WHEAT ◆ PROGRAM ◆ SPECIAL ◆ REPORT

WPSR No. 49

Bread Wheat, Durum Wheat, and Synthetic Hexaploid Wheat in Saline and Non-Saline Soils

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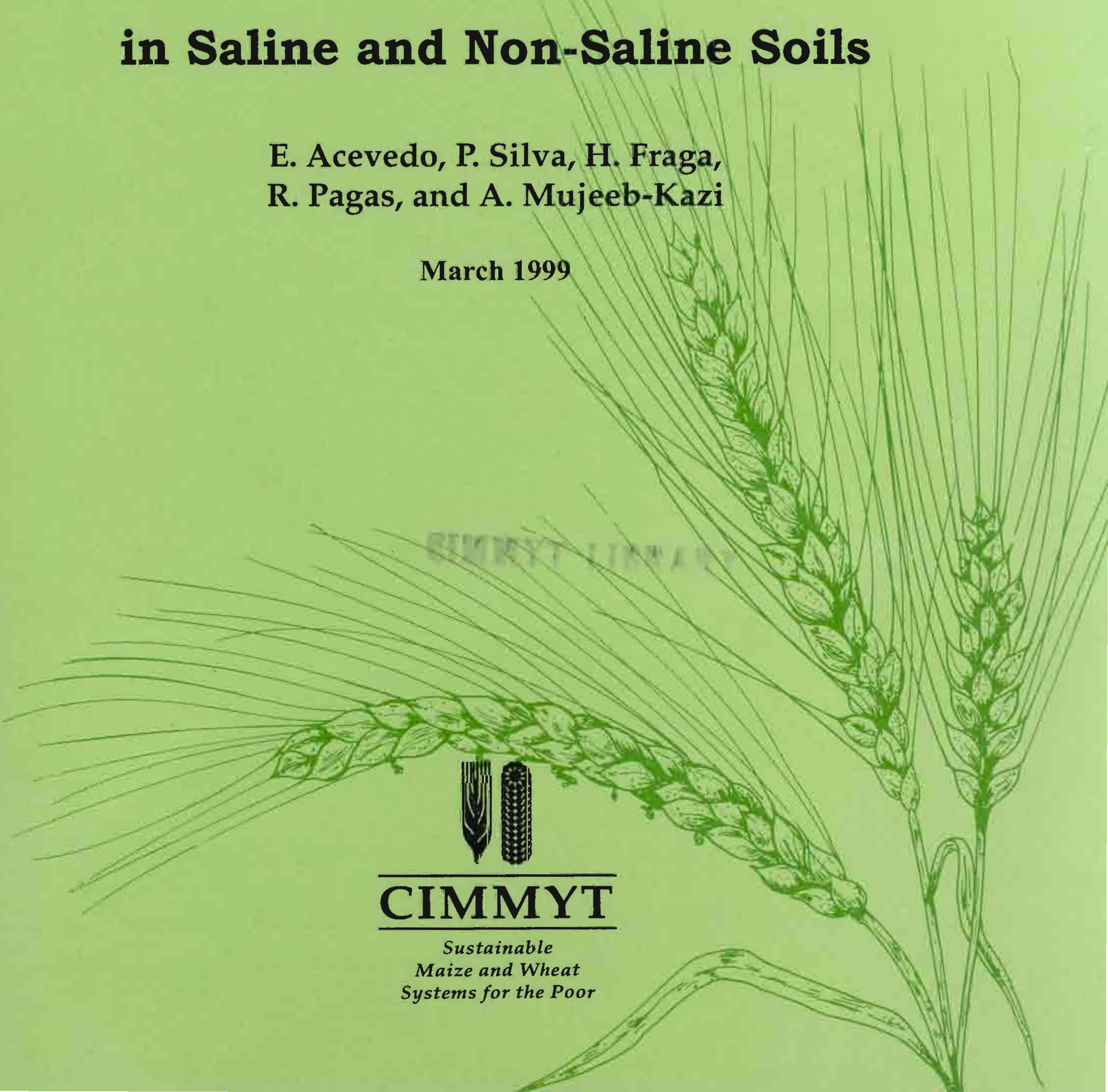
March 1999



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Preface

The accumulation of soluble salts in the soil can have a detrimental effect on crop production. The best way of dealing with the problem of excessive amounts of salts is to prevent it from happening in the first place—for example, through improved water management used in combination with appropriate crop management practices. When excessive salt has built up in the soil, it can be reduced through such strategies as leaching or by increasing the amount of soil organic matter to improve water infiltration.

Though plant breeding cannot solve the problem, it can help alleviate the negative impact of salinity on production through the development of salt tolerant crop varieties. Soil salinity reduces plant growth and decreases yields, but tolerant varieties are able to produce reasonably high yields despite the stress.

Salt tolerant wheat varieties could make a big difference in certain regions, such as South Asia, home to millions of the world's poorest people. In large tracts of India and Pakistan where wheat is cultivated under irrigation, the ever increasing salinity of irrigated areas poses a major threat to future wheat production. Solving this problem (for example, through improved drainage) will require great engineering efforts. Salt tolerant varieties could contribute to maintaining yields while a more permanent solution to the problem is implemented. In other areas where such radical solutions are not feasible, salt tolerant varieties may provide farmers with the only means of maintaining their yield levels.

For these reasons, it is urgent to breed salt tolerance into wheat varieties adapted to the affected regions. The study reported in this document contributes to this effort, for it compares the response to salinity of different kinds of wheat genotypes, including bread wheats, durum wheats, and synthetic hexaploid wheats. Among the study´s useful conclusions is that, though necessary, high yield potential alone does not determine that a genotype will yield well under saline conditions, nor does salt tolerance *per se* ensure that a genotype will produce high yields under stress. Rather, genotypes possessing a combination of traits seem to perform best.

We hope that the valuable results recorded here will be used to advance towards the goal of developing wheat varieties that farmers in saline environments can depend on to produce enough grain to satisfy the food needs in their areas.

Sanjaya Rajaram
Director
CIMMYT Wheat Program

Abstract

Genetic improvement of crops for salt tolerance will become ever more important as it becomes necessary to cultivate marginal soils. The work reported here evaluated the intra- and interspecific variability in yield response to soil salinity of four *Triticum* groups: synthetic hexaploid wheats (*T. turgidum* x *T. tauschii*), bread wheats (*T. aestivum* L.), durum wheats (*T. turgidum* L.), and a reference group of salt tolerant bread wheats. The yield potential of these genotypes and their salt tolerance *per se* were also evaluated.

The test genotypes were grown in five environments (two locations and three years) variably affected by soil salinity. The mean grain yield ranged from 1,805 to 5,788 kg/ha. The bread wheat, durum wheat, and salinity reference groups of genotypes had significantly higher yields than the synthetic hexaploids. The synthetic hexaploid group showed the characteristics of unimproved wheat: late flowering, tall plant height, low number of grains per ear, and a low harvest index, which resulted in high yield stability but low grain yield. The best adapted genetic materials belonged to the bread wheat and reference groups.

The salinity reference group had the highest grain and biomass yields in the lowest yielding environment. The synthetic and bread wheat groups did not show variability for biomass yield, while variability for both biomass and grain yield was nil in the durum wheat group. Soil salinity tolerance was evaluated using a tolerance index. Improved bread wheats, including those in the reference group, showed higher yield potential and better salt tolerance.

Bread Wheat, Durum Wheat, and Synthetic Hexaploid Wheat in Saline and Non-Saline Soils

E. Acevedo, P. Silva, H. Fraga, R. Pagas, and A. Mujeeb-Kazi

Introduction

Soil salinity is a major problem in many developing countries. The problem is particularly severe where soils are irrigated with poor-quality water and becomes exacerbated in arid climates.

In cereals, salt reduces yield mainly due to the inhibition of cell elongation, which reduces the photosynthetically active area, and to ion toxicity caused by gradual ion accumulation in the leaves. In wheat, salt toxicity is particularly apparent after anthesis and characterized by early senescence and poor grainfilling (Wyn Jones and Gorham, 1991), which causes distal spikelets to abort, produces low grain weight, and reduces grain yield (Grieve *et al.*, 1992). The yield component most affected by salinity in cereals is the number of spikes per plant (Maas and Grieve, 1990). Maas *et al.* (1994) showed that high salinity reduces the percentage of tillers with spikes, but not the total number of tillers.

Wheat yield is reduced by 50% at 13 dS/m electrical conductivity of the extract at soil saturation (Ayers and Westcott, 1976). Maas (1986) found that the threshold for damage in durum wheat comes at a lower soil electrical conductivity level than is the case in bread wheat (5.9 and 8.6 dS/m, respectively). In other words, durum wheat is more sensitive to salt than bread wheat. The same author notes that durum yields decrease more rapidly than bread wheat yields in saline environments.

Breeders have made little progress towards improving wheat yields in saline environments, possibly because of the low genetic variability for this trait in breeding materials (Wyn Jones and Gorham, 1991) and a lack of understanding of the importance of a genotype's yield potential and stress tolerance *per se* for producing higher yields under saline conditions.

Diploid *Triticum tauschii* (Coss.) Schmal. (syn. *Aegilops squarrosa* L.) is one of the species being used to increase this variability. *Triticum tauschii* is one of hexaploid bread wheat's progenitors, to which it donated the D genome (McFadden and Sears, 1946). Several authors note that genes located in the D genome should contribute to greater salt tolerance in bread wheat by limiting the accumulation of Na^+ in leaf tissue (Shah *et al.*, 1987, Gorham *et al.*, 1987) and discriminating in favor of K^+ (Schachtman *et al.*, 1991).

Triticum tauschii is present in large and diverse regions of Asia (Appels and Lagudah, 1990). There is wide diversity in natural populations of *T. tauschii* that has not yet been incorporated into modern hexaploid wheats. Therefore *T. tauschii* is a new source of germplasm that could be used to increase stress tolerance in wheat.

The D genome of *T. tauschii* is homologous to the D genome of modern wheats, which makes it possible to develop genetically normal recombinants known as synthetic hexaploid wheats. Synthetic hexaploids are produced by crossing tetraploid durum wheat (*T. turgidum* L.), containing only two genomes designated AA and BB, with the D genome diploid *T. tauschii*, and then doubling the chromosome number with colchicine (Rees *et al.*, 1994).

Directly selecting genotypes for yield under stress conditions does not guarantee they will be stress tolerant because yield under stress is also highly dependent on yield potential, the genotype's tolerance *per se*, and crop phenology (Acevedo *et al.*, 1997).

Several authors note that selecting genotypes for high yield may be the best strategy for increasing yield in saline soils. Because soil salinity differs widely in terms of area and depth, the crop will grow and yield more in areas with soils that contain less salt (McCall, 1987, in Jana, 1991; Richards *et al.*, 1987).

The salt tolerance *per se* of genotypes has rarely been evaluated, given the difficulty of separating the effects of yield potential and crop phenology, which show a high degree of environment x genotype interaction (Acevedo, 1991). Bidinger *et al.* (1987a, 1987b) proposed using response to drought as an index for avoiding these effects. This index evaluates the salt tolerance *per se* of the highest yielding genotypes under saline conditions.

The objective of this study was to evaluate the intra- and interspecific variability of four *Triticum* groups: synthetic wheats (*T. turgidum* x *T. tauschii*), bread wheats (*T. aestivum* L.), durum wheats (*T. turgidum* L.) and a salt tolerant reference group (spring bread wheats that have performed well under saline conditions in different breeding programs); and to visualize the effect of unstressed yield and salt tolerance *per se* on the highest yield of the genotypes in these groups under saline conditions.

Materials and Methods

Forty wheat lines (Table 1) divided into four groups were used in this study: synthetic hexaploid wheats produced by crossing *T. tauschii* with *T. turgidum* (9 lines), bread wheats (10 lines), durum wheats (11 lines) and a group of salt-tolerant reference wheats (10 lines).

The study was conducted at the following locations: La Paz, Baja California Sur, Mexico (24°09'LN, 110°20'LE) 16 m above sea level (masl), on sandy loam, irrigated with saline water, very high in sodium; and in Ciudad Obregón, Sonora, Mexico (27°48'LN, 109°92'LE) 38.4 masl, on soil with no salinity problems (Figure 1).

The study was repeated during three cycles (1991/92, 1992/93, 1993/94) and two cycles (1992/93, 1993/94) in La Paz and Ciudad Obregón, respectively, for a total of five different environments. The seeding rate (120 kg/ha) was the same for all genotypes in all environments where the trial was carried out. Fertilization, as well as weed, pest, and disease control, followed CIMMYT's recommended practices. The trials were conducted under irrigation, so there was no water stress during crop growth.

Observations

The following observations were made for each of the trials:

- ***Plant height***. Measured at harvest, from the base of the stalk to the tip of the awns of the main spike.
- ***Days from emergence to anthesis***. The date of anthesis was determined at the moment of yellow anthers (Zadoks *et al.*, 1974).
- ***Days from emergence to physiological maturity***. Physiological maturity was reached when chlorophyll between the last node and the spike disappeared completely.
- ***Observations at harvest***. The following measurements were taken at harvest:
  - Biomass
  - Yield
  - Harvest index
  - 1000-grain weight
  - Number of spikes per square meter
  - Number of grains per spike
- ***Na^+ and K^+ content***. Sampling was done on the flag leaf at anthesis in the trial conducted in La Paz, 92/93 cycle. Samples were tested in CIMMYT's Plant Nutrition and Soils Laboratory in Mexico.

Statistical analysis

The experiment was treated as five independent trials, one for each environment, in the statistical analysis. Each trial consisted of 40 treatments (genotypes) in a randomized complete block design, with four replications in La Paz and three in Obregón. Plot size was 5 rows, 3.5 m long, 20 cm row spacing, 3.5 m^2 per plot.

Group comparison. Groups were compared for the measured parameters using an orthogonal contrast analysis.

Yield stability analysis. The criteria of Finlay and Wilkinson (1963) and Eberhart and Russell (1966) were used to analyze yield stability. Linear regressions of the mean yield and average biomass of all genotypes were performed across all five environments to determine the adaptation of each genotype.

Stress response index. This index was calculated using the equation described by Bidinger *et al.* (1987a, 1987b), which includes the following parameters:

$$Ys = a + bY + cFL + DRI + e$$

where Ys is yield under stress, Y is yield potential, FL days from emergence to flowering, DRI the stress response index, and e the experimental error. Yield values obtained in the La Paz location, 1992/93, were used as yield under stress because they were the lowest. Values for yield potential and days to flowering were calculated based on data collected in Ciudad Obregón during 1993-94, when the highest yields were recorded.

The DRI was designed to provide an estimate of genotype response to a particular stress, which is independent of the effect of flowering and the genotype's yield potential. DRI is defined as follows:

1) If $\frac{Ys - \hat{Ys}}{\sigma} \leq 1$, then DRI = 0

2) If $\frac{Ys - \hat{Ys}}{\sigma} > 1$, then DRI = $\frac{Ys - \hat{Ys}}{\sigma}$

where Ys is yield under stress, $\hat{Ys}$ is the estimated yield, and σ the standard error of the estimated yield.

When DRI = 0, this indicates that yield under stress was correctly estimated based on yield potential and flowering date.

When DRI = $\frac{Ys - \hat{Ys}}{\sigma}$, this indicates that the genotypes have a different response to stress (susceptibility or tolerance); genotypes having a positive DRI greater than 1 are considered drought tolerant.

The MSTAT-C software package (Michigan State University, 1988) was used for the statistical analysis.

Results and Discussion

Characterizing the test environments

Richards (1983) considers that in general yield under field conditions is not reduced if soil electrical conductivity is between 0 and 4 dS/m. Wheat is less salt tolerant during the germination and seedling stages, when soil electrical conductivity should not exceed 4 or 5 dS/m (Ayers and Westcott, 1976).

Soil salinity values at the La Paz location gave an electrical conductivity of around 3 dS/m (Table 2), which does not reduce yields in durum wheats and bread wheats, since they easily tolerate up to 5.9 dS/m and 8.6 dS/m, respectively (Maas, 1986).

However, water salinity is different from soil salinity, and genotypes under water salinity stress are sensitive to lower electrical conductivity values. Ayers and Westcott (1976) found that salinity begins to affect the water available to crops when water electrical conductivity is at about 0.75 dS/m. As may be seen in Table 2, water electrical conductivity in La Paz fluctuated between 2.6 dS/m and 3.5 dS/m; it is considered a serious problem when it rises above 3 dS/m (Ayers and Westcott, 1976). At that level the real conductivity of soil water is approximately three times higher than that of "plain" water.

The mean yield of all genotypes in each environment was used (Table 3) to quantify the test environments. The lowest yield, 1,805 kg/ha, was recorded in the La Paz location, which had salinity problems in the 92/93 season. The highest yields were recorded (5,787 kg/ha) in the Obregón location, which had no salinity problems in the 93/94 season.

Group stability

The stability analysis based on yield of the *Triticum* groups showed that the lowest yielding group across environments was the synthetic wheat group. It was also the most stable group, since it showed a smaller reduction in yield when environments worsened. This is in agreement with Acevedo (1991), who observed that, in general, the more stable the genotype, the lower the yield potential.

The improved wheats (bread wheats and durum wheats) and the reference group performed similarly, yielding more than the synthetics across environments. Among the improved wheats, the reference group was the most stable and the durum wheats, the most unstable. The instability of durum wheats is reflected in the greater rate of yield reduction in each low-yield environment (Figure 2). Their greater instability corroborates durum's greater sensitivity to salinity; its yield decreases at lower levels of soil electrical conductivity than that of bread wheat (Maas, 1986).

Given that the synthetic wheats have not been improved for grain yield, it was necessary to compare them based on biomass production. However, as may be seen in Figure 3, the stability analysis for biomass shows a great similarity among the four *Triticum* groups studied, especially under favorable conditions. In unfavorable environments the durums had the lowest biomass production, while the reference group had the greatest stability and highest biomass production.

High yield environment

In the high yield environment (5,876 kg/ha) the improved wheats (bread wheats, durum wheats, and the reference group) had high yields with no statistically significant differences among them. Yield components and the harvest index showed no statistically significant differences among the groups of improved wheats.

The synthetic wheat group had low yield, half that of the improved wheats. The lower yield of the synthetic wheats was due to a lower number of grains per spike, a lower rate of grain production, and a lower harvest index, in addition to greater plant height (Table 4). These characteristics are typical of unimproved genotypes, as noted by Evans and Dunstone (1970), who added a shorter grainfilling period, smaller leaves, and a longer tillering period.

Among the *Triticum* groups no differences were observed in biomass production under favorable conditions. The final weight of the synthetic hexaploids was comparable to that of the improved wheats, but with a very different distribution that was reflected in their lower harvest index.

Results of the analysis of variance within each group show that there is no variability for biomass or yield within the synthetics and durum wheats, the reference group and bread wheats being the ones with the greatest variability for both biomass and yield under high yield conditions (Table 5). This was in contrast to the situation found by Rees *et al.*, (1994), who observed high biomass variation among synthetic wheats.

The highest yielding genotypes in this environment were entries 38 (Q19, an Australian bread wheat with high yield potential), 21 (bread wheat), 36 (Sakha 8, a bread wheat in the reference group), 1 (Altar, durum wheat) and 14 (bread wheat). As may be seen from this ranking, the bread wheat genotypes were outstanding (Table 6).

Low yield environment

In the low yield environment (1,821 kg/ha), the synthetics group had the lowest yield due to their low number of spikes per unit area, low number of grains per spike, and low harvest index (Table 7). The bread wheats and the salt tolerant reference group were the highest yielding. Under unfavorable conditions there were differences in biomass production among the *Triticum* groups, with the reference group and the durum wheats showing the highest and lowest biomass production, respectively.

Results of the analysis of variance in the low yield environment are different from results in the high yield environment. Under these conditions, the durum wheats show no variability for biomass or yield, unlike the synthetic wheats, which do present variability for yield in this environment. The reference group is the only group with variability for yield and biomass in this environment (Table 8), and the only one that maintained the same variability as was observed in the high yield environment.

Five genotypes had the highest yields under stress conditions: entries 21 (bread wheat), 36 (Sakha 8, reference bread wheat), 33 (Karchia 65, reference bread wheat), 15 (Kauz, bread wheat), and 37 (Shorowaki, bread wheat) (Table 9). The genotypes that had the best yields in this environment were bread wheats. Entries 15, 21, and 36 are high yielding genotypes, as observed in the unstressed environment (Table 5).

Although yields of high yielding genotypes 15, 21, and 36 decreased sharply, they nonetheless produced the highest yields under saline conditions. This agrees with the findings of other authors (McCall, 1987, in Jana, 1991; Richards *et al.*, 1987), and leads to the conclusion that selecting for high yield under non-saline conditions may be a good strategy to increase yield in saline soils. However, it should be remembered that not all genotypes that show high yield under unstressed conditions will produce higher yields under stress, since other traits may contribute to a genotype's higher yield under stress conditions. This was the case of genotypes 33 and 37, which did not have high yields in the high yield environment.

Effect of flowering on yield under saline conditions

In the La Paz location during the 92/93 season, there was a linear correlation of -0.687 ($P \leq 0.000$) between anthesis and grain yield of the 40 *Triticum* genotypes. However, in the bread wheats and the reference group, which included the genotypes that had the highest yields in this environment (15, 21, 33, 36, and 37), there was no correlation between yield and anthesis. The highest yielding genotypes in the location with the lowest yield were neither the earliest nor the latest genotypes among the 40 entries tested (Table 10).

Salt tolerance *per se*

In the La Paz location during 92/93 season, there was a linear correlation of 0.769 ($P \leq 0.000$) between DRI and grain yield of the 40 *Triticum* genotypes (Table 11). Yield under stress was higher when the DRI was greater.

The DRI (Bidinger *et al.*, 1987b) allowed each genotype's salt tolerance *per se* to be determined independently of the effect of each genotype's yield potential or earliness. The following genotypes were found to be salt tolerant: 15 (Kauz, bread wheat), 21 (bread wheat), 32 (Candeal, reference wheat), 33 (Karchia 65, reference wheat), 36 (Sakha 8, reference wheat), and 37 (Shorowaki, reference wheat) (Table 12). Salt tolerance determined using DRI did not identify any salt tolerant genotypes within the synthetic or the durum wheats.

During the 92/93 season, the five highest yielding genotypes in La Paz (genotypes 21, 36, 33, 15, and 37) were tolerant to salt according to Bidinger's resistance index. Of these genotypes, three have high yield potential (within the five best genotypes studied): 21 (bread wheat), 15 (Kauz, bread wheat), and 36 (Sakha 8, reference wheat). The highest yielding genotypes in the low yield environment were bread wheats and wheats from the reference group, with good salt tolerance *per se* and high yield potential (Table 13).

Genotype 32 (Candeal, reference wheat) showed salt tolerance according to Bidinger's index, but its yield potential of 2,803 kg/ha did not allow it to produce high yields in saline environments. Therefore, the genotypes' tolerance has a strong influence on their yields under stress, which shows that high yield potential is not the only important trait under saline conditions, nor is salt tolerance *per se* enough to produce high yields under stress.

Na^+ concentration in the leaves

In the La Paz location during the 92/93 season, there was a linear correlation of -0.601 ($P \leq 0.000$) between biomass and Na^+ content in the flag leaf of the 40 *Triticum* genotypes and 0.42 ($P \leq 0.007$) between biomass and the K^+/Na^+ ratio measured in the flag leaf of the same genotypes. These results confirm that biomass decreases as Na^+ content in the flag leaf increases. There was also a linear correlation of 0.467 ($P \leq 0.002$) between Na^+ content in the flag leaf and the DRI of the 40 *Triticum* genotypes, which shows a correlation between Na^+ content in the flag leaf and the genotypes' susceptibility or tolerance to salt stress.

Table 14 shows the $Na^+$and K^+ contents and the K^+/Na^+ ratio for the four *Triticum* groups. These data confirm the findings of previous studies by Shah *et al.* (1987) and Wyn Jones and Gorham (1991), who found high Na^+ content in the flag leaf of durum wheats, which do not have the D genome, and lower Na^+ content and greater K^+/Na^+ discrimination in hexaploid wheats, which do possess the D genome. There were no statistically significant differences in the NA^+ and K^+ contents and the K^+/Na^+ ratio among the *Triticum* groups that possess the D genome (synthetics, bread wheats, and reference group wheats).

Results of the analysis of variance showed variability for K^+ content in the flag leaf of the synthetic, bread wheat, and reference groups; variability for Na^+ content in the flag leaf of the synthetic and durum groups; and variability for the K^+/Na^+ ratio in the synthetic, durum, and reference groups (Table 15). Despite the high Na^+ content and the low level of K^+/Na^+ discrimination of the durum wheats, it is important to note the variability observed with the analysis of variance in this group. The synthetic hexaploid wheats show a variability for Na^+ content in their leaves that neither the bread wheats nor the salt tolerant reference group possess.

Conclusions

The following conclusions may be drawn from this study:

- The synthetic wheats showed the characteristics of unimproved genotypes: low yield, low number of grains per spike, low grain production rate, greater height, and low harvest index.
- The synthetic wheats showed the greatest stability and the lowest yield. Improved wheats had higher yields, and the reference group was the most stable.
- The synthetic wheats showed low variability for salt tolerance, while the durum wheats showed no variability.
- The highest yielding genotypes under saline conditions showed good salt tolerance *per se*.
- Though important for producing higher yields under saline conditions, high yield potential does not in itself imply that a genotype will yield better under those conditions.
- The highest salt tolerance *per se* was associated with low Na^+ content in the flag leaf.

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Tables and Figures

Table 1. Genotypes used in this study.

No.	Group	Seed origin	Name	Cross/Pedigree
1	III	W-4 BV-91	ALTAR	
2	II	BV-9I	OPATA	
3	III	BV-91	ACONCHI	
4	IV	BV-91	OASIS	
5	I	W-13 BV-91		CHEN"S"/*Ae. squarrosa* (168) CIGM 87.2755-IB-OPR-OB
6	I	W-14 BV-91		CNDO/R143//ENTE"S"/MEXI"S"/3/*Ae. squarrosa*(221) CIGM86.953-IM-M-OB-OPR-OB
7	I	W-40 BV-91		PBW114/*Ae. squarrosa* -OB-OPR-OB
8	I	W-73 BV-91		68111/RGB//WARD RESEL/3/STIL"S"/4/*Ae.squarrosa*(164) CIGM88. 1161-OB
9	I	W-75 BV-91		DOY 1/*Ae. squarrosa* (188) CIGM 88.1175-OB
10	I	W-80 BV-91		CPT/GEDIZ"S"/3/GOD"S"//JO"S"/CR"S"/4/*Ae.squarrosa*(196) CIGM 88.1186-OB
11	I	W-82 BV-91		CPT/GEDI"Z"/3/GOO"S"//JO"S"/CR "S"/4/*Ae. squarrosa* (205) CIGM88.1192-OB
12	I	W-84 BV-91		CPT/GEDIZ"S"/3/GOO"S"//JO"S"/CR/ "S"/4/ *Ae. squarrosa* (208) CIGM 88.1194-OB
13	I	W-124 BV-91		DOYI/*Ae. squarrosa* (488) CIGM 88.1353-OB
14	II	S-2 MV-91		BUC/FL K^{+}//MYNA/VUL CH 91575-28Y-OM-OY-1M-OY
15	II	S-6 MV-91	KAUZ	
16	II	S-9 MV-91	TUI	
17	II	S-13 MV-91		SPB/BOW//SPB CM96547-AG-OY-OM-OY-6M-ORES
18	II	S-15 MV-91		C079"2"/PRL//CHIL CM92354-61Y-OM-OY-1M-ORES

I=Synthetic; II=Bread; III=Durum; IV=Reference group

Table 1. Genotypes used in this study. (cont.)

No.	Group	Seed origin	Name	Cross/Pedigree
19	II	S-18 MV-91		F12.71/COC//BAU/3/BAU CM96251-Y-OY-OM-OY-4M-ORES
20	II	S-20 MV-91		CNO79/PRL//CIL"S" CM92313-25M-OY-OM-3Y-OB
21	II	S-23 MV-91		SERI"3"//BUC"S" CRG-68-H-6Y-3B-OY
22	II	S-35 MV-91		BUC/B JY//PRL CM95521-BY-OH-OSY-3M-ORES
23	III	EPC 393		CHEN/RBC11HUI/TUB CD68653-A-9Y-4B-2Y-IB-OY-OAB-OREC
24	III	EPC 304		TCHO"S"/MORUS//SILVER CD80739-A-IM-OYRC-OM-7REC-OPA
25	III	EPC 188		MEH"S"/PEN//STINT"S" CD74548-A-2Y-02OH-OAP-OTR-1M-OREL
26	III	EPC 288		SRN/GOTE"S" CD74059-2Y-02OH-IY-IM-2YRC-2B-OREC
27	III	EPC 222		QFN/RILL"S" CD69426-10B-4Y-2B-5 YRC-2B-OREC
28	III	EPC 105		CHEN"S"/RISSA"S"/4/FUJA"S"/ CIT71//CIT71/CII/3/SHWA"S" CD83277-B-2M-OYRC-OM-15REC-OPA
29	III	EPC 229		EUPODA CD75150-A-IY-BM-IY-IM-4YRC-2M-OREC
30	III	EPC 367		ALTAR 84//BOY"S"/YAV"S" CD72562-Q-2Y-OM-OYREC-3M-OREC
31	III	EPC 355		ALLA"S"/SRN3/CHEN"S"//CIT71/CII CD83671-F-1M-OYRC-OM-9REC-OPM
32	IV		CANDEAL	
33	IV		KARCHIA 65	
34	IV		KRL 1-4	
35	1V		LU 26-5	
36	IV		SA KHA 8	
37	1V		SHOROWA KI	
38	IV		Q19	
39	IV		SNH9	
40	IV		WH-157	

I=Synthetic; II=Bread; III=Durum; IV=Reference group

Table 2. Soil and irrigation water parameters in La Paz.

Year	Month	Soil		Irrigation water	
		pH	EC (dS/m)	pH	EC (dS/m)
1991	December	8.0	3.8		
1992	February	8.3	2.3	7.3	3.2
	March	7.8	1.8	7.5	3.0
	April	7.4	1.9	7.2	3.5
	December			8.1	3.2
1993	January			7.9	3.2
	February			8.0	2.6
	March			7.3	2.8
	April			8.2	2.9

Table 3. Quantification of test environments based on mean yields.

Environment	Site	Season	Yield (kg/ha)
1	La Paz	91/92	2,493.4
2	La Paz	92/93	1,805.1
3	La Paz	93/94	4,769.5
4	Obregón	92/93	4,402.5
5	Obregón	93/94	5,787.6

Table 4. Mean values for yield components of the *Triticum* groups in the highest yielding environment, Ciudad Obregón, 1993/94 cycle.

Parameters	Synthetics N=9	Bread wheats n=10	Durum wheats n=11	Ref. group n=10
Biomass (kg/ha)	13,886.7a	16,216.8a	16,587.2a	15,200.7a
Yield (kg/ha)	3,353.5b	6,801.6a	6,914.5a	6,080.8a
Harvest index	0.25b	0.43a	0.42a	0.4ab
Spikes/m^2	225.2a	323.4a	290.6a	352.7a
1000-grain weight	37.8a	40.0a	39.0a	41.4a
Grains/spike	36.9b	54.6ab	62.7a	44.6ab
TPG (g/ha/day)	81.3	140.0	138.9	128.1
Height (cm)	127.4a	90.9b	94.6b	93.8b

$P \leq 0.05$

Table 5. Analysis of variance for biomass and yield within the *Triticum* groups in the highest yielding environment, Ciudad Obregón, 1993/94 cycle.

Parameters	Synthetics n=9	Bread wheats n=10	Durum wheats n=11	Ref. group n=10
Biomass	NS[†]	**	NS	**
Yield	NS	**	NS	**

* = $P \leq 0.05$
** = $P \leq 0.01$
[†] NS = Non-significant

Table 6. The highest yielding genotypes under unstressed conditions, Ciudad Obregón, 1993/94 cycle.

Genotype	Group	Yield (kg/ha)
38	Ref. group	9,292
21	Bread wheat	7,840
36	Ref. group	7,827
1	Durum wheat	7,807
14	Bread wheat	7,711

Table 7. Yield and yield components of the *Triticum* groups in the lowest yielding environment, La Paz, 1992/93 cycle.

Parameters	Synthetics n=9	Bread wheats n=10	Durum wheats n=11	Ref. group n=10
Biomass (kg/ha)	5,429.9 ab	6,532.9 ab	4,765.0 b	6,750.1 a
Yield (kg/ha)	1,063.3 b	2,237.5 a	1,734.9 ab	2,184.7 a
Harvest index	0.19 b	0.34 a	0.37 a	0.33 a
Spikes/m^2	184.9 b	199.1 ab	145.6 b	249.6 a
W 1000 grain	42.8 a	37.8 b	43.2 a	35.6 c
Grains/spike	14.0 b	30.7 a	28.7 a	26.4 a
TPG (g/ha/day)	32.9	69.8	54.6	66.8
Height (cm)	71.6 a	62.9 b	65.3 ab	69.4 ab

$P \leq 0.05$

Table 8. Analysis of variance for yield and biomass within the *Triticum* groups in the lowest yielding environment, La Paz, 1992/93 cycle.

Parameters	Synthetics n=9	Bread wheats n=10	Durum wheats n=11	Ref. group n=10
Biomass	NS[†]	NS	NS	*
Yield	*	*	NS	**

* = $P \leq 0.05$

** = $P \leq 0.01$

† NS = Non-significant

Table 9. Genotypes with the highest yield under stress conditions, La Paz, 1992/93 cycle.

Genotype	Group	Yield (kg/ha)
21	Bread wheats	2,810
36	Ref. group	2,613
33	Ref. group	2,611
15	Bread wheats	2,593
37	Ref. group	2,450

Table 10. Maturity observed in the highest yielding *Triticum* genotypes, La Paz, 1992/93 cycle.

Genotype	Days to anthesis	Maturity
37	77.8	Semi late
36	76.8	Semi late
21	74.0	Semi early
15	73.0	Semi early
33	71.1	Semi early

Table 11. Correlation between DRI and yield and yield components, La Paz, 1992/93 cycle.

DRI versus:	
Yield (kg/ha)	0.769 ***
Spikes/m^2	0.545
1000-grain weight	-0.397 *
Grains/spike	0.467 **

* = $P \leq 0.05$
** = $P \leq 0.01$
*** = $P \leq 0.001$

Table 12. Salt tolerant genotypes according to the index proposed by Bidinger *et al.* (1987b).

Genotypes	Group	$\frac{Ys - \hat{Ys}}{\sigma}$
15	Bread wheat	1.14
21	Bread wheat	1.47
32	Reference group	1.68
33	Reference group	1.64
36	Reference group	1.31
37	Reference group	2.22

Table 13. Yield and salt tolerance of the highest yielding genotypes under saline conditions according to the index proposed by Bidinger *et al.* (1987b).

Genotype	Unstressed yield (kg/ha)	Bidinger index
21	7,840†	Tolerant
36	7,827†	Tolerant
33	5,362	Tolerant
15	7,564†	Tolerant
37	4,368	Tolerant

†Unstressed high yielding genotypes.

Table 14. Na^+ and K^+ contents and the K^+/Na^+ ratio in the flag leaf of the *Triticum* groups.

Parameters	Synthetics n=9	Bread wheats n=10	Durum wheats n=11	Ref. group n=10
K^+	28,497.8 a	20,860.0 b	18,534.8 b	22,235.0 b
Na^+	999.0 b	482.0 b	5,803.7 a	436.0 b
K^+/Na^+	67.7 a	43.2 a	3.8 b	74.3 a

$P \leq 0.05$

Table 15. Analysis of variance of K^+ and Na^+ contents and the K^+/Na^+ ratio within the *Triticum* groups.

Parameters	Synthetics n=9	Bread wheats n=10	Durum wheats n=11	Ref. group n=10
K^+	**	**	NS†	**
Na^+	*	NS	**	NS
K^+/Na^+	**	NS	*	**

* = $P \leq 0.05$

** = $P \leq 0.01$

† NS = Non-significant

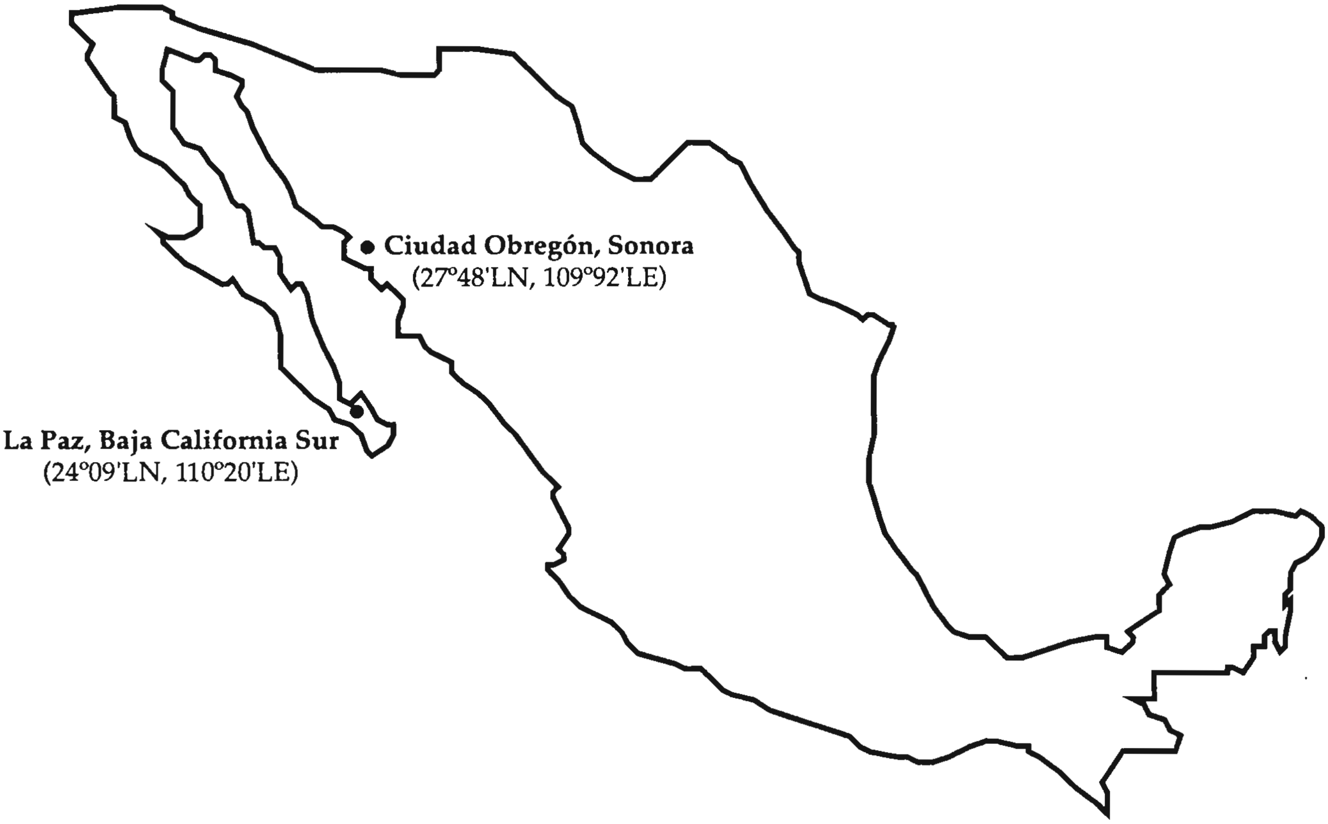

Figure 1. Geographic location of the La Paz and Ciudad Obregón sites.

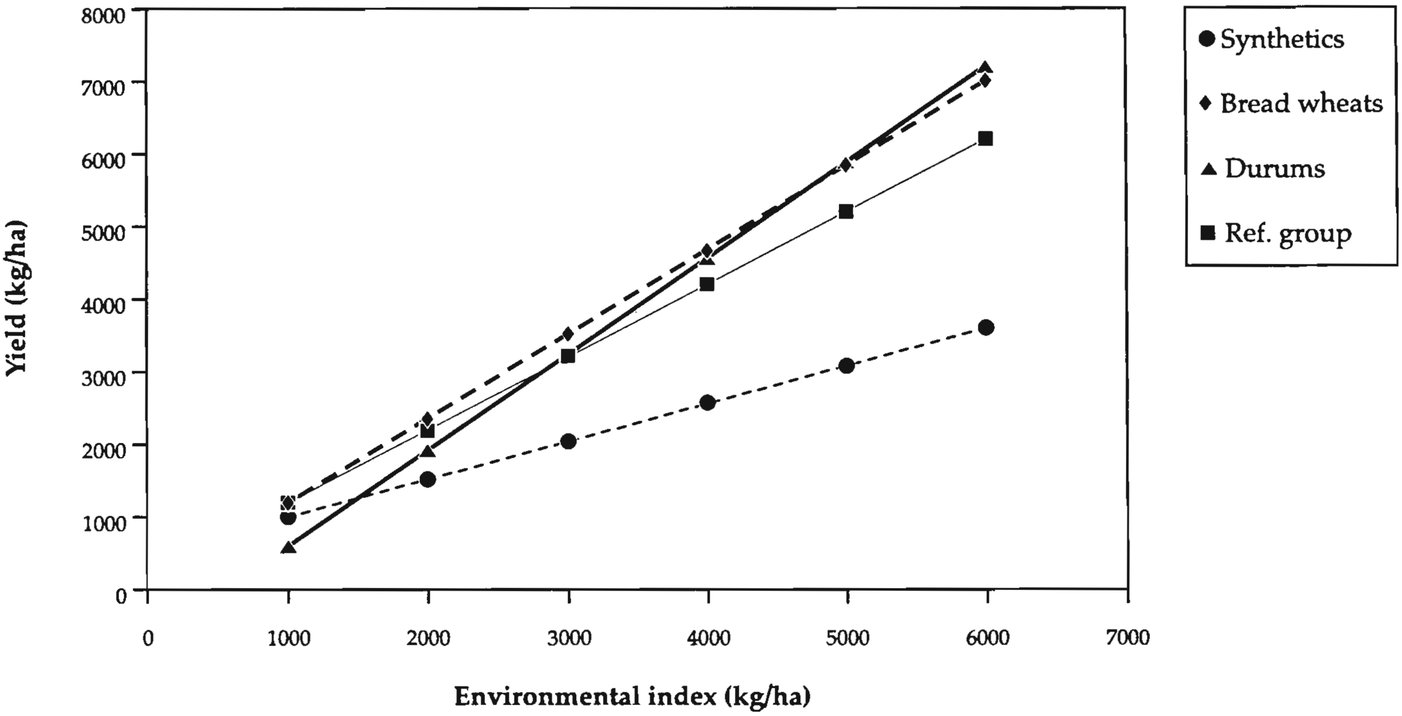

Figure 2. Yield stability of the *Triticum* groups.

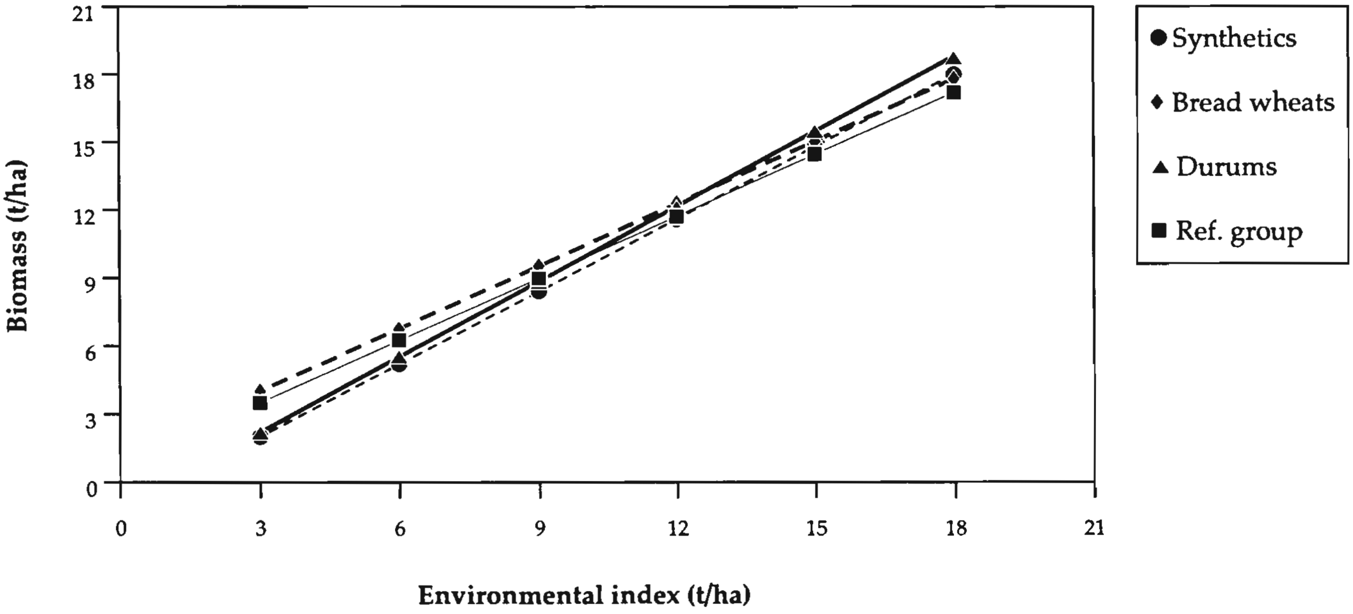

Figure 3. Biomass stability of the *Triticum* groups.

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