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Evaluation of drought tolerance indices in durum wheat recombinant inbred lines

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Abstract. Two hundred forty nine F_7 RILs were tested for their yielding ability under both irrigated (GYi) and rainfed (GYp) conditions. Six drought tolerance indices involving: Stress Tolerance Index (STI), Stress Susceptibility Index (SSI), Mean Productivity (MP), Geometric Mean Productivity (GMP), Yield Stability Index (YSI) and Stress Tolerance (TOL) were used to identify high yielding and drought tolerant RILs. MP explained 72% of GYi. GMP and STI explained around 58% of GYp. TOL under favourable and SSI or YSI under water deficit discriminate between tolerant genotypes to stress. Greater values of GMP, STI and MP indices were associated with higher yielding RILs under both growing conditions. Inversion of RILs ranking was obtained for SSI and TOL as compared to YSI. Higher TOL and SSI values were associated with significant grain yield reduction in stressed environment suggesting higher stress responses of RILs. Significant positive associations between MP, STI and GMP and negative between YSI and SSI were noted. The former three indices were independent from YSI, SSI and TOL.

Keywords. Grain yield – Drought tolerance – Stress tolerance indices.

Évaluation des indices de tolérance à la sécheresse chez des lignées autogames recombinantes de blé dur

Résumé. *Deux cent quarante-neuf RILs issues du croisement entre Kofa et Svevo, ont été évaluées pour leur aptitude au rendement en grains sous des conditions irriguées (GYi) et pluviales (GYp). Six indices de tolérance au stress ont été utilisés incluant : l'Indice de Tolérance au Stress (STI), l'Indice de Sensibilité au Stress (SSI), la Productivité Moyenne (MP), la Productivité Moyenne Géométrique (GMP), l'Indice de Stabilité du Rendement (YSI) et la Tolérance au Stress (TOL). La MP explique 72% de la variation du GYi. La GMP et le STI expliquent 58% de la variation du GYp. La TOL sous les conditions favorables et le SSI ou le YSI sous déficit hydrique permettent la discrimination des génotypes résistants par rapport aux plus sensibles. Les valeurs élevées de la MP, du STI et de la GMP ont été associées aux RILs les plus productives sous les deux régimes. Toutefois, les classements selon le SSI et la TOL sont dans un ordre inverse à celui obtenu par le YSI. Les valeurs élevées de la TOL et du SSI ont été associées à une réduction significative des rendements sous les conditions de stress hydrique suggérant une forte réponse au stress des RILs. Des corrélations hautement significatives sont observées entre les indices STI, MP et GMP. L'YSI, le SSI et la TOL, hautement corrélés entre eux, ne sont pas corrélés aux indices STI, MP et GMP.*

Mots-clés. *Rendement – Tolérance à la sécheresse – Indices de tolérance.*

I – Introduction

Drought is a wide-spread problem seriously influencing wheat production and quality (Sio-Se Mardeh *et al.*, 2006). Managing drought is necessary to identify and to appropriate solutions fulfilling the objectives of each region. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress (Blum, 1988). While drought resistance was defined as the relative yield of genotype compared to other genotypes subjected to the same drought stress (Hall, 1993). But development of resistant cultivars is hampered by the lack of effective selection criteria (Sio-Se Mardeh *et al.*, 2006). Drought tolerance indices, based on yield reduction under drought conditions in comparison to normal conditions, were defined to provide a measure of drought constraint and to screen the most drought-tolerant genotypes (Mitra, 2001). They constitute consistent research tools permitting quantification of water constraint effects on yielding which were subjected to genetic and G × E interaction (Golabadi *et al.*, 2006). Selection based on a combination of different indices would be able to typify potential upper yielding and drought tolerant genotypes (Mitra, 2001).

II – Materials and methods

For this study 252 genotypes were evaluated involving a population of 249 durum wheat F_7 recombinant inbred lines (RILs), the parents Kofa and Svevo and Vitron as three checks. Kofa and Svevo were both well adapted to the Mediterranean climate where they can be classified as early-flowering. RILs were tested in unreplicated field trials, using an augmented design with three checks. Four irrigations were applied, 30 mm each, during December, January, March, and May to compensate for lack and irregularity of rain. GYi, G$\bar{Y}$i, GYp and G$\bar{Y}$p were yield and yield means of all genotypes under irrigated and rainfed conditions respectively. Indices were expressed by the following formula (Table 1).

Table 1. Drought tolerance indices

Index	Formula	Reference
Stress Tolerance Index	STI = [(GYi) × (GYp) / (G$\bar{Y}$i)^2]	(Fernández, 1992)
Mean Productivity	MP = (GYi + GYp) / 2	(Rosielle and Hamblin, 1981)
Geometric Mean Productivity	GMP = [(GYi) × (GYp)]$^{0.5}$	(Fernández, 1992)
Stress Tolerance	TOL = (GYi - GYp)	(Rosielle and Hamblin, 1981)
Stress Susceptibility Index	SSI = [1 - (GYp) / (GYi)] / SI	(Fischer and Maurer, 1978)
(Stress Intensity)	SI = [1 - (G$\bar{Y}$p) / (G$\bar{Y}$i)]	
Yield Stability Index	YSI = GYp / GYi	(Bouslama and Schapaugh, 1984)

Correlation between stress indices and GYi and GYp was estimated by CORR proc. of SAS (SAS Institute, 2001). Regression was established between these parameters by REG proc. of SAS (SAS Institute, 2001).

III – Results and discussion

1. Correlation between grain yields and indices

Correlation analysis didn't reveal any significant association between irrigated and rainfed grain yield (Table 2). Sio-Se Mardeh *et al.* (2006) deduced that the correlation lack is related to the fact that high potential production under optimal conditions doesn't result necessarily on a high yield under stress conditions.

Significant positive correlation was noticed among GYi and the majority of drought tolerance indices (STI, SSI, TOL, MP and GMP), while YSI showed high negative correlation. MP and TOL showed the highest coefficients of correlation (Table 2). Similar results were observed with GYp against STI, GMP, YSI and MP, but SSI and TOL were highly negative correlated to GYp, while the most closely correlated to GYp were STI and GMP. MP was the strongly correlated index to GYi and highly correlated to GYp; whilst STI and GMP were the highest correlated to GYp and highly correlated to GYi (Table 2). These results may advise MP, STI and GMP to be the best predicates for both conditions. SSI and TOL showed disparity against GYi and GYp indicating the population segregated for genes conditioning yield potential and drought resistance. Sio-Se Mardeh *et al.* (2006) suggested that these traits can contribute to increase yield under stress and reduce stress susceptibility. Golabadi *et al.* (2006) reported that selection for TOL will be worthwhile only when the target environment is no-drought stressed.

Table 2. Correlation coefficients matrix between GYi, GYp and stress tolerance indices

	GYi	GYp	YSI	SSI	TOL	MP	STI
GYi							
GYp	0.055						
YSI	-0.611**	0.622**					
SSI	0.611**	-0.622**	-1.000**				
TOL	0.830**	-0.511**	-0.874**	0.874**			
MP	0.848**	0.576**	-0.170	0.170	0.408*		
STI	0.654**	0.755**	0.023	-0.023	0.142	0.936**	
GMP	0.667**	0.767**	0.027	-0.027	0.147	0.953**	0.983**

** and *: significant at $p < 0.001$ and $p < 0.05$ levels of probability, respectively.
GYi and GYp: irrigated and rainfed grain yield, YSI: yield stability index,
SSI: stress susceptibility index, TOL: tolerance index, MP: mean productivity,
STI: stress tolerance index, GMP: geometric mean productivity.

STI and GMP were not correlated to YSI, SSI and TOL. Low correlation between STI, GMP and MP against YSI, TOL and SSI suggest that each index may be a potential indicator of different biological response to drought (Hassanzadeh *et al.*, 2009). Golabadi *et al.* (2006) leading to similar results, stated that combination is biologically attainable in wheat, thereby combining traits that associate with each index. Thus, RILs that have high STI, MP and GMP and low TOL and SSI were suited for both irrigated and rainfed environments.

2. Relationships between grain yields and indices

Variance analysis revealed that the model was significant for all variables showing simple linear relation between GYi and GYp and the six tolerance indices (Boussen *et al.*, 2010). Linear relations among GYi and GYp with STI, MP and GMP indices were described by upward slopes. Upward trends were obtained between SSI and TOL and GYi, while their variations against GYp were inversely proportioned showing downward slopes.

A. Relationships between grain yields GYi and GYp

GYi to GYp linear regression revealed adverse variation in our conditions. Thus, a high yield potential under favourable conditions doesn't result necessarily in improved yield potential under stress conditions and the reverse is true. Clarke *et al.* (1992) accredited the lack of response to optimum conditions to the lack of genotype adaptation to high-moisture conditions, while Ceccarelli and Grando (1991) stated that low potential yielding genotypes were upper yielding under stress conditions. In fact, the genes controlling yield under both conditions are different (Rosielle and Hamblin, 1981).

B. Relationships between grain yields and indices

Linear regressions revealed that coefficients of determination between GYi and the six tolerance indices were $R^2_{STI/GYi} = 0.43$, $R^2_{MP/GYi} = 0.72$, $R^2_{GMP/GYi} = 0.45$, $R^2_{SSI/GYi} = 0.37$, $R^2_{YSI/GYi} = 0.37$ and $R^2_{TOL/GYi} = 0.69$. Thus, these results revealed that MP index may be considered the best predicate to explain grain yield variations under irrigated regime. Conversely, the coefficients of determination between GYp and the indices were $R^2_{STI/GYp} = 0.57$, $R^2_{MP/GYp} = 0.33$, $R^2_{GMP/GYp} = 0.59$, $R^2_{SSI/GYp} = 0.39$, $R^2_{YSI/GYp} = 0.39$ and

$R^2_{TOL/GYp}$ = 0.26, showing that GMP or STI indices can be a potential indicator allowing interpretation of GYp variation under rainfed treatment. While TOL, under favourable conditions, SSI or YSI, under stress conditions, can be used to explain tolerance degree but not the yield variation. Variability among RILs is detected beside trials hydrous conditions with all tolerance indices. Each index provides its proper RILs ranking according to its appropriate formula.

RILs ranks based on different indices revealed that the targeted RILs under rainfed and irrigated conditions, with high STI, MP and GMP values, were the upper yielding under both regimes. Our results come to an agreement with those of Fernández (1992), who concluded that selection based on STI and GMP indices leads to over yielding and upper tolerant genotypes. Golabadi *et al.* (2006) obtaining similar result on durum wheat, stated that selection for MP should give positive response in both environments. STI index was even suggested for heat temperature tolerance selection (Porch, 2006; Porch *et al.*, 2009). However, Hohls (2001) thought that MP should increase yield in both environments unless the genetic variance under stress is more than double that under non-stress and the genetic correlation between yields in contrasting environments is highly negative.

Conversely YSI, SSI and TOL rankings were in reverse order from those obtained according to RILs yields, STI, MP and GMP. They consider RILs tolerance degree but couldn't distinguish between potentially drought-tolerant genotypes from the low overall yield potential ones. Sio-Se Mardeh *et al.* (2006) suggested that selection based on TOL will result in reduced yield under well-watered conditions. Such genotypes may be inapt to increase the value of improvement conditions. High TOL and SSI values were obtained for high differences between GYi and GYp, then for no-tolerant RILs, whilst low values were given to tolerant RILs which have GYp near to GYi. Sio-Se Mardeh *et al.* (2006) concluded that the greater the TOL value, the larger the yield reduction under stress condition and the higher the drought sensitivity. Golabadi *et al.* (2006) stated that selection for TOL should decrease yield in the moisture stress environment, and increase grain yield under non-moisture stress.

RILs with high yield under stress conditions associated to low yield under irrigated regime have the highest YSI values. These results disagree with Bouslama and Schapaugh (1984) who stated that cultivars with a high YSI were expected to have high yield under both stress and non-stress conditions. However, Sio-Se Mardeh *et al.* (2006) found that cultivars with the highest YSI exhibited the least yield under non-stressed conditions and the highest yield under stressed conditions.

Results suggested indices arrangement into two factions:

(i) STI, GMP and MP highly correlated, describing yield variation under hydrous regimes.

(ii) YSI, SSI and TOL highly correlated, revealing stress tolerance aptitude of lines.

However, using STI as well as GMP and SSI just as well as YSI appears to be sufficient to avoid redundant term since relationships between these indices were demonstrated (Boussen *et al*., 2010) as:

$STI = GMP^2 / (G\bar{Y}i)^2$ in which $(G\bar{Y}i)^2$ is a constant;

$SSI = (1 - YSI) / SI$ in which SI is a constant.

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