favorable environments is a common starting point in the quantification of drought tolerance. Yield stability analyses as proposed by Finlay and Wilkinson (1963) and Eberhardt and Russell (1966) are often used where genotypes have been tested over a range of environments. However, Lin et al. (1986) concluded that regression techniques have not contributed to an understanding of genotype environmental interactions. Another approach is measurement of drought tolerance in terms of minimization of the reduction in yield caused by unfavorable compared to favorable environments (Blum 1973, Fischer and Maurer 1978, Langer et al. 1979). Fischer and Maurer (1978) calculated a drought susceptibility index (S) based on this premise, and S has become widely used in studies of the response of wheat genotypes to drought (e.g., Bruckner and Frohberg 1987, Ceccarelli 1987). Although the index was useful in the context of Fischer and Maurer's data, it and similar indices have perhaps been used more widely than warranted.

Bruckner and Frohberg (1987) suggested that S is useful for comparison of performance of genotypes under drought because it accounts for differences in yield potential. However, S does not account for differences in yield potential among genotypes--it measures the ratio of rainfed to irrigated yields in individual genotypes in comparison to the overall ratio for all genotypes in the experiment. Both high and low yield genotypes can, therefore, have the same S value if both have the same proportional yield change from rainfed to irrigated conditions.

Genotypes with low values of S are presumed to be drought-resistant or -tolerant (Bruckner and Frohberg 1987) because they exhibit smaller reductions in yield in rainfed compared to irrigated conditions than the mean of all genotypes. Considered in the opposite manner, these genotypes show a smaller than average yield increase in response to improved environment. This is analogous to the problem of considering stability in the Finlay and Wilkinson (1963) fashion. Lack of response to improved environment may be related to lack of adaptation to high moisture conditions due to factors such as lodging or disease susceptibility (Baker 1987) rather than to specific drought tolerance traits that are negatively correlated with yield. Sojka et al. (1981) noted that one cultivar might have higher yield than another under dry conditions not because of superior drought resistance, but because of higher yield potential under both drought and nondrought conditions. This distinction is not particularly important agronomically.

It is possible that low yield, nonresponsive genotypes carry traits associated with improved adaptation to dry environments, but identification of these traits is not easy given that yield is our only agronomic measure of stress tolerance. It is perhaps better to avoid the use of terms such as 'drought tolerance' or 'drought resistance' because they are very difficult to quantify in the way that say disease resistance and tolerance can through use of standard differential genotypes and specified races of pathogens. Thinking in terms of genotype adaptation to a specific environment is perhaps a more agronomically-sound approach to the topic.

Definition of our agronomic goals in breeding for dry environments is important. It is often assumed that the environment for which we are breeding is well known and perhaps homogeneous, but what is really meant, for example, by 'dry' or 'drought-prone' environments? Temporal and spatial variability in precipitation tends to be large in many environments. Therefore, the mean precipitation as well as its standard deviation are important considerations in defining the 'target population of environments' (Comstock 1977) for which improved cultivars are being developed. Information on edaphic and hydrologic factors, and crop yield over environments, is also required. From these data, it may be possible to determine the crop developmental stage at which water deficit stress is greatest, and to propose a plant ideotype with better adaptation to the stress.

Many researchers speak of stability of yield as an important concern, but concepts of stability seem to define genotypes that do not respond to improved environmental conditions. I think most farmers are interested in obtaining the highest possible yield of grain averaged over years, but at the same time, are usually unwilling to accept cultivars that perform worse than average under severe stress conditions. Rather than stability we should be concerned with developing an understanding of genotype environmental interactions, which are the result of differential genotype response to environments (Baker 1987). In breeding and selection, crossover interactions are of greatest interest. The point, in terms of level of water stress, at which genotype yield response curves intersect is important in defining the desired level of adaptation to stress. For example, if the point of intersection is generally at stress levels more than one standard deviation below the mean water availability for an environment, differential stress tolerance is perhaps irrelevant to the breeder. However, if the intersection point is within the normal range of conditions in the target environment, it is of more consequence. Understanding and dealing with genotype environmental interactions is fundamental to breeding for drought-prone environments.

The Analytical Approach

The efficacy of manipulation of a physiological trait to improve yield or another agronomic trait can be assessed in terms of three basic approaches. The first is to use correlated responses--selection for yield in a particular environment will perhaps change the trait in the desired direction. Choice of parental genotypes for hybridization is an example of this approach. Indirect selection, that is, selection for the physiological trait rather than yield, is a second possibility. This concept is actually closely related to the former, but the selection is considered in the opposite manner--for the secondary trait rather than yield itself. A third approach is index or combined selection for both the physiological trait and yield. These approaches can be evaluated using quantitative genetic principles, but in practical terms, economic factors--relative costs--must be considered as well.

Screening and selection of potential parents carrying desired traits are frequently suggested for incorporation of physiological or morphological traits into new cultivars. Following crossing with adapted local parents, normal selection procedures are followed; it is assumed that the traits of interest will be selected through their correlated relationship to the character, such as yield, for which selection is being practiced. Hurd (1971), for example, suggested such an approach in breeding for drought resistance in wheat, and demonstrated it in the development of the cultivar 'Wascana' (Hurd and Townley-Smith 1972). Zobel (1983) called this process 'associative breeding'.

How effectively the desired physiological trait is incorporated depends upon its heritability and genetic correlation with yield. The correlated response to selection for an indirect trait, X, through selection for a direct trait, Y, can be calculated as follows (Falconer 1989):

$$CR_x = ih_y h_x r_g \sigma_{px} \qquad (1)$$

where: i is the standardized selection differential, h_y and h_x are the square roots of the heritabilities of the two traits, r_g is the genotypic correlation between them, and σ_{px} is the phenotypic standard deviation of x.

Reliance on the correlated response of the nonselected trait will clearly be less efficient than direct selection unless the heritabilities and genetic correlations are high. However, where the physiological or morphological trait is difficult to select for, the correlated response approach has merit, permitting the manipulation of complex traits that would be prohibitively expensive to breed for directly (Zobel 1983). Further, selection for yield will presumably optimize the combinations of traits, such as root/shoot ratio, in the environments in which selection is carried out. The consistency of the environments in which selection is practiced affects the relationship between traits, and will influence the correlated response. For example, where one is trying to increase rooting depth, high yield may be associated with deep rooting in the dry but not the wetter seasons encountered during the selection cycle.

Blum (1979) proposed development of cultivars that are buffered against adverse environmental conditions. Careful screening and selection of parents might be the easiest way to achieve this goal. Detailed knowledge of desirable traits and their interactions with environment is required, however, to permit an informed choice of prospective parents. Hurd (1974) stressed the need to carefully evaluate a small number of targeted crosses among well-known parents rather than superficially evaluating a large number of crosses among unknown parents. Nonadapted parents, although they may carry putative drought tolerance or other desirable traits, may be difficult to use in a breeding program. An example of the effect of a nonadapted parent on yield performance of a cross can be seen in the work of Richards and Passioura (1989) to modify a root system trait; only after five backcrosses was the yield of the adapted local parents recovered. In addition to backcrossing, double or three-way crosses may be useful for transfer of physiological traits from introduced to adapted genotypes (Clarke and Townley-Smith 1984).

Now consider indirect selection for improvement in a primary agronomic trait by way of a physiological or morphological trait. Searle (1965) suggested that the relative efficiencies of direct and indirect selection must be compared before indirect selection can be advocated. This can be done if the heritabilities of the two traits and the genetic correlation between them are known. For example, Searle (1965) described a relative selection efficiency parameter (RSE) for direct selection for a basic trait Y versus indirect selection for Y through an alternative trait X:

$$\text{RSE}\,(X,Y,y) = r_g\sqrt{(h_x^2/h_y^2)} \qquad (2)$$

where: y is the genotype corresponding to Y, rg is the genetic correlation between Y and X, and h_x^2 and h_y^2 are the heritabilities of X and Y, respectively. RSE > 1 suggests that indirect selection for Y by way of X would be advantageous. It is useful to explore the relationships among the components of RSE to illustrate the basic conditions that must be met before indirect selection can be advocated. If the ratio of h_x^2/h_y^2 is large, RSE will be greater than 1 at lower rg than is the case when the ratio is small (Figure 1). Clearly, the heritability of the indirect trait must be very much greater than that of the direct trait, or the genetic correlation between yield and the indirect trait has to be strong, to consider indirect selection for yield.

The desirability of selection for yield versus a physiological trait also has an economic consideration. Even if RSE is somewhat greater than 1, the cost of selecting for the physiological trait vs. the cost of determining yield has to be taken into account. Consider a situation where the cost of testing for the indirect physiological trait is 1.5 times greater than that of testing for yield. The breeder must consider the best allocation of resources, that is, to commit them to selection for the physiological trait or to increased yield testing. Response to selection (R) depends upon the selection intensity (i), the square root of the heritability of the trait (h), and the measured genotypic standard deviation (σ_g) as follows:

$$R = ih\sigma_g \qquad (3)$$

Baker (1984) indicated that h can be increased by increasing the number of replications of each line because of the following relationship:

$$h_m^2 = rh_s^2/(1+h_s^2(r-1)) \qquad (4)$$

where: h_m^2=heritability of means of lines, h_s^2=heritability on a single plot basis, and r=number of replications. With constant i and σ_g, increasing r by 1.5 (say from 4 to 6 replications) will improve R by a factor of approximately 1.1. Therefore, the breeder must actually compare response to indirect selection for the physiological trait with response to yield selection with a 1.5 increase in resource allocation to yield testing.

Under some circumstances, a breeder might consider use of the indirect selection trait even if RSE is somewhat less than one. For example, deep rooting might be desirable in a dry environment, but consistently dry environments might not be available for yield selection. Indirect selection for yield by selection for deep rooting could produce a correlated improvement in yield potential in the dry environment. However, there is a strong possibility that traits other than the root trait under selection would not be optimized as they would be through direct selection for yield in the target environment. Index selection for both yield and the root trait would perhaps be more useful in this case than indirect selection alone.

An index combining the direct and indirect traits is always better than using the direct trait alone (Searle 1965), with the magnitude of the improvement dependent on the phenotypic correlation between the direct and indirect traits. When the basic trait Y and the indirect trait X are combined into an index, I, the relative selection efficiency becomes:

$$\text{RSE}(I,Y,y) = \sqrt{[1+((p-r_p)^2/(1-r_p^2))]} \qquad (5)$$

where: p is RSE (X,Y,y) (Equation 2), and r_p is the phenotypic correlation between X and Y (Searle 1965). This function cannot be less than 1, and may be quite large if the phenotypic correlation is high. The value RSE (I,Y,y) is equivalent to the ratio of selection responses of index selection to simple selection given by Falconer (1989). It is important to note that, unless heritabilities and inter-trait correlations are measured in numerous crosses and environments, erroneous conclusions could be drawn.

As with indirect selection, there is an economic consideration in assessment of an index. The total cost of testing includes the cost for yield testing plus that of the additional traits. Adding traits that can be visually observed on existing yield plots to an index has little impact on the cost of testing. However, if the cost of screening a trait is high, as it would be to test for rooting depth, the efficiency of index selection would have to be substantially better than could be achieved by expanded yield testing alone.

The parental selection approach suggested by Hurd (1971) will probably be the most effective means of incorporating difficult to screen traits into new cultivars. Where the trait is transferred from a nonadapted background, pre-breeding, backcrossing, or complex crosses will be required.

Identification of traits

There are two general approaches to determination of physiological traits related to crop performance under drought (Fischer 1981). The first is to proceed from observed yield differences to investigation of possible physiological causes, and the second is to define an ideotype for a particular stress environment based on an understanding of physiological processes. Definition of an ideotype is limited by current knowledge of the relation of particular physiological traits to yield. Consequently, the ideotype is redefined and improved as knowledge of particular traits increases. We do not have adequate knowledge to define a complete ideotype that crop physiologists would be happy with. However, most breeders do have a functional ideotype for the environments in which they work, probably based on current knowledge of physiological processes and their own unpublished observations. The success with which this ideotype is defined and selected probably comprises part of the 'art' of plant breeding.

Several researchers have suggested trait evaluation procedures that encompass both of the above approaches (Zobel 1983, Clarke 1987, O'Toole and Bland 1987). These generally include definition of limitations and possible solutions, determination of genetic variation, hybridization and selection, and field evaluation of resultant genotypes. Development and assessment of breeding strategies should be added to this list.

The search for relationships between physiological traits and yield in dry environments usually begins with studies of genotypes differing in putative drought tolerance. As discussed above, the quantification of drought tolerance is a large research effort in itself. Having established the genotypes that will be used to look for traits related to yield in dry environments, the researcher is still faced with the daunting task of developing relationships between single traits and grain yield. The further these traits are removed from the agronomic character of interest, grain yield, the more difficult the task because yield is a truly quantitative trait and thus not overly influenced by any single physiological character. For example, Hurd (1968) stated that he did not consider it possible to show a correlation between root length or weight and grain yield of wheat. Consequently there are actually very few correlation coefficients between yield and physiological traits reported in the literature. This may also stem partly from the fact that some physiological traits are very difficult to measure and so only a few genotypes can be measured at one time.

Genotype environmental interactions are a problem in definition of the ideotype. Particular traits, such as an extensive root system or low stomatal conductance, may be desirable in the driest seasons at a particular site, but a disadvantage in seasons with average to above average precipitation. It may be possible to define an ideotype that is adapted to a broad range of environments. This can be illustrated by considering contrasting root system ideotypes proposed by Hurd (1974) and Passioura (1972). The former ideotype consisted of an extensive root system, while the latter comprised a root system that restricted the rate of water uptake to conserve water for grain-filling. The Passioura ideotype addresses the problem of adaptation to only dry environments by relying on increased hydraulic resistance of the seminal root system. This system is of paramount importance in dry conditions that limit tillering and development of nodal roots, but water and nutrient uptake is not restricted in favorable growing conditions because development of a prolific nodal root system by-passes the seminal system. In other cases, a broadly-adapted ideotype may not be possible. For example, low stomatal conductance is associated with high yield in dry environments (Jones 1977), but high conductance is desirable in favorable environments (Shimshi and Ephrat 1975). Current research to select for stomatal conductance integrated over time via carbon isotope discrimination (Condon et al. 1987) must address this conundrum.

There are relatively few examples in the literature of detailed, long-term efforts to genetically manipulate and evaluate specific traits related to adaptation of wheat to dry growing conditions. An exception is the work by Richards and Passioura (1981b, 1989) to reduce seminal root xylem vessel diameter in wheat to test the hypothesis that a reduced rate of water use would be beneficial under drought (Passioura 1972). This research demonstrates the high degree of effort that is required to prove association between a morphological and an agronomic trait.

Preliminary investigations demonstrated the need to maintain consistent environmental conditions and to use seed of uniform size to maximize the expression of heritable differences in seminal root morphology (Richards and Passioura 1981a). Richards and Passioura (1981b) then surveyed over 1000 accessions of wheat, including diploid, tetraploid, and hexaploid forms, for maximum xylem vessel diameter and related traits. They concluded that maximum xylem vessel diameter was the most amenable to selection, because this trait had greater genetic variation than the others. Narrow-sense heritability for vessel diameter ranged from 0.38 to 0.78, with a mean of 0.52 (Richards and Passioura, 1981b). A single cycle of divergent selection for maximum xylem vessel diameter produced highly significant ($P<0.01$) differences in diameter in several populations.

Richards and Passioura (1981b) were unable to find maximum xylem vessel diameters of less than 60 µm in modern wheat cultivars, so embarked on a breeding program to transfer narrow diameter vessels (50 µm) from a landrace wheat from Turkey into two well-adapted Australian cultivars with vessel diameters of 60 and 65 µm (Richards and Passioura, 1989). In backcross-three derived lines, narrow vessel selections out-yielded unselected lines in one cross, but not in the other (Table 1). For the most part, however, the recurrent parents had higher grain yields than the narrow vessel selections. Backcross-five lines had recovered the yield potential of the recurrent parents, but in only two of the tests did narrow-vessel lines yield more than unselected lines (Table 1). In another environment with low levels of stored soil water, the narrow vessel selections did not show higher yields than the unselected lines (Richards and Passioura, 1989).

Rate of water loss through the cuticle of wheat, as estimated using excised leaves, is another trait that has been extensively studied. Low rate of water loss through the plant cuticle is reported to be an important drought survival mechanism, and ranges from 1 to 50% of total transpiration in different species (Oppenheimer 1960). Species adapted to xeric habitats tend to show lower rates of water loss than those adapted to wetter environments (Larcher 1980). Observed differences among crop genotypes in the rate of this loss has been suggested as a basis for screening for adaptation to dry environments in wheat (Bayles et al. 1937, Clarke and McCaig 1982). The trait is readily measured gravimetrically on excised leaves of moderate numbers of genotypes, and its measurement is not dependant on growth of plants under drought stress (Clarke 1987), suggesting that it is a constitutive rather than an adaptive trait. The physiological basis

Table 1. Grain yields of backcross-3 and backcross-5 wheat lines selected for narrow maximum seminal root xylem vessel diameter in comparison to unselected controls and the two recurrent parents Kite and Cook (from Richards and Passioura 1989).

Year		Grain yield relative to recurrent parent (%)			
		Kite		Cook	
		Narrow	Unseal.	Narrow	Unseal.
Backcross-3 lines:					
1981		90	81*	98	93
1982		79	73*	80	77
1983	Site 1	106	95*	98	98
	Site 2	94	89*	88	85
Backcross-5 lines:					
1984	Site 1	99	103	103	101
	Site 2	108	111	101	96*
1985		104	97*	99	102

* Unselected significantly different from narrow selections ($P<0.05$).

for genotypic differences in rate of water loss from excised leaves (RWL) are not well understood (Clarke and Romagosa 1991).

In a study of several durum wheat crosses, Clarke and Townley-Smith (1986) found that in dry environments RWL tended to be negatively associated with grain yield. However, in favorable environments RWL was positively related to yield in some of the crosses. Another study (Clarke et al. 1989) suggested that genotypes with low RWL had a yield advantage in dry environments, and no yield disadvantage in moist environments. Results from another set of durum crosses (Clarke and Romagosa 1991) indicates a trend similar to that reported earlier by Clarke and Townley-Smith (1986). Rate of water loss was generally negatively correlated with yield under rainfed conditions, but sometimes positively correlated with yield under irrigated conditions (Table 2). More research must be done to clarify the RWL-yield relationship, since this is of fundamental importance in developing selection strategies.A study of eight durum crosses indicated that RWL is moderately heritable (Clarke and Townley-Smith 1986), averaging 0.31 with a range of 0.14 to 0.49.

Table 2. Correlation of excised-leaf water loss rate and grain yields of individual F_4 plants in four durum crosses grown under rainfed and irrigated conditions (Clarke and Romagosa 1991).

Cross	Environment	n	r
Cross 1	Rainfed	335	-0.11*
	Irrigated	265	0.24**
Cross 2	Rainfed	288	-0.28**
	Irrigated	180	0.03
Cross 3	Rainfed	347	-0.17**
	Irrigated	218	0.10
Cross 4	Rainfed	360	-0.05
	Irrigated	202	0.14*

At present, there is only limited data on the effectiveness of indirect selection for yield using RWL. In two of the crosses from the Clarke and Townley-Smith (1986) study, there is some evidence that the correlated response for yield stability following selection for low RWL may be more effective than direct selection for yield in dry environments. Lines selected for high yield (greater than one standard deviation above the test mean) in the F_4 generation in Cross 1 had F_6 yields above the test mean, but F_8 yields did not differ from the test mean. Conversely, F_6 and F_8 yields of lines selected for low RWL in the F_4 generation did not differ from the test mean, but lines selected for low RWL in the F_6 had F8 yields higher than the test mean. These differences are probably related to growing season precipitation differences; precipitation was 244 mm in 1982, 187 mm in 1983, and 101 mm in 1984 compared to the long-term average of 167 mm. In these crosses, selection for yield in favorable environments had little success in identifying lines that performed well under dry conditions. Indirect selection for low RWL was of some use in selecting lines with better yield under drought. However, the small number of lines in these crosses (about 50) makes it difficult to draw firm conclusions, and does not permit the investigation of selection for both yield and RWL.

The efficacy of RWL for selection of durum genotypes for adaptation to dry environments was compared with visual scoring of other traits in approximately 4300 accessions from the ICARDA germplasm collection (Clarke et al. 1991). The visually scored traits were glaucousness, days to heading, relative maturity, an agronomic score (agronomic suitability and estimated yield potential), flag leaf size, and leaf rolling. High RWL was negatively associated with yield, and superior agronomic score was positively associated with yield in a subsequent year. Glaucousness, leaf size, and leaf rolling showed no significant relationship with yield. Glaucousness of wheat is positively associated with yield under dry, hot conditions (Johnson et al. 1983), and improves water use efficiency (Richards et al. 1986). The lack of association between glaucousness and yield in the Clarke et al. (1991) study was probably due to the small number of non-glaucous entries: 93% of the 3600 genotypes were glaucous. Similarly, Jain et al. (1975) reported 9% glossy leaf sheaths (presumably nonglaucous) among 3100 durum entries from the USDA collection. The preponderance of glaucous genotypes in durum probably reflects the adaptive significance of the trait, confirming research results with near-isogenic pairs (Johnson et al. 1983, Richards et al. 1986). The lack of association of leaf rolling and yield under dry conditions is consistent with other studies (Clarke 1986), suggesting that rolling is perhaps a symptom of stress rather than a stress avoidance mechanism.

Selection of genotypes on the basis of heading date or maturity score within the range of the local checks did not reduce the population for further testing by more than 50%, and the mean yields of the selected genotypes did not differ from those of the unselected genotypes in a subsequent year of testing (Figure 2). Selection for superior agronomic score increased the mean of the selected relative to the unselected groups in the subsequent year. Combination of selection for agronomic score and heading date or maturity score reduced population size and increased mean yield of the selected genotypes further. Selection for low RWL alone did not improve yields. Combined selection for low RWL and agronomic score, heading date, or maturity score reduced the size of the selected population, but with the exception of low RWL plus heading date, these combinations were no more effective in improving yields than the combinations of the visual selection criteria alone. The further expense of measuring RWL appears unwarranted. Furthermore, the highest yielding group of genotypes had intermediate RWL, so strong selection pressure for RWL would have been counter-productive. Removal of genotypes with very high RWL, which tended to be very late heading and had low yields, was effectively accomplished by selection for agronomic score.

Concurrent physiological and genetic studies could speed up the process of evaluation of physiological traits. One of the major problems in evaluation of complexly-inherited physiological or morphological traits, particularly when they are difficult to measure, is the development of homozygous lines for study. Screening the large populations required can be very tedious and expensive. It is worth considering procedures to facilitate the evaluation process.

Development of isogenics, whether through repeated selection of homozygous individuals or repeated backcrossing to divergent parents, is a valuable tool for physiological studies. This approach is more effective for simply-inherited traits that can be readily measured. However, due to possible linkages and epistatic or pleiotropic effects, more than one pair of parents should be used to develop the isogenics. Where it is not possible to develop isogenics, divergent selection for the trait of interest can be used to assess its effect on yield (Richards 1989).

Generation of random inbred lines from crosses of parents showing diverse expression of the trait may facilitate evaluation of difficult to measure traits. The single seed descent procedure is a proven and reliable means of generating such lines. Homozygosity can be attained rapidly if haploidy can be readily induced. Doubling the chromosome number of induced haploids produces homozygous lines which can then be used to assess the effects of the different alleles on agronomic performance, or to backcross the traits of interest into adapted genotypes. To date, however, production of double haploids in wheat is by no means routine, and is highly genotype-dependant.

Genome mapping may eventually provide techniques that will simplify screening for relatively simply-inherited, but difficult to measure traits. The restriction fragment length polymorphism (RFLP) maps being generated could be used to identify the genotype of segregating lines, thus facilitating the development of homozygous lines carrying the trait of interest. Tanksley and Hewitt (1988), however, pointed out that the effects of traits transferred in this way still must be evaluated in a range of genetic backgrounds. In fact, the restrictions of the classical methods of producing homozygous lines apply to the new biotechnologies, including the need to determine the interaction of the trait of interest with other important traits.

Progress

It is very difficult to provide definitive examples where the analytical approach to yield improvement has made a practical contribution in breeding programs. However, it may have made contributions that are not readily demonstrable, such as through influencing choice of parental lines and modification of the breeder's ideotype. In our breeding program, choice of parents on the basis of particular physiological attributes has contributed to the development of several high-yielding lines, but it is not clear whether this was due to the physiological trait in question or to the introgression of new genetic material into the program. Rasmusson (1987) suggested that introgression of genes for ideotype traits into adapted backgrounds is an important aspect of breeding for yield.

There have been numerous suggestions that the analytical approach to improvement of yield in dry environments will only be effective if physiological, genetic, and breeding questions are addressed in an integrated manner (e.g., Clarke and Townley-Smith 1984, Acevedo and Ceccarelli 1989). This strategy is being followed in a limited number of institutions. One outcome of this approach seems to be the emergence of a more pragmatic and empirical approach to the evaluation of physiological or morphological traits. Effort is being focused on 'integrative' techniques (Acevedo and Ceccarelli 1989) that measure traits having a greater direct association with yield than do very specific, possibly cellular level, individual physiological traits. This is perhaps similar to the approach taken by R.A. Fischer and colleagues at CIMMYT in the 1970s.

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Discussion Notes

Fischer: When selecting for plant height, how do you know what height is undesirable?

Clarke: Stay in the range of 100-105 cm--use the local check to determine the height for that season.

Winkelmann: Could we have some history on Canadian durum breeding?
Leisle: There was no durum breeding project until 1956 at Winnepeg. Hercules was the first variety to come out of that program in 1969.

Fischer: How do you set up yield trials at the F_4.
Clarke: Four rows, 3 m long, 2 reps--using the newer spatial models.

Varughese: What stage do you do reselection so you have fixed lines?
Clarke: The ultimate lines are F_6-derived if the F_6s look uniform.

van Ginkel: What do you think about osmotic adjustment?
Clarke: There is an advantage to osmotic adjustment in dry environments.

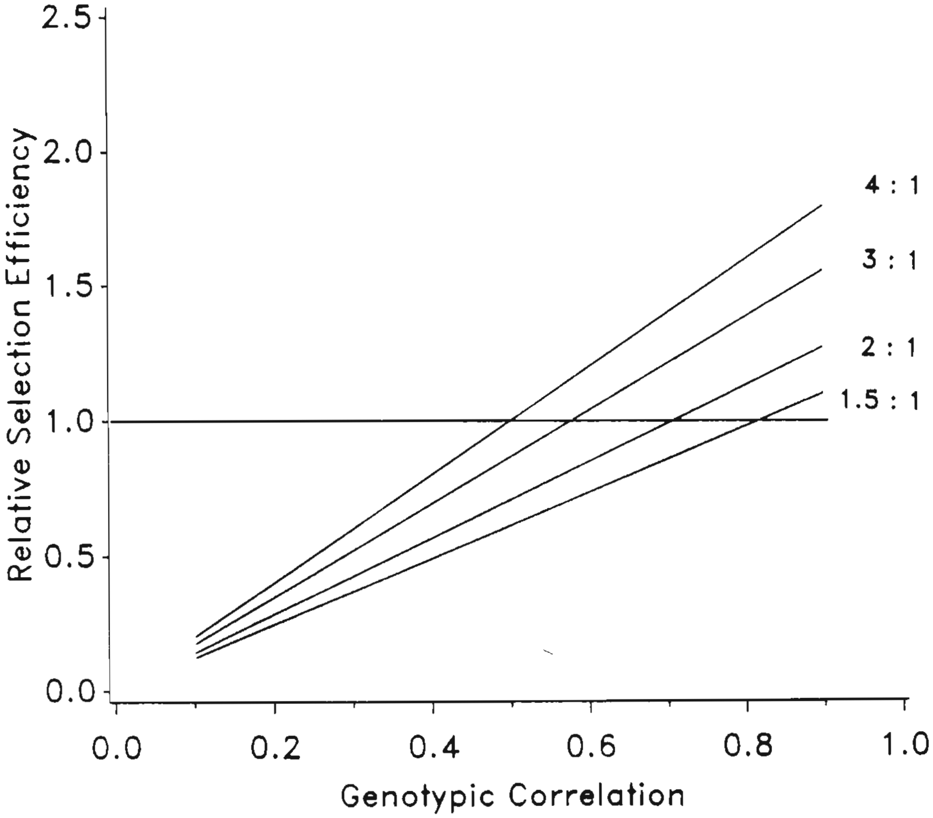

Figure 1. Relationship of relative selection efficiency (RSE; Searle 1965) with genotypic correlation between a direct and an indirect trait at different ratios of heritability of the indirect trait to that of the direct trait. RSE > 1 indicates that selection response is greater for selection for the indirect trait.

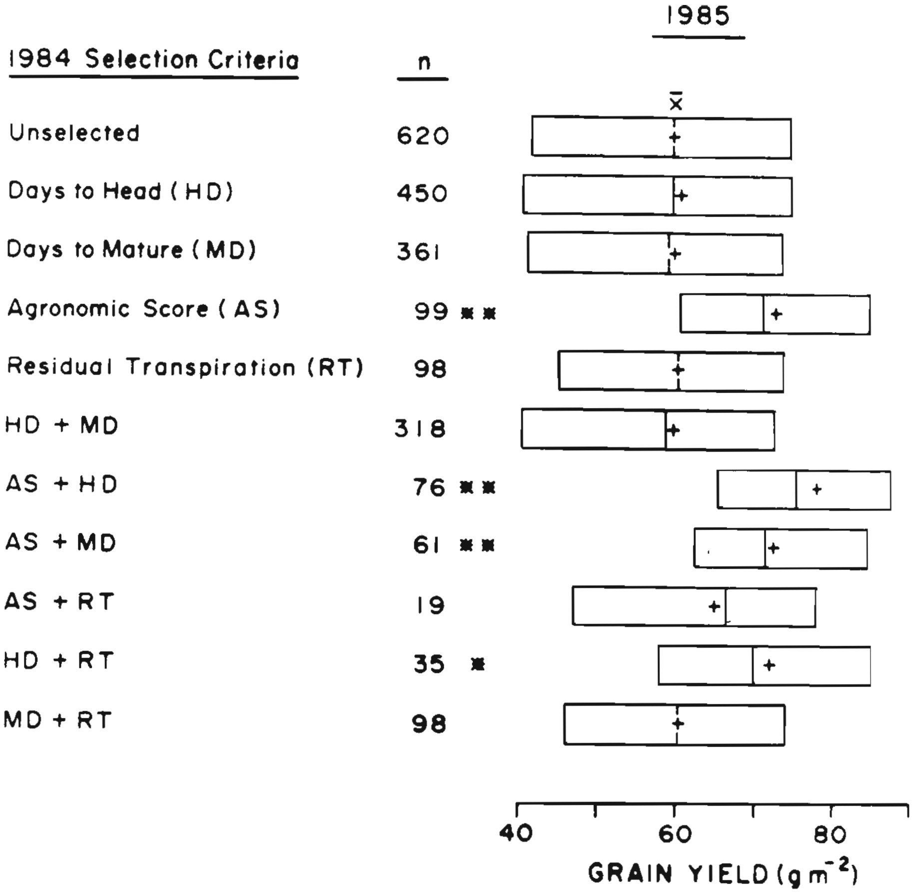

Figure 2. Effect on 1985 durum grain yields of selection based on morphological and physiological criteria in 1984. Selection was for HD and MD within the range of the local checks, superior agronomic score (based on objective and subjective characters including straw strength, uniformity, and estimated yield potential), and low excised-leaf water loss (RT, mean--1 SD). Left and right edges of the boxes represent the 25th and 75th percentiles, respectively; the central vertical line is the sample mean; + indicates the median; n = sample size. *, ** denote significant difference from the unselected mean according to the t-test ($P<0.05$ and $P<0.01$). Source: Clarke et al. (1991).

DURUM WHEAT YIELD POTENTIAL IN MEGA-ENVIRONMENT 1

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Introduction

Breeders, in general, are pre-occupied with applying selection strategies that lead to continued increases in genetic yield potential--and durum wheat breeders at CIMMYT are no exceptions. Continued improvements in genetic yield potential have been an especially important selection criterion for favorable high-yield environments. This paper attempts to outline progress that has been made over the past 25 to 30 years in breeding for increased yield potential for durum wheat at CIMMYT. Relevant comparisons to improvements in bread wheat yield potential are made. The results clearly indicate the remarkable progress that has been made over the past 40 years in increasing genetic yield potential for durum wheats as well as bread wheats under the conditions of Mega-Environment 1. This advance in yield potential has been directly reflected in increasing yields in farmers' fields. The increase in yield potential in bread wheats, at low as well as high N levels, is noteworthy as well.

The Yaqui Valley

CIMMYT wheat breeders rely on the INIFAP experiment station (CIANO) in Mexico to provide reliable estimates and the best selection conditions for genetic yield potential under favorable conditions. It is located in the Yaqui Valley in the state of Sonora in northwestern Mexico. The Valley is representative of an irrigated, temperate, low-elevation, low-rainfall wheat growing area designated as Mega-Environment 1 (ME1) by the CIMMYT Wheat Program. Figure 1 presents a view of the trend in average farmer wheat yields in the Yaqui Valley from the early 1950s to the present. This parallels the nearly 40 years of breeding efforts by CIMMYT/CIANO and its predecessors and provides a microcosm of the Green Revolution for wheat that has occurred in many favored irrigated regions of the developing world. The Yaqui Valley has shown an annual rate of yield increase of 3.2% per year over the past 40 years. Similar trends have occurred in other ME1 locations.

Table 1 breaks down this pattern of yield increase in 10-year periods from 1950 onward and demonstrates that there has been a steadily declining trend in the annual rate of yield increase for each succeeding time period. As we shall see later, this tends to parallel the similar declining rate of increase in genetic yield potential over time for both durum wheat and bread wheat under optimum production conditions in the Yaqui Valley.

Yield gap in the Yaqui Valley

The Agronomy Section of the Crop Management and Physiology Subprogram, in collaboration with CIANO breeders and agronomists and CIMMYT breeders, has routinely conducted trials on farmers' fields to test new, advanced lines of bread wheat and durum wheat along with the most widely grown cultivars of both wheat types. These trials are conducted under the direct management of each farmer. This kind of trial is not only crucial in helping breeders identify promising lines for potential cultivar release, but it also provides on estimate of farmers' yields under their current levels of wheat management as compared to on-station yields, estimating the so-called "yield gap". Table 2 summarizes the results of 6 years of these trials including the yields from each of the

Table 1. Annual rate of increase in average farmer wheat yields in the Yaqui Valley for various time periods.

Time period	% yield increase/year
1950-1991	3.2
1950-1959	5.0
1960-1969	4.0
1970-1979	2.0
1980-1989	1.3
1990-1991	0.7

six on-farm trials conducted each cycle and their means, the yield of the same set of lines grown each cycle under the best current management at the CIANO station, and the annual mean yield of wheat in the Yaqui Valley. Figure 2 presents this same information in graphic form. The average yield advantage of the CIANO trial mean over that of the on-farm trial farmers' mean is about 21%--a rather small difference, if we consider the CIANO yield as a useful approximation of the genetic yield potential under near-optimum management in the Yaqui Valley. In addition, some of the individual on-farm trial means presented in Table 2 include occasional farmers' yields similar to slightly above the CIANO yields. It would seem that some farmers are near to fully exploiting the genetic yield potential of the available cultivars.

If we make comparisons with the average yield in the Yaqui Valley, then the CIANO yield is about 56% greater than the Valley average and the on-farm trial mean is about 29% more. In general, this would indicate that there is still a wide yield gap between the cultivar genetic yield potential and current farmers' fields. However, in setting breeding strategies, it may make more sense to give due attention to the fact that many farmers are obtaining yields quite near the apparent genetic yield potential under these conditions.

The on-farm trials conducted in the Yaqui Valley also provide a forum to compare yield potentials of durum wheat versus bread wheat since advanced lines and released cultivars of both types are routinely included in the trials (Table 3). As a group, the durum wheats tend to have a slight, but consistent yield advantage. However, if we compare the highest yielding genotype of each type each year, the differences do not reflect a definite trend.

Estimating Improvement in Genetic Yield Potential

We have used two different approaches to evaluate improvements in durum wheat genetic yield potential under the ME1 conditions of the Yaqui Valley.

First approach

We have utilized yield data from the normal, full-management yield trials conducted each year by the CIMMYT Durum Section at the CIANO Station. This approach uses Mexicali 75 as the basis for comparative yield improvement of new, superior lines. It has been included as a check in the yield trials since 1973 and, according to the pathologists, has not suffered significant erosion in its level of disease resistance, especially to the prevalent rust diseases in the Yaqui Valley. This procedure does, however, only provide an estimate of yield improvement over the time period that Mexicali 75 has been included as a regular check in the yield trials (1973 to the present). The procedure uses

Table 2. Yields results from 6 years of on-farm testing of advanced bread and durum wheat lines and widely grown varieties in the Yaqui Valley.

Cycle	CIANO Trial Mean Yield	On-Farm Trial Yield in the Yaqui Valley						On-Farm Mean Yield	Yaqui Valley Mean
		1	2	3	4	5	6		
	(t/ha at 12% moisture)								
1985/86	7.17	4.55	6.09	6.01	4.78	6.53	6.09	5.66	4.60
1986/87	7.90	7.71	8.56	7.16	5.41	8.24	4.34	6.91	4.66
1987/88	8.60	6.04	7.16	6.87	7.93	7.71	8.26	7.32	5.44
1988/89	7.11	7.45	6.60	5.49	6.71	7.04	5.91	6.53	4.92
1989/90	8.17	6.78	6.20	6.95	6.38	6.44	5.64	6.40	5.51
1990/91	7.70	6.01	5.66	6.53	4.80	6.36	4.73	5.68	4.60
Mean	7.78	-	-	-	-	-	-	6.42	4.96

Table 3. Comparative performance of durum and bread wheat genotypes tested in on-farm trials under farmer management in the Yaqui Valley.

Growing Season	No. Genotypes in Trial	Durum Wheat Mean Yield All Durum Wheats (kg/ha)	Mean of Highest Yielding Durum (kg/ha)	No. Genotypes in Trial	Bread Wheat Mean Yield All Bread Wheats (kg/ha)	Mean of Highest Yield Bread Wheat (kg/ha)
Y1985/86	4	6250	6790	7	5780	6150
Y1986/87	3	7408	8085	6	7462	8331
Y1987/88	7	7672	8246	5	7237	7545
Y1988/89	4	6981	7319	8	6433	7005
Y1989/90	3	6795	6987	9	6461	6929
Y1990/91	3	6140	6230	9	5912	6217
Mean	-	6874	-	-	6548	-

both the yield of the highest yielding durum advanced line each year and the corresponding yield of Mexicali 75 from the identical trial.

Figure 3 presents a plot of these data along with their trend lines as well as the corresponding mean wheat yields for the Yaqui Valley from 1973 until 1991. The data show a slight (nonsignificant) downward trend in the Mexicali 75 yields and a modest positive yield trend for the high yield durum genotype. The Yaqui Valley mean wheat yield and trend line for the same period shows a significant positive yield increase.

Figure 4 presents the relative increase of the highest yielding durum genotype each year over Mexicali 75. The trend line shows a 0.6% yield increase per year as one estimate of the genetic potential yield increase in durum wheat at CIMMYT for ME1 conditions from 1973 to 1992.

As an aside, Figure 5 shows the percent Yaqui Valley yield of the highest yielding durum genotype for each year. The trend tends to illustrate that wheat yields increased faster in farmers' fields than did increases in the genetic yield potential of the CIMMYT durum wheats over this time period. There does, however, appear to be a flattening of the Yaqui Valley farmer curve from 1985 onward.

Second approach

We have conducted defined yield potential trials with the following genotypes and characteristics:

- Seven to eight historical, landmark cultivars going back to the first important semidwarf up through the most recently released, widely grown cultivars. This group provides an estimate of rate of genetic yield improvement over a 30-year period.

- Six to seven new advanced lines submitted by the breeders as selections possessing potentially higher yield potential levels than these previously released cultivars.

- The most optimum management available at CIANO including control of biotic stresses, nonlimiting amounts of H_2O and nutrients, and use of nets to prevent lodging.

- Repeated trials with the same recurring set of historical cultivars to provide useful yield estimates over the years. This type of trial provides an immediate, objective comparison of the genetic yield potentials for the cultivars/advanced lines included under the trial conditions. The Agronomy Section routinely conducts these trials for each crop (durum wheat and bread wheat, triticale, and barley) each cycle at CIANO, each year with the same set of historical lines, plus whatever new advanced lines breeders provided for comparison.

Figure 6 presents the results for the recurring genotypes plus the highest yielding advanced line in the durum yield potential trial conducted during the 1990-91 cycle. The yields plotted in the figure are for Chapala 67, Jori 69, Cocorit 71, Mexicali 75, Yavaros 79, Altar 84, Aconchi 89, and the highest yielding advanced line. As can be seen, genetic yield potential appears to have reached a plateau between 1979 and 1984. None of the new advanced lines outyielded Aconchi 89 (the last point on the right side of Figure 6 is the highest yielding advanced line included in the trial). The yield gain from 1967 until 1990 has been 1.4% per year. From 1971 to 1990, it has been 0.6% per year, the same as estimated from 1973 to 1991 using the normal durum yield trial data relative to Mexicali 75 yields over time as explained above.

Figure 7 presents similar results from the bread wheat yield potential trial conducted in the same year. The bread wheat cultivars plotted are: Pitic 62, Siete Cerros 66, Yecora 70, Nacozari 76, CIANO 79, Seri 82, Opata 85, and Super Kauz 88 and the best advanced line. Again, we observe an even more severe plateau effect with no apparent yield increase since Seri 82. None of the advanced lines outyielded Seri 82 (see last point on right of Figure 7 for highest yielding advanced line). Yield gain has been less as compared to durum wheat with an estimated 0.7%/year between 1962 and 1990 and only 0.2%/year between 1970 and 1990. Other estimates, however, show this to be closer to 1% per year.

It appears clear there is a need for concern about the apparent leveling off of increases in genetic yield potential for both durum wheat and bread wheat, especially when we add the evidence that some Yaqui farmers are managing their crops in the Valley to obtain yields approaching what appears to be the limit of yield potential for available cultivars under this environment. Furthermore, Table 1 clearly illustrates a gradual reduction overtime in the rate of yield increase at the farmer level in the Yaqui Valley. If we compare the same time periods in Figures 6 and 7, we see a similar trend. Certainly, the question that must be asked is: how related are these two phenomena? Are yield increases in farmers' fields in the Yaqui Valley slowing down because there has been a concurrent slow-down in the rate of increase in cultivar genetic yield increase or are other confounding factors involved?

Improvement in Genetic Yield Potential under Different Nitrogen Levels

The above discussion has dealt primarily with estimations of increases in genetic yield potential under optimum or near-optimum conditions. The Agronomy Section has also developed estimates of improvements in genetic yield potential of durum and bread wheat over time related to different nitrogen levels. The approach has been to again use a historical set of landmark cultivars starting with the first important semidwarf cultivars to the most recently released ones. They have been grown under different N levels from low to high with control of biotic stresses and elimination of other abiotic stresses through optimum management. This allows an unconfounded expression of grain yield under the different N levels.

Figure 8 presents the results of the durum wheat N trials, which plot year of cultivar release against grain yields at four N levels. The cultivars are essentially the same as listed above for the genetic yield potential trials. For durums, there has been very little improvement in yield potential over time at the 0 and 75 kg/ha N rates, but strong improvement at the two higher N levels. In contrast, Figure 9 presents the results for bread wheat (again with the same cultivars as listed for the genetic yield potential trials). Similar and significant annual rates of yield potential increase have been achieved at all four N rates. This may, in part, reflect the generally wider adaptation spectrum of bread wheats as compared to durum wheats.

Conclusions

The results presented here clearly indicate the remarkable progress that has been made over the past 40 years in increasing genetic yield potential for durum wheat as well as bread wheat under ME1 conditions. This advance in yield potential has been directly reflected in increasing yields in farmers' fields. The increase in yield potential in bread wheats at low as well as high N levels is also noteworthy.

However, the apparent leveling-off in the rate of increase of genetic yield potential for both durum and bread wheat is troubling. We should be giving considerable attention to clarify how further yield advances can be achieved.

Discussion Notes

Hamblin: What N rate do farmers apply in the Yaqui Valley?
Sayre: The set of Yaqui farmers identified by the CIMMYT Economics Program use, on average, 230 kg N/ha.

Fischer: Durum wheats seem to be more adapted to the high yield environments.
Rajaram: The durum wheats are usually 10 points higher than the bread wheats in thousand grain weight.
Varughese: I believe it is difficult to compare crops with different ploidy levels.
Braun: We need to be very careful when comparing durum wheats with bread wheats. Humans are closer to monkeys than durum wheats are to bread wheats.

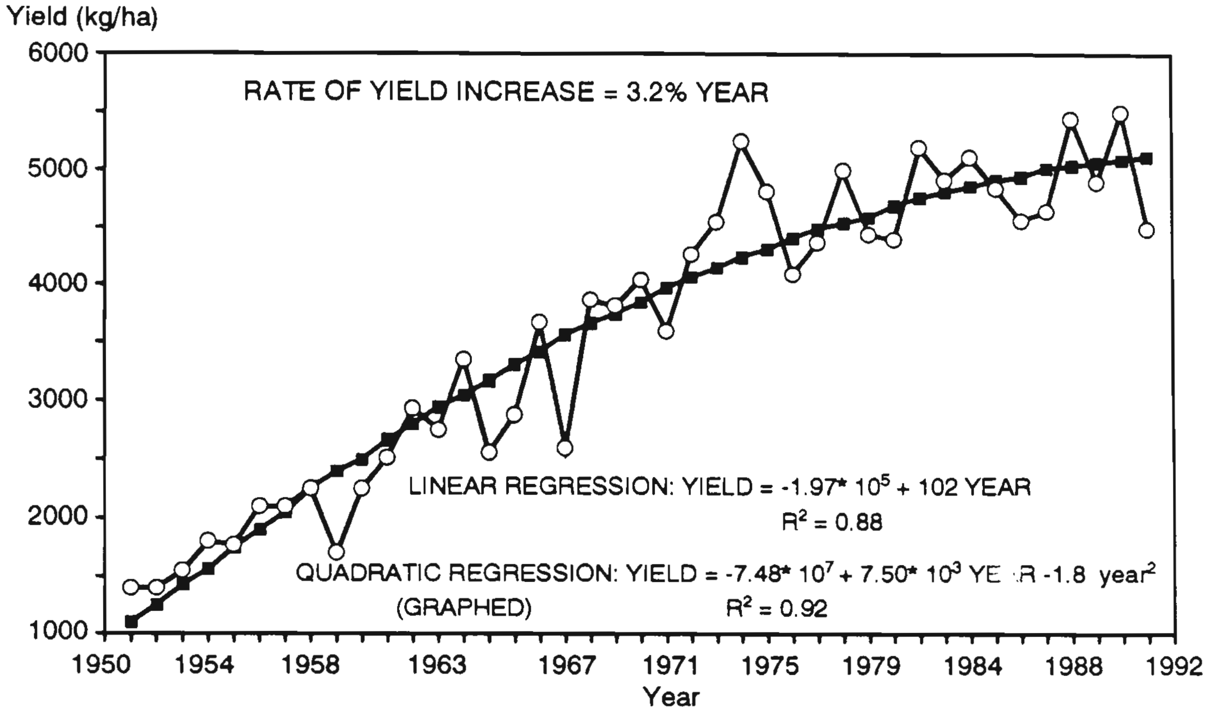

Figure 1. Trend in average wheat yield in farmers' fields in the Yaqui Valley, Sonora, Mexico. (1951-1991)

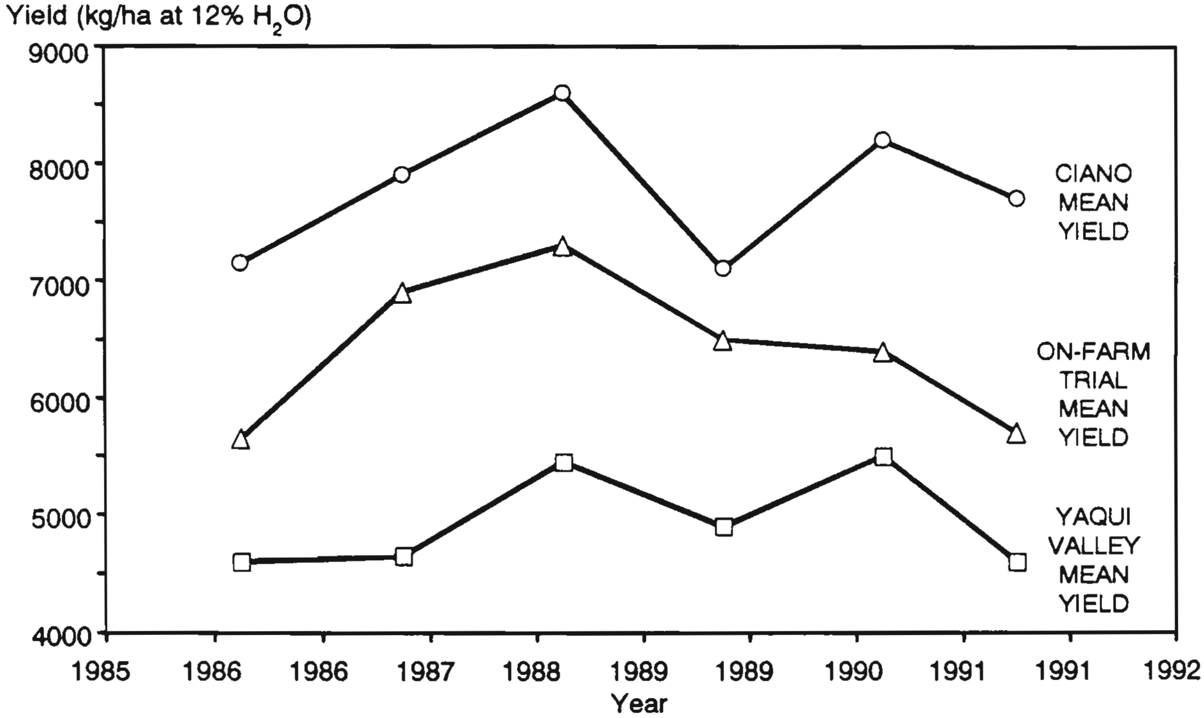

Figure 2. Comparison of wheat yield gap between CIANO on-farm trial and Yaqui Valley yields from 1986 to 1991.

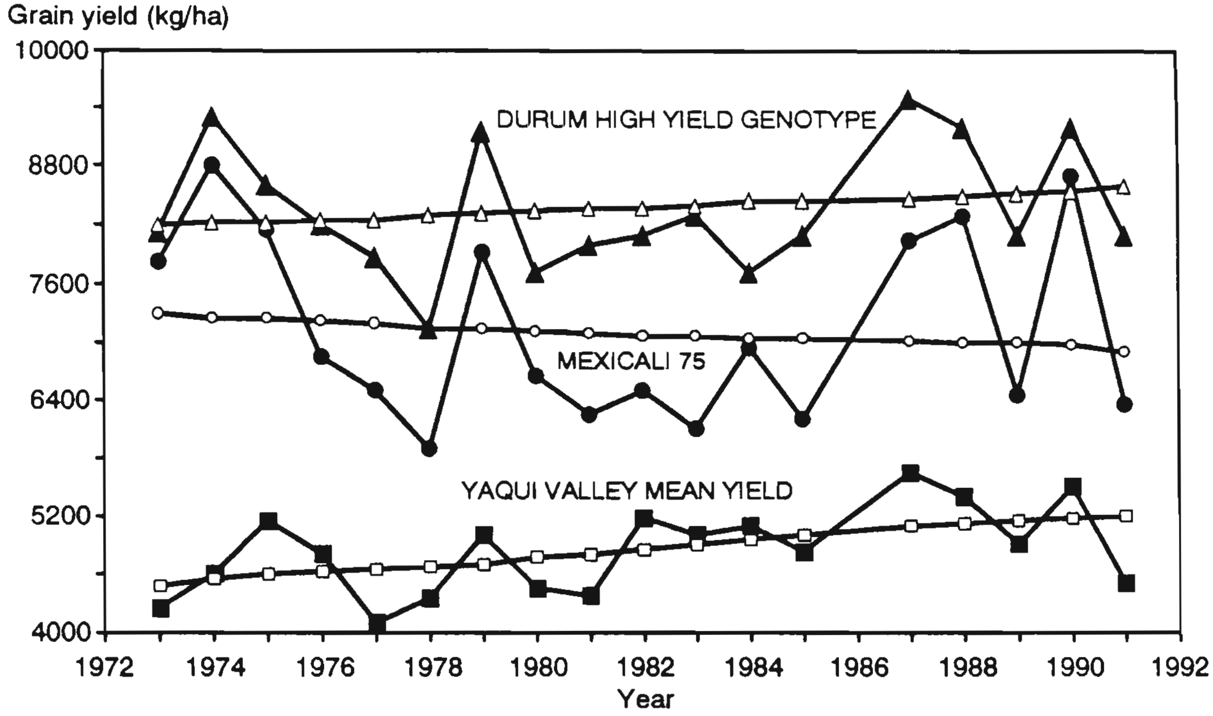

Figure 3. Trends in the yields of the highest yielding durum wheat genotype and Mexicali 75 in durum yield trials at CIANO and Yaqui Valley wheat yields from 1973 until 1991.

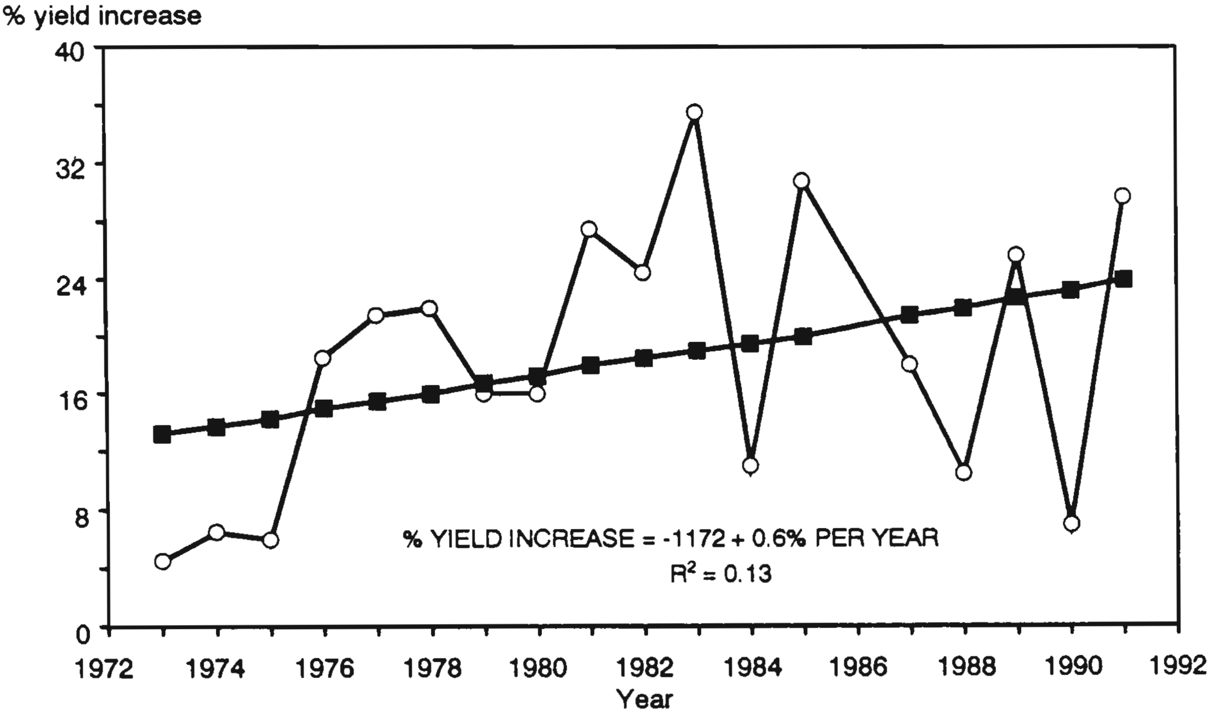

Figure 4. Percent yield increase of the highest yielding durum genotype relative to Mexicali 75 from 1973 to 1992 at CIANO.

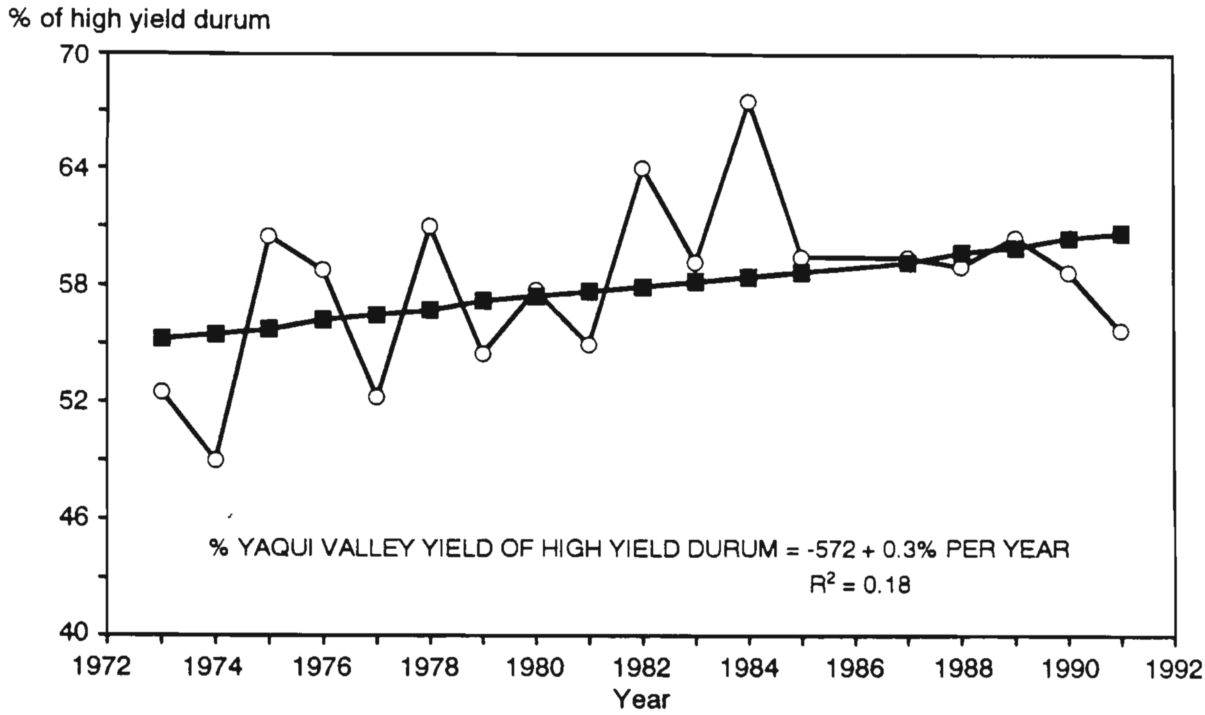

Figure 5. Percent Yaqui Valley wheat yield of the highest yielding durum genotipe from 1973 to 1992.

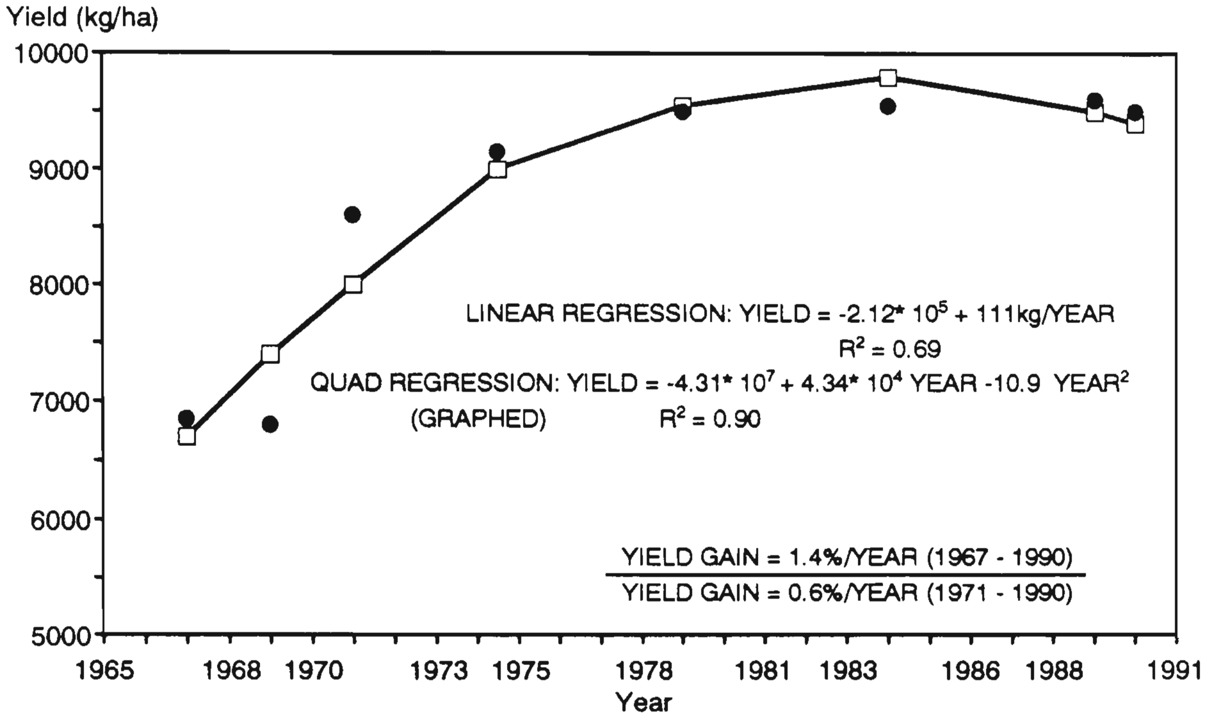

Figure 6. Durum wheat yield potential trend from the yield potential trial in 1990/91 at CIANO.

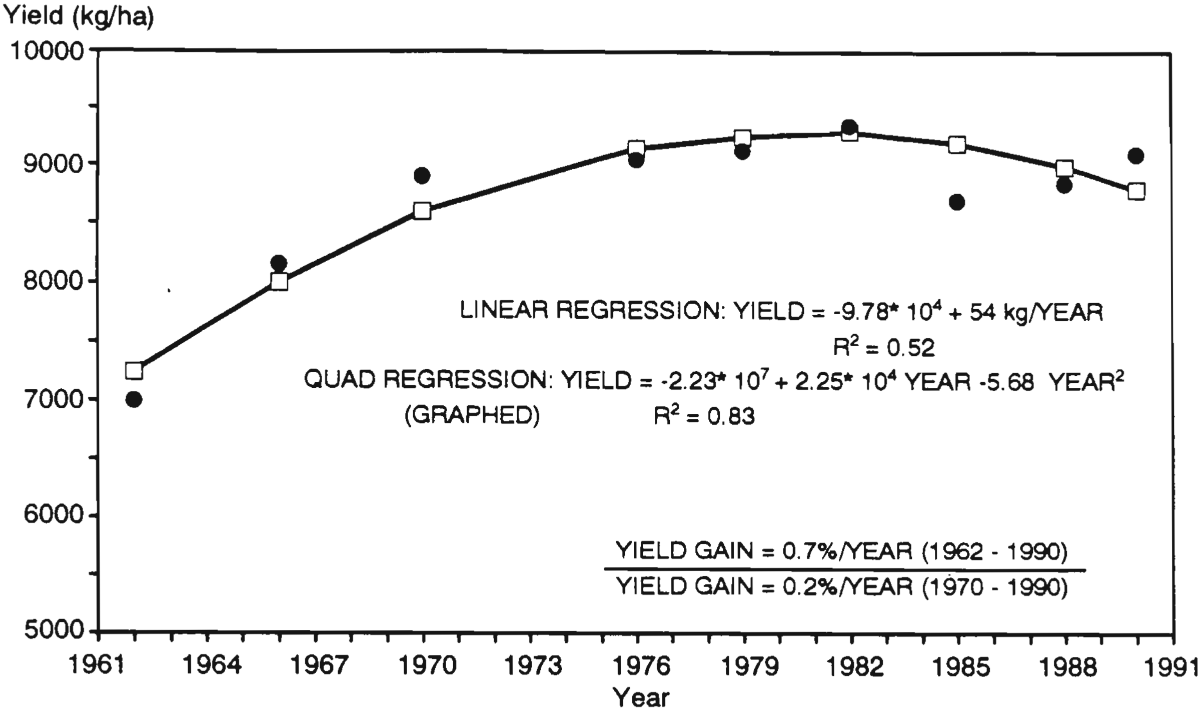

Figure 7. Bread wheat yield potential trend from the yield potential trial in 1990/91 at CIANO.

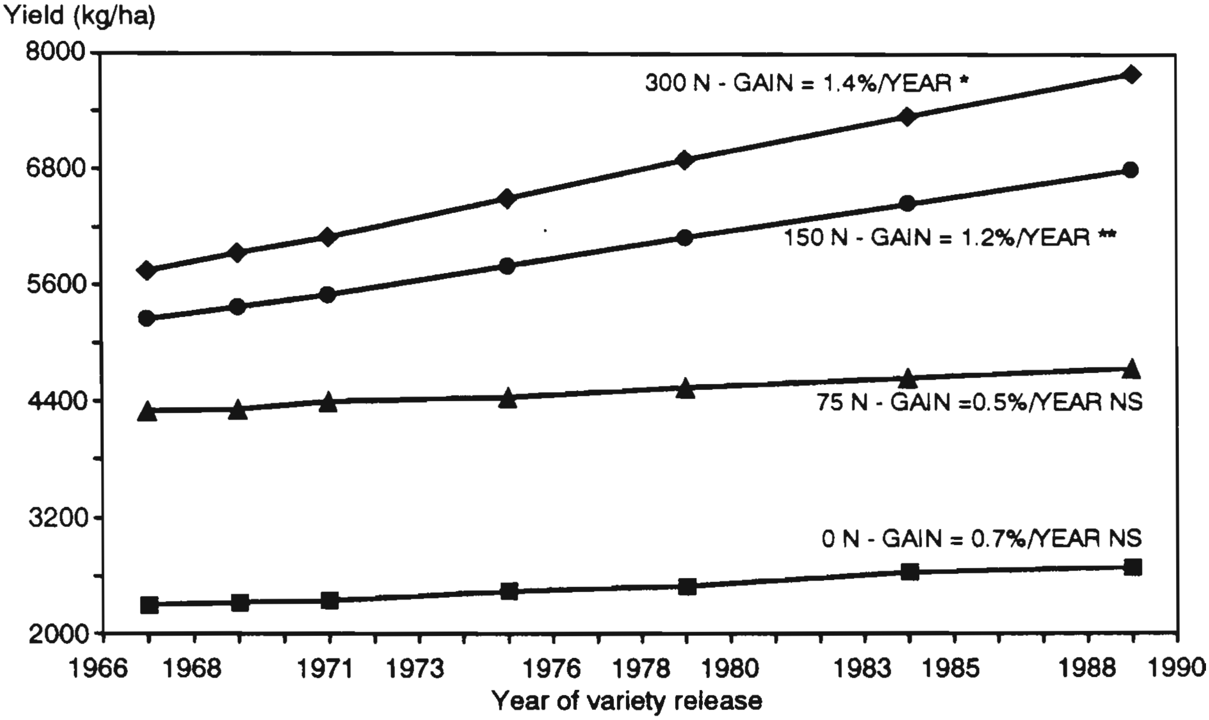

Figure 8. Durum wheat yield potential trend at different nitrogen levels in 1990/91 at CIANO.

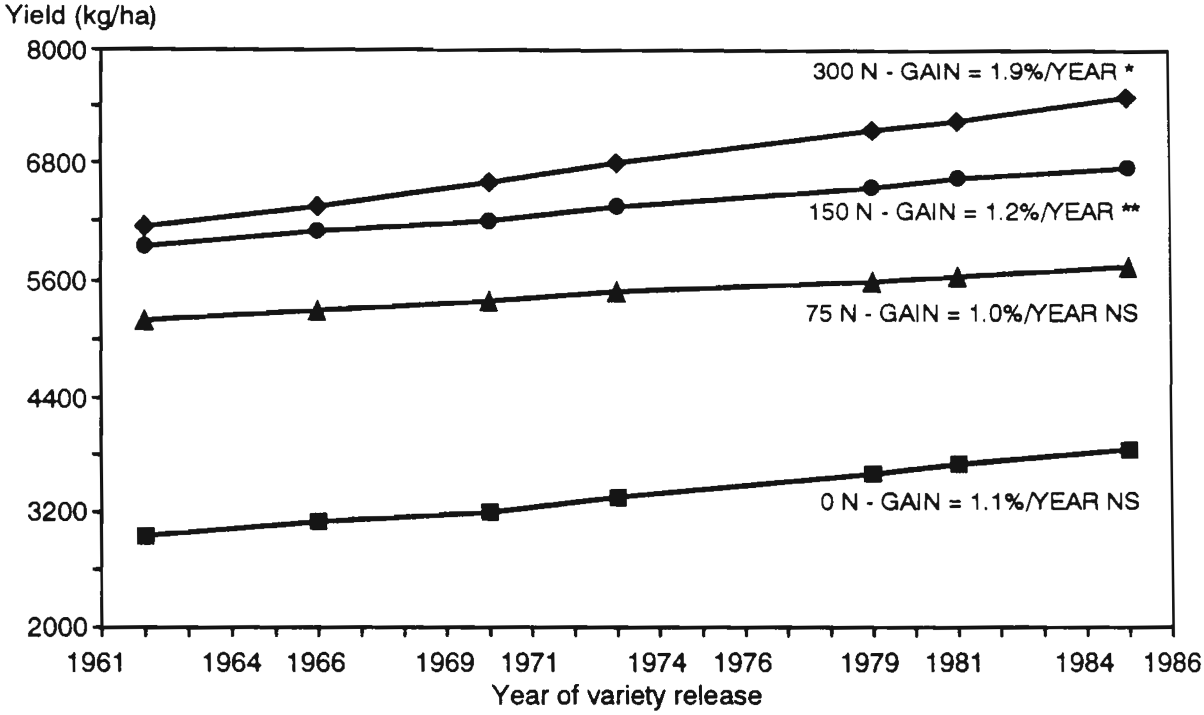

Figure 9. Bread wheat yield potential trend at different nitrogen levels in 1990/91 at CIANO.

QUALITY EVALUATION OF LINES DERIVED FROM CROSSES OF LANGDON (*TRITICUM DICOCCOIDES*) SUBSTITUTION LINES TO A COMMON DURUM WHEAT

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Introduction

The quality of pasta extruded from durum wheat (*Triticum turgidum* L. var. *durum*) is related to the protein quality (gluten strength) and the protein quantity of the grain (Dick and Youngs 1988). Accessions of wild emmer (*T. turgidum* L. var. *dicoccoides*), a progenitor of durum wheat, have high protein content (Avivi 1978). Joppa and Cantrell (1990) developed a complete set of 'Langdon' (*T. dicoccoides*) [LDN(DIC)] substitution lines that have been used to identify chromosomes from DIC conferring increased grain-protein content in tetraploid wheat. Joppa and Cantrell (1990) reported that DIC-6B, DIC-2A, DIC-5B, DIC-3A, and DIC-6A had significantly increased grain protein over the Langdon parent. This study was conducted to assess the potential of using these LDN(DIC) substitution lines in a breeding program for deriving lines with increased protein content and acceptable agronomic characteristics.

Materials and Methods

Fifteen populations were developed from crosses involving several plants of a representative line from each of the 14 LDN(DIC) chromosome substitution lines (Joppa and Cantrell 1990) and the Langdon parent (plant #16) to a common male parent, 'Vic' (Quick et al. 1980) (Table 1). Langdon and Vic have equivalent protein contents, but Vic has a significantly greater sedimentation value and therefore greater gluten strength. The F_2-derived F_4 lines and the 16 parents were grown in a hill-plot grid (44.5-cm spacing) with 10 seeds planted per hill at two locations (Prosper and Langdon, ND) in 1989. The design was a 25x25 simple lattice repeated three times (six replications). Locations were analyzed as a lattice (SAP, Hammond, NDSU) and analysis of variance was conducted on the adjusted treatment means for the combined analysis (SAS v6.06). Locations, replications, and lines within populations were considered as random effects. Populations were considered fixed effects.

Comparisons of the population means and variances to those of the base population (LDN/VIC) were used to assess the potential use of these LDN(DIC) substitution lines in a durum breeding program. Pearson correlations between selected traits were performed on a location basis and tested for homogeneity before pooled correlations were reported (Steele and Torrie 1980). Lines were field-evaluated for heading date (from date of planting to 50% spikes fully emerged) and plant height (cm from base of the plant to tip of the spike, excluding awns). Plots were hand-harvested and grain yield was measured in g/hill-plot. Kernel weight was determined by weight of 320 unbroken kernels/plot and converted to 1000-kernel weight. The same kernels were ground in a Udy Cyclone Mill (UDY Corp., Ft. Collins, CO) using a 1-mm screen. Protein concentration of the whole-meal flour was determined using near-infrared reflectance (Technicon InfraAlyser 400) at 14% moisture basis after adjusting the bias using Kjeldahl procedures. Gluten strength was estimated using the 1-g sodium dodecyl sulfate-microsedimentation test (MST) modified by Dick and Quick (1983).

Table 1. Parental substitution lines, seed source, and numbers of $F_{2:4}$ lines for each population field tested in 1989 (Prosper and Langdon, ND).

Parent	Seed Source[a]	# OF $F_{2:4}$ LINES
LDN(DIC-1A)	J86I-76	47
LDN(DIC-2A)	J87I-1-GH	46
LDN(DIC-3A)	J87I-17-GH	47
LDN(DIC-4A)	J86I-11	47
LDN(DIC-5A)	J86I-19	46
LDN(DIC-6A)	J86I-28	46
LDN(DIC-7A)	J86I-89	35
LDN(DIC-1B)	J86I-36	43
LDN(DIC-2B)	J86I-45	41
LDN(DIC-3B)	J86I-52	46
LDN(DIC-4B)	J87I-17-GH	40
LDN(DIC-5B)	J86I-60	32
LDN(DIC-6B)	J86I-8-GH	32
LDN(DIC-7B)	J86I-108	27
Langdon #16	Plant #16	34
Male Parent		
VIC	Single plant	

[a] Source corresponds to seed inventory of Dr. L.R. Joppa (USDA-ARS, NDSU, Fargo, ND).

Results and Discussion

Seven of the 14 LDN(DIC)/VIC populations had a mean protein content significantly greater than the base population. As expected, parents LDN and Vic were equivalent in protein content to the base population (LDN/VIC) (Table 2). While the minimum protein content of lines within populations was equivalent, all populations, except LDN(1B)/VIC, had lines that exceeded the maximum protein content of lines within the base population (Figure 1). The level of genetic variance in populations LDN(5B)/VIC and LDN(6B)/VIC of 0.189 and 0.316, respectively versus 0.031 for the base population indicates use of LDN(5B) and LDN(6B) as parents may result in measurable gain from selection among derived lines for increased protein content. The recurrent substitution parent LDN had a significantly lower MST height than the base population while the common male parent Vic had a significantly higher MST height indicating their respective gluten strengths (Table 3).

Four populations had a significantly higher mean MST height than the base population. With the exception of population LDN(1B)/VIC, the maximum MST height of lines in the three populations exceeded that of lines in the base population. Only population LDN(3A)/VIC had a genetic variance greater than the base population. Gain from selection for gluten strength may be limited in these populations, however, a small percentage of lines within populations did have MST heights in excess of the base population lines (Figure 2). Based on the population mean and variance for both protein content and MST height as well as frequency of lines exceeding maximum values in the

Table 2. Mean protein content (14% moisture basis) and genetic variance of populations, and minimum and maximum performance of lines within populations evaluated at two locations (Langdon and Prosper, ND) in 1989.

Population[a] Pedigree	Pop'n Mean	Min. Value	Max. Value	Range	Genetic[b] Variance
LDN(1A)/VIC	16.15**	14.8	17.8	2.97	0.107±.041
LDN(2A)/VIC	16.02**	14.6	17.7	3.07	0.107±.033
LDN(3A)/VIC	16.02**	14.7	17.4	2.7	0.058±.023
LDN(6A)/VIC	16.21**	15.0	17.3	2.3	0.134±.038
LDN(1B)/VIC	15.91**	14.8	16.9	2.1	0.034±.016
LDN(5B)/VIC	16.04**	14.5	17.5	2.93	0.189±.057
LDN(6B)/VIC	16.21**	14.6	18.0	3.36	0.316±.088
LDN/VIC	15.76	14.8	16.9	2.09	0.031±.021
Parent Langdon	15.60	15.5	15.8	0.29	
Parent VIC	15.60	15.3	16.0	0.66	
CV %	1.8				

** Population mean significantly different from base population at the 0.01 probability level.

[a] LDN = Langdon durum. Information in parentheses indicates the chromosome from *T. dicoccoides* that was substituted into Langdon.

[b] (±SE).

Table 3. Mean sedimentation height (mm) and genetic variance of populations, and minimum and maximum performance of lines within populations evaluated at two locations (Langdon and Prosper, ND) in 1989.

Population[a] Pedigree	Pop'n Mean	Min. Value	Max. Value	Range	Gentiec[b] Variance
LDN(3A)/VIC	29.2**	20.5	45.5	25.0	27.41±6.22
LDN(7A)/VIC	29.5**	20.2	44.8	24.6	20.53±5.32
LDN(1B)/VIC	29.4**	20.5	42.9	42.9	17.18±4.16
LDN(6B)/VIC	29.0*	19.9	46.0	26.1	18.23±5.41
LDN/VIC	28.3	21.0	42.9	21.9	21.88±5.85
Parent Langdon	23.0**	21.0	24.9	3.9	
PARENT VIC	34.4**	30.1	38.6	8.5	
CV %	7.3				

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*, ** significantly different from base population at the 0.05 and 0.01 probability levels, respectively.

[a] LDN = Langdon durum. Information in parentheses indicates the chromosome from *T. dicoccoides* that was substituted into Langdon.

[b] (± SE).

base population, LDN(6B)/VIC should be especially useful in a plant breeding program for improving both protein content and gluten strength of derived lines.

Agronomically, when compared to the base population, LDN(4A)/VIC and LDN(4B)/VIC had significantly greater yield, which supports previous findings by Cantrell and Joppa (1991). Populations with DIC-2A, DIC-3A, DIC-6A, DIC-1B, DIC-2B, and DIC-5B had a significantly greater 1000-kernel weight. Most populations except LDN(DIC-3A)/VIC were significantly shorter in stature than the base population. The LDN parent was significantly later in days to heading, however, 12 of 14 populations were significantly earlier in heading date (Table 4).

Table 4. Deviations from the mean of the base population for agronomic characters evaluated at two locations in 1989 (Langdon and Prosper, ND).

Population[a] Pedigree	Yield (g/plot)	KWT (mg)	Height (cm)	Days to Heading
LDN/VIC	31.4	42.7	99.4	59.0
LDN(1A)/VIC	-3.1**	-1.7**	-4.0**	-0.8**
LDN(2A)/VIC	-4.3**	+1.9**	-1.4**	-0.6**
LDN(3A)/VIC	-2.8**	+1.7**	+2.7**	-1.0**
LDN(4A)/VIC	+1.6**	+0.2	-4.0**	-1.0**
LDN(5A)/VIC	-0.1	0.0	-0.9	-0.6**
LDN(6A)/VIC	-2.6*	+0.9**	-4.3**	-1.3**
LDN(7A)/VIC	-1.0	-1.5**	-1.6**	-0.5**
LDN(1B)/VIC	-5.5**	+1.0**	-4.0**	-0.8**
LDN(2B)/VIC	-4.3**	+0.4*	-1.4**	-0.6**
LDN(3B)/VIC	-2.3**	+0.1	-1.7**	-1.2**
LDN(4B)/VIC	+2.4**	-0.3	-0.9*	-0.2
LDN(5B)/VIC	-4.6**	+2.7**	-1.3*	-0.0
LDN(6B)/VIC	-1.4*	-1.1**	-2.4**	-0.5**
LDN(7B)/VIC	-2.6**	-2.5**	-0.9	-0.7**
PARENT LDN	-3.8	-3.0**	+6.9**	+2.6**
PARENT VIC	+4.2	+1.9*	-7.5**	-0.7
CV %	12.6	3.0	3.0	1.1

*, ** population mean significantly different from the base population (LDN/VIC) at 0.05 and 0.01 probability levels, respectively.

[a] LDN = Langdon durum. Information in parentheses indicates the chromosome from *T. dicoccoides*, which was substituted into Langdon durum.

Most populations had a negative correlation between yield and protein and yield and days to heading. Lines with earlier heading dates had a yield advantage. There was no correlation between yield and kernel weight for any of the populations. Only populations with DIC-6A and DIC-6B had a significant and positive correlation between kernel weight and protein. Seven of the populations had a positive correlation between kernel weight and height indicating that taller lines may have slightly greater kernel weights in these populations. Only three populations exhibited positive but small correlations between kernel weight and days to heading. The base population and three of the 14 populations had a positive correlation between protein and days to heading. Although these correlations may indicate a trend, more conclusive comments can be made only after data from a second year of research are summarized.

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Discussion Notes

Peña: You might introduce more protein content, but not the right protein content. You need to look at it very closely.
Elias: I agree with you. Increasing protein content does not necessarily mean increasing quality.

Payne: You had a negative correlation between yield and protein content, but not that great--why was there one at all?
Elias: Yield is actually questionable on hill plots. I think some of the correlations will change.

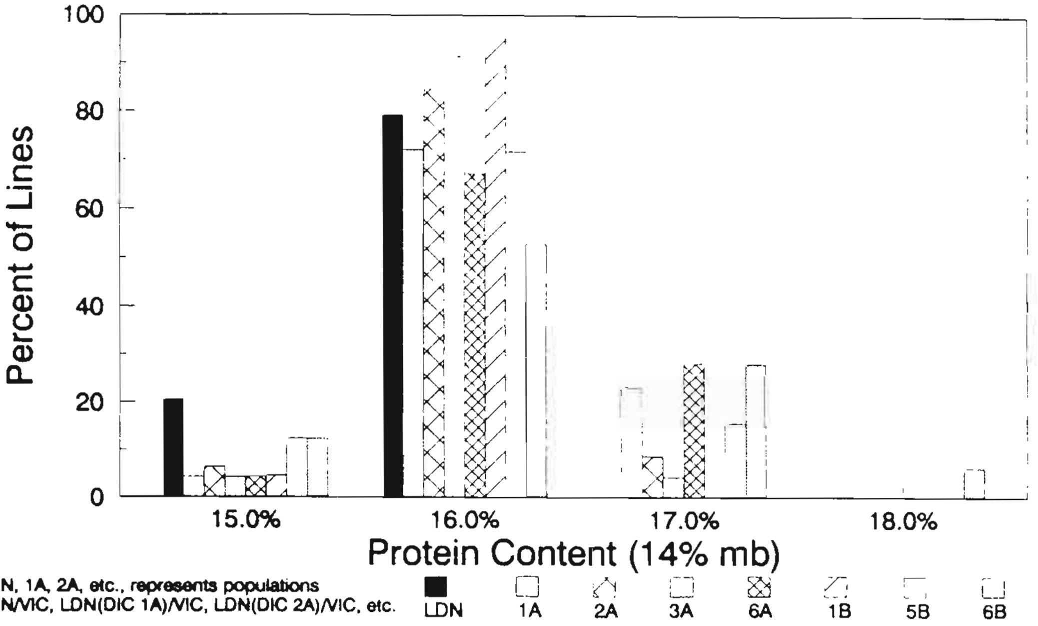

Figure 1. Percentage of lines with populations for mean protein content.

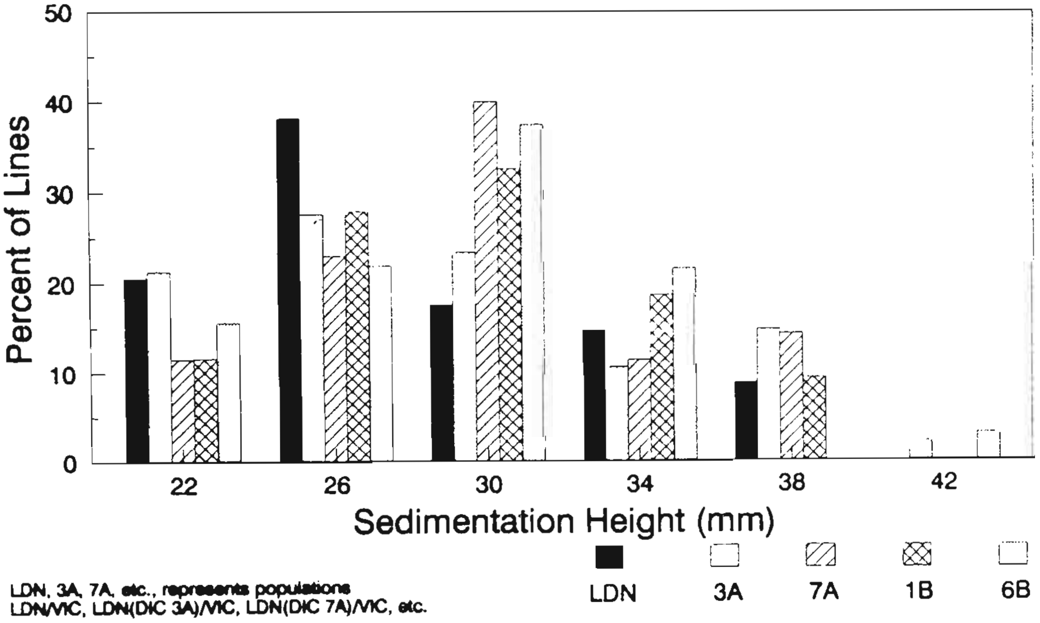

Figure 2. Percentage of lines with populations for mean sedimentation height.

UTILIZATION AND QUALITY OF DURUM WHEAT

A. Amaya and R.J. Peña
CIMMYT Wheat Program

Introduction

Durum wheat quality (pasta-making) plays a significant role in the acceptability of new varieties. In the CIMMYT wheat quality laboratory, research efforts on durum wheat are directed towards the genetic diversification of the germplasm. In addition to good agronomic characteristics and disease resistance, the germplasm should have good industrial quality. In the latter case, the breeders select the appropriate materials for the different uses in the countries where CIMMYT materials are grown.

Even when durum wheat is grown mainly for pasta preparation, there are other products that are prepared using durum wheats. These are summarized in Table 1.

Table 1. Food uses of durum wheat around the world.

Country or region	Food product	Raw material	Grain quality requirements
Europe, North Africa, The Americas, Australia	Pasta	Semolina	Medium to strong gluten, high yellow pigment
North Africa	Couscous	Semolina	Medium to strong gluten, high yellow pigment
Middle East	Unleavened bread	Semolina or flour	Medium to strong gluten
Near and Middle East	Bulgur	Cooked grain	Hard grain, yellow gluten
Andean Region	Mote	Cooked grain	Hard grain

Priority Quality Traits

In order to fulfill the grain quality requirements in the CIMMYT durum breeding program, three main factors are considered:

- Grain characteristics,
- Gluten quality,
- Pigment content.

Grain characteristics

In the CIMMYT durum wheat section, materials are selected according to grain characteristics starting in the segregating material. Seed from F3 and F6 individual plants is selected on the basis of seed size, shape, uniformity, kernel vitreousness, and absence of yellow berry and black point. All plants with small and shrivelled seeds are discarded. This selection also serves as an inspection to detect plants with Karnal bunt; when one or more infected grains are detected, not only is the plant discarded, but all plants from the same cross as well.

Grain size--Grain size seems to be the best single index of potential semolina yield. Large kernels are also better because of the lower ratio of pericarp to endosperm.

Vitreousness--Grain vitreousness is considered an important quality factor of durum wheat kernels because it is associated with semolina yield and protein content. It has been found that a high incidence of grains with yellow berry not only decreases test weight and the semolina yield, but gluten quantity and subsequent dough strength as well (Tables 2 and 3).

Table 2. SDS-sedimentation values (dough strength test) of samples with yellow berry and vitreous grains from four durum varieties.

	SDS-sedimentation (cc)	
Variety	YB[a]	V[b]
1	7.8	10.6
2	7.4	14.4
3	6.8	10.8
4	5.4	8.4

[a] = Grains with yellow berry.
[b] = Vitreous grains.

Table 3. Protein percentage of grain samples with yellow berry and vitreous grains from six wheat varieties.

Variety	Yellow berry	Vitreous
1	9.9%	12.6%
2	10.1%	13.5%
3	8.7%	12.5%
4	9.2%	13.0%
5	9.6%	13.0%
6	8.5%	11.7%

In segregating material, all plants with red color or other than vitreous amber are discarded unless the cross was made to deal with traits other than quality. In the segregating material, the individual plants selected for good grain characteristics are evaluated for gluten strength.

Gluten strength--This is a significant factor that affects pasta cooking quality, particularly with respect to firmness and cooking stability. Strong gluten is reflected in good pasta cooking quality characteristics and increases bite resistance of durum semolina products. In the durum breeding section, gluten strength is estimated as early as the F3.

For the evaluation of gluten strength, CIMMYT has used a modified version of the SDS-sedimentation test of Dick and Quick (1983) since 1985. This test can be applied to whole meal for segregating material and to flour for advanced material. Since only 1 g of flour is necessary, a large number of individual plants in F3 and F6 can be evaluated.

From the Yaqui 1990-91 cycle, close to 20,000 plants in the F3 and F6 were evaluated for gluten strength; 48% were discarded (Table 4) because of weak gluten (< 9.0 cc). Of the lines from the 22th IDSN and candidates for the 24th IDSN, the number of lines with strong gluten was higher than 80% (Table 5).

Table 4. Individual plants evaluated for gluten strength and yellow pigment content (Yaqui 1990-91 crop cycle).

		No. of plants evaluated	Discarded
F3	Individual		
	SDS-Sedimentation	8865	63%
	Pigment	3272	46%
F3	Quality Group		
	SDS-Sedimentation	4942	37%
	Pigment	3098	45%
F6	Individual		
	SDS-Sedimentation	5548	40%
	Pigment	3300	44%
Total			
	SDS-Sedimentation	19805	48%
	Pigment	9670	45%

Yellow pigment content--For many countries, yellow pigment content is one important quality parameter in durum wheat. A high yellow pigment content is necessary to obtain pasta products with a desirable, bright yellow color.

Table 5. Percentage of lines from the 22th IDSN and candidates for the 24th IDSN with high values for SDS-Sedimentation and pigment content (Yaqui 1990-91).

	SDS-Sedimentation (> 9 cc)	Pigment (> 8 ppm)
22th IDSN = 157	82%	57%
Candidates, 24th IDSN = 208	84%	37%

For the evaluation of yellow pigment in the individual plants, CIMMYT uses the standard method of the American Association of Cereal Chemists 14-50 (AACC 1983), with the following modifications:

AACC Method 14-50	**CIMMYT Wheat Quality Lab**
• Weight: 8-g sample,	• Weight: 3-g sample,
• Add 40 ml reagent,	• 15 ml reagent,
• Let stand 16-18 hrs,	• Shake 1 hr,
• Filter through Whatman No. 1 filter paper,	• Centrifuge at 7000 rpm for 5 minutes,
• Determine yellow color in clear extract.	• Determine yellow color in clear supernatant.

These modifications allow evaluation of a large number of individual plants with small amounts of seed. Only plants with a pigment content equal to or higher than that of the quality check are selected.

From the Yaqui 1990-91 cycle, close to 10,000 plants in the F3 and F6 were evaluated for pigment color; 45% were discarded (Table 4). Of the lines from 22th IDSN and candidates to the 24th IDSN, the number of lines with good yellow pigment was 57 and 37%, respectively (Table 5).

Spaghetti processing

When lines become commercial variety candidates, a complete evaluation for spaghetti quality is performed. Samples are milled on a Brabender Quadrumat Jr. Mill; only corrugated (breaking) rolls are used. Prior to milling, the wheat is tempered overnight to a 15.5% moisture content. The whole milling products are sifted for 7 sec. on a rotomatic sifter equipped with 30W and 100W sieves to separate semolina from the other ground material. The "overs" on the 30W are bran; the "throughs" on the 100W are flour; the "middle overs" on the 100W and "throughs" on the 30W are semolina.

The semolina samples are processed into spaghetti using a Namad vacuum pasta extruder. The samples are processed with an absorption of 34.5% and extruded through a Teflon spaghetti die. Spaghetti is dried in an experimental pasta dryer for 18 hr. During the drying period, the humidity of the dryer decreases from 100 to 70% R.H. while the temperature is held constant at 40°C.

Spaghetti cooking quality is evaluated at optimum (10-12 min.) and overcooked (15 min.) cooking times. Cooked spaghetti is evaluated for firmness and stickiness. The data are made available to the breeders so that they can define which lines to use in their crosses and which ones to discard.

Recently Selected Lines

Table 6 lists five lines with good quality selected during the Yaqui 1989-90 cycle.

Table 6. Quality characteristics of some agronomically good durum wheat advanced lines (Yaqui 1989-90).

Cultivar	Yellow pigment (ppm)	SDS sediment (cc)
KKV5/AIX'S' CD76892-0GH-1YRC-1M-0Y-REC	8.2	12.5
LUGLUG/ALTAR 84 CD-80518-D-6Y-0H-DARG-2PA-0Y	7.5	12.5
SRN/CHUR'S'/HUI'S'//POC'S' /4/MOEWE CD81175-M-6Y-0H-OARG-2PA-0Y	6.3	12.0
RASCON CD83484-B-1M-0YRC-0REL-1PA-0Y	7.6	13.5
ACONCHI 89	6.6	11.5

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Dick, J.W., and J.S. Quick. 1983. A modified screening test for rapid estimation of gluten strength in early generation durum wheat breeding lines. Cereal Chemistry 60:315.

WIDE CROSSES AT CIMMYT WITH A DURUM WHEAT FOCUS

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Introduction

Major emphasis of CIMMYT's Wheat Wide Crosses Section over the past decade had been with bread wheat for both intergeneric and interspecific alien introgression. Recently, research interests have been directed towards incorporating alien chromatin into durum wheats, an area that has been actively pursued over the past 2 years.

For such a program to be viable, certain prerequisites exist. These are (recognizing the objectives):

- Production and validation of hybrids,
- Encompass intergeneric and interspecific areas, and
- Support to the above areas with novel techniques.

This paper briefly discusses some developments.

Intergeneric Hybrids

Durum wheats (Laru, Chen, Altar, Memo/Mex, Cndo/Ente//Memo/ Mex, and Aconchi) have been hybridized with alien species belonging to the following groups:

- *Thinopyrum* (perennial),
- *Psathyrostachys*, (perennial),
- *Elymus* (perennial), and
- *Aegilops* (annual).

Some F_1 hybrids have been colchicine-doubled. No hybrid combination gave meiotic evidence of wheat/alien chromosome recombination, hence genetic manipulations will be a necessity. Table 1 lists some of the crosses made between durum wheats and alien species.

Interspecific Hybrids

Findings reported by researchers and our observations with haploids of wheat cv. Chinese Spring (*ph* mutant for high pairing) support the preferential pairing between the A and D genomes, leaving the B genome quite dissociated. In durums, such a *ph* high pairing system exists in cv. Cappelli. Hybrids between Cappelli (*ph*) and *Triticum tauschii* accessions (identified for biotic/abiotic resistances/tolerances) are to pave the way for demonstrating D genome transfers to the A genome and through this bridge hopefully enrich the durum wheats. Our current emphasis is on crossing the susceptible durums to *H. sativum*- and *F. graminearum*-resistant *T. tauschii* accessions identified from field screening of synthetic hexaploids.

Table 1. Intergeneric durum wheat/alien species hybrids/amphiploids produced at CIMMYT.

Durum cultivar	Fertile amphiploid produced	Alien species	F_1 somatic count	Resistance/ tolerance attributes
Yavaros 79		*Th. acutum*(6x)	35	BYDV
Yavaros 79		*Th. intermedium*(6x)	35	BYDV
Yavaros 79		*Th. varnense*(6x)	35	BYDV
Cocorit 71	Yes	*Th. pulcherrimum*(6x)	35	BYDV
Mexicali 75	Yes	*Th. trichophorum*(6x)	35	BYDV
Cocorit 71	Yes	*Th. junceiforme*(4x)	28	Salt
Cocorit 71		*Th. junceum*(6x)	35	Salt
Mexicali 75		*Th. podperae*(6x)	35	Salt
Altar 84		*Th. scirpeum*(4x)	28	Salt
Cocorit 71		*Th. campestre*(8x)	42	Salt
Cndo/..../Mex.		*Ps. juncea*(4x)	28	BYDV, salt, drought
Cocorit	Yes	*E. fibrosus*(4x)	28	*H. sativum*
Yavaros		*Th. elongatum*(2x)	21	Salt
Laru	Yes	*Ae. variabilis*(4x)	28	Al^{+++}, KB
Gan	Yes	*Ae. umbellulata*(2x)	21	KB
Gan	Yes	*Ae. ovata*(4x)	28	KB
Gan	Yes	*Ae. ventricosa*(4x)	28	KB, salt
Gan	Yes	*Ae. vavilovi*(6x)	35	Salt

Hybrids between durum wheats and A genome species (*T. monococcum*, *T. boeticum*, and *T. urartu*, all 2n=2x=14) have been produced. The program needs further development, but the potential of exploiting the A genome traits missing in durums or adding diversity to existing genes is very high.

Hybrids between *T. dicoccum* accessions resistant to the Russian wheat aphid (RWA) (screening data from Germplasm Bank) and susceptible durums are being produced. Into this simplistic cross, backcrossing to elite durum parents and achieving homozygosity through haploidy is projected. The haploid procedure involves durum x maize or durum x *Tripsacum*; procedures routinely used in CIMMYT wheat wide crosses.

Special Areas

Haploid production

Crosses between durum and maize or durum x *Tripsacum*, assisted by 2,4-D application and embryo rescue, have yielded durum polyhaploids with 14 chromosomes. With maize, the embryo recovery percentage is 16.9% (11.8-22.2), with 73.9% plantlet regeneration and 69.5% colchicine induced doubling. With *Tripsacum*, embryo recovery is 26.8% and regeneration is 66.7%. No doubling was attempted for this experiment since it was no longer considered a constraint.

Near isogenic line development

Bread wheat germplasm has received considerable advantage from the 1B/1R chromosome translocation for yield attributes associated by its presence. Unequivocal answers supporting the 1B/1R contribution can be made through evaluation of near-isogenic lines. While these are being developed for bread wheats, several durum wheats are being made recipients of the 1B/1R chromosome. An Altar 84 isogenic line is at the BCVIII selfing stage from which Altar 84 (1B, 1B:Extracted) and Altar (1B/1R, 1B/1R) shall be obtained. There is another batch of eight durums in early BC stages. The 1B, 1B/1R heterozygote was diagnosed by C-banding and GPI isozyme assay.

RECOMBINATION PATTERN AND CHIASMA INTERFERENCE IN TETRAPLOID WHEAT

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Introduction

Evidence accumulated over the years has suggested a considerable distortion between physical and genetic location of genes in wheat. In general, genes tightly linked to the centromeres were physically localized in much more distal physical positions. A good example is the *Ph1* gene on chromosome arm 5BL which was mapped within 1 cM of the centromere (Sears 1984), but was physically located in the middle of the arm (Jampates and Dvorak 1986). On the other hand, physical distances in distal chromosome regions are overly extended on genetic maps. The satellite of chromosome 1B, which occupies distal about 30% of the 1BS arm contributes about 80% of that arm's genetic map length (Snape et al. 1985). Because very few genes in wheat have been mapped both genetically and physically, the evidence on the distortion between physical and genetic distances is only fragmentary. However, polymorphism for physical attributes of chromosomes, like C-bands or translocation breakpoints, when used in classical genetic mapping, allows an instantaneous integration of physical and genetic maps and thus a precise study of relationships between genetic and physical distances.

Materials and Methods

In this study, polymorphism for C-banding patterns among different accessions of *Triticum dicoccoides* and between *T. dicoccoides* and *T. durum* 'Langdon' was used to study the recombination in 67 segments in chromosome arms 1BS, 1BL, 2BS, 2BL, 3BS, 3BL, 5BL, 6BS, 6BL, 7BS, and 7BL (Figure 1). The analysis was performed in both F_2 and backcross progenies and up to three chromosomes were studied in any single hybrid combination. The segments varied in length from 3% to 70% of the relative arm length. The total number of chromosomes analyzed was 916.

To study the effect of the physical arm length on the distribution of recombination, the 11 chromosome arms were divided into two classes of physically short (1BS, 2BS, 3BS, 6BS, 6BL, and 7BS) and physically long arms (1BL, 2BL, 3BL, 5BL, and 7BL).

Results

The results demonstrated that the frequency of recombination in wheat chromosomes increased exponentially with the distance from the centromere. Among all chromosomes analyzed, the single most proximal recombination event was detected in a segment between 18.4 and 37.4% of the relative arm length from the centromere. No recombination was detected in segments ending closer to the centromere. In all arms analyzed recombination was absent in the proximal regions and was concentrated in the distal regions. There were no statistically significant differences in this pattern of recombination between different chromosome arms studied. However, significant differences in recombination frequencies were observed for the same segments in different hybrid combinations. Two-fold or higher differences in recombination frequencies were common. This probably reflects variation in the pairing affinity between different homologous chromosomes and suggests that genetic distances should not be treated as constant values. Instead, they appear specific only to a given hybrid combination.

The analysis of regression of recombination frequency over physical distances indicated that the proportion of distal recombination was higher and of proximal recombination was lower in the physically short than in the physically long arms (Figure 2). The genetic maps of the short arms are derived almost exclusively from recombination in the distal 25-30% of arm lengths. In physically long arms, while again recombination was concentrated in the distal regions and absent in the proximal regions, the interstitial regions showed a consistently detectable low level of recombination and hence, contributed to the lengths of their genetic maps. The lengths of genetic maps obtained in this study corresponded very closely to those calculated on the basis of the cytologically observed chiasma frequencies (Salle and Kimber 1978). This is in contrast to RFLP maps which in general exceed the expected lengths by wide margins.

While no recombination was observed in the proximal regions of chromosome arms there appears to be no reason to believe that these regions are inherently incapable of crossing over. Analysis of metaphase I pairing of wheat chromosomes deficient for up to 50% of their relative arm length has demonstrated that the proximal halves of the arms are fully capable of MI pairing and chiasma formation (Curtis et al. 1991). A pattern of recombination skewed toward the distal regions may instead be related to the telomeric initiation of pairing. Such initiation of pairing would conceivably offer a greater opportunity for the formation of distal chiasma. Once a distal chiasma is established positive chiasma interference would restrict the formation of a second, interstitial chiasma.

Positive chiasma interference was observed in all combinations studied. In 35 pairs of adjacent segments in which any recombination was detected the interference level was calculated at 0.81. When the shorter segments were consolidated into two longer segments covering the entire recombining portions of chromosome arms the interference value was 0.57. This means that in the entire recombining portions of wheat chromosomes only 43% of the expected double cross-overs actually occurred. The reduction in the interference value over distance may explain the differences in the pattern of recombination between the physically short and long arms. In long arms, sufficient physical distance may exists for interference to weaken to the point where a second, interstitial chiasma may occasionally be established.

There is some fragmentary evidence indicating that recombination is concentrated distally also in the A- and D-genome chromosomes in wheat. Use of C-banding polymorphism in genetic mapping showed that this is also the case in rye (Lukaszewski 1992) and in barley (Linde-Laursen 1982). That all these species also have distinctly terminal chiasmata in metaphase I suggests there may be no chiasma terminalization.

Conclusions

The strong tendency of wheat chromosomes to form only a single chiasma in the terminal regions of chromosome arms may explain some of the strong linkages observed in breeding programs. Strong genetic linkage may be a result not only of close physical proximity of genes but, perhaps more frequently, a result of their location in non-recombining portions of chromosome arms. Genes located in these regions would always segregate as a block with little opportunity for recombination.

If linked genes are located in a nonrecombining portion of a chromosome an increase in the size of a segregating population may not necessarily improve chances of breaking the linkage. Preliminary observations indicate that the pattern of distal recombination in wheat may be changed experimentally. Premeiotic applications of weak solutions of colchicine significantly increased the ratio of proximal to distal recombination in wheat (Curtis, unpublished). It is believed that colchicine disturbs the normal alignment of telomeres at the nuclear membrane and thus reduces the strong tendency for telomeric initiation of synapses. Consequently, if pairing initiation is less restricted there may be more chance for the formation of interstitial or proximal chiasmata. If the speculations on the mode of action of colchicine are correct, a similar effect could be obtained by properly timed heat shocks or by manipulation of the dosage of the *Ph* genes.

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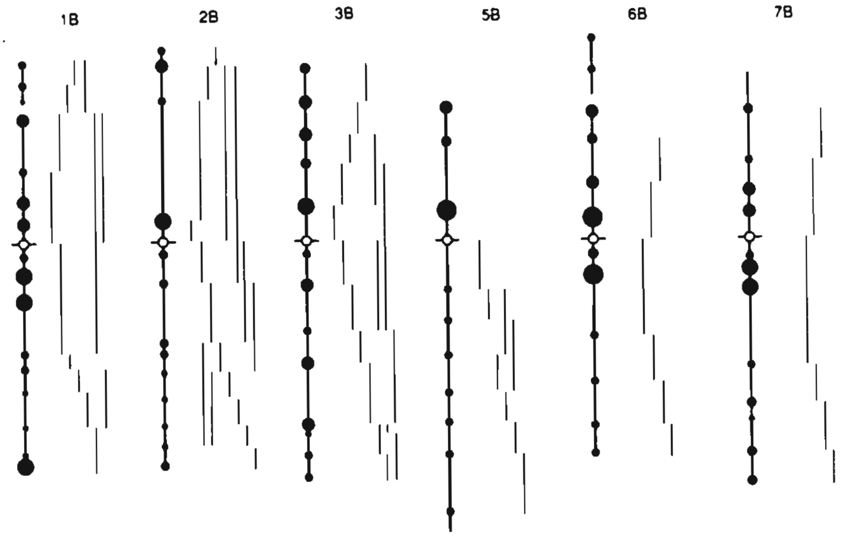

Figure 1. Schematic diagram of C-band positions and the distribution and physical lengths of 67 segments on chromosomes 1B, 2B, 3B, 5B, 6B, and 7B in which recombination was monitored. Centromere positions are indicated by open circles.

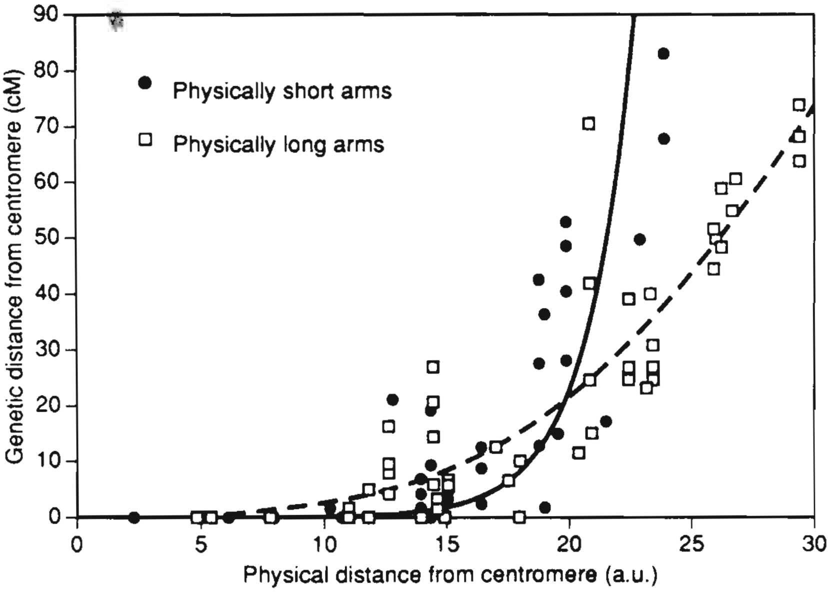

Figure 2. Relationship between genetic and physical distances in physically short (1BS, 2BS, 3BS, 6BS, 6BL, and 7BS) and physically long (1BL, 2BL, 3BL, 5BL, and 7BL) chromosome arms in tetraploid wheat. Physical length expressed in arbitrary units (a.u.).

CLOSING REMARKS

ICARDA, J. Hamblin

The selection environment is very important. There is no hope of selecting in one environment for progress in another. One must select in the environment being targeted. The pattern of environment available determines the selection procedure.

Like John Clarke in Canada, we are pushing for F_4 yield trials. Some breeders are getting their first yield indications at F_7--that is too late. In the mega-environment where water stress is a key issue, one has to measure yield early. Early generation screening is the key. Also, whenever testing near the limit, one must have the best trial possible.

One final point: CIMMYT has had an enormous impact in training. However, I believe we must make sure we are providing a series of options to trainees based on the ME they will be returning to back home.

I would like to thank CIMMYT for organizing this very informative international workshop on durum wheats.

CIMMYT, R.A. Fischer

Durum wheats are generally grown under dry conditions: WANA, Turkey, central India (even drier than Swift Current, Saskatchewan), Ethiopia, Bolivia, and Argentina. Some wet niches are in Mexico, Chile, and pockets of West Asia and North Africa (WANA). Dry areas will dominate for the durums even more in the future. So the important question is: are we selecting in the right way?

Unlike bread wheats, our statistics appear to be poor for durum wheats in developing countries. I urge M. Nachit in Syria to obtain statistics on the adoption of the new wave of durum wheat varieties coming out of the ICARDA-CIMMYT effort.

Durum wheat breeding issues

The following are some breeding issues I think we should contemplate:

- Yield--should we have early generation yield testing in developing country dry areas?

- Winterhardiness--Do we push for it? If durums are already growing in a particular area under question, I would suggest no.

- Acid soils--As I stated earlier, we do not need a new challenge of introducing durums into acid soil areas.

- Diseases--How much emphasis do we place on them since durums are grown mostly in the dry areas?

- Quality--I was struck by how fussy the developed world has become. When a country moves to the export market, quality requirements go up by a factor of 10! Do we need to worry about protein? I believe a protein standard is pushed by the industry because it is easy to measure. About 20% of this meeting was on quality. Are we giving quality too much emphasis?

- Salt tolerance--This was not mentioned at this meeting. I say good, let's not worry about it.

How do we move forward?
A number of persons at this meeting have voiced a need for earlier yield trials. Should we have a joint screening nursery where we can have a rational distribution of materials and provide an easier comparison of our two different screening methodologies?

Can we cut our investment by giving less emphasis to quality and certain diseases? For example, perhaps an advanced institution in a developed country could help us with tan spot.

One final point: It is quite conceivable that the IARCs will be asked to take on collaboration with some of the new Soviet countries where there are more than 2 million hectares of spring durum wheats.

PAPER ABSTRACTS

Breeding Durum Wheat at CIMMYT

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Page 1

Durum wheat is cultivated on approximately 17 million hectares worldwide, representing only 8% of the world's total wheat area. The crop's importance stems from its concentrated production in localized areas in developing countries where it is the main staple food. This paper outlines CIMMYT's objectives and breeding methodology for durum wheats. Achievements and progress in increased yield potential, drought tolerance, and improved grain quality are presented. Current and future challenges involving the yield gap and marginal and nontraditional areas are discussed.

Durum Wheat Breeding for Mediterranean Drylands of North Africa and West Asia

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Page 14

Durum wheat grain is included in most dishes and food products consumed in the West Asia and North Africa (WANA) region with consumption of such traditional products as burghul, frike, couscous, pasta being highest in rural areas. This paper outlines the agro-ecological zones for durum wheat in WANA and outlines the breeding methodology of the CIMMYT/ICARDA Cooperative Program in the region. Breeding for drought tolerance, disease and insect resistance, and improved grain quality are addressed. Recent varieties emanating from the cooperative program are listed.

Impact of Durum Wheat Breeding in the Third World: A Dilemma for the Future

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Page 28

This paper provides a global overview of the impact of durum wheat improvement research in the Third World with particular reference to the work undertaken by CIMMYT. Evidence convincingly shows CIMMYT's work in durum wheats has had a spectacular impact in irrigated and well watered environments. However, at the same time, impact to date in dryland areas has been disappointing. This is despite many years of research focussed on developing varieties for these more marginal areas. This raises an important dilemma--what should be CIMMYT's relative emphasis in the future in breeding for these very difficult environments. This paper also suggests that the 11 to 12 million hectares of durum wheats grown in developing countries cited by some authors are an overestimate.

Durum Wheat Breeding in India

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Page 44

Durum wheat accounts for around 8% of India's total wheat area. Durums are used mainly in preparing semolina known as dalia, unleavened bread (chapati), and various sweet and salty preparations. High susceptibility to stripe rust has resulted in the total elimination of durum wheats in several parts of the country. Rainfed durum cultivation is now confined to the peninsular and central states. The durum wheat improvement effort in India is described and 10 varieties currently recommended to farmers are listed. The main aim of durum wheat breeders in India will be to continue developing new varieties that are stable, high yielding, rust resistant, and of high grain quality.

Production Constraints of Durum Wheat in Ethiopia and Use of Ethiopian Durum Landrace Varieties in Breeding

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Page 49

Ethiopia is considered to be the center of genetic diversity for durum wheat. Production is concentrated in the central and northwestern parts of the country under rainfed conditions at altitudes between 1800 and 2800 meters above sea level. Of 700,000 hectares of wheat currently under production, it is estimated that 60% is planted to durum wheat. Although nearly all of the durum wheat varieties grown in the country are landraces with location-specific adaptation, very limited activities have been carried out to utilize this indigenous germplasm in local improvement. Production constraints involving farmers' practices, available varieties, soil fertility, diseases and pests, and low prices are discussed.

Breeding for Grain Yield and Quality of Durum Wheat in Australia

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Page 58

Australian durum wheat production is small by comparison with that for bread wheat (i.e., 0.5% of the total). Since the mid-1970s, durum wheat production has increased rapidly from about 8000 tons annually to 80,000 tons in 1992. Most durum wheat is grown in northwestern New South Wales with smaller amounts in southern Queensland and southeastern South Australia. This paper discusses grain production as it is related to soils, rainfall, and sowing time. Durum breeding activities and objectives in Australia are outlined.

Facultative and Winter Durum Wheat Breeding in West Asia and North Africa (WANA)

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Page 63

The primary breeding objectives for facultative and winter durum wheat improvement reflect WANA environments in which their production is intended, i.e., cold winters and hot, dry summers. This is why winterhardiness is of primary importance to allow survival of autumn-sown crops followed by a targeted maturity to avoid late occurring frosts during anthesis while providing early physiological maturity to avoid hot, dry desiccating summer conditions. National breeding programs in Turkey, the Commonwealth of Independent States (former Soviet Union) and the Balkan countries are briefly discussed.

Utilization of Genetic Resources in Durum Wheat Improvement

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Page 66

One of CIMMYT's major objectives is increasing farm-level productivity while safeguarding against genetic vulnerability. The preservation, evaluation, documentation, enhancement, and easy availability of genetic resources are central to those ends. Genetic variability is available from different collections of durum wheat around the world. The CGIAR wheat collections found at CIMMYT and ICARDA are part of this worldwide system. The CIMMYT wheat collection presently consists of about 100,000 accessions of which 14,835 accessions of *Triticum durum*, *T. dicoccon*, and *T. carthlicum* have direct application to durum wheat improvement. Approximately 34% of the durum accessions are landrace cultivars; another 36% are CIMMYT-derived advanced lines that have entered the international nursery system.

Durum Wheat in South America

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Page 70

This paper deals with the durum wheat needs and potential of five South American countries: Argentina, Bolivia, Chile, Peru, and Brazil. The first four countries produce sufficient quantities of durum wheat to satisfy their domestic needs. Brazil, which consumes many pasta products, either imports them directly or makes them from bread wheat like many other countries. There is room for market expansion and the five countries have durum wheat breeding programs of varying abilities. However, the amount of genetic variability available for required characters has not been rapidly forthcoming. There are strong indications that the expansion of durum wheat area in South America has been primarily limited by diseases. If any area expansion in the region is to take place, availability of disease-resistant germplasm will be the key.

Stem Rust and Leaf Rust Resistance in Durum Wheats

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Page 82

Stem rust and leaf rust resistance genes have been found on most chromosomes of wheat. It is interesting to note that most of the loci for leaf rust genes are on the B and D genomes. Virulence of *Puccinia graminis* f.sp. *tritici* (stem rust) to durum cultivars has not been a real concern in many countries as many cultivars are resistant. It seems that we know little about stem rust resistance existing in durum wheat. In recent years, little effort has been expended on developing resistance. One of the missing links is a durum wheat susceptible to all races. Virulence of *P. recondita* f.sp. *tritici* (leaf rust) to durum wheats has not been considered a major problem in the United States and Canada. Most studies of virulence to durum wheat have involved tests to determine the potential value of durum resistance for improving bread wheat cultivars.

Durum Wheat Diseases in West Asia and North Africa (WANA)

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Page 89

Durum wheat diseases are the same as bread wheat except for some peculiarities of the agroclimatic areas where they are grown and for the host preference demonstrated by the pathogen. Major durum wheat diseases in the WANA are stripe rust stem rust, septoria tritici blotch, common bunt, barley yellow dwarf, and powdery mildew. Foot rot, root rot, and bacterial leaf streak are becoming more important. The level of resistance to the major diseases in the durum wheat germplasm can still be improved, especially that of leaf rust. Identification/postulation of resistant genes in the established germplasm pools for sources of resistance to diseases is essential. This will give a better understanding of the genetic basis used in the breeding programs of the WANA region. This paper presents methodologies for screening for resistance of the major diseases and conveys recent achievements.

Tan Spot of Durum Wheat

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Page 108

The leaf spot disease known as tan spot or yellow spot (*Pyrenophora tritici-repentis* Died. Drechs.) has recently become a concern of durum wheat growers and allied scientists internationally. Tan spot incidence is more common now than formerly, probably because wheat straw is more frequently being left on fields as a crop residue. This paper briefly reviews the biology of tan spot and discusses the development of resistant durum cultivars. Additional information on these topics can be found in the reference list.

Septoria Diseases of Durum Wheat

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Page 115

The septoria diseases of wheat predominate in the Mediterranean area and in similar environments in other part of the world when environmental conditions are favorable. Disease development is favored with high rainfall of 700 mm and above. *Septoria tritici*, the causal agent of septoria leaf blotch has been identified as a major problem in durum wheat growing areas. This paper concentrates on S. tritici and its virulence patterns and resistance in durum wheat and other *Triticum* spp.

Breeding Disease-Resistant Durum Wheats in Western Canada

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Page 125

This paper focuses on efforts to develop durum wheat cultivars with adequate disease resistance for western Canada. Diseases discussed include stem rust, leaf rust, bunt, kernel smudge/black point, loose smut, tan spot, fusarium head blight, septoria leaf plot, common root rot, wheat streak mosaic virus, and barley yellow dwarf virus. For a number of these diseases, efforts have been quite recent and results are still forthcoming.

Karnal Bunt and Durum Wheat

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Page 129

The most important objective of Karnal bunt research at CIMMYT has been to identify sources of resistance to *Tilletia indica* that could be used by CIMMYT breeders to develop advanced lines for national programs, especially for those countries where KB is a problem. Durum wheats and triticale have shown to be more resistant to T. indica than bread wheats. It is important to point out that in recent tests some durum lines have not been in the resistant category. In general, durum wheat resistance to KB, along with durum's high yields, have had important implications at the commercial level in Mexico. In large areas of northwestern Mexico, durum wheats have replaced KB-susceptible bread wheats.

Wheats for Dry Environments

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Page 133

Empirical or conventional plant breeding has a proven record of improving yield in dry growing conditions. Yield improvements in particular macro-environments have arisen from direct selection for yield and agronomic traits such as maturity within those environments. A common strategy involves careful planning of crosses and multi-location selection for yield in early generations. Early identification of well adapted lines is desirable. Efforts are ongoing to improve methods of selection for improved adaptation to dry growing conditions. Progress is dependant on maximization of heritability of yield in the target environments, which is being addressed in studies to determine the best environments for selection, and in use of improved statistical tools such as spatial or neighboring models to improve the accuracy of yield determination. The analytical approach has so far failed to make large direct contributions to improved yields of wheat in dry environments. This can be attributed to the failure of most physiological investigations to be carried to the point of evaluating enough genotypes to measure heritability and genetic correlations, and to the very quantitative nature of the inheritance of yield. Concerted efforts may change this in the future, but the chances of obtaining the massive resources required to do so appear somewhat remote at present. The extent to which physiological knowledge has contributed to breeders' ideotypes and choice of parents is not easily quantifiable, but may be substantial.

Durum Wheat Yield Potential in Mega-Environment 1

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Breeders, in general, are pre-occupied with applying selection strategies that lead to continued increases in genetic yield potential--and durum wheat breeders at CIMMYT are no exceptions. Continued improvements in genetic yield potential have been an especially important selection criterion for favorable high-yield environments. This paper attempts to outline progress that has been made over the past 25 to 30 years in breeding for increased yield potential for durum wheat at CIMMYT. Relevant comparisons to improvements in bread wheat yield potential are made. The results clearly indicate the remarkable progress that has been made over the past 40 years in increasing genetic yield potential for durum wheats as well as bread wheats under the conditions of ME 1. This advance in yield potential has been directly reflected in increasing yields in farmers' fields. The increase in yield potential in bread wheats, at low as well as high N levels, is noteworthy as well.

Quality Evaluation of Lines Derived from Crosses of Langdon (*Triticum dicoccoides*) Substitution Lines to a Common Durum Wheat

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Protein quality (gluten strength) and grain-protein quantity affect the quality of pasta extruded from durum wheat (*Triticum turgidum* L. var. *durum*). Previously, an accession of wild emmer (*T. turgidum* L. var. *dicoccoides*) having high protein content was used to develop a complete set of 'Langdon' (*T. dicoccoides*) [LDN(DIC)] substitution lines. This study was conducted to assess the potential of using these LDN(DIC) substitution lines as parents for deriving lines with increased protein content and acceptable gluten strength. Each of the 14 substitution lines and the original LDN parent was crossed to a common male parent 'Vic'. Parents and F_2-derived F_4 lines were grown in replicated trials at two locations in 1989. The comparison of population means and genetic variances to those of the base population were used to identify those substitution lines conferring quality characteristics (protein content and gluten strength) and their potential use in a breeding program. Indications are that selected LDN(DIC) substitution lines, especially LDN(DIC-5B) an LDN(DIC-6B), when crossed to a strong gluten parent, may be useful in deriving lines with both increased protein quantity and quality.

Utilization and Quality of Durum Wheat

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Durum wheat quality plays a significant role in the acceptability of new varieties. Genetic diversity of germplasm where quality is concerned is the main goal of the CIMMYT wheat quality laboratory. Priority quality traits of grain size, vitreousness, gluten strength, and yellow pigment content are discussed. The evaluation process for evaluating spaghetti quality is reviewed.

Wide Crosses at CIMMYT with a Durum Wheat Focus

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This paper briefly discusses some developments in the work of the CIMMYT Wide Crosses Section involving intergeneric and interspecific hybrids, haploid production, and near-isogenic line development. Durum wheats have been hybridized with alien species in the *Thinopyrum*, *Psathyrostachys*, *Elymus*, and *Aegilops* genera where traits being sought include resistance to BYDV and *Helminthosporium sativum* and tolerance to salt, drought, and aluminum. In interspecific work, hybrids between the durum wheat Cappelli and *Triticum tauschii* accessions are paving the way for demonstrating D genome transfers to the A genome; through this bridge an avenue for improving durum wheats will be found. Crosses between durum wheat and maize or durum x *Tripsacum*, assisted by 2,4-D application and embryo rescue, have yielded durum polyhaploids with 14 chromosomes.

Recombination Pattern and Chiasma Interference in Tetraploid Wheat

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Evidence accumulated over the years has suggested a considerable distortion between physical and genetic location of genes in wheat. In the present study, polymorphism for C-banding patterns among different accessions of *Triticum dicoccoides* and between *T. durum* 'Langdon' and *T. dicoccoides* was used to study the recombination in 67 segments in 12 chromosome arms. The results demonstrated that the frequency of recombination in wheat chromosomes increased exponentially with the distance from the centromere. There is a strong tendency of wheat chromosomes to form only a single chiasma in the terminal regions of chromosome arms. This may explain some of the strong linkages observed in breeding programs.

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