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Stability analysis of yield component traits in 25 durum wheat (*Triticum durum* Desf.) genotypes under contrasting irrigation water salinity

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ABSTRACT

Stable straw and grain yield constituted a challenging objective for breeders to cope with environmental changes as salinity increase. For this purpose, an assessment of grain yield (GY) and yield components stability of 25 durum wheat genotypes was conducted in three semi-arid sites differing by their irrigation water salinity: Echbika (S1, 6 dS m^{-1}), Barrouta (S2, 12 dS m^{-1}) and Sidi Bouzid (S3, 18 dS m^{-1}) during three growing seasons (2010, 2011 and 2012). A significant average effect ($P \leq 0.05$) of sites × genotypes was observed for all measured parameters. GY was the most salinity affected trait showing decrease of 20% in S2, and 50% in S3 compared to control conditions in S1. A significant linear regression exists between GY at control site S1 and GY at saline site S2 ($R^2 = 0.79$; $P < 0.001$) and saline site S3 ($R^2 = 0.36$; $P < 0.001$). Improved genotypes overstep landraces for all yield components. As a result, GY is about 30% higher for improved varieties. This trend was inverted for agronomic traits such as plant height, biomass and straw yield (SY). According to stability analysis, only the improved genotype Maali showed stability for GY and SY in the contrasting salinity water irrigation sites. This genotype had a high average GY mean of 0.49 kg/m^2 ($bi = 1.12$; $S^2d = 0.84$) and high SY of 0.70 kg/m^2 ($bi = 0.85$; $S^2d = 0.42$). Our data suggest that improved genotypes could be used under contrasting salinity environment in arid area as well as breeding materials.

1. Introduction

Drought is the main factor limiting agricultural productivity in arid and semi-arid regions (Mir et al., 2012), such as the Mediterranean area, which is characterized by irregular precipitations (Habash et al., 2009). In Tunisia, crop yielding limitation is likely to increase in the future as climatic change is expected to decrease precipitation and increase evapo-transpiration (Latiri et al., 2010). New climatic conditions might induce plant terminal growth stress resulting from a more pronounced heat and drought stress during the late stages of the wheat growth cycle (Araus et al., 2008). Durum wheat is the most cultivated crop in Mediterranean basin (Elias and Manthey, 2005), representing the main population diet component for pasta, couscous and bulgur. In fact, wheat is the primary food source in Tunisia as the consumption reaches 258 kg per year per capita (Chahed, 2009). However, durum wheat yield showed high fluctuations through Tunisia, ranging from 1 t ha^{-1} to 6 t ha^{-1} and were attributed mainly to poor crop management (Rezgui and Fakhfakh, 2010) and drought stress (Rajaram and Braun, 2008). To increase and ensure stable yield, supplemental irrigation during the growth stage is required (De Vita et al., 2007). Salt stress significantly reduces agricultural crop yields by affecting vegetative growth as well as fertility parameters (Roy et al., 2014). Identifying stable and high yielding genotypes can promote the sustainable use of salty water resources in arid and semi-arid regions. Often, the use of water is facing quality problems related mainly to salinity. Durum wheat is the most salt sensitive cereal species (Munns, 2002). Therefore, selecting for salt stress tolerant wheat genotypes (Munns and Tester, 2008) associated with a more accurate agronomical practices (Regmi et al., 2002) are two complementary ways

Abbreviations: *bi*, regression coefficient; SY, straw yield; Ec, electrical conductivity; G, genotype; GY, grain yield; GY_{S1}, grain yield at control conditions; NKS, number of kernels per spike; NS, number of spike per square meter; OM, organic matter; PLH, plant height; S, site; S^2d, mean square deviation; TKW, thousand kernels weight; Y, year.

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to a more stable yield in contrasting and water quality limiting growth conditions (Yousfi et al., 2010). Salinity reduces the number of spike per m^2, the number of kernels per spike (NKS) (Araus et al., 2013) and hence thousand kernels weight (TKW) and grain yield (GY) (Royo and Abiò, 2003). Salt stress wheat tolerance GY is influenced by genotype (G), environment (E), and their interaction (G × E) (Rharrabti et al., 2003). High and significant G × E have been defined as the failure of genotypes to achieve the same relative performance in different environments (Rharrabti et al., 2003; Araus et al., 2008). Identification of yield contributing traits and understanding the G × E interactions and yield stability are important for breeding new cultivars with improved adaptation to the environmental constraints (Rharrabti et al., 2003). The agronomic concept of genotypic stability is closely related to conformity between real yield performance over changing environments and the level of its corresponding prediction or estimation (Messina et al., 2011). To reach this goal, minimizing G × E interactions is crucial mainly through the use of yield stable durum wheat genotypes. G × E interaction affects breeding progress as it makes difficult the evaluation and selection of superior genotypes. Ideal genotype has to perform well both across years as across a wide range of environments as suggested by Fufa et al. (2005).

Most of the statistical models used for stability studies rely on the assumption that linear correlation exists between growing conditions and genotypic performance (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966). Moreover, regression analysis has been extensively used by plant breeders to describe yield genotypic stability over contrasting environments (Eberhart and Russell, 1966). Several statistical methods have been developed for stability analysis with a view of explaining the information comprised in the G × E data matrix. The most widely models used by breeders to describe dynamic yield stability are (*bi*) the regression coefficient (Finlay and Wilkinson, 1963) and (S^2d) deviation from regression (Eberhart and Russell, 1966). Other models were used as (*a*) regression line intercept and (R^2) coefficient of determination (Akçura et al., 2005). The stability of cultivars was defined by high mean yield and regression coefficient ($bi > 1$) and a low deviation from regression line (S^2di) (Berzsenyi et al., 2000; Akçura et al., 2005). The ideal situation would be characterized by a highly stable improved genotype with high yield potential (Tollenaar and Lee, 2002; Duvick et al., 2004) compared to landraces in contrasting environments.

This investigation aimed to assess the GY stability and performance of 25 durum wheat genotypes under different salt stress conditions in three different sites during three cropping seasons.

2. Materials and methods

2.1. Plant material, experimental design and treatments

Twenty five (25) durum wheat genotypes (*Triticum turgidum* ssp. *durum*) constituted by 19 landraces (Aoudhay, Jeneh Khotifa, Biskri Pubescent, Agili, Bidi AP4, Azizi, Bayadha, Swebei Algia, Derbessi, Mahmoudi, Souri, INRAT 69, Ward Bled, Arbi, Hamira, Sbei, Chili, Agili Glabre, Richi) and 06 cultivated varieties (Karim, Razzak, Om Rabia, Mâali, Nasr and Khiar) were evaluated from 2010 to 2012.

The experiments were conducted in three semi-arid regions in the center area of Tunisia: Echbika (S1) (35°37 N, 9°56 E), Barrouta (S2) (35°34 N, 10°02 E) and Sidi Bouzid (S3) (35°02 N, 9°33 E). All genotypes were cultivated in all sites. Randomized complete-block design with three replications was used in this study. Each plot was constituted by 10 rows of 1 m long, spaced by 0.20 m. Precipitation and temperature variation were collected from synoptic weather station of the National Institute of Meteorology of Tunisia (Table 1).

Five soil samples were taken in each site from each block from the horizon 0 to 40 cm before sowing and after harvest to assess soil physical and chemical characteristics of the three tested sites during the three cropping seasons. The soils had almost the same texture with a silt loam for S1, silt clay loam for S2 and S3 (Table 2). Salinity of water used for irrigation was 6, 12 and 18 dS m^{-1}, for S1, S2 and S3, respectively.

2.2. Plant growth and yield components

All seeding operations were carried out in the first week of December for the three cropping seasons at the three locations at a seeding rate of 300 viable seeds/m^2. Nitrogen was applied as ammonium nitrate at 25 kg N/ha at sowing and 25 kg N/ha at stem elongation stage. Irrigation was made using a drip system. In order to ensure homogeneous water supply, a line source emitters was installed at each planting row. Emitter discharge was 4 l h^{-1} at 1.0 bar operating pressure and 30 cm spacing between emitters of the same line. Physiological maturity was achieved around mid May and harvest was performed about 1 month later. At anthesis, 1 m was harvested in the two central rows for the determination of dry above-ground biomass. Plant height (PLH) of five plants randomly chosen was measured 1 week after anthesis as the distance from ground to the spike's tip. 1 m^2 of each experimental unit was hand harvested. Spike number was counted. Grains were collected using a *shredder* (Wentersteiger, LD-180, Germany). Straw yield (SY, kg m^{-2}), number of spike per meter square (NS), number of kernels per spike (NKS), thousand kernels weight (TKW, g) and grain yield (GY, kg m^{-2}) were measured.

2.3. Statistical analysis

Analysis of variance (ANOVA) was performed using the PROC GLM SAS procedure to assess the effect of year, genotypes, sites and their interactions for all measured traits. Stability analysis was described by Eberhart and Russell (1966), as a function of slope and deviations from regression of entry yield on the environmental index. For that purpose the regression coefficient (*bi*) and the mean square deviation (S^2d) were calculated. Multiple linear regression analysis (stepwise) using PROC REG option (STEPWISE) SAS procedure was used to analyze the relationship between GY and all other traits. Linear stepwise models were built from each experimental saline site (S2 and S3) in order to determine the effect of intermediate and high salinity on yield building: vigor and fertility. Data were analyzed using the SAS version 9.1 for windows (SAS Institute, Cary, NC, USA). Simple linear regression was used to detect relationships between GY under both level of salinity and GY under control condition. Means were compared by Duncan's test ($P < 0.05$).

3. Results

3.1. Effect of growing conditions, year and genotype on straw and yield components

Analysis of variance showed significant variations among the genotypes (G), site (S) and S × G for all the tested agronomic traits. Year (Y) had no significant effect on most measured parameters except for plant biomass and SY (Table 3). Moreover, Y × S interaction showed highly significant ($P < 0.01$) effect on PLH, and a significant effect ($P < 0.05$) on SY, NS and NKS; whereas significant interaction G × Y was observed only for plant Biomass and NKS. A significant triple interaction S × G × Y was observed only for PLH and SY (Table 3).

The results showed that all measured growth and agronomic traits were significantly affected by variation of water irrigation

Table 1
Mean air temperature and rainfall of the three experimental sites: Echbika (S1, 6 dS m^{-1}), Barrouta (S2, 12 dS m^{-1}) and Sidi Bouzid (S3, 18 dS m^{-1}), measured from 2010 to 2012.

Sites		November	December	January	February	March	April	May	June
S1	*T*min (°C)	11.6 ± 3	8.9 ± 3	6.8 ± 6	7.1 ± 4	8.3 ± 3	11.5 ± 4	13.9 ± 4	16.7 ± 2
S2	*T*max (°C)	25.2 ± 4	21.4 ± 5	15.5 ± 3	18.9 ± 7	18.4 ± 5	22.5 ± 3	31.2 ± 6	39.6 ± 3
	Precipitation (mm)	4 ± 2	6 ± 3	8.5 ± 2	12.3 ± 1	40.8 ± 7	25.2 ± 6	14.7 ± 2	1 ± 1
S3	*T*min (°C)	7.9 ± 2	7.1 ± 4	5.4 ± 6	6.3 ± 4	7.8 ± 2	11.2 ± 2	12.5 ± 3	18.2 ± 1
	*T*max (°C)	21.5 ± 2	18.5 ± 3	15.9 ± 4	19.1 ± 3	21.5 ± 2	23.6 ± 1	26.7 ± 2	34.2 ± 2
	Precipitation (mm)	0.4 ± 04	14.8 ± 4	2.4 ± 2	7.2 ± 4	11.6 ± 3	21 ± 2	13.6 ± 3	0 ± 0

Table 2
Overall mean of soil and water physical and chemical characteristics of the three tested sites measured during the three cropping seasons.

	S1			S2			S3		
% O M	2.73			2.65			2.14		
% Clay	21.0			37.8			35.9		
% Silt	65.7			45.5			48.5		
% Sand	12.9			14.8			19.4		
Year	2010	2011	2012	2010	2011	2012	2010	2011	2012
Soil									
Na^+ (ppm)	246	256	247	291	287	285	334	339	345
Ca^{2+} (ppm)	146	142	146	132	135	133	126	124	121
K^+ (ppm)	553	531	553	466	437	434	243	236	240
EC_a (dS m^{-1})	0.11	0.12	0.11	0.25	0.27	0.26	0.37	0.38	0.37
EC_b (dS m^{-1})	0.13	0.14	0.14	0.38	0.37	0.39	0.42	0.41	0.43
Water									
Na^+ (ppm)	410	389	395	570	540	553	720	780	785
Ca^{2+} (ppm)	62	53	58	66	65	69	75	80	60
K^+ (ppm)	19	20	16	16	17	21	18	17	19
EC (dS m^{-1})	6	5	6	12	12	13	18	19	18

OM, organic matter; EC, electrical conductivity, a, before sowing; b, after harvest.

Table 3
Year, treatment and genotype effects on the plant height (PLH), biomass, straw yield (SY), number of spike per meter square (NS), number of kernels per spike (NKS), thousand kernels weight (TKW) and grain yield (GY) for 25 durum wheat genotypes from three sites.

	PLH (cm)	Biomass (g m^{-2})	SY (kg m^{-2})	NS	NKS	TKW (g)	GY (kg m^{-2})
Year (Y)	0.060	0.041	0.035	0.060	0.051	0.761	0.068
2010	116.92a	355.12a	1.11a	311a	24a	49.12a	0.33a
2011	119.17a	363.32a	1.31a	317a	22a	49.98a	0.34a
2012	118.55a	321.72b	0.96b	304a	24a	47.91a	0.35a
Site (S)	0.001	0.001	0.001	0.000	0.013	0.002	0.000
S1	122.37a	424.50a	1.16a	342a	26.34a	50.39a	0.45a
S2	111.10a	353.56b	0.97b	317b	22.66a	49.61a	0.38b
S3	103.01b	282.71c	0.66c	275c	18.12b	42.33b	0.22c
Genotype (G)	0.001	0.001	0.000	0.001	0.003	0.000	0.001
Landraces	131.11a	382.64a	1.15a	284b	22.38b	47.01b	0.29b
Improved	90.62b	261.57b	0.69b	339a	25.11a	51.33a	0.41a
ANOVA							
Y × S	0.001	0.341	0.041	0.033	0.038	0.191	0.091
Y × G	0.056	0.041	0.161	0.811	0.041	0.093	0.171
S × G	0.000	0.042	0.001	0.000	0.000	0.022	0.001
Y × S × G	0.001	0.783	0.110	0.636	0.783	0.958	0.110

The associated probabilities level calculated through the analysis of variance (ANOVA) is shown for year (Y), site (S), genotype (G) and interaction (Y × S), (Y × G) (S × G) and (Y × S × G) effects. Means followed by different letters are significantly different ($P < 0.05$) according to Duncan's test.

salinity among sites. Indeed, the increase in salinity in S3 significantly affected all studied growth traits (Table 3). PLH was reduced by 16% in S3 (18 dS m^{-1}), compared to the control S1 (6 dS m^{-1}). The average biomass at flowering decreased also markedly by around 17% and 20% in S2 and S3 compared with control conditions in S1. Yield and its components were severely affected by salinity. GY was the most affected trait by salinity decreasing by 20% in S2, and 50% in S3 compared to S1. The average NKS of the 25 genotypes did not differ between S1 and S2 and was decreased by 31% in S3. TKW were also affected at S3, but with a lesser extent. The NS and TKW decreased only by 21% and 16% in S3, respectively, as compared with control. PLH, yield components (NS, NKS, TKW) and GY showed stability across the three consecutive growing seasons. However, SY was significantly affected by Y, and varied by +14% and −13% in 2011 and 2012 (compared to 2010) and was mostly affected by salinity level with a reduction of 17% and 44% under 12 dS m^{-1} (S2) and 18 dS m^{-1} (S3), respectively, compared to the control of 6 dS m^{-1} (S1).

Overall, the average highest biomass at flowering was obtained for the landraces genotypes (382.64 g m^{-2}), while improved cultivars showed less biomass (261.57 g m^{-2}). The prevalence of landraces genotypes was also observed for SY and PLH with,

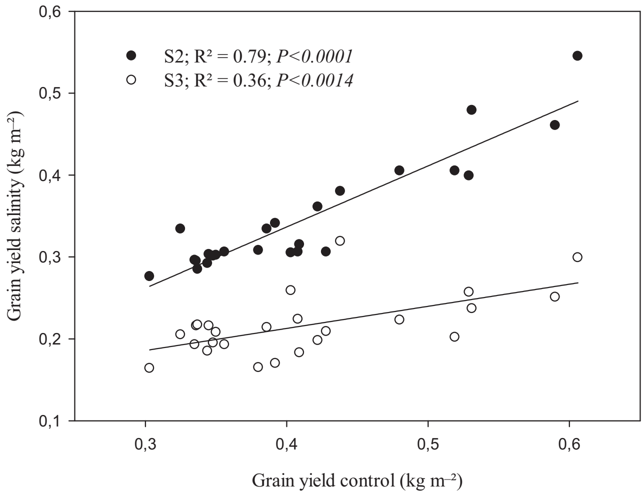

Fig. 1. Relationship between grain yield (GY) under control conditions and in the two saline sites S2 and S3 across 25 durum wheat genotypes. Each point is the average value of one genotype under the two saline sites across the three consecutive years.

respectively, 40% and 30% of average increase compared to improved ones (Table 3). This genotypic trend was reversed for NS, NKS, TKW and GY with a prevalence of improved genotypes compared to landraces by respectively, 16%, 11%, 8% and 29%.

3.2. Growth in low salinity and genotype performance under salt stress

The average GY attained by the 25 durum wheat genotypes under control conditions was positively and significantly correlated ($P < 0.001$) with the GY of these genotypes at each of the two saline sites (Fig. 1). A significant correlation ($P < 0.001$) existed between GY at control and saline site 2 of 12 dS m^{-1} ($R^2 = 0.79$; $P < 0.001$). This regression was less marked in saline site 3 of 18 dS m^{-1} ($R^2 = 0.36$; $P < 0.0014$).

In order to assess the relative contribution in predicting GY in saline conditions, we performed a regression analysis according to the stepwise procedure. The dependent variable was GY at different conditions for all genotypes. The independent variables were GY, PLH, NS and biomass at flowering, measured in the control and at different saline sites (Table 3). For GY at S2 and S3, the independent variable that was chosen first by the model was GY under control conditions (an indicator of potential yield), followed by other variables related to salinity tolerance (PLH and NKS for S2 and S3 respectively). TKW and SY were not chosen by the model in none of the cases. In fact, they showed a week and non-significant correlation to yield (data not shown).

GY_{S1}, PLH and biomass were determinant components for GY at S2 ($r = 0.84$; $R^2 = 0.71$). However, GY S3 was determined by yield components as GY_{S1}, NKS, NS ($r = 0.69$; $R^2 = 0.47$) (Table 3).

3.3. Stability traits

GY showed large variation within the tested durum wheat genotypes ranging from 0.25 kg m^{-2} obtained for the landrace Richi to 0.49 kg m^{-2} registered for the improved genotype Maali (Table 4). Average GY was quite stable during the three cropping seasons but was highly affected by salinity as it varied between 0.22 and 0.45 kg m^{-2} in S3 and S1 respectively (Table 3). GY stability is an important component mainly under salt stress conditions. The stability parameters were determined according to Eberhart and Russell (1966). The variations in *bi* values indicated that the 25

Table 4
Stepwise analysis with GY for the whole set of 25 durum wheat genotypes in both saline condition sites as a dependent variable, and, plant height PLH, grain yield under control condition (GY_{S1}), number of spike per meter square (NS), number of kernels per spike (NKS), thousand kernels weight (TKW) and straw yield (SY) as independent variables.

Grain Yield	Chosen variable	R^2	Sig
S2	GY_{S1}	0.46	***
	GY_{S1}, PLH	0.51	***
	GY_{S1}, PLH, Biomass	0.71	***
S3	GY_{S1}	0.30	***
	GY_{S1}, NKS	0.39	***
	GY_{S1}, NKS, NS	0.47	***

*** $P < 0.001$.

genotypes responded differently to salinity site environments. The *bi* of SY ranged from 0.01 to 2.11. However, the *bi* of GY ranged from −0.55 to 2.05.

The regression coefficient for GY showed a stable genotypic tendency under different salinity sites for almost all improved genotypes except Razzak. GY stability was less marked in landraces where only 5 genotypes among 19 showed a $bi > 1$.

Despite that, high *bi*, the mean of GY and slow deviation are required for stable genotypes. According to those considerations the improved genotypes were in average more stable than the landraces. The improved genotype Maali showed comparatively a stable response with the highest GY mean (0.49 kg m^{-2}) and least mean square deviation ($S^2d = 0.84$).

Integrating the SY as important agronomical component with GY for stability analysis showed that the genotypes combining high mean, *bi* and low S^2d were very few: Maali and Mahmoudi. The improved genotype Maali showed the best stability for GY and SY in the contrasting salinity sites (data not shown). This genotype had a high average GY mean of 0.49 kg/m^2 ($bi = 1.12$; $S^2d = 0.84$) and high SY of 0.70 kg m^{-2} ($bi = 0.85$; $S^2d = 0.42$). Mahmoudi had a lower yield stability performance than Maali showing an average GY mean of 0.40 kg m^{-2} ($bi = 0.9$; $S^2d = 0.57$) and high SY of 1.10 kg m^{-2} ($bi = 0.81$; $S^2d = 0.71$).

4. Discussion

This study showed a significant effect of years only on SY and plant biomass. S × G was significant as reported in many previous studies on bread and durum wheat (Marti and Slafer, 2014).

Salinity, genotypes and their interaction differed significantly for biomass and PLH; traits that can be considered useful for screening durum wheat germplasm under salinity and water stress (Munns, 2002; Munns and James, 2003). The present study showed that the decrease of biomass and PLH is strongly correlated to irrigation by salty water. These results are in complete agreement with previous studies on durum wheat indicating that biomass at flowering accumulation could be a reliable indicator of plant performance under salt stress conditions (Yousfi et al., 2009, 2010).

Many reports showed that salinity decreased significantly GY and yield components such as NS, NKS and TKW (Husain et al., 2003; El-Hendawy et al., 2005; Houshmand et al., 2005). In the present study, GY and its components such as the number of spike per m^2, and number of kernels per spike, indicator of spike fertility, showed significant decrease under salinity site conditions. These results were in concordance with those obtained by Husain et al. (2003). However, the effect of salinity in this study is less pronounced than in their case where a reduction about70 – 85% in GY was reported under 7.5 dS m^{-1} and reached 90% under 15 dS m^{-1}. Moreover, salinity decreased significantly GY components such as

NS, NKS and TKW (Husain et al., 2003; El-Hendawy et al., 2005; Houshmand et al., 2005). The TKW was less sensitive to salinity, whereas NKS was the most sensitive trait. This observation was in agreement with findings in bread wheat (El-Hendawy et al., 2005) and durum wheat (Houshmand et al., 2005). Indeed, in this latter study, 150 mM NaCl induced a 70% reduction of NKS compared to 50% for TKW. Moreover, Royo and Abiò (2003) indicated that TKW was less affected by salinity than GY showing a decrease of 0.32 g to 1.82 g for each dS m^{-1} increase in salinity.

Average GY over all saline sites was higher in the improved cultivars than landraces, which was associated mostly with a higher NS (339) and shorter PLH (90.62 cm). The reduction in plant height could be attributed to the introduction of semi-dwarfing genes. *Rht* dwarfing gene reduces plant height to increase grain number and yield as *Rht13* for bread wheat (Rebetzke et al., 2011) and *Rht1* and *Rht2* for durum wheat (Trethowan et al., 2001). In the case of Tunisia the genes were introduced in 1967, which subsequently affected plant height and improved the NKS and TKW. The same trend was observed for the durum wheat Cham-1, created by ICARDA compared to landrace Haurani under salinity ranging from 0.9 to 6.9 dS m^{-1} (Katerji et al., 2005).

On opposite, tested durum wheat landraces showed 40% higher SY than improved genotypes. Similar pattern of differences between landraces and improved cultivars has been reported in durum wheat (Royo et al., 2007; Alvaro et al., 2008) and was attributed to the absence of semi-dwarf genes in landraces (Trethowan et al., 2001).

With our set of genotypes, TKW of improved varieties was higher than that of landraces. Many reports (Royo et al., 2007; Alvaro et al., 2008; Araus et al., 2013) have indicated that the introduction of semi-dwarfing genes *Rht-B1* increased number of grain per spike and was associated with a reduction of TKW. However, Sánchez-García et al. (2013) concluded that yield genetic improvement was accounted by an increased in number of kernels while TKW remained unchanged.

Genotypic variation in GY has been largely reported in durum wheat and other cereals under saline condition (El-Hendawy et al., 2005; Royo et al., 2007; Araus et al., 2013). Such variability was observed in our set of genotypes for GY, biomass at flowering, PLH and yield components. Under moderate saline conditions (S2), stepwise analysis showed that GY in S1 followed by PLH and biomass are the parameters that discriminate best between genotypes. However, under severe stress (S3), GY in S1 was followed by NKS and NS were the most reliable parameters to distinguish tolerant genotypes form sensitive ones. Indeed, GY under both saline conditions was positively associated with GY under control condition GY_{S1} (Fig. 1). However the correlation was highly significant only under moderate stress (irrigation with 12 dS m^{-1}). Positive correlation between GY under control and saline irrigation were found in a wide range of saline conditions (Yousfi et al., 2009).

The level of correlation between GY and agronomical traits (PLH and plant biomass) was in general higher under moderate salt stress (12 dS m^{-1}). Osmotic stress is the first component of salt stress. Under severe stress and in continuous exposure to salinity, ionic component occur later (Munns and Tester, 2008). Munns and James (2003) suggested as screening techniques for wheat tolerance under moderate salinity (50–150 mM NaCl) the measurements of plant growth as leaf elongation which are more sensitive to osmotic change The high levels of correlation (R^2 = 0.71) revealed by the stepwise analysis (Table 4) reinforce the importance of those traits in the selection index under moderate stress.

In S3, stepwise showed that growth parameter could no longer discriminate between the genotypes in field conditions as reported by Munns and James (2003) under 200–300 mM NaCl.

Genotypic stability is considered as an important aspect of yield trials. Diverse environments are crucial to assess yield stability with high accuracy. The locations used for this experiment are representative of irrigated durum wheat fields in semi-arid areas. The three selected sites represented a wide variability with respect to water salinity used for irrigation.

Table 5
Mean traits and estimates of stability parameters for straw yield (SY) and grain yield (GY) of 25 durum wheat genotypes.

Genotypes	SY (kg m^{-2})			GY (kg m^{-2})		
	Means	*bi*	S^2d	Means	*bi*	S^2d
Improved genotypes						
Karim	0.64	0.01	1.14	0.46	1.81	5.34
Khiar	0.75	0.77	2.19	0.41	1.67	3.42
Maali	0.70	0.85	0.42	0.49	1.12	0.84
Nasr	0.74	1.63	1.23	0.38	1.75	4.79
Om Rabia	1.10	1.91	1.17	0.40	1.08	0.92
Razzak	0.63	1.51	3.21	0.42	0.89	4.09
Landraces						
Agili	1.05	0.77	1.36	0.34	0.82	1.25
Agili Glaber	1.12	0.81	0.99	0.28	0.78	0.22
Aoudhay	1.24	1.44	3.29	0.27	0.46	1.94
Arbi	1.16	0.63	1.60	0.29	0.58	3.87
Azizi	1.09	0.77	2.31	0.29	2.05	2.49
Bayadha	1.27	0.87	1.51	0.33	1.63	2.79
Beskri Peubescent	1.17	0.73	2.31	0.30	0.46	0.99
Bidi AP4	1.16	0.42	1.35	0.29	-0.55	1.95
Chili	1.07	0.73	1.21	0.44	0.63	0.81
Derbessi	0.92	1.22	3.22	0.30	0.88	1.54
Hamira	1.07	0.34	2.27	0.28	0.93	0.95
INRAT 69	0.89	0.25	1.24	0.33	1.62	3.10
Mahmoudi	1.10	0.81	0.71	0.40	0.9	0.57
Jeneh Khotifa	1.26	0.51	2.49	0.32	0.77	3.43
Richi	1.30	1.61	1.17	0.25	0.28	1.02
Sbay	1.21	1.75	1.33	0.29	1.49	1.06
Souri	1.16	0.84	2.25	0.32	0.68	2.47
Swebei Algia	1.08	1.56	1.39	0.28	0.48	1.82
Ward Bled	1.12	2.11	5.37	0.34	1.68	1.64

Regression coefficient (*bi*); deviation mean square (S^2d).

The number of environments needed to study single genotype yield stability varied based on theoretical considerations, from 10 environments (Becker and Leon, 1988) to up to 200 environments (Piepho, 1998). However, for G × E yield stability studies fewer environments are required because the variance can be estimated with better precision than for individual genotypes (Rowe and Andrew, 1964; Mühleisen et al., 2014).

The present investigation showed that on average, the improved durum wheat genotypes were specifically adapted to the less stressed environments (S1 and S2) showing a better responsiveness to good irrigation water quality when compared with landraces specifically adapted to poor environments (Fig. 1; Tables 3 and 5). The same patterns have been observed in previous studies (De Vita et al., 2007; Royo et al., 2007; Alvaro et al., 2008). Based on the stability statistics, the improved genotypes Maali, Om Rabia, and the landraces Mahmoudi and Agili Glabre can be classified as stable genotypes. Razzak, which showed a low *bi* for GY, is considered as an instable genotype. In fact this genotype has been characterized as the most sensitive durum wheat for salt stress (Chaabane et al., 2011). In addition to all analysis and based on the linear regression model, the genotypes Maali and Mahmoudi showed the widest adaptability and are found as most stable cultivars most likely due to their ability to tolerate salinity conditions.

5. Conclusion

Durum wheat is widely cultivated in rainfed conditions in Mediterranean area, requiring in most cases complementary irrigation to reach a suitable yield. Stability for GY and SY evolution among 25 durum wheat genotypes lead to the identification of a set of interesting cultivars from which the improved genotype Maali could be the most stable in the contrasting water irrigation salinity sites varying from 6 to 18 dS m^{-1}. However, the results needed to be confirmed by future studies, including cultivation in more saline conditions and confirmation through evaluation of key salt stress tolerance markers.

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References

Akçura, M., Kaya, Y., Taner, S., 2005. Genotype-environment interaction and phenotypic stability analysis for grain yield of durum wheat in the central Anatolia. Turk. J. Agric. For. 29, 369–375.

Alvaro, F., Isidro, J., Villegas, D., Garcia Del Moral, L.F., Royo, C., 2008. Old and modern durum wheat varieties from Italy and Spain differ in main spike components. Field Crops Res. 106, 86–93.

Araus, J.L., Cabrera-Bosquet, L., Serret, M.D., Bort, J., Nieto-Taladriz, M.T., 2013. Comparative performance of ^{13}C, ^{18}O and ^{15}N for phenotyping durum wheat adaptation to a dryland environment. Funct. Plant Biol. 40, 595–608.

Araus, J.L., Slafer, G., Royo, C., Serret, M.D., 2008. Breeding for yield potential and stress adaptation in cereals. Crit. Rev. Plant Sci. 27, 377–412.

Becker, H.C., Leon, J., 1988. Stability analysis in plant breeding. Plant Breed. 101, 1–23.

Berzsenyi, Z., Gyrffy, B., Lap, D.Q., 2000. Effect of crop rotation and fertilisation on maize and wheat yields and yield stability in a long-term experiment. Eur. J. Agron. 13, 225–244.

Chaabane, R., Bchini, H., Ouji, H., Ben Salah, H., Khamassi, K., Khoufi, S., Babay, E., Ben Naceur, M., 2011. Behaviour of Tunisian Durum wheat (*Triticum turgidum* L.) varieties under saline stress. Pak. J. Nutr. 10 (6), 539–542.

Chahed, Y., 2009. Tunisia GRAIN 2009 Grain and Feed Annual. USDA Foreign Agriculture service. Grain report.

De Vita, P., Li Destri Nicosia, O., Nigro, F., Platani, C., Riefolo, C., Di Fonzo, N., Cattivelli, L., 2007. Breeding progress in morpho-physiological, agronomical and qualitative traits of durum wheat cultivars released in Italy during the 20th century. Eur. J. Agron. 26, 39–53.

Duvick, D.N., Smith, J.S.C., Cooper, M., 2004. Changes in performance, parentage, and genetic diversity of successful corn hybrids, 1930 to 2000. In: Smith, C.W., Betrian, J., Runge, E.C.A. (Eds.), Corn: Origin, History, Technology and Production. John Wiley & Sons, Inc., Hoboken, NJ, pp. 65–97.

Eberhart, S.A., Russell, W.A., 1966. Stability parameters for comparing varieties. Crop Sci. 6, 36–40.

El-Hendawy, S.E., Hu, Y., Yakout, G.M., Awad, A.M., Hafiz, S.E., Schmidhalter, U., 2005. Evaluating salt tolerance of wheat genotypes using multiple parameters. Eur. J. Agron. 22, 243–253.

Elias, E.M., Manthey, F.A., 2005. End products: present and future uses. In: Royo, C., Nachit, M.M., DiFonzo, N., Araus, J.L., Pfeiffer, W.H., Slafer, G.A. (Eds.), Durum Wheat Breeding Current Approaches and Future Strategies. Food Products Press, New York, pp. 63–86.

Finlay, K.W., Wilkinson, G.N., 1963. The analysis of adaptation in a plant breeding program. Aust. J. Agric. Res. 14, 742–754.

Fufa, H., Baenziger, P.S., Beecher, B.S., Graybosch, R.A., Eskridge, K.M., 2005. Genetic improvement trends in agronomic performances and end-use quality characteristics among hard red winter wheat cultivars in Nebraska. Euphytica 144, 187–198.

Habash, D.Z., Kehel, Z., Nachit, M., 2009. Genomic approaches for designing durum wheat ready for climate change with a focus on drought. J. Exp. Bot. 60 (10), 2805–2815.

Houshmand, S., Arzani, A., Maibody, S.A.M., Feizi, M., 2005. Evaluation of salt-tolerant genotypes of durum wheat derived from in vitro and field experiments. Field Crops Res. 91, 345–354.

Husain, S., Munns, R., Condon, A.G., 2003. Effect of sodium exclusion trait on chlorophyll retention and growth of durum wheat in saline soil. Aust. J. Agric. Res. 54, 589–597.

Katerji, N., Van Hoorn, J.W., Fares, C., Hamdy, A., Mastrorilli, M., Oweis, T., 2005. Salinity effect on grain quality of two durum wheat varieties differing in salt tolerance. Agric. Water Manage. 75, 85–91.

Latiri, K., Lhomme, J.P., Annabi, M., Setter, T.L., 2010. Wheat production in Tunisia: progress, inter-annual variability and relation to rainfall. Eur. J. Agron. 33, 33–42.

Marti, J., Slafer, G.A., 2014. Bread and durum wheat yields under a wide range of environmental conditions. Field Crops Res. 156, 258–271.

Messina, C.D., Podlich, D., Dong, Z., Samples, M., Cooper, M., 2011. Yield–trait performance landscapes: from theory to application in breeding maize for drought tolerance. J. Exp. Bot. 62 (3), 855–868.

Mir, R.R., Zaman-Allah, M., Sreenivasulu, N., Trethowan, R., Varshney, R.K., 2012. Integrated genomics, physiology and breeding approaches for improving drought tolerance in crops. Theor. Appl. Genet. 125, 625–645.

Mühleisen, J., Piepho, H.P., Maurer, H.P., Longin, C.F.H., Reif, J.C., 2014. Yield stability of hybrids versus lines in wheat, barley, and triticale. Theor. Appl. Genet. 127, 309–316.

Munns, R., 2002. Comparative physiology of salt and water stress. Plant Cell Environ. 25, 239–250.

Munns, R., James, R.A., 2003. Screening methods for salinity tolerance: a case study with tetraploid wheat. Plant Soil 253, 201–218.

Munns, R., Tester, M., 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol. 59, 651–681.

Piepho, H.P., 1998. Methods for comparing the yield stability of cropping systems. Rev. J. Agron. Crop Sci. 180, 193–213.

Rajaram, S., Braun, H.J., 2008. Wheat yield potential. In: Reynolds, M.P., Pietragalla, J., Braun, H.J. (Eds.), International Symposium on Wheat Yield Potential: Challenges to International Wheat Breeding. CIMMYT, Mexico, D.F., pp. 103–107.

Rebetzke, G.J., Ellis, M.H., Bonnetta, D.G., Condona, A.G., Falkb, D., Richards, R.A., 2011. The Rht13 dwarfing gene reduces peduncle length and plant height to increase grain number and yield of wheat. Field Crops Res. 124, 323–331.

Regmi, A.P., Ladha, J.K., Pasuquin, E., Pathak, H., Hobbs, P.R., Shrestha, L.L., Gharti, D.B., Duveiller, E., 2002. The role of potassium in sustaining yields in a long-term rice-wheat experiment in the Indo-Gangetic Plains of Nepal. Biol. Fertil. Soils 36, 240–247.

Rezgui, S., Fakhfakh, M., 2010. Optimizing nitrogen use on the farm. In: El Mourid, M., Macpherson, H.G., Rawson, H.M. (Eds.), Explore on-Farm: The Case of North Africa. ICARDA and FAO, pp. 85–96.

Rharrabti, Y., Villegas, D., Royo, C., Martos-Nunez, V., García Del Moral, L.F., 2003. Durum quality in Mediterranean environments II. Influence of climatic variables and relationships between quality parameters. Field Crops Res. 80, 133–140.

Rowe, P.R., Andrew, R.H., 1964. Phenotypic stability for a systematic series of corn genotypes. Crop Sci. 4, 563–567.

Roy, S.J., Negrão, S., Tester, M., 2014. Salt resistant crop plants. Curr. Opin. Biotechnol. 26, 115–124.

Royo, A., Abiò, D., 2003. Salt tolerance in durum wheat cultivars. Span. J. Agric. Res. 1 (3), 27–35.

Royo, C., Álvaro, F., Martos, V., Ramdani, A., Isidro, J., Villegas, D., García Del Moral, L.F., 2007. Genetic changes in durum wheat yield components and associated traits in Italian and Spanish varieties during the 20th century. Euphytica 155, 259–270.

Sánchez-García, M., Royo, C., Aparicio, N., Martín-Sánchez, J.A., Álvaro, F., 2013. Genetic improvement of bread wheat yield and associated traits in Spain during the 20th century. J. Agric. Sci. 151, 105–118.

Tollenaar, M., Lee, E.A., 2002. Yield potential, yield stability and stress tolerance in maize. Field Crops Res. 75, 161–169.

Trethowan, R.M., Singh, R.P., Huerta-Espino, J., Crossa, J., Van Ginkel, M., 2001. Coleoptile length variation of near-isogenic *Rht* lines of modern CIMMYT bread and durum wheats. Field Crops Res. 70, 167–176.

Yousfi, S., Serret, M.D., Araus, J.L., 2009. Shoot $d^{15}N$ gives a better indication than ion concentration or D13C of genotypic differences in the response of durum wheat to salinity. Funct. Plant Biol. 36, 144–155.

Yousfi, S., Serret, M.D., Voltas, J., Araus, J.L., 2010. Effect of salinity and water stress during the reproductive stage on growth, ion concentrations, D13C and d15N of durum wheat and related amphiploids. J. Exp. Bot. 61, 3529–3542.