Wheat Breeding in Mexico and Yield Increases

R. A. Fischer

P. C. Wall

Summary

This paper examines spring wheat breeding in Mexico from the point of view of the biological factors associated with recent yield increases and discusses the likelihood of further progress. Studies of old and new varieties, planted together at various levels of soil nitrogen, suggest that the dramatic yield jump of the 1960s in north-west Mexico can be attributed almost equally to increased soil fertility, greater resistance to lodging and, finally, other desirable characteristics closely associated with the Norin 10 dwarfing genes which are universally found in the newer short-statured wheats. Future progress in yield potential is likely to be much slower.

International experiments, while demonstrating the broad adaptability of the Mexican wheats, indicate slower progress in the recent past, probably because of the generally less favourable test environments involved. Nevertheless, there have been sharp rises in national productivity as a result of the spread of a few key Norin 10-derived semidwarf genotypes, derived directly or indirectly from Mexico. The implications for future progress in breeding as a result of the major restraints on productivity found in such situations, namely water, disease, nitrogen and weeds, are discussed.

Introduction

Sharp increases in yield over the last 10 years or so in bread wheats in certain countries, particularly Mexico, India and Pakistan, have been generally attributed to improved agronomic practices, such as heavier fertilization and better watering, combined with new short-statured wheats. Putting aside the socio-economic problems that some believe seriously limit the value of this so-called 'green revolution' in wheat, it is useful to attempt to quantify the biological factors, notably genetic change, that have led to this yield progress, and to examine the possibilities of further progress. This is especially timely in Australia, where we are now seeing for the first time extensive sowings of semidwarf wheats, e.g. the new cultivars Condor, Oxley, Egret and Kite (Pugsley 1974).

Although the breeding of semidwarf winter wheats has been in progress for many years in Japan, Italy and U.S.A., the introduction of dwarfing genes into spring wheats has been dominated until recently by the Mexican wheat-breeding program. This involved initially the Oficina de Estudios Especiales and, at a later date, the wheat program of the Instituto Nacional de Investigaciones Agricolas (INIA) of the Mexican Government in cooperation with that of the International Maize and Wheat Improvement Centre, commonly known as CIMMYT. The dwarfing genes used were derived largely from the Japanese line Norin 10, by way of the winter wheat breeding program in the State of Washington, U.S.A. (Rietz and Salmon 1968). Mexico, through the distribution of pure lines and segregating populations, has in turn supplied the

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Dr Tony Fischer was on the staff of the International Maize and Wheat Improvement Centre (CIMMYT) in Mexico from 1970 to 1975 as a physiologist/agronomist in the wheat program. He is presently a Reserve Bank Senior Research Fellow (Agriculture) in the Division of Plant Industry, CSIRO, Canberra.

Pat Wall graduated B.Agri.Sc. from the University of Rhodesia in 1967 and M.Sc. Reading University in 1972. He joined the wheat program of CIMMYT as a physiologist in 1975.

dwarfing genes from which most of the short-statured spring wheats presently being grown in the world were derived by crossing and/or selection. It is therefore appropriate that an analysis of progress be based on experiments conducted within the Mexican breeding program, in this case the wheat physiology and international nursery sections of CIMMYT. The physiology experiments involved old and new Mexican wheat cultivars grown in north-west Mexico under various levels of agronomy during the period 1970–75. The international trials, containing a wide selection of world spring wheat cultivars, have been sent each year since the early 1960s to many sites in the world.

TABLE 1

Mean temperature and mean daily solar radiation for CIANO (27°N), Cairo (29°N), Lahore (31°N), New Delhi (28°N) and Narrabri (30°S)[A]

Month	CIANO (Mexico)	Cairo[B] (UAR)	Lahore (Pakistan)	New Delhi (India)	Narrabri (Australia)
		Mean temperature (°C)			
Nov.	20	20	18	20	15
Dec.	16	16	14	15	11
Jan.	15	14	13	14	10
Feb.	16	15	14	17	12
Mar.	18	18	20	23	15
Apr.	21	21	26	28	20
May	24	26	31	33	24
		Mean daily solar radiation (1y/day)			
Nov.	340	320	390	390	300
Dec.	290	270	310	320	250
Jan.	310	290	320	340	280
Feb.	400	380	410	430	360
Mar.	510	500	510	510	460
Apr.	590	580	610	590	560
May	620	640	660	620	640

[A] For months of the winter cropping season; for Narrabri, in the southern hemisphere the months are actually May to November.
[B] Radiation data from nearby Giza Station.

Experiments in Mexico

Wheat breeders in Mexico conduct two cropping cycles a year under contrasting conditions, a fact that is believed to have contributed to the broad adaptability of the Mexican wheats (Finlay 1968). The experiments reported here were carried out in the winter cropping cycle in north–west Mexico. This is the same season and region in which the bulk of Mexico's wheat is grown and in which the major yield testing effort in the CIMMYT breeding program occurs.

The experimental site, the Centro de Investigaciones Agricolas del Noroeste, widely known as CIANO and belonging to INIA is near Ciudad Obregon in the State of Sonora. It is located within the Yaqui Valley irrigation system, which comprises over 300,000 ha of irrigation on alluvial soils along the east coast of the Sea of Cortes, between 27 and 28°N. Approximately 100,000 ha of wheat are grown annually under climatic conditions representative not only of most of the current wheat–producing regions of Mexico, but also of large parts of the wheat areas of India, Pakistan and the Middle East (Table 1).

The Yaqui Valley climate is semi-arid with a summer peak of rainfall and little rain or cloudiness during the winter cropping season. Wheat is planted in November or early December. Winters are cool, but frosts are uncommon. Temperatures and solar radiation rise steadily as crop maturity is approached in April. The wheat crop receives five or six irrigations for a total of about 500 mm water, and is presently heavily fertilized (*c.* 150 kg nitrogen per ha and 20 kg phosphorus per ha). Weather conditions for the experimental years 1970–75 and general agronomic management of the CIMMYT physiology experiments have been described elsewhere (Fischer 1975).

Wheat breeding began in the Yaqui Valley in the late 1940s. At that time the farmers were growing tall, introduced wheats such as Mentana. New cultivars carried as a suffix the last two digits of the year of release, e.g.

TABLE 2

Heights and relative yields of major cultivars released in the Yaqui Valley, Sonora, Mexico, over the last 25 years (see text)

Cultivar	Height class[A]	Mature height (cm)[B]	Mean grain yield[C] Siete Cerros 66 (%)	Years' data
Yaqui 50	Tall	142	79	3
Nainari 60	Tall	126	89	5
Pitic 62	Single dwarf	109	97	5
Penjamo 62	Single dwarf	105	95	2
Sonora 64	Double dwarf	102	86	4
Inia 66	Single dwarf	107	92	4
Siete Cerros 66	Single dwarf	106	100	5
Potam 70	Double dwarf	92	96	4
Yecora 70	Triple dwarf	84	109	5
Cajeme 71	Triple dwarf	87	106	5
Vicam 71	Triple dwarf	72	105	4
Tanori 71	Double dwarf	103	95	2
Torim 73	Triple dwarf	84	109	3
Jupateco 73	Single dwarf	111	99	2
Zaragoza 75	Double dwarf	98	106	3

[A] Wheat breeders' terminology for dwarf wheats reflecting an estimation of the of dwarfing genes present.
[B] Taken from a single trial in 1974–75.
[C] The mean yield for Siete Cerros 66 over these experiments was 7.2 t/ha. The standard deviations of relative yield for any season calculated from pooling the data for all varieties and years was 7% of the Siete Cerros 66 yield.

one of the first released was Yaqui 50 in 1950. Crossing to sources of the Norin 10 dwarfing genes began in 1955 and the first short cultivars were Pitic 62 and Penjamo 62 (Borlaug 1968). Since the outset, selection has been carried out under irrigation and relatively high soil fertility, as such conditions maximize genetic differences and minimize experimental errors (Krull *et al.* 1966).

A representative set of all cultivars released in the Yaqui Valley were grown together by the CIMMYT physiology section in yield trials under optimal agronomic practices in each of the five experimental years. The data presented in Table 2 were obtained under disease-free conditions and in the absence of lodging which, where necessary, was prevented by growing the taller cultivars through wiremesh. Moreover, adequate border rows surrounded the portion of the plots which was harvested. Table 2 shows progress in yield that has been obtained, albeit under constant and very favourable agronomic practices, as new cultivars have been developed over the last 25 years. The yield increase of *c.* 40% since Yaqui 50 was released was closely associated with reduction in stature, culminating in the production of very high yielding, so-called triple dwarf varieties (about 80–90 cm tall), with a yield potential of around 8 t/ha under the best experimental conditions. It should be emphasized that the superiority of shorter wheats over taller ones even in the absence of lodging (Table 2) has been observed in many experiments.

The data in Table 2 are shown as stepwise progress in Fig. 1*a* which also includes most of the other cultivars released for the Yaqui Valley during the 25-year period. Many of the cultivars, although being short-statured, fall well below the best yielders of any vintage. This probably reflects the lack of extensive yield testing before release — a situation induced by the continuous pressure to keep ahead of the changing leaf and stem rust races, and in response to demands for wheats of different industrial quality.

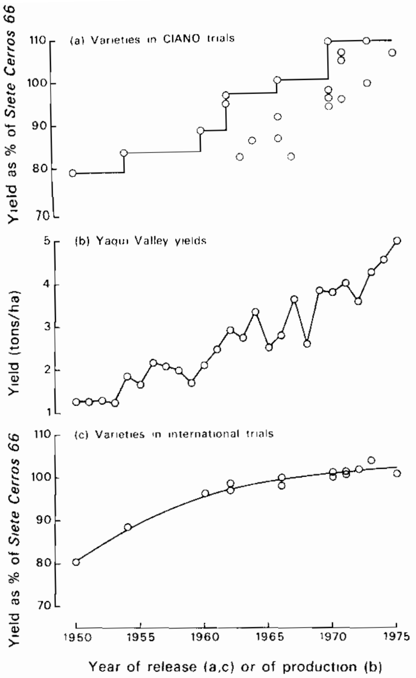


Fig. 1 (*a*) Yield potential as a percentage of Siete Cerros 66 of varieties released in the Yaqui Valley as a function of year of release of the variety. (CIMMYT wheat physiology trials under high fertility irrigated conditions, without disease and lodging.)
(*b*) Time changes in wheat productivity (t/ha) in the Yaqui Valley. (Source: Economia Agricola, Secretaria de Agricultura y Ganaderia, Mexico.)
(*c*) Yield, as a percentage of Siete Cerros 66, of key outstanding varieties in international trials as a function of the year of release of the variety. Mean yield of Siete Cerros 66 in these trials was 3.6 t/ha. (Source: International Spring Wheat Yield Nursery (ISWYN) trial reports, CIMMYT.)

The full extent of the consequences of genetic change are masked in Table 2 and Fig. 1*a* by the lodging protection applied to the taller, old cultivars and by the use of high fertility levels for all varieties. Actually in the 1950s and to a lesser extent in the early '60s, nitrogen applications to wheat were much less than present applications in order to avoid serious lodging. Zero nitrogen in Table 3 was probably representative of soil nitrogen levels for wheat in the farmers' fields in the '50s and 75 kg nitrogen per ha would be representative of today's levels.

At zero nitrogen the tall, old cultivars stood well and showed maximum yields of 3.5–4 t/ha, but the response of these varieties to nitrogen was limited on account of lodging. For example, in an adjacent trial at very high nitrogen, Nainari 60 yielded 4.5 t/ha with lodging and 5.8 t/ha without lodging, while Yecora 70 did not lodge and yielded 7.3 t/ha.

In other words, to see the full extent of the genetic progress, the genetic change must be combined with the change in fertility that it has permitted: this gives a yield change from 3.6 t/ha to 6.7 t/ha according to Table 3 or an increase of 87%.

It is interesting that the average yield of wheat in the Yaqui Valley has shown the same relative increase (Fig. 1*b*). Although these average farmer yields were consistently about 50% less than the experimental yields reported here, the best farmer yields appeared to be within 10% of the experimental yields in each of the 5 seasons.

On the basis of the above experiments Table 4 has been prepared to summarize the progress in wheat yields in Mexico. Obviously, the green revolution was, biologically speaking, a unique example of an agronomic management × genotype interaction and is unlikely to be repeated. The final column of Table 4 attempts to extrapolate beyond the green revolution, beyond 1970 when the first triple dwarf varieties were released.

Several reasons suggest that the projected yield advance of 25% from improvement in other genetic factors (Table 4) is too optimistic. Firstly, the 25% figure for other genetic factors in 1960–70 is probably closely tied to positive pleiotropic effects of the Norin 10 dwarfing genes. In particular, reduced stature represents a more

An aerial view of the CIANO station and Yaqui Valley, Mexico, in April 1975. Approximately 100 ha of cereal nurseries and trials are laid out behind the station buildings occupying the left foreground.

efficient plant type as reflected in the associated increase in harvest index without any reduction in total dry matter production (Aguilar and Fischer 1975). With present day triple dwarf varieties no taller than 80–90 cm there would seem to be limited room for further progress in this direction. Reduction in height to 70 cm should be attempted, especially as 80–90-cm cultivars are giving some lodging problems in farmers' fields. One rather unsuccessful 70-cm cultivar (Vicam 71) has been released; some erect-leaved lines in this height class showed considerable promise in physiology trials in 1974–75. However, reductions in height to below 70 cm appear unlikely to succeed as 50–60-cm wheat currently available show reduced total dry matter production.

In summary, compared to the indirect yield selection via reduction in stature, which was probably a major aspect of progress in the period 1960–70, indirect selection via other less obviously desirable traits, or direct selection for yield, must now be more difficult. A second point here is that Fig. 1*a* shows no evidence of further progress in yield potential since the release of the 1970 cultivars. Considering that varieties are undergoing testing for several years before release and that no outstanding advanced lines were evident in the 1975 tests, it appears that there has been no advance in yield potentials in the last 7 years or so.

To conclude more optimistically one should point out that progress has always been stepwise and that breeders believe the next step in spring wheat yields will soon come from the cooperative winter × spring wheat crossing program initiated in various countries a few years ago (Kronstad *et al.* 1975). At the same time, breeders are now placing greater emphasis on stabilizing present yield levels, via better sources of disease resistance and the use of multilines (CIMMYT 1975). Also physiologists' calculations based on fairly conservative assumptions place the theoretical maximum grain yield for the light

TABLE 3

Grain yield in responses to applied nitrogen for key varieties in absence of disease but without lodging protection[A]
Experiment in 1971–72 season at CIANO

Variety	Grain yield (t/ha, 14% moisture) Nitrogen (0 kg/h)	Nitrogen (75 kg/ha)	Percentage response to nitrogen
Yaqui 50	3.60	4.35	21
Nainari 60	3.85	4.47	16
Siete Cerros, Inia 66	4.30	5.99	39
Yecora 70, Cajeme 71	4.94	6.74	36
Overall response[B] (%)	37	55	

[A] Nainari 60 lodged slightly and Yaqui 50 moderately at 75 kg nitrogen/ha.
[B] Increase of Yecora 70, Cajeme 71 over Yaqui 50 as a percentage of Yaqui 50.

TABLE 4

Estimated progress by decades in experimental wheat yields under irrigated disease-free conditions at CIANO
Data from experiments over the period 1970–75 with Yaqui 50, Nainari 60 and Yecora 70

Source of progress	1950–60	1960–70	1970–80
Soil fertility	Slight	Moderate (+ 25%)	Nil
Lodging resistance	Slight	Moderate (+ 25%)	Nil
Other genetic factors	Slight	Moderate (+ 25%)	Moderate + 25% (?)
Overall yield advance	+ 15%	+ 75% (green revolution)	+ 25% (?)

and temperature regime of the Yaqui Valley at about 20 t/ha (Evans 1973).

International Experiments

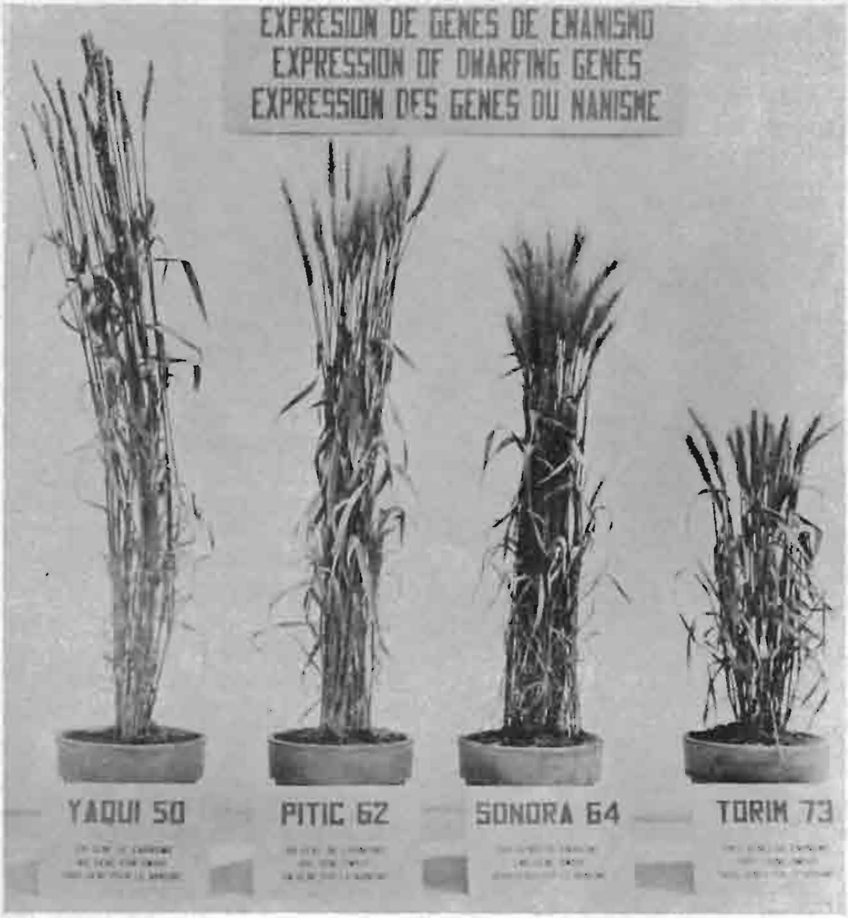
The major series of international experiments sent out annually from Mexico has been the International Spring Wheat Yield Nurseries (ISWYN), initiated in 1964 as an expansion of the Inter-American Wheat Yield Nursery which began 4 years earlier. Presently CIMMYT coordinates the ISWYN and in 1975 the 12th ISWYN was despatched to some 80 sites in over 50 countries. The ISWYN trial contains 50 varieties, drawn from many countries but predominantly of direct or indirect Mexican origin. Sufficient seed of each entry for an approximate plot size of 3 m^2, replicated three times, is sent to each site. Entries change gradually from year to year, but certain key varieties have been retained as recurrent checks. Such check varieties permit the calculation of the points shown in Fig. 1*c*, which has utilized all the above international trials from 1960 up to and including the 10th ISWYN, which was grown largely in 1973 and 1974.

Fig. 1*c* shows only the best varieties of the international trials. With three exceptions these are genetically the same or very similar to the best varieties of the same vintage in Fig. 1*a*, i.e. the varieties released in Mexico. Two of the exceptions are Inia 66 and Jupateco 73, both released in Mexico, where they were not outstanding performers according to the trials at CIANO (Table 2). Internationally, however (Fig. 1*c*) they have done better, being 98 and 104% of the Siete Cerros 66 base respectively. The third exception is the cultivar Anza, released in California in 1972 and closely related to the well-known Australian line WW15 and the cultivars Condor, Oxley and Egret (Pugsley 1974). Anza appears in Fig. 1*c* only; actually in the Yaqui Valley it yields about 97% (4 years' data) of Siete Cerros 66. Anza is also unique in that it is the only one among the cultivars selected and released outside Mexico to have consistently reached a top-yielding position in the ISWYN trials, upon which Fig 1c is based.

Neither Fig. 1*a* nor 1*c* shows one major advance that came early in the Mexican breeding program and has been an essential component of the broad adaptability (high mean yields across many sites) of the wheats in Fig. 1*c*. We refer to the relative insensitivity of these cultivars to day length which permits sufficiently rapid crop development in the short days of low latitude winter plantings. Compared to the day length sensitive wheats from high latitudes, which were grown in the earlier international trials, the insensitive tall wheats from Mexico and Australia, for example, gave an approximate doubling of yield averaged over all sites in these trials.

Following Nainari 60, when the short-statured wheats began to appear, the yield advances in the international experiments (Fig. 1*c*) have not been as great as those seen at CIANO (Fig. 1*a*). In fact the first semidwarf wheat, Pitic 62, represented little advance over the last tall one, Nainari 60, a point often overlooked. The slower yield advance more recently in the international experiments is probably related to two main factors, namely the diversity of the test environments and their less favourable nature.

Insofar as some varietal traits are positive for yield in some environments and negative in others, diversity of environment must restrict progress in broad adaptability and stimulate the development of specifically adapted varieties. Since it is not easy to conceive of such traits, and since few wheat varieties have appeared recently with obvious specific adaptability, diversity of the test environments may not be a major limitation to yield advances in Fig. 1*c*. The easily demonstrable



Plant height classes for Mexican bread wheats. For actual heights see Table 2.

fact that at most test sites the wheat crop is under less favourable environmental conditions than in the Yaqui Valley would seem more important.

The Yaqui Valley has one of the highest mean site yields of all the international trial sites: radiation is high, temperatures reasonably favourable, water and nutrients are rarely limiting, weeds are controlled, and disease is never severe (in fact the data in Fig. 1*a* came from disease-free conditions). It is not surprising that the response to genetic change in yield potential seen in this environment is not fully reflected in the response seen across 80 or more world sites, most of which are less favourably endowed with radiation and water and suffer from pathogens.

On the other hand, the yield-positive traits associated with yield advance in the '60s in Mexico (largely reduced stature resulting from the incorporation of Norin 10 genes), have been associated with some progress, albeit less, in yields under these less favourable conditions. Reduced stature leading to higher harvest index ought to be positive in all environments; lodging resistance should be an added bonus in many environments. Reduced stature could be sufficient to explain the 5% yield gain in the '60s as seen in Fig. 1*c*.

While varietal comparisons in Fig. 1*a* at constant agronomy led to an underestimation of the actual yield advances resulting from genetic change, this, too, is the case in Fig. 1*c*. The occurrence of substantial jumps in yield, probably of the order of those seen for the Yaqui Valley as a whole in Fig. 1*b*, can be assumed from the release and widespread planting of short-statured spring wheats in regions of the world with more favourable environments, including parts of India, Pakistan, Turkey, Iran, Israel, Tunisia, Sudan, Rhodesia, South Africa, Canada, U.S.A. and Chile (Dalrymple 1974). For example, the progress is well documented for India (Rao 1972) and Israel (Ephrat 1974). Most, if not all, of these wheats came either directly or indirectly from the Mexican breeding program and all with a few possible exceptions appear to contain Norin 10 dwarfing genes.

It is very interesting that these cultivars were derived from few crosses and consequently comprise few distinctive phenotypes and apparently few underlying genotypic differences. The major types among these at present are shown in Table 5. Undoubtedly one genotype (Siete Cerros 66) has, in the past, dominated on a world-wide area basis. It is possible that Anza and its relatives will grow to an equally large acreage. It is interesting to note a slight tendency towards specific adaptability, especially reflected in the Yecora, Era and Soltane genotypes. Although not obvious from Table 6, it is important to mention the tendency towards an increase in diversity of types accompanying a move away from dominance by the Mexican breeding program. However, other sources of dwarfing, several of which are available, have as yet been unable to assert themselves in this process.

Productivity Restraints

No discussion of the Mexican wheat breeding program should avoid the question, introduced a little earlier, of performance under less favourable conditions than in the Yaqui Valley. Four widespread restraints on yield have achieved prominence in recent times; these are the supplies of water and nitrogen, diseases and weeds. Indeed, it has been suggested recently that breeding programs, such as the one in Mexico, which is based largely on selection under well-watered, high fertility conditions, may not produce the

TABLE 5

Norin 10-derived spring wheat cultivars presently under widespread cultivation

Type variety	Parentage[A]	Related[B] cultivars	Regions in which presently cultivated
Pitic 62	Yaktana 54 × N10B	Mexico 120, Hira, Lakhish	Canada, India, Israel
Penjamo 62	Frontana × Kenya 58– Newthach/N10B		Turkey
Inia 66	Lerma Rojo 64–Sonora 64	Norteno 67, Noroeste 66	Iran
Siete Cerros 66	Penjamo "S"–Gabo 55	Kalyansona, Zambesi, Mivhor 1177, Super X, Mexipak	India, Pakistan, Middle East
Yecora 70	Ciano "S" × Sonora 64–Klein Rendidor/Siete Cerros "S"	Cajeme 71	Mexico, Rhodesia, south-west USA
Era	Complex cross involving Frontana, Thacher, Mida, Kenya 117A, Kenya 58, Lee, Newthach, Polk, N10B	Fletcher	Red River Valley (USA)
Soltane	Sonora 64–Klein Rendidor	Zaafrane, Marcos Juarez INTA.	North Africa, Argentina
Anza	Lerma Rojo 64 × N10B/Andes$_{E}^{3}$	Moghan, Mexicani, Karamu, WW15, Condor, Egret, Oxley	South-west USA, Iran, Sudan, Australia, New Zealand

[A] All original crosses made in Mexico, except Era, which is a Minnesota cross. All selection in Mexico except Era (Minnesota), Soltane (Algeria) and Anza (Sudan, California). Pedigrees written according to CIMMYT where cross order is –, ×, /, (); N10B = Norin 10 – Brevor. The following pedigrees complete this picture: Sonora 64 = Yaktana 54 × N10B/Yaqui 54^{2}; Lerma Rojo 64 = (Yaqui 50 × N10B/Lerma 52) Lerma Rojo^{2}.

[B] Usually resulting from simultaneous selection, backcrossing and/or reselection in other countries.

most efficient cultivars for situations where water or nitrogen are limiting. Notwithstanding the difficulties of detecting real differences and making selections under less than optimal conditions, these suggestions merit discussion.

With regard to water, there is some evidence that the varieties most suited to situations of water stress are not necessarily those which perform best in the absence of stress. This was seen, for instance, in an analysis of ISWYN yield data (Laing and Fischer 1977) and in trials under simulated drought conditions at CIANO (R. A. Fischer, unpublished data). It is also conceivable that some traits may be yield–positive in the stress situation and yield–negative without stress.

Nevertheless, this does not mean that substantial progress in dryland wheat yields had not come about as a result of the growing of wheats such as those mentioned in Table 5 and selected largely under well-watered conditions. This apparent contradiction arises because certain traits of the shorter statured wheats (notably high harvest index) have a sufficiently strong positive effect on yield under all conditions to give them obvious superiority over the taller, traditional, dryland wheats even under dry conditions and despite any specific drought resistance mechanisms the latter group may possess. Moreover, there is no strong evidence that the shorter wheats have generally poorer root systems as was originally hypothesised. Syme (1970) showed that it takes a fairly severe water stress to bring the yield level of the semidwarf wheat cultivar WW15 down to the yield levels of the traditional Australian cultivars.

Such considerations suggest that the breeding strategy adopted in Mexico (selection under well-watered conditions) was very likely the most efficient for bringing about rapid progress at the time. It does not mean, however, that there is not now good reason for breeding programs there and elsewhere to direct part of their effort specifically towards dryland conditions. In fact CIMMYT now distributes

TABLE 6

Height, grain yield and aspects of nitrogen utilization for several cultivars CIMMYT wheat physiology experiment in 1970-71 under optimal conditions; cultivars ranked according to year of release

Cultivar	Height (cm)	Grain yield[A] (t/ha)	Total N uptake[B] (kg/ha)	Grain yield/ N uptake (kg/kg)	N harvest index[C] (%)
Gabo	140	5.95	205	29.0	68.5
Nainari 60	140	5.52	202	27.3	65.8
Penjamo 62	110	6.48	220	29.5	67.5
Pitic 62	123	6.63	210	31.6	72.5
Inia 66	113	6.59	192	34.3	73.3
Siete Cerros 66	105	7.57	219	34.6	71.5
Cajeme 71	90	7.42	225	33.0	71.3
Anza	100	7.62	210	36.3	71.3
Torim 73	90	7.32	198	37.0	76.3
SD ($P < 0.05$)	—	0.86	ns	—	0.5

[A] At 14% moisture content.

[B] Nitrogen analyses by courtesy CIMMYT Service Laboratories.

[C] Grain nitrogen uptake divided by total nitrogen uptake.

Wheat harvest in the Yaqui Valley, Mexico. Average yields for the valley reached 5 t/ha or 75 bushels per acre in the 1974–75 season.

segregating populations which have been derived without selection from the widest possible crosses, often involving reputedly drought-resistant parents. Such populations can be screened in whatever local environment and at whatever level of water stress their recipient desires. For example, the INIA wheat program in Mexico has been testing such populations under water stress and as a result recently released new semidwarf cultivars specifically adapted to dryland conditions.

Restraints on yield owing to disease need little discussion here. This aspect has always been a major consideration in wheat-

Physiological research conducted by the CIMMYT wheat program at CIANO included studies of the effect of reductions through shading in solar radiation received by irrigated crops of the short-statured cultivar Yecora 70. The plots shown here in 1971 yielded 8 t/ha in the absence of shading.

breeding programs not only because of the yield losses diseases can cause, but also because of the early recognition of simple genetic control of disease resistance. International testing serves to emphasize yield losses because susceptible varieties often yield nothing. A great advantage of such testing is that entries are exposed to a wide range of diseases and of races within diseases: susceptibility is quickly recognized.

Despite this and other early warning systems that have been developed as a consequence of international efforts, such programs have led to the wispread planting of a relatively small number of genotypes with a high yield potential (Table 5), two facts which must increase the vulnerability of wheat production to diseases. It suffices to point out that certainly in Mexico, and probably elsewhere, the maintenance of disease resistance occupies more than one half of the resources devoted to wheat breeding. Moreover, there is some hope that new approaches such as the harnessing of horizontal resistance and the use of multilines, plus better information on diseases from international trap nurseries, will substantially reinforce the control being achieved through more conventional breeding methods.

Yield restraint by low soil fertility has long been recognized. However, the possibility of breeding varieties better adapted to soils of low fertility is a recent idea, stimulated by the low availability and high cost of fertilizers, as well as by sociological and ecological considerations. This question is discussed here only with respect to nitrogen, the major soil nutrient deficiency encountered by wheat.

Selection for higher yields at low soil nitrogen levels would seem unwise since the expected yields must always be low, because nitrogen is a major constituent of plants. Selection for greater efficiency of nitrogen use at close to optimum soil nitrogen levels and hence higher yield levels may have some possibilities, since little attention has been paid to this point in past breeding programs which have tended to operate at above optimal levels of soil nitrogen. These possibilities seem to lie in the difficult area of preventing nitrogen losses via leaching or denitrification, through having more efficient root systems. On the other hand, it should be pointed out that the efficiency of use of the nitrogen absorbed by the crop has increased substantially as an indirect consequence of yield advance. As stature has been reduced, and grain yield and harvest index increased, the grain yield per unit nitrogen uptake and the proportion of absorbed nitrogen found in grain at maturity have also increased (Table 6). It would seem that current breeding efforts to increase grain yield still further will continue to provide indirect selection pressure on efficiency of use of the nitrogen absorbed by the plant. Finally, selection for nitrogen fixation in wheat roots has recently become a feasible long-term research goal (Dobereiner *et al.* 1957).

Weed competition is undoubtedly a major restraint on wheat production. The implication of this for plant-breeding programs has received little consideration, partly because of the belief that agronomic techniques provide the answer to weeds. Nevertheless, these techniques are expensive and often relatively complex. Besides, it is commonly stated that short wheats have more weed problems than taller ones. It ought to be worth while to try to locate other genetically controlled mechanisms by which the ability of wheat to compete with weeds is enhanced. The production of lines of wheat that compete with weeds as well as do current barley cultivars would be a major advance.

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