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Research Article

Diallel-cross analysis of grain yield and stress tolerance-related traits under semi-arid conditions in Durum wheat (*Triticum durum* Desf.)

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Abstract

Half-diallel analysis with six genotypes of durum wheat was conducted for grain yield, yield components and agronomic traits related to abiotic stress tolerance. Aim of this study is to identify best parents for hybridization. Cultivar Guemgoum Rkhem proved to be best general combiner for number of days to heading, straw yield, plant height and thousand-kernel weight. Gaviota durum was best combiner for number of grains per spike, and cultivar Ofanto for Chlorophyll content and harvest index. Waha proved to be a poor general combiner for flag leaf area, straw yield, plant height and thousand-kernel weight. Mexicali$_{75}$/Guemgoum Rkhem cross is best suited to improve earliness, straw yield, plant height, and grain yield. Narrow-sense heritability was low for grain yield. Waha//Zenati Bouteille/Flamingo and Waha/ Guemgoum hybrids showed significant mid-parent heterosis for grain yield.

Keywords:

Durum wheat, diallel, combining ability, gene action, heterosis.

Introduction

Producing more cereals is becoming an urgent task for Algerian agricultural sector. In fact, Algeria needs to import, in near future, more than 11 million tons of cereals to cover the demand of an overgrowing population. To produce more cereals, the prevailing environmental constraints must be mastered and adequate producing technologies put forward. This is not the case of Algeria where the main cereal producing zones are characterized by harsh and variable climate and soils with continuous fertility declining due to decades of mining agriculture (Lahmar and Ruellan, 2007). Option to increase cereals production by expanding the area under cultivation has already been exploited, leaving the alternative to tentatively increase production per unit of cropped area; either through irrigation or through adoption of high yielding and stress resilient cultivars (Chennafi *et al.*, 2006; Benmahammed *et al.*, 2010). Increasing cereal production through genetic improvement is appealing. Besides grain yield, which represents the ultimate selection objective, a number of yield-related and stress tolerance- related traits have received much attention, such as chlorophyll content, flag leaf area, days to heading, plant height, straw yield, harvest index, 1000-kernel weight, peduncle length, grains per spike and spikes per plant.

Early maturity is an important breeding objective in durum wheat (*Triticum durum* Desf.) under semi- arid growth conditions. Earliness minimizes the effect of terminal heat and drought stresses on plant, as short-cycle cultivars grow mostly under more favorable conditions than their long-cycle counterparts (Wiegand and Cuellar, 1981; Al-Khatib and Paulsen, 1984; Przulj and Mladenov, 1999). Under rainfed growth conditions of the Algerian eastern high plateaus region, tall wheat cultivars are preferred, because of better seedling emergence and ease of harvest. They offer the possibility to remove enough straw for animal feeding and bedding, while still keeping adequate residues for soil protection against wind and water erosion, as no-till sowing is slowly gaining acceptance in the region (Chennafi *et al.*, 2011). Grain yield was found to be highly associated with harvest index, biological yield, thousand- kernel weight and number of productive tillers per plant, suggesting the use of these traits, individually or combined in an index, as selection criteria for yield improvement (Richards *et al.*, 2002;Verma and Srivastava, 2004; Condon *et al.*, 2004; Moragues *et al.*, 2006). Grain yield and traits controlling stress tolerance are complex polygenic characters, sensitive to environmental changes, showing low response to selection (Ferdous *et al.*, 2010). Improvements of such traits rely upon identification of genetically superior and suitable genotypes and their exploitation through either heterosis breeding or pedigree breeding. Selection of parents and crosses is based on knowledge of the magnitude and the nature of the genetic variances available in the base population. The present study was conducted with the objectives of determining general and specific combining ability of traits of agronomic interest in durum wheat and to provide base material for the durum wheat improvement program developed at the Setif, INRAA research unit.

Material and methods

Six durum wheat winter genotypes (*Triticum durum* Desf.) representing a wide range for plant type, maturity, yield potential, and genetic background were selected for this study. These were Waha, Zenati Bouteille/Flamengo, Mexicali$_{75}$, Ofanto, Gaviota durum, and Guemgoum Rkhem. Waha, Zenati Bouteille/ Flamengo, Mexicali$_{75}$ and Gaviota durum are breeding lines selected from material originating from CIMMYT-ICARDA. Ofanto is an Italian cultivar and Guemgoum Rkhem is a selection from a local land race (Table 1).

These six genotypes were crossed in a diallel mating system without reciprocals to produce 15 F1 populations during the 2010/2011 growing season. The F1's and their six parents were grown in the field at the Agricultural Experimental Station (AES) of Setif (Algeria) in the 2011/2012 growing season. Seeds of 15 F1 along with their self-pollinated parents were sown in a single row, 2.5 m long, per replicate in a randomized complete block design with three replications. Rows were 30 cm apart and seeds were spaced 15 cm on the row. The soil type at the AES station is a clay-loam, according to the FAO soil texture classification (FAO, 1990), with a low organic matter content of 1.32%, and a pH value of 8.2. Trail mineral fertilization and chemical weed control were applied as per the AES recommendations (Chennafi *et al*., 2006). The following traits were measured: Number of calendar days from emergence to 50% heading (DHE, days); plant height (PHT, cm); flag leaf chlorophyll content (Chl), measured with a SPAD-502; flag leaf area, estimated as leaf length x leaf with x 0.607, according to Spagnoletti-Zeuli and Qualset (1990); number of fertile tillers per plant (FT, number); number of grains per spike (NG, number); thousand-kernel weight (TKW, g), harvest index (HI, %), estimated as the ratio of grain yield to above ground biomass per plant x 100; straw yield, estimated as above ground biomass minus grain yield (STR, g) and grain yield (GY, g). Data, recorded on 10 random plants per replicate, were subjected to analysis of variance (ANOVA) according to Steel and Torrie (1980). Parents and hybrids sum of squares of the traits, showing significant differences among genotypes, were further partitioned into general combining ability (GCA) and specific combining ability (SCA) effects according to Griffing (1956) method-2 (parents and one set of F1 without reciprocal) and model-I (fixed effect), using the online free software (OPSTAT). Mid-parent (HMP) heterosis was estimated according to the following formulae: HMP = 100[(XF1-XMP)/XMP] (Oettler *et al*., 2005; Hung and Holland, 2012). Narrow-sense heritability was calculated according to Falconer and Mackay (1996), after derivation of variance components.

Results and discussion

The choice of parents, with maximum potential of transmitting desirable genes to the progenies, is a very important task in a breeding program. Results of some studies showed that high yielding genotypes do not always perform well for different economic traits when crossed, suggesting the existence of inherent differences among genotypes for combing ability (Bouzerzour and Djekoun, 1998; Ottler *et al.,* 2005). Six durum wheat cultivars were evaluated in this study, in a half-diallel cross, to assess the magnitude of genetic variation and combining ability for different traits related to yield. Mean squares due to genotypes were significant for chlorophyll content, flag leaf area, number of days to heading, plant height, straw yield, harvest index and yield components (Table 2) as revealed by ANOVA. This provides evidence for sufficient genetic variability, which allows further assessment of general combining ability analysis. General combining ability (GCA) mean squares were significant except for number of fertile tillers and grain yield, while specific combining ability (SCA) mean squares were significant except for harvest index, number of kernels per spike and thousand-kernel weight (Table 2). Significance of GCA and SCA mean squares indicates that both additive and non-additive types of gene action are involved in the genetic system controlling these traits. Ratio of GCA/SCA was less than unity for the fertile tillers and grain yield, suggesting that non-additive types of gene effects playing the major role in the inheritance of these traits. For the other trait, the ratio was largely superior to 2.7, suggesting the preponderance of additive gene action (Table 2).

No genotype among the six durum cultivars evaluated showed significant GCA effects for grain yield and the number of fertile tillers (Table 3). Cultivar Guemgoum Rkhem proved to be a general combiner for the number of days to heading, straw yield, plant height and thousand-kernel weight. This cultivar showed significant and negative GCA effects for chlorophyll content and the number of kernels per spike (Table 3). Gaviota durum was best combiner for the number of grains per spike, and Ofanto showed positive and significant GCA effects for Chlorophyll content and harvest index. Zb/Fg was best combiner for reducing plant height. Flag leaf size is an important character under stress, as it is the last major photosynthetic site remaining on activity, thereby enhancing grain yield. Vogele and Grossman (1985) mentioned that flag leaf removal after ear emergence caused 9% reduction in kernel weight. Mexicali$_{75}$ was best combiner to increase flag leaf area, and among the six durum genotypes, Waha proved to be a poor general combiner for flag leaf area, straw yield, plant height and thousand-kernel weight (Table 3). Results revealed that *per se* performance of the parents is a reflection of their GCA effects for most traits. The correlation coefficients between GCA effects and parental *per se* performances were 0.510^{ns}, 0.732^{ns} and 0.898^{*} for the number of fertile tillers, grain yield and the number of kernels per spike, respectively, and over 0.990^{**} for the others traits.

The cross Waha//Zb/FG, showed high and significant SCA effects for grain yield and flag leaf area, with values 9.27 and 3.72 respectively (Table 4). Hybrids Waha/Guemgoum Rkhem, Mexicali/ Guemgoum Rkhem showed positive and significant SCA effects for straw yield and plant height varying from 6.29 to 10.05 and from 4.92 to 7.91 respectively. Ofanto/Gaviota durum showed a significant SCA effect for the number of grains per spike, flag leaf area and chlorophyll content. Waha/Guemgoum Rkhem and $Mexicali_{75}$ /Guemgoum Rkhem exhibited significant SCA effect for plant height (Table 4). Both crosses had Guemgoum Rkhem as constant parent which showed a high and significant GCA effect for this trait (Table 3). Waha/Mexicali showed a significant and positive SCA effect for the number of days to heading. Ofanto/Gaviota durum cross offers the opportunity to improve, simultaneously, chlorophyll content, flag leaf area, straw yield and grain number per spike. No hybrids expressed significant SCA effects for harvest index, number of fertile tillers and thousand-kernel weight (Table 4).

$Mexicali_{75}$/Guemgoum Rkhem is best suited to improve, simultaneously, earliness, straw yield and plant height. Both crosses had at least one parent which showed significant GCA effect for one or more traits (Tables 3, 4). According to Ottler *et al*, (2005), best hybrid combinations are those with most favorable estimates for SCA effects that have at least one parent with most favorable GCA effect for the target traits. The results suggested that Guemgoum Rkhem, Gaviota durum, Ofanto, $Mexicali_{75}$ and Waha can be used in durum wheat crossing program to generate desirable offspring lines.

Narrow-sense heritability values were high for chlorophyll content (71.0%), number of days to heading (87.0%), plant height (81.0%), harvest index (91.2%) and thousand-kernel weight (86.3%). They were just moderate for flag leaf area (50.6%), straw yield (54.1%) and number of grains per spike (62.5%). They were low for number of fertile tillers (3.5%) and grain yield (2.7%). These results further supported the involvement of additive gene action for chlorophyll content, number of days to heading, plant height, harvest index and thousand-kernel weight. Additive and non-additive gene effects were involved for flag leaf area, straw yield, number of grains per spike, number of fertile tillers, and grain yield. Crosses showing positive and significant mid-parent grain yield heterosis were Waha//Zenati Bouteille/Flamingo (72.1%) and Waha/ Guemgoum (50.5%). No significant relationship was observed between hybrid and mid-parent grain yields. Besides grain yield, Waha//Zenati Bouteille/Flamingo presented also significant and positive mid-parent heterosis for flag leaf area (19.7%), straw yield (48.1%), plant height (10.9%) and number of fertile tillers (44.7%). Waha/Guemgoum Rkhem presented a significant and positive mid-parent heterosis for plant height (12.4%).

Kashif et al. (2003) observed dominance type of gene action for the number of fertile tillers per plant. Chaudhry *et al*. (2001) and Rahman *et al*. (2003) reported predominance of additive gene action for plant height, and a partial dominance type of gene action for thousand-kernel weight. The results of this study indicated an additive type of gene action for 1000-kernel weight and predominance of additive gene action for plant height. Ahmed *et al.*, (2011) reported partial dominance and additive gene effects for days to heading, which corroborates the results of the present study. Grain yield appeared to be under non-additive gene action. Majeed *et al.,* (2011) mentioned that SCA variance was significant and much higher than GCA variance for grain yield per plant. However Farshadfar *et al.,* (2000) reported that additive gene action was predominant for grain yield. Mahmood and Chaudhry (2000) found that flag leaf area was controlled by additive gene action and partial dominance, which supports the results of the present study. Mann *et al.,* (1995) reported highly significant GCA and SCA effects in durum wheat for yield component and harvest index, suggesting the importance of both additive and non-additive gene effects in controlling the inheritance of traits under study, with a predominance of non-additive gene effect for grain yield. In triticale, Oettler *et al.,* (2005) mentioned that GCA variance was more important than SCA variance for all traits except grain yield.

Conclusions

For successful hybridization durum wheat program, a full understanding of the genetic inheritance of important traits must be achieved. The results indicated that both additive and non-additive types of gene action are involved in the genetic system controlling these traits. Cultivar Guemgoum Rkhem proved to be a general combiner for the number of days to heading, straw yield, plant height and thousand-kernel weight. Cultivar Gaviota durum was best combiner for the number of grains per spike, Ofanto for Chlorophyll content and harvest index, Zb/Fg for plant height and Mexicali$_{75}$ for flag leaf area. Waha proved to be a poor general combiner for flag leaf area, straw yield, plant height and thousand-kernel weight. Ofanto/Gaviota durum hybrid showed significant SCA effects for number of grains per spike, flag leaf area and chlorophyll content, offering the opportunity to improve, simultaneously, these traits. Mexicali$_{75}$/Guemgoum Rkhem is best suited to improve earliness, straw yield, plant height, and grain yield. Narrow-sense heritability was low for grain yield and fertile tillers and high for number of days to heading, plant height and thousand-kernel weight. Waha//Zenati Bouteille/Flamingo and Waha/ Guemgoum hybrids showed significant mid-parent heterosis for grain yield. Since the traits under study are primarily controlled by additive gene action, selection within segregating progenies should be effective in identifying homozygous lines as good or better than the F_1 hybrids.

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Table 1. Origin and pedigree of durum wheat cultivars used as parental genotypes for the diallel cross

Cultivar	Origin	Pedigree
Waha	Icarda	Plc/Ruff//Gta's/3/Rolette CM.17904
Zb/Fg	Cimmyt	Zb/Fg's//Lk/3/Ko_{120}/4/Ward
$Mexicali_{75}$	Cimmyt	Gdo.vz 469/3/Jo's//61.130/ Lds/4/Stk. CM .470
Ofanto	Italy	Adamelo /Appulo
Gaviota durum	Cimmyt	Crane/4/PolonicumPI_{185309}//*Triticum glutinosum* enano / 2*$Tehuacan_{60}$/3/Grulla
Guemgoum Rkhem	Algeria	local land race

Table 2. Mean squares of the analysis of variance of parental lines and F1 hybrids for the studied characters

Source	Replicate	Genotypes	Error	GCA	SCA	Error	GCA/SCA
DF	2	20	40	5	15	40	
Chl	20.4	62.6*	7.4	63.9*	6.5*	2.46	9.8
FLA	185.1	60.2*	15.7	48.1*	10.7*	5.23	4.5
DHE	19.0	37.7*	1.4	41.7*	1.5	1.24	27.8
PHT	278.2	373.3*	43.67	427.2*	23.5	14.56	18.2
STR	460.0	338.0*	113.0	214.6*	78.9*	37.8	2.7
HI	9.6	81.0*	11.7	100.8*	2.4^{ns}	3.9	42.0
FT	47.3	28.0	20.6	8.2^{ns}	10.0*	4.57	0.8
GN	95.1	335.1*	85.0	314.5*	44.1^{ns}	28.3	7.1
TKW	43.4	49.2*	24.8	59.6*	2.0^{ns}	8.3	29.8
GY	485.5	138.0	89.8	33.1^{ns}	50.3*	28.96	0.7

Chl=chlorophyll, FLA= Flag leaf area (cm^2), DHE= days to heading, STR = straw yield (g/plant), PHT = Plant height (cm), HI= harvest index (%), FT= fertile tillers, GN= number of grains per spike, TKW= 100-kernel weight (g), GY= Grain yield (g/plant).

Table 3. Estimates of general combining ability effects for grain yield, yield component and agronomic traits of six durum wheat used as parents in the diallel cross

Parents	Waha	Zb/Fg	Mexicali	Ofanto	Gaviota	Guemgoum	$se_{(gi)}$
Chl	0.75	-0.45	0.24	3.94*	0.37	-4.85*	0.5
FLA	-4.89*	0.24	1.83*	1.17	0.93	0.71	0.7
DHE	-1.40*	-0.11	0.72	-3.11*	0.18	3.72*	0.4
STR	-4.55*	1.33	-0.65	-4.97*	-0.47	9.29*	1.2
PHT	-2.39*	-4.43*	-3.09*	-2.21	-2.70*	14.83*	1.8
HI	2.09*	0.02	0.12	3.28*	1.3	-6.80*	0.6
FT	0.16	1.53	-0.55	-1.11	0.78	-0.81	1.0
GN	0.99	-0.45	2.85*	3.11*	5.60*	-12.09*	1.7
TKW	-2.46*	-0.41	-1.28	1.29	-2.01*	4.87*	0.9
GY	-1.59	1.86	-0.16	0.05	2.62	-2.79	1.8

Chl=chlorophyll, FLA= Flag leaf area (cm^2), DHE= days to heading, STR = straw yield (g/plant), PHT = Plant height (cm), HI= harvest index (%), FT= fertile tillers, GN= number of grains per spike, TKW= 100-kernel weight (g), GY= Grain yield (g/plant).

Table 4. Estimates of specific combining ability effects for grain yield, yield component and agronomic traits exhibited by hybrids of six durum wheat used as parents in a diallel cross.

Xss	Chl	FLA	DHE	STR	PHT	HI	FT	GN	TKW	GY
WH/ZF	3.52	3.72*	0.2	6.68	3.51	1.29	3.98	1.35	2.56	9.27*
WH/MX	2.13	-1.58	2.36*	-2.52	-3.91	-1.49	-0.08	-2.82	-1.52	-3.2
WH/OF	0.52	-1.34	1.53	-2.35	-0.87	-2.52	-1.08	7.84*	-0.55	-7.19
WH/GD	-0.49	0.66	-0.1	-1.02	-2.26	0.66	-0.48	2.23	0.26	-0.38
WH/GG	-4.04*	0.23	-0.97	6.29*	7.91*	0.81	2.17	2.39	1.3	7.12
ZF/MX	-3.42	1.41	0.28	-3.04	1.17	0.84	-0.96	3.27	0.09	-1.56
ZF/OF	-0.06	2.17*	-0.1	2.6	1.59	1.18	1.23	0.42	-0.35	3.84
ZF/GD	-5.85*	-0.31	-0.05	3.56	4.24	-1.47	-0.51	8.00*	0.85	0.83
ZF/GG	-3.43	0.65	-0.93	0.74	-0.95	1.02	0.46	-2.37	0.18	1.92
MX/OF	2.54	-1.04	-0.26	-1.27	-1.73	0.03	-1.11	-9.14*	2.57	-0.81
MX/GD	8.04*	-1.73	-0.43	-13.3	-10.49*	0.14	-4.54	-3.95	-2.61	-9.21*
MX/GG	-2.99	1.34	-1.76	10.05*	4.92*	-0.04	3.88	2.00	0.03	7.83
OF/GD	5.79*	3.45*	-0.05	9.27*	1.25	0.94	2.62	8.37*	1.03	7.64
OF/GG	-4.33*	-2.98*	-0.93	-13.65*	1.25	1.76	-3.39	-1.87	0.72	-4.28
GD/GG	-1.35	-8.28*	1.45	-18.71*	-8.41*	0.59	-5.13	-11.79*	-1.74	-11.15*
se(ij)	1.91	1.03	0.99	5.40	2.38	1.75	2.67	2.72	2.55	3.85

WH= Waha, ZF = Zenati Bouteille/Flamengo, MX= Mexicali, OF= Ofanto, GD= Gaviota durum, GG= Guemgoum Rkhem Chl=chlorophyll, FLA= Flag leaf area (cm^2), DHE= days to heading, STR = straw yield (g/plant), PHT = Plant height (cm), HI= harvest index (%), FT= fertile tillers, GN= number of grains per spike, TKW= 100-kernel weight (g), GY= Grain yield (g/plant).