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Selection of High Yielding and Risk Efficient Durum Wheat (*Triticum durum* Desf.) Cultivars under Semi-arid Conditions

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Abstract: An experiment was conducted, during the successive cropping seasons 1997/98 to 2002/03, to study grain yield performances and yield stability of 10 durum wheat (*Triticum durum* Desf.) varieties in order to identify the productive, stable and risk efficient genotypes for a subsistence agriculture. Grain yield analysis showed high seasons and season x genotype interaction effects reducing the genotypic main effect. Regression coefficients, variance across seasons and safety-first indices based on these parameters classified differently the tested genotypes for stability and risks of giving a low yield under stress. FW index was correlated with grain yield, regression coefficient and the mean square of the contribution of the test cultivar to GxS interaction. The EV index did not show a significant correlation with the measured variables. It was possible within the set of genotypes tested to select high yielding and risk efficient cultivars compared to the check cultivar Mohammed Ben Bachir.

Key words: *Triticum durum*, GxS interaction, safety-first index, yield stability, semi-arid

INTRODUCTION

Under the variable environments experienced by cereal crops in semi-arid areas, selection is directed toward the identification of cultivars that perform well in a wide range of seasons and locations[1]. However the identification of such broadly adapted varieties becomes difficult when the phenotypic response to changes in the environment varies among selected entries[2,3]. Plant characters that influence performance often have differing opportunities for expression in different environments and become sources of genotype x environment interaction (G x E) that may reduce selection progress[4,5].

In order to allow a proper estimate of genotypic yield response to the environment, plant breeders developed the multi-site/multi-location testing system from which the performance and stability of a given genotype may be derived. When genotype x location is the main source of interaction, selection is directed toward specific adaptation to the target area. When genotype x year is the major source of variation due to changes in growth conditions from year to year, selection for wide adaptation is favoured[1,3,6].

Genotype x environment interaction is almost omnipresent under semi-arid conditions because yearly variation is typically the largest source of yield variation. It is commonly believed that conducting variety trials at the same location for several years is necessary, since the greater number of years genotype is tested and its evaluation will be more reliable[7]. Grain yield stability is defined, in this context, as a decreasing crop failure frequency[8]. Stability is also defined as a low range between extreme environments[9,10].

When selecting varieties to be adopted in variable environments, breeders are concerned with the avoidance of crop failure under harsh growth conditions. This is because a large proportion of cereals are grown under low input conditions by subsistence farmers. Lin *et al.*[11] reviewed numerous stability methods which could be used as aids to select stable cultivars in the presence of G x E. When selecting in the presence of G x E breeders need to weigh the importance of a cultivar's stability relative to its performance across environments[12]. Many researchers[11,13-16] suggested using the regression coefficient of yield response to environmental variation as well as grain yield mean to characterize the desirability of a cultivar. Eskridge[17] introduced the application to plant selection of the safety-first index relating mean yield to a stability parameter. Selection practiced on a safety-first index allows choice of cultivars which have a low probability to produce poor yield under unfavourable growth conditions. The objective of this study was to

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analyze grain yield data in a trial of 10 genotypes conducted during 6 cropping seasons at the Setif's ITGC-Agricultural Research Station (Algeria), in terms of yield performance and yield stability.

MATERIALS AND METHODS

Ten durum cultivars and advanced breeding lines were grown during 6 cropping seasons from 1997/98 to 2002/03 at the Technical Institute of Field Crop (ITGC) Agricultural Research Station (ARS) of Sétif. The experimental site is located on the eastern highland of Algeria. This site is a representative of quite a large agricultural semi-arid region where the dominant farming enterprise is sheep production and the purpose of the cereal cropping is to provide staple food for the farmer's family and feed for ruminants. Stubble is grazed just after harvesting and straw is stored and distributed during the winter months as supplementary feed when outdoor vegetation becomes scarce[18].

The 10 durum wheat genotypes included in this study (Table 1) represent a wide range of plant type and grain yield potential. They were selected in 1997/98 from an international yield trial at the Setif's ARS experimental site on the basis of their superiority over the local check variety Mohammed Ben Bachir[19].

Seeding was done by mid-November in 6 rows x 5 m long plots at a rate of 250 kernels m^{-2} in a field which was fallowed the preceding year (black fallow). Triple super-phosphate was drilled just before seeding at a rate of 46 and 34 units ha^{-1} of urea were broad casted during tillering stage. Weeds were controlled with an application of 12 g ha^{-1} of Granstar (Methyl Triberunon) herbicide. Harvest was done mechanically by mid-June.

Grain yield data were subjected to an analysis of variance of an experiment laid out as a Randomized Complete Block with three replications, including the factors season, genotype and block. Seasons were considered as random and genotypes as fixed and testing of effects and estimate of variance components were performed as recommended by Mc Intosh[20]. The contribution of each tested cultivar or line to the genotype x season variance was estimated relatively to yield variation of the check cultivar Mohammed Ben Bachir (MBB) according to the procedure outlined by Lin and Binns[21]:

$$MS_{GxS}i = \sum (Y_{MBB}j - Y_{MBB.} - Y'ij + Y'i.)^2/2(n-1)$$

Where:

$Y_{MBB}j$ = Observed grain yield of MBB measured in the season j
$Y_{MBB.}$ = Mean grain yield of MBB averaged over seasons
$Y'ij$ = Observed grain yield of the tested genotype i in the season j
$Y'i.$ = Mean grain yield of the genotype i averaged across seasons
n = Number of seasons experienced = 6.

MS_{GxS} i was tested against the error term of the combined analysis of variance.

Genotypic stability measures were based on both the Finlay and Wilkinson[13] regression coefficient (FW) and the across seasons variance (EV). The regression coefficient was calculated as outlined by Lin *et al.*[11]:

$$b = \sum (Y_{ij} - Y_{i.})(Y_{.j} - Y..)/ \sum (Y_{.j} - Y..)^2$$

Where, $\sum$ = Summation is done from season j = 1 to season j = q = 6

Y_{ij} = Yield of the ith genotype in the jth season
$Y_{i.}$ = Average yield of the ith genotype = $(\sum Yij)/q$
$Y_{.j}$ = Average yield of the jth season = $(\sum Yij)/n$, n is the number of genotypes = 10
Y.. = Overall mean grain yield

The coefficients of regression were tested against their respective Standard Error (SE) as follow:

t. = (1-b)/se, observed and t. observed is compared to t. table with q-1 degrees of freedom[22].

The across seasons variance of the i th genotype was calculated as:

$$S^2i = \sum (Yij - Yi.)^2/ (q-1)$$

To weigh yield performance relatively to stability, the safety-first index was derived assuming a 5% probability of an undesirable event. This probability is used to compute for each cultivar the lower confidence limit representing grain yield which would be obtained with only a 5% chance, that is once in 20 seasons The index

Table 1: Pedigree, origin and abbreviation of the genotypes under study

Pedigree	Origin	Abbreviation
Adamillo/Duillio//Semito 439-97	Italy	ADS
Massara1	Syria	MAS
MRB5	Syria	MRB
Cyprus1	Cyprus	CYP
Waha	Algeria	WAH
Derraa	Syria	DER
Heider/Martes//Huevos de Oro	Algeria	HMH
Heider	Syria	HEID
Mohammed Ben Bachir	Algeria	MBB
Beliouni3258	Algeria	BEL

based on the regression coefficient as a measure of stability was computed according to Eskridge[17]:

$$FW_{index} = Yi.- Z(1- \alpha) [(b - 1)^2 S^2y (1-1/q)]^{1/2}$$

Where, $S^2y = \sum (Y.j - Y..)^2/(q-1)$ = seasons variance

q = Number of seasons and Z(1-α) is the 1-α percentile from the standard normal distribution, with α sets in the present study at 5% level.

Based on the across seasons variance, the index was computed as:

$$Ev_{index} = Yi.- Z(1- \alpha) (S^2i)^{1/2}$$

Kendall's τ coefficient of rank correlation was calculated between genotype grain yield, coefficient of regression, across seasons variance, contribution to G x S interaction (CM_{GxS}) and safety-first index values. Predicted grain yields of each genotype were calculated from the regression equation simulating an environment grain yields range varying from 50 to 400 g m^{-2}. Ratios, expressed as percentages, were then calculated for predicted yields of each variety to the predicted yields of the check cultivar MBB. Statitcf computer package was used for all statistical analysis[23].

RESULTS AND DISCUSSION

Performance and stability: Grain yield analysis of variance showed significant genotype x season (G x S) interaction effect (Table 2). The season variance was much larger than the genotypic variance component and explained 43.5% of the total sum square. Seasons grain yield (Y.j) varied widely from 179.6 to 357.8 g m^{-2}. Two years had below average grain yield and 4 years had above average grain yield, reflecting the large year to year variation in rainfall and temperature (Table 3). Due to the high GxS, explaining about 43% of the total variation and used as error term, the genotypic main effect was not significant. Genotypic grain yield means (Yi.) were then less variable compared with season grain yield (Y.j) and varied from 241.0 to 312.4 g m^{-2} yield of Cyprus1 (Table 4).

The usual definition of genotype x environment interaction implies that interactions exist if differences between genotypes are not consistent from one environment to another. Baker[24] reported that interactions are of consequence in selection only if some genotypes are superior in particular environments while other genotypes are superior in other environments.

Table 2: Mean square of grain yield over combined seasons

Source of variation	df	MS	Contribution SS(%)
Season (S)	5	160249.9**	43.54
Blocks/Season (B/S)	12	1578.0	--
Genotype (G)	9	17796.8ns	6.36
G x S	45	17698.4**	42.90
Pooled error	108	1116.1	

ns and ** = non significant and significant effect at 1% level of probability, respectively

Table 3: Season mean grain yield rainfall accumulated and mean temperature for the vegetative and reproductive growth periods

		Rainfall (mm)		Temperature (°C)	
Seasons	Grain yield (g m^{-2})	Vegetative$^{\lambda}$	Reproductive	Vegetative	Reproductive
1997/98	306.9	207.6	185.7	6.9	11.6
1998/99	315.2	179.1	54.3	7.7	15.4
1999/00	357.8	128.5	103.3	8.2	14.0
2000/01	326.8	198.5	51.2	8.0	14.9
2001/02	179.6	104.9	62.3	10.7	15.9
2002/03	199.9	322.1	204.0	7.1	14.7

$^{\lambda}$Vegetative = Oct- Feb, Reproductive = March -May

Changes in rank order are so required before genotype x environment interaction becomes important.

The presence of genotype by season interaction indicated by the combined analysis of variance was expressed in the change of genotypic performances in the different seasons experienced as shown by the range magnitude (Table 4). In fact MRB5 out yielded the evaluated entries in three seasons out of six. Cyprus1, Waha and Derraa were high yielding in one season and Adamillo/Duillio//Semito 439-97 (ADS), Massara1, Cyprus1, Beliouni 3852 and MBB were poor yielding during at least one season. None of the entries out yielded significantly the check cultivar MBB in all the 6 seasons tested. This indicated that stability over time represented by the set of seasons experienced was lacking in the selected entries.

ADS, Waha, Derraa and Heider/Martes//Huevos de Oro (HMH) were characterized by a slope significantly greater than 1 and a large variance across environments which was 4.5 times higher than the variance pertaining to Massara1 (Table 4). These genotypes had below average stability and are specifically adapted to favorable seasons, according to the stability definition of Finlay and Wilkinson[13]. Cyprus1 had a slope equal to 1 and a large across environments variance, while Beliouni3258 had a slope equal to 1 and an intermediate across environments variance (Table 4). These two genotypes had average stability and a general adaptation to variable environments (Fig. 1).

MRB5, Heider and MBB had a slope less than 1 and a low across environments variance. They are specifically adapted to unfavorable seasons. So adaptation to unfavorable seasons is associated with a above average stability (b<1) and low grain yield potential. Massara1

Table 4: Genotype performance, safety-first index and its interaction with treatments

	Performances		Stability			Safety-first index			
Genotype	GY (g m^{-2})	range (g m^{-2})	CM_{GxS}	b	S^2i^{λ}	FW	Rank	EV	Rank
ADS	273.5	140.5-392.7	4186.0*	$1.35^{§}$	11.2	256.3	6	98.8	8
Massara1	237.9	190.7-308.3	929.9ns	$0.28^{¤}$	2.4	201.9	7	157.0	2
MRB5	300.5	163.9-426.6	1234.8ns	$0.75^{£}$	9.8	261.5	5	137.2	3
Cyprus1	312.4	194.0-557.3	13461.3*	$1.12^{¥}$	18.1	308.8	1	90.4	9
Waha	283.7	149.7-431.6	1241.4ns	$1.22^{§}$	10.7	279.7	3	113.0	6
Derraa	298.3	179.8-593.0	15652.5*	$1.40^{§}$	23.5	278.6	4	45.3	10
HMH	312.4	197.2-500.0	6368.4*	$1.29^{§}$	11.7	298.1	2	133.9	4
Heider	293.4	204.6-385.0	402.2ns	$0.75^{£}$	5.7	192.2	8	168.8	1
MBB	241.0	147.6-328.3	….	$0.75^{£}$	6.2	135.3	10	111.0	7
Beliouni	257.0	152.9-384.3	1057.6ns	$0.94^{¥}$	7.1	149.9	9	117.9	5

£ = b significant < 1, ¥ = b = 1, § = b significantly >1 and ¤ = b not significantly different from zero., $^{\lambda}$ = variance to $x10^3$

GY: Grain yield, CM_{GxS}: Contribution and GXS interaction, b: Coefficient of regression, Si^2: Variance across environments, Fw: Regression coefficient, EV: Across seasons variance

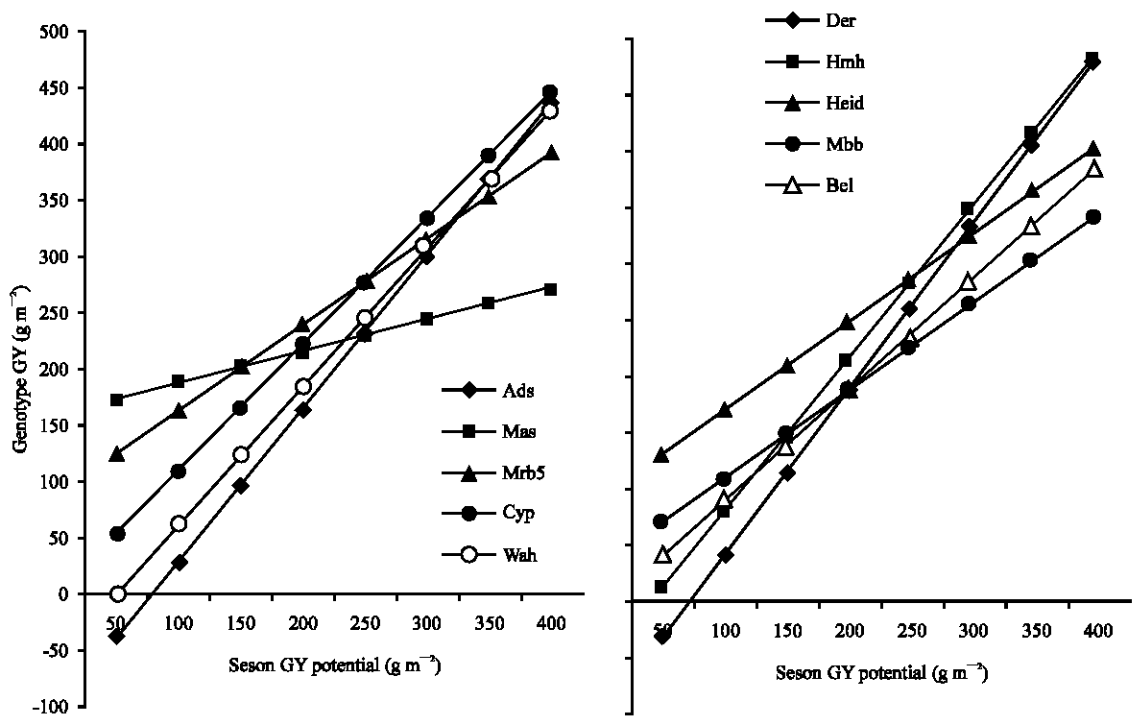

Fig. 1: Predicted grain yield variation in relation to season grain yields potential of the various genotypes

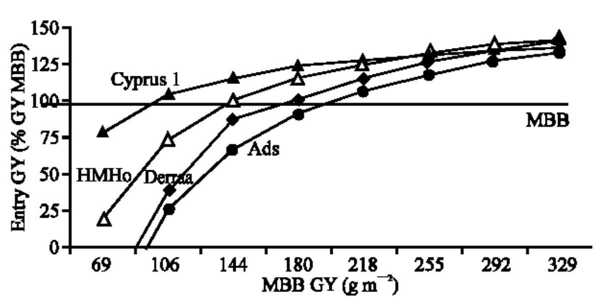

Fig. 2: Variation of grain yield of genotypes contributing significantly to GXS interaction as % of MBB yield

presented a relatively low across environments variance and a slope not significantly different from zero. This genotype responded poorly to the linear variation of grain yield (Fig. 1), it shows a high stability based on the variance across seasons. Massara1, MRB5, Waha, Heider and Beliouni3852 make no significant contribution to G x S interaction as compared to MBB (Table 4). This indicated that the differences between grain yield of MBB and the means of these genotypes are constant over the range of seasons experienced. These differences were tested for significance using the LSD test based on the error term of the combined analysis of variance.

Based on the LSD test which takes the value of 22.2 g m^{-2}, grain yield means of Massara1 and Beliouni 3852 are not significantly different from that of MBB. MRB5, Waha and Heider showed a yielding capacity significantly greater than that of MBB over the grain yield range of the seasons tested. The differences between the yielding ability of these three genotypes are not significant when compared to the LSD. Derraa, Cyprus1, ADS and HMH contributed significantly to the G x S interaction (Table 4).

Figure 2 indicated that ADS, Derraa and to a lesser extent HMH are poorly adapted to the seasonal yield variation experienced. In fact when MBB expressed a grain yield of 106 g m^{-2}, which is the average grain yield observed at the farm level, these cultivars yielded 27, 39 and 73%, respectively. As far as crop failure is concerned these cultivars appeared to be more risky in comparison with Cyprus1 which maintains a yield equal or higher than the one of MBB in the range 106 to 320 g m^{-2} (Fig. 2).

Risk efficiency: Based on the FW index all tested genotypes appeared to be risk efficient as compared to the local check, while Cyprus1 and HMH showed the higher values for the FW index. The EV index identified Heider and Massara1 as the most risk efficient cultivars and Derraa, Cyprus1 and ADS the least risk efficient (Table 4). Based on Kendall's Tau coefficient of rank correlation FW index showed a significant correlation with grain yield, variance across seasons, the contribution to GxS mean square and a non significant correlation with the EV index. The EV index did not show any significant correlation with the measured parameters (Table 5).

The absence of significant correlation between both indices indicated that, within the set of entries evaluated and under the set of seasons experienced, each safety-index identified a specific risk efficient genotype but it is possible to select a genotype which has a medium risk efficiency according to both indices. This is the case of MRB5 which was classified 5th and 3rd and HMH which was classified 2nd and 4th by the FW and EV indices (Table 4).

Present results are in agreement with those reported by Ceccarelli and Grando[8] who found that ranks of genotypes using the EV index were poorly correlated with the FW index. Erskridge[17] reported that the index based on EV was poorly related with the one based on FW and explains that the EV index defines stability based on across environments variance which differed from stability based on FW. The FW index is based on type 2 stability[11], where a genotype is said to be stable if its response to seasonal variation is parallel to the average response to all genotypes included in the test.

Table 5: Kendall's τ coefficient of rank correlation between safety-first index and yield stability parameter

	GY (g m^{-2})	b	S^2i	MS_{GxS}	FW
FW	0.79*	0.53ns	0.77*	0.84*	..
EV	-0.17ns	-0.70ns	-0.76ns	-0.64ns	-0.33ns

ns = non significant and * significant coefficient at 5 % level of probability, respectively.

The EV index is based on stability across environments (type 1) and a genotype is stable under such conditions when it is characterized by a low across environments variance. When environments are quite diverse, as the set of seasons experienced, the EV index may not be very meaningful. The FW index is more reliable since it describes the response of a cultivar to varying seasons in terms of grain yield potential relative to the average response of all genotypes included in the test or relatively to the check cultivar. Among the genotypes tested Cyprus1 appears as a genotype which associates high grain yield, good stability and risk efficiency.

Stability and risk efficiency are generally explained by the differential genotypes sensitivity to environmental variables such as minimum temperature during the spike growth[25], spring frost hazard at the heading stage[26], drought and high temperature during the grain filling period[27]. All these climatic factors explained a large portion of the genotype x environment interaction in durum wheat, as phenological, morphological and physiological adaptation mechanisms operating in different environments as not the same in the different genotypes tested. Statistical tools like those developed here and more sophisticated ones such as the Additive Main Effect and Multiplicative Interaction model and the Partial Least Squares Regression allow to select genotypes best suited for a specific set of environments from those suited for the entire environments tested[5,25].

CONCLUSIONS

For a cultivar to be commercially successful it must perform well across the range of environments in which it may be grown. Multi-sites and multi-seasons trails are conducted for that purpose to investigate the magnitude of genotype x environment. The results of this study indicated that the safety-first rule index is useful for selection in environments where interaction is large and low grain yield may have adverse consequences. Assuming that the set of seasons experienced provided a representative sample of a semi-arid growing conditions, the combination of average grain yield, response to environmental variation and the safety-first rule based on the regression coefficient were helpful in identifying desirable cultivars as far as yield level, stability and risk efficiency are concerned. This investigation makes apparent the magnitude of genotype x season interaction that must be confronted in a durum breeding evaluation program. The extent to which these results would apply to other locations of the same region needs to be further investigated.

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