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RESEARCH ARTICLE

APPLICATION OF SALT TOLERANCE INDICES FOR SCREENING BARLEY (*Hordeum vulgare* L.) CULTIVARS

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ABSTRACT

Salinity is a wide-spread problem seriously influencing barley (*Hordeum vulgare* L.) production, but development of tolerant cultivars is hampered by the lack of effective selection criteria. The objective of this study was to produce screening techniques for selecting salt-tolerant progeny in barley breeding program. Fourteen barley cultivars differing in yield performance were grown in separate experiments under salt stress and non-salt stress conditions in 2008–2009. Eight selection indices including salt susceptibility index (SSI), salt tolerance index (STI), tolerance (TOL), regression coefficient of cultivar yield on environmental index (b), yield index (YI), yield stability index (YSI), mean productivity (MP), and geometric mean productivity (GMP) were calculated based on grain yield under salt and non-salt stress conditions. Results showed that the effectiveness of selection indices in differentiating tolerant cultivars varies with the salt stress intensity. Thus, under moderate salt stress, MP, GMP and STI were more effective in identifying high yielding cultivars in both salt and non-salt stress conditions. Under severe stress, regression coefficient (b) and SSI were found to be more useful in discriminating tolerant cultivars. Breeders should, therefore, take the stress intensity of the environment into account in choosing an index.

INTRODUCTION

Salinity stress remains one of the world's oldest and the most serious environmental problem, which substantially hampers crop productivity in many arid and semi arid regions (CLARK and DUNCAN 1993). Soil salinisation is one of the major factors of the soil degradation. It has reached 40 % of the irrigated land and 2.1% of the globe. Salinity effects are more conspicuous in arid and semi-arid areas where 25% of the irrigated land is affected by salts (BHATTY, 1999). The increase of salt-affected soils due to poor soil and water management in the irrigated areas, the salinity problem become of great importance for agriculture production in this region (SAYAR *et al.,* 2010). New sources of salinity tolerance are needed for barley grown on salt-affected land. This would be particularly effective in areas with subsoil salinity, which is extensive in many landscapes dominated by sodic soils. Tolerance to salinity stress can be defined as the capacity of the plant to take up sufficient quantities of water from the soil despite the low water potential, and to tolerate sodium toxicity and deficiency in other minerals antagonist to sodium and chlorine (ELLIS *et al.,* 2002). There are vast numbers of barley cultivars with significant differences in salt stress tolerance. The development of salt tolerant crop cultivars presents an alternative to expensive approaches to bring saline marginal lands under cultivation (HOLLINGTON 1998). Understanding the diversity for salt tolerance in barley (*Hordeum vulgare* L.) cultivars will facilitate their use in genetic improvement. Indeed, the development of tolerant cultivars, however, is hampered by low heritability for salt tolerance and a lack of effective selection strategies (ASHRAF 2004). The relative yield performance of cultivars in salt-stressed and more favourable environments seems to be a common starting point in the identification of traits related to salt tolerance and the selection of cultivars for use in breeding for salt environments (CLARKE *et al.*, 1992). According to FERNANDEZ (1992), cultivars can be divided into four groups based on their yield response to salt stress conditions: (i) cultivars producing high yield under both salt stress and non-salt stress conditions (group A), (ii) cultivars with high yield under non-salt stress (group B) or (iii) salt stress (group C) conditions and (iiii) cultivars with poor performance under

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both salt stress and non-salt stress conditions (group D). The question is: should breeding for stress-prone environments rely on selection under both potential and stress conditions or on selection in either environment alone? Some researchers believe in selection under favourable (non-salt stress) condition (BETRAN *et al.,* 2003). Selection in the target stress condition has been highly recommended too (RATHJEN 1994). Several researchers have chosen the mid-way and believe in selection under both non salt stress and salt stress conditions (CHEESEMAN 1988; WANGXIA *et al.,* 2003).

The use of saline water for irrigation is a subject of increasing interest because of the increasing water requirements for irrigation and the competition between human, industrial and agricultural use and moreover because of the pressure for the disposal of drainage water through reuse. In the Mediterranean area, Tunisia for example, where the fresh water resources for agricultural use are rather limited, and extension of irrigated agriculture is mainly possible by using saline water. To differentiate salt tolerance cultivars, several selection indices have been suggested on the basis of a mathematical relationship between favourable (non salt stress) and salt stress conditions (HUANG, 2000). Tolerance (TOL) (CLARKE *et al.*, 1992), mean productivity (MP) (MCCAIG and CLARKE, 1982), salt susceptibility index (SSI) (FISCHER and MAURER, 1978), geometric mean productivity (GMP) and salt tolerance index (STI) (FERNANDEZ, 1992) have all been employed under various conditions. FISCHER and MAURER (1978) explained that cultivars with an SSI of less than a unit are salt tolerant, since their yield reduction in salt condition is smaller than the mean yield reduction of all cultivars (BRUCKNER and FROHBERG, 1987). The objective of this study was to test these hypotheses in order to identify the most suitable indices for screening barley cultivars under various salinity treatments.

MATERIAL AND METHODS

Germplasm

A collection of fourteen barley cultivars (Table 1) representing a wide range in genetic diversity. This set of cultivars had previously been screened for their reputed differences in yield performance under salt stress and non-salt stress conditions (BCHINI *et al.,* 2010). The experiments were conducted at El-Afareg research station of the Field Crop Research Center at Beja in northwest of Tunisia.

Greenhouse experiment and plant material

Whole plant responses to salinity were studied in greenhouse experiment without supplemental lighting. Relative humidity was maintained at about 70 (±5) %, and the day/night temperature was maintained at 24/16 (±2) °C. Seeds were previously sterilized with 5% calcium hypochlorite for 10 min and thoroughly washed with sterile deionised water. Five seeds of the fourteen barley (*Hordeum vulgare* L,) cultivars (Table 1) were sown in each soil-filled polyethylene tubes (20 × 133 cm) containing 70% vertisoil and 30% sand. All seeds were irrigated with tap water (0 mM NaCl) until 15 days after planting (DAP). Plants were thinned to one per container 14 DAP. Plants were irrigated with the assigned saline solution (Ec = 0.73 $dS.m^{-1}$, Ec = 10.76 $dS.m^{-1}$ Ec = 15.38 $dS.m^{-1}$) at 15 DAP. Irrigation occurred every 5 d and involved wetting the soil to beyond field capacity. The 0.73 $dS.m^{-1}$ saline solution was used to simulate natural field conditions. The 10.76 $dS.m^{-1}$ salinity level was chosen to represent the predominant salinity level of saline water aquifers in Tunisia (BEN NACEUR *et al.,* 2005). Thus, more than 65% of the water used for cereal irrigation has a salinity varying from 4.7 to 10.94 $dS.m^{-1}$ (BCHINI *et al.,* 2010)

Table 1. Origin or pedigree of used barley cultivars

Cultivar	Origin
JND1	Local cultivar from Jendouba region (sub humid region)
JND2	Local cultivar from Jendouba region (sub humid region)
KLA	Local cultivar from Kalaa region (semiarid region)
KSR	Local cultivar from Kasserine region (semiarid region)
KBL1	Local cultivar from Kebili region (saharian region)
KBL3	Local cultivar from Kebili region (saharian region)
KLB2	Local cultivar from Kelibia region (costal region)
MNL	Line527/5/As54/Tra//2*Cer/Tol1/3/Avt/Tol1/1CB81-607-1Kf-1Bj-12Bj-1BJ-1Bj-0Bjselected 1996
MRT	Six row variety. late, selected from an Algerian population since 1931
RHN	Atlas 46 /Arivat //Athenais ICB76-2L-1AP-0AP selected at ICARDA (1976)
SBZ	Local cultivar from Sidi Bouzid region (semiarid region)
SWH	Local cultivar from Sahel region (costal region)
TZ1	Local cultivar fromTozeur region (saharian region)
TZ2	Local cultivar fromTozeur region (saharian region)

Abbreviation: Jendouba 1 = JND1, Jendouba 2 = JND2, Kalaa = KLA, Kasserine = KSR, Kebili 1 = KBL1, Kebili 3 = KBL3, Kelibia 2 = KLB2, Manel = MNL, Martin = MRT, Rihane = RHN, Sidi Bouzid = SBZ, Swihli = SWH, Tozeur 1 = TZ1, Tozeur 2 = TZ2

At maturity stage according to ZADOKS scale (Z99), roots were carefully washed to remove soil and laid flat and plants were removed from the tubes. Primary roots number (RN), root dry matter (RDM), grain yield (GY), and grain per spike (GS^{-1}) were measured for each replicate, cultivar, and treatment. Salt tolerance indices were calculated using the following relationships:

1) SSI (salt susceptibility index) = $[1-(Y_s/Y_p)]/ [1-(\bar{Y}_s/\bar{Y}_p)]$ (FISCHER and MAURER, 1978). Where Y_s is the yield of cultivar under stress (Ec = 15.38 $dS.m^{-1}$) Y_p the yield of cultivar under non salt stress (potential) condition (Ec = 0.73 $dS.m^{-1}$) $\bar{Y}_s$ and $\bar{Y}_p$ the mean yields of all cultivars respectively under salt stress and non-salt stress conditions, and $[1-(\bar{Y}_s/\bar{Y}_p)]$ is the salt stress intensity. The treatment of Ec = 0.73 $dS.m^{-1}$ was considered to be a non-stress condition in order to have a better estimation of optimum environment.
2) MP (mean productivity) = $(Y_p + Y_s)/2$ (HOSSAIN *et al.,* 1990).
3) TOL (tolerance) = $Y_p - Y_s$ (HOSSAIN *et al.,* 1990).
4) STI (salt tolerance index) = $(Y_p + Y_s)/ (\bar{Y}_p)^2$ (FERNANDEZ 1992).
5) GMP (geometric mean productivity) = $(Y_p \text{ x } Y_s)^{0.5}$ (FERNANDEZ 1992).
6) YI (yield index) = $Y_s/\bar{Y}_s$ (GAVUZZI *et al.,* 1997).
7) YSI (yield stability index) = Y_s/Y_p (BOUSLAMA and SCHAPAUGH 1984).
8) The coefficient of linear regression of grain yield of a cultivar in each environment (b) on the environmental index (mean yield of all cultivars at any environment) proposed by BANSAL and SINHA (1991).

Experimental design

The study was conducted in a randomized complete block design arranged as a split plot with salinity level as the main plot factor and accessions (cultivars) as the subplot factor. The total number of plots sown was 126 (14 cultivars × 3 replications × 3 salinities treatments). Data for each variable from all replicates within a salinity treatment were combined for statistical analyses. Correlations between two traits were evaluated using linear correlation analysis. The positive and significant correlation coefficients ($r > 0.92$; $P < 0.01$) found among replicates of a certain treatment, were considered as indicators of repeatability of the experiment.

Statistical analysis

Data were analyzed using MSTATC statistical program package (2000). Pearson correlation analysis was performed using SPSS13 statistical package. Mean comparisons were performed using Duncan's Multiple Range Test (DMRT).

RESULTS

Results presented in Table 2 showed a significant difference among salinity treatments and cultivars for all studied traits (primary roots number (RN), root dry matter (RDM), grain/ spike (GS^{-1}) and grain yield (GY)). Interaction between treatments and cultivars showed highly significant differences too in GY and other traits except RDM and GS^{-1}, indicating that cultivars performance changed over various salinity levels. Grain yield of cultivars varied, particularly under salt stress conditions. This variation can be explained, in part, by the fact that traits suitable for a given environment with its own salinity level may be unsuitable in another environment (VAN GINKEL *et al.*, 1998).

Table 2.Analyse of variance of physiological traits of 14 barley cultivars grown under various salinity levels

Traits	treatment	cultivar	treatment x cultivar	CV
Primary root number (RN)	**	**	**	10.28
Root dry matter (RDM)	*	**	ns	16.00
Grain/spike (G/S)	*	*	ns	19.30
Grain yield (GY)	**	**	**	18.00

*P<0.05. *P<0.01 and ns: not significant

KBL1, SWH and JND1 genotypes were the most productive cultivars in non salt stress (Ec = 0.73 $dS.m^{-1}$) and among the least productive ones in salt stress conditions (Ec = 15.38 $dS.m^{-1}$). SBZ, MNL, KBL3, KSR and JND2 genotypes performed visa-versa (Table 3). Grain yield under non saline condition was positively correlated with saline condition (Fig. 2) suggesting that a high potential yield under optimum condition does necessarily result in improved yield under stress condition. Thus, indirect selection for a salt-prone environment based on the results of optimum condition will be efficient. These results are not in agreement with those of CECCARELLI and GRANDO (1991) who found that landraces of barley and wheat with low yield potential were more productive under stress condition. The good response to salt stress conditions may be related to an adaptation to high-salt conditions (CLARKE *et al.*1992). The poor yielding cultivars in the present study were with small number of primary roots and grains $spike^{-1}$ (Table 3), the desirable traits for non salt condition but undesirable for high-salt condition. Several studies indicated that semi-dwarf stature is preferred in no saline condition (FISCHER and MAURER, 1978; RICHARDS, 1996; VAN GINKEL *et al.*, 1998). VAN GINKEL *et al.* (1998) also found that many grains $spike^{-1}$ was critical to high yield only in non salt condition and it was negatively correlated with yield under salt condition. Resistance indices calculated on the basis of grain yield of cultivars over the salinities levels (Table 4) showed a positive correlation (r = 0.67*) between TOL and yield under non salt stress (Yp) and a negative correlation (-0.34) between TOL and yield under salt stress (Ys) (Table 5) suggesting that selection based on TOL will result in reduced yield under non salt conditions. Similar results were reported by CLARKE *et al.* (1992). However, RIZZA *et al.* (2004) showed that a selection based on minimum yield decrease under salt stress with respect to favourable conditions (TOL) failed to identify the best genotypes.

In the present study, mean yields were 24.80, 25.79 and 22.18 $g.plant^{-1}$ under low, moderate and high salt stress respectively. Since MP is mean production under both salt stress and non salt stress conditions (ROSIELLE and HAMBLIN, 1981), it was highly correlated with yield under low and high salinity levels (Table 5). For this reason, MP was able to differentiate cultivars belonging to group A (susceptible cultivars) from the others. Selection for MP should increase yield in both stressed and non-stressed environments because of its highly positive correlation with yield in contrasting environments. This is not the condition found in our experiment. TZ2, TZ1, RHN, and MNL for example, with relatively low yields under stress conditions, exhibited low MP values. The MP can be related to yield only under severe stress and the difference between yield under stress and non-stress conditions is too large (Table 5). Cultivars with high MP would belong to group B (tolerant cultivars). HOSSAIN *et al.* (1990) used MP as a resistance criterion for wheat cultivars in moderate stress conditions. SSI showed a negative correlation (-0.28) with yield under high salt stress (Table 5). The cultivars JND2, KSR, KLB2, SBZ and TZ1 with high yield under salt stress produced a lower yield under non-stress conditions and showed the lowest SSI. WINTER *et al.* (1988) also reported that tall wheat cultivars had a lower SSI. No significant correlation was found between yield under salt stress and SSI in moderate and high stress conditions (Table 5), showing that SSI will not discriminate salt sensitive cultivars under such conditions.

SSI was significantly correlated with grain yield under low salt stress (Table 5). SSI was adversely correlated with GS^{-1} under all salinity levels (Table 5) suggesting that this trait can contribute to increased yield under salt stress and reduce stress susceptibility (FERNANDEZ 1992). SSI has been widely used by researchers to identify sensitive and resistant genotypes (CLARKE *et al.*, 1984, 1992). In the present study, the mean SSI over salinity levels appeared to be a suitable selection index to distinguish resistant cultivars. JND2, KSR, KLB2, SBZ and TZ1 with a lower SSI were identified as the most resistant cultivars whereas JND1, KBL1, MNL, SWH and TZ1, with the highest SSI were sensitive (Tables 4). The difference between the highest and lowest yield in cultivars was about 32.80 and 24.01$g.plant^{-1}$ respectively in non-stress and stress conditions, (Table 3).

Table 3: Primary roots number (RN), root dry matter (RDM), grain yield and grain per spike (G/S) of the cultivars in the three salinities levels in 2007-2008

Cultivar	0.73 dS.m-1 (non-salt stress)				10.76 dS.m-1 (medium salt stress)				15.38 dS.m-1 (high salt stress)			
	RN	RDM	GS-1	GYb	RN	RDM	GS-1	GYb	RN	RDM	GS-1	GYb
JND1	211.3	4.38	32.3	33.77[3]	190.7	2.02	32.48	26.79[9]	171.00	1.49	32.07	19.69[9]
JND2	214.7	3.34	32.94	19.65[12]	174.7	2.78	35.33	26.5[10]	225.7	1.857	34.19	24.54[4]
KLA	210.7	3.90	32.74	27.64[4]	223.3	2.643	34.43	27.16[8]	265.7	2.907	26.49	23.81[6]
KSR	189.7	1.25	37.56	20.07[11]	209.7	1.717	30.6	21.29[12]	244.3	1.997	28.01	24.39[5]
KBL1	260.3	3.01	33.59	42.44[1]	220.7	1.543	26.05	23.31[11]	230.00	2.27	35.52	30.28[2]
KBL3	224.3	4.35	39.73	24.43[7]	289.00	2.09	33.06	30.42[4]	186.00	0.93	35.18	20.94[8]
KLB2	203.3	4.24	30.06	27.59[5]	246.7	3.943	35.75	32.52[1]	271.00	3.153	31.21	38.25[1]
MNL	198.7	2.46	32.01	22.42[9]	189.7	1.733	36.09	29.37[5]	143.7	0.896	29.13	15.04[13]
MRT	173.0	3.21	23.08	15.68[13]	206.00	2.24	31.78	29.44[4]	158.00	1.267	26.37	14.24[14]
RHN	156.7	2.04	41.56	20.47[10]	115.7	1.253	31.32	15.80[13]	171.00	1.67	26.19	17.09[11]
SBZ	173.3	2.50	28.66	23.27[8]	204.00	1.223	30.4	27.58[7]	233.3	1.807	34.15	25.98[3]
SWH	214.3	2.39	32.9	34.58[2]	218.7	2.897	38.95	29.02[6]	207.7	1.421	32.72	22.75[7]
TZ1	150.3	0.82	19.64	9.60[14]	125.7	1.083	24.59	10.24[14]	178.3	1.17	29.82	17.25[10]
TZ2	136.3	2.62	36.63	25.61[6]	158.00	2.87	34.69	31.63[2]	197.00	1.563	33.22	16.28[12]
Mean	194.06	2.89	32.39	24.80	198.04	2.15	32.54	25.79	205.91	1.74	31.02	22.18

[b] Superscript values are ranking of cultivars.

Table 4: Resistance indices of the 14 barley cultivars (averaged over 3 replications)

Cultivars	SSI	MP	TOL	STI	GMP	YI	YSI
JND1	3,95	26,73	14,08	0,09	25,79	0,89	0,58
JND2	-2,36	22,1	-4,89	0,07	21,96	1,11	1,25
KLA	1,31	25,73	3,83	0,08	25,65	1,07	0,86
KSR	-2,04	22,23	-4,32	0,07	22,12	1,1	1,22
KBL1	2,71	36,36	12,16	0,12	35,85	1,37	0,71
KBL3	1,35	22,69	3,49	0,07	22,62	0,94	0,86
KLB2	-3,66	32,92	-10,66	0,11	32,49	1,72	1,39
MNL	3,12	18,73	7,38	0,06	18,36	0,68	0,67
MRT	0,87	14,96	1,44	0,05	14,94	0,64	0,91
RHN	1,56	18,78	3,38	0,06	18,7	0,77	0,83
SBZ	-1,10	24,63	-2,71	0,08	24,59	1,17	1,12
SWH	3,24	28,67	11,83	0,09	28,05	1,03	0,66
TZ1	-7,54	13,43	-7,65	0,04	12,87	0,78	1,8
TZ2	3,45	20,95	9,33	0,07	20,42	0,73	0,64
Mean	0,35	23,49	2,62	0,08	23,17	1,00	0,96

Table 5: Correlation coefficients between resistance indices and GY, RN, RDM, GS-1 and HI of 14 barley cultivars (averaged over at 0.73dS.m-1, 10.76 dS.m-1 and 15.38dS.m-1.

Salinity level	Traits	SSI	MP	TOL	STI	GMP	YI	YSI
0.73 dS.m-1 (Non salt stress)	RN	0,27	0,72*	0,29	0,72*	0,72*	0,52	-0,27
	RDM	0,38	0,47	0,22	0,47	0,48	0,33	-0,37
	HI	-0,10	-0,39	-0,25	-0,39	-0,37	-0,22	0,10
	G/S	0,52	0,27	0,35	0,27	0,28	0,06	-0,52
	GY	0,63*	0,89**	0,67*	0,89**	0,88**	0,46	-0,64
10.76 dS.m-1 (Moderate salt stress)	RN	0,18	0,54	0,04	0,54	0,55	0,50	-0,18
	RDM	0,07	0,41	-0,09	0,40	0,4	0,44	-0,07
	HI	-0,02	0,48	-0,04	0,47	0,48	0,5	0,02
	G/S	0,42	0,15	0,18	0,15	0,15	0,04	-0,42
	GY	0,49	0,38	0,24	0,38	0,38	0,22	-0,49
15.38 dS.m-1 (High salt stress)	RN	-0,31	0,63*	-0,38	0,63*	0,65*	0,84**	0,30
	RDM	-0,19	0,63*	-0,31	0,63*	0,64*	0,79**	0,20
	HI	-0,15	0,4	-0,22	0,40	0,41	0,51	0,15
	G/S	0,11	0,51	0,19	0,50	0,49	0,37	-0,10
	GY	-0,28	0,82**	-0,34	0,81**	0,82**	0,99**	0,28

* $p < 0.05$; ** $p < 0.01$.

YI, proposed by GAVUZZI *et al.* (1997), was significantly correlated (r = 0.99**) with high salt stress yield. This index ranks cultivars only on the basis of their yield under stress (Tables 4) and so does not discriminate genotypes of group A. YSI, as BOUSLAMA and SCHAPAUGH (1984) stated, evaluates the yield under stress of a cultivar relative to its non-stress yield, and should be an indicator of salt resistant genetic materials. So the cultivars with high YSI are expected to have high yield under both stress and non-stress conditions. In the present study, cultivars with the highest YSI exhibited the least yield under non-stress conditions and the highest yield under stress conditions (Table 3). Linear regression of cultivar yield on the mean cultivar yield over salinity levels was shown in Figure 2. The regression coefficient (b) of KLB2, KSR, RHN, KBL3, JND2, SBZ and TZ1 were significantly lower than those of other cultivars, being more stable. TZ2, MNL and MRT had the highest linear regression coefficient (b), producing the lowest yields under salt stress condition. However, KLB2 had the lowest b coefficient, producing the highest yield under stress conditions (Table 3). BANSAL and SINHA (1991) used this method to assess the stability of wheat accessions over variable environments. HOHLS (2001) showed that genotypes with a high stress tolerance had low b coefficient even when a range of stress and non-stress environments was used.

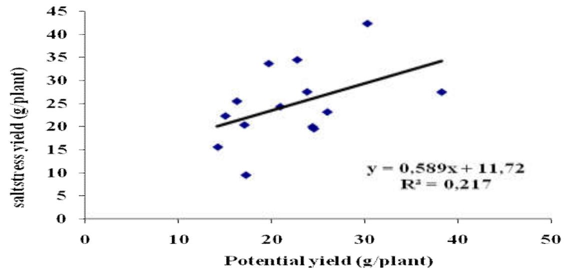

Fig. 1. Association between grain yield of barley cultivars under salt stress (Ec = 15.38dS.m^{-1}) and non –salt stress (Ec = 0.73 dS.m^{-1}). Each point is the mean yield over the 3 replications

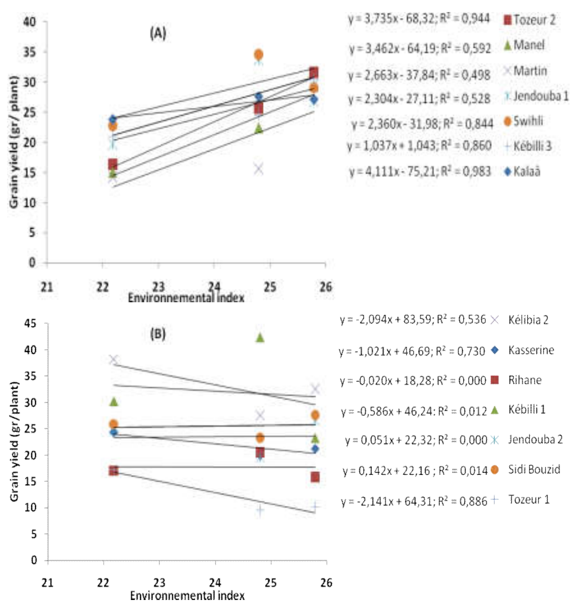

Fig. 2 Association between mean grain yield and the environmental index (mean yield of all cultivars in each environment): (A) susceptible cultivars and (B) tolerant cultivars.

DISCUSSION

STI, GMP and MP were able to identify cultivars producing high yield in both conditions. Under severe stress, linear regression coefficient (b) and SSI were found to be more useful index discriminating resistant cultivars, although none of the indicators could clearly identify cultivars with high yield under both stress and non-stress conditions (group A cultivars). It is concluded that the effectiveness of selection index depends on the stress severity supporting the idea that only under moderate stress condition, potential yield greatly influences yield under stress (PANTHUWAN *et al.,* 2002).

Two primary schools of thought have influenced plant breeders who target their germplasm to salt-prone areas. The first of these philosophies states that high input responsiveness and inherently high yielding potential, combined with stress-adaptive traits will improve performance in salt-affected environments (BETRAN *et al.,* 2003). The breeders who advocate selection in favourable environments follow this philosophy. Producers, therefore, prefer cultivars that produce high yields when salt is not so limiting but suffer minimum loss (NASIR UD DIN *et al.,* 1992). The second is the belief that progress in yield and adaptation in salt affected environments can be achieved only by selecting under the prevailing conditions found in target environments (RATHJEN, 1994). The theoretical framework to this issue has been provided by FALCONER (1952) who wrote, ‘‘ yield in low and high yielding environments can be considered as separate traits which are not necessarily maximized by identical sets of alleles’’. VAN GINKEL *et al.* (1998) showed that the traits suitable for a given environment with its own weather conditions may be unsuitable (or even harmful) in another environment. PANTHUWAN *et al.* (2002) believe that potential yield has a large impact on yield only under moderate salt stress conditions, before stress is severe enough to induce a genotype x environment (G x E) interaction for yield. Whether direct or indirect selection is superior depends upon the heritability of the selected trait in stress and non-stress environments and the genetic correlation between stress and non-stress environments (NASIR UD-DIN *et al.* 1992). Several researchers have concluded that selection will be most effective when the experiments are done under both favourable and stress conditions (FERNANDEZ 1992; VAN GINKLE, 1998). TRETHOWAN *et al.* (2002) showed that selection in alternating stress and non-stress environments at the International Maize and Wheat Improvement Center (CIMMYT) has resulted in a significant progress in the development of wheat germplasm adapted to dry areas globally. When breeding for salt tolerance is the aim, two situations seem to be clearly distinguished in order to choose a selection strategy: (1) where the salt-affected land is predominant over the country and non salt areas are infrequent, and (2) where the non salt situations are predominant. In the regions with the former situation (such as many parts of Tunisia), selection should be based on the yield in the target environments as suggested by CECCARELLI and GrANDO (1991), RATHJEN (1994) and BETRAN *et al.* (2003).

Conclusions

If the strategy of breeding program is to improve yield in a small stress or non-stress environment, it may be possible to explain local adaptation to increase gains from selection conducted directly in that environment (HOHLS 2001). However, selection should be based on the resistance indices calculated from the yield under both conditions, when the breeder is looking for the cultivars adapted for a wide range of environments. The findings of this study showed that the breeders should choose the indices on the basis of stress severity in the target environment. The linear regression coefficient (b) and SSI are suggested as useful indicators for barley breeding, where the stress is severe while MP, GMP and STI are suggested if the stress is moderate.

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