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COMBINING ABILITY AND STABILITY STUDIES IN F_1 POPULATIONS OF *TRITICUM DURUM* ACROSS ENVIRONMENTS

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Abstract

In the developing world, plant breeding and seed improvement systems must be promoted to reduce the crops vulnerability. Development of improved genotypes of different crop plants through enlightened plant breeding are earnestly needed to deliver climate change adaptation and help in food security. Five durum wheat cultivars (Syrian–4, Dumes–1, Sham–7, Yousef–1 and Haurani) were crossed during 2016–17 in a half diallel fashion to create 10 F_1 hybrids at Duhok University, Iraq. During 2017–18, the seeds of all the genotypes (five parental genotypes + 10 F_1 hybrids) were grown with early (November 20, 2017) and late (December 20, 2017) sowing in a randomized complete block design (RCBD) with three replications at two different locations i.e., Sumel – Duhok University and Amedi – Duhok city, Iraq. The combined analysis of variance showed significant ($p\leq0.01$) differences for hybrids, environments, and hybrid x environment interactions. Analysis of variance for combining ability showed that mean squares due to GCA and SCA were significant ($p\leq0.01$) indicating the role of both additive and non-additive gene effects in inheritance of studied traits. In general, parental lines i.e., Sham–7 and Haurani were found as good general combiners for most of characters. The SCA effects were significant for three hybrids i.e., Syrian–4 × Sham–7, Sham–7 × Haurani and Duma–1 × Haurani for majority of the characters. In order to determine the stability of genotypes in four different environments, the stability parameters were used to identify the stable genotypes through regression coefficient (Bi) and variance of deviation from regression (S^2d). Results further revealed that genotypes differed in their response across various environments for all the variables. Some genotypes reflected stability for one character and unstable for other trait, showing a wide range of variation. According to stability parameters parental lines (Sham–7 and Haurani) and F_1 hybrids i.e., Duma–1 × Haurani, Sham–7 × Haurani and Duma–1 × Sham–7, had the best stability for grain yield and its components, thus indicating a wide range of adaptation across environments. These investigations will play an important role in managing some strategies for improvement in durum wheat through diallel cross in future breeding program.

Key words: Combining ability, Additive and non-additive gene action, Stability analysis, Earliness and yield traits, *Triticum durum* Desf.

Introduction

Durum wheat (*Triticum durum* Desf.) is the most important cereal crop and worldwide widely used in the food industry due to its good quality (Karimizadeh *et al*., 2011). Durum wheat is a tetraploid (AABB, 2n = 4x = 28) wheat with high protein and gluten strength than bread wheat (Von-Buren, 2001). More than 80% of the durum cultivars released in the developing world, covering more than 50% of the area planted to this crop (Al-Doss *et al*., 2011). Durum wheat is an economically very important crop because of its unique characteristics and products. Grains of durum wheat are bigger, heavier, and harder than those of bread wheat. Its high protein content and strength make durum wheat feasible for different uses. In middle east, the durum wheat is second to bread wheat (*T. aestivum* L.) as the endosperm of durum wheat has the hardest texture and that make it suitable to produce variety of food products i.e., semolina for macaroni, spaghetti and other pasta products (Dexter *et al*., 1990; Korkut *et al*., 2007). However, durum wheat dough is less elastic than bread wheat and is low-grade for producing leavened loaves (El-Shazly *et al*., 2000). Durum wheat is best adapted to regions having a relatively dry climate, with hot days and cool nights during the growing season, typical of Mediterranean and temperate climates (Srivastava *et al*., 1988).

Diallel analyses used for genetic analysis of vital traits are helpful to the plant breeder in picking improved genotypes for different existing environments and production systems. Diallel analyses are the well-known mechanisms of conventional breeding to understand allelic and non-allelic gene action, nature and amount of genetic variance utilized by genotypes in specific combinations (Griffing, 1956; Mather & Jinks, 1982).

To develop high yielding wheat cultivars, it is important to study the genetic make-up of diverse wheat lines, inheritance pattern of yield contributing traits and association of various traits with yield under existing environmental conditions (Afridi, 2016; Afridi *et al*., 2017; Tabassum *and Prasad*., 2017). Breeders are looking for desirable genes and gene complexes, and identification of promising individuals are very important in any breeding program. Diallel mating design is one of the tools which help the breeder to identify the potential genotypes (parents) and the promising recombinants produced by combining the parental individuals through general combining ability (GCA) and specific combining ability (SCA) (Akram *et al*., 2009; Araus and Cairns, 2016; Afridi *et al*., 2018). In diallel mating, the parental genotypes are crossed in all possible combinations to identify genotypes (as best / poor general combiners) through GCA and the specific cross combinations through SCA (Parveen *et al*., 2019).

In crop plants, the offspring performance is predicted from their parental genotypes by using half and full diallel crosses. Combining ability was found important for studying the crossing in wheat breeding programs to distinguish high yielding hybrids and recognize the best general and specific combiners (Fehr, 1993; Aslam *et al*., 2014; Abro *et al*., 2016). Significant effects due to GCA and SCA were reported for spikes per plant, grains per spike and grain yield in half diallel crosses of wheat (Joshi *et al*., 2004; Mandal and Madhuri, 2016).

The genotypes may have adaptability across different environmental conditions that a stable and high yielding genotype in a particular environment could be selected (Karimizadeh & Mohammadi, 2010; Sharma *et al*., 2012). The yield performance of genotype is a result of interaction between genotype and environment. The new wheat genotype must possess ability for grain yield and other traits related to quantity and quality of grain yield that could resist the influence of weather conditions on such characters (Johansson & Svensson, 1998). Stable genotype is defined by Becher and Leon (1988) as one having an unchanged performance regardless of any variation in environmental conditions. There are a number of statistical methods have been developed for stability analysis along with information explanation about each method (Mohammadi & Amri, 2008; Hamam & Abdel-Sabour, 2009;Ali *et al*, 2019).

Among these methods, the regression coefficient (Bi) (Finlay & Wilkinson, 1965) and S^2d deviation from regression (Eberhart & Russel, 1966) are most widely used. Linear regression coefficient used by Ulker *et al*., (2006), showed significant influence of genotypes and environments with varied values of Bi in durum wheat. Josephides (1992) found high adaptability in durum wheat genotypes across various environments with various stability parameters. In the past studies, for stability the different parameters were used and obtained high stable genotypes of durum wheat across diverse environments (Bahlouli *et al*., 2005). High yielding and stable genotypes were identified in the study of durum wheat genotypes in varied environmental conditions (Oku-Yama *et al*., 2005).

In light of above elucidation, the current research was planned with the objectives to study, a) the genetic potential of durum wheat parental genotypes and their F_1 half diallel hybrids, b) the GCA and SCA effects and gene action in parents and their half diallel crosses, respectively, and b) to identify and select the stable genotypes in durum wheat for yield and yield components under different environmental conditions.

Table 1. Breeding material of *T. Durum* used in the study.

S.No.	Parental genotypes	S.No.	F_1 half diallel populations
1.	Syrian–4	8.	Syrian–4 × Yousef–1
2.	Duma–1	9.	Syrian–4 × Haurani
3.	Sham–7	10.	Duma–1 × Sham–7
4.	Yousef–1	11.	Duma–1 × Yousef–1
5.	Haurani	12.	Duma–1 × Haurani
	F_1 half diallel populations	13.	Sham–7 × Yousef–1
6.	Syrian–4 × Duma–1	14.	Sham–7 × Haurani
7.	Syrian–4 × Sham–7	15.	Yousef–1 × Haurani

Material and Methods

Experimental sites and procedure: Five durum wheat cultivars (Syrian–4, Dumes–1, Sham–7, Yousef–1, and Haurani) were crossed during 2016–17 in a half diallel mating design to create 10 F_1 hybrids at Duhok University, Iraq (Table 1). During 2017–18, the seeds of all the genotypes (five parental genotypes + 10 F_1 hybrids) were grown with early (November 20, 2017) and late (December 20, 2017) sowing in a randomized complete block design (RCBD) with three replications at two different locations i.e., Sumel – Duhok University, and Amedi – Duhok city, Iraq. Rows and plants spacing were kept 30 and 20 cm, respectively with two meters length.

Data recorded and statistical analyses: Data were recorded on days to 50% flowering, plant height (cm), biological yield plant^{-1}, spikes plant$^{-1,}$ seed index, and harvest index. For comparison of genotype means for various traits, the data were subjected to analysis of variance (Al-Zubaidy & Al-Falahy, 2016). General and specific combining ability were estimated by using Griffing's Method-2 (Griffing, 1956). General (GCA) specific combining ability (SCA) linear model was used for analysis with following equations.

Yijk= M+gi+gj+sij+rk+

Yijk = Observed value of experimental unit

M = Population mean.

gi = General combining ability (GCA) effect of i parents.

gj = General combining ability (GCA) effect of j parents.

Sij= specific combining ability (SCA) for the cross involving parents i and j.

Estimation of GCA and SCA effects:

$$\hat{g}i = \frac{1}{r(n+2)} = [zi\ldots\ldots(z\ \ldots.)/n]$$

$$\hat{S}ij = \frac{Yij.}{r} - \frac{[zi\ldots + zj..]}{r(n+2)} + \frac{2Y..}{r(n-1)(n+1)}$$

where:

$\hat{g}i$ = Effects due to GCA.

$\hat{S}ij$ = Effects due to SCA.

Yij = F_1 Overall mean as a result of crossing parents i with parent j

Y…= Sum of overall mean of all parent and F_1 hybrid.

Estimation of components of variance for GCA and SCA.

$$6^2\hat{g}i = (\hat{g}i)^2 - \frac{(n-1)}{2n^2}\, 6^2e$$

$$\hat{S}ij = \frac{1}{(n-2)} . \left[Sij^2 - \frac{1}{2n^2} + (n^2-2n+2)6^2e\right.$$

$$6^2sij = \frac{1}{(n-2)}\ [sij^2 -$$

The analysis of variance was done for each environment and pooled analysis over environments to determine regression coefficient (Bi) and deviation from regression (S^2d) which were used as stability parameters to determine the stability of the genotypes over environments (Table 2) (Eberhart & Russel, 1966). Genotypes with high mean for each character with nonsignificant value of Bi and S^2d were determined as stable genotypes.

Table 2. Mean squares partitioning according to Eberhart and Russel (1966) analysis of variance in *T. Durum* at four environments.

Source of variation	d.f.	SS	MS
Genotypes	G - 1	$\frac{\Sigma yi.2}{e} - \frac{(y..)2}{ge}$	$\frac{SSG}{g-1}$
Environment	E - 1	$\frac{\Sigma y.j2}{g} - \frac{(y..)2}{ge}$	$\frac{SSE}{e-1}$
G × E	(g – 1) (e – 1)	$\Sigma yij^2 - \frac{\Sigma yij2}{e} + \frac{\Sigma yij2}{g} + \frac{(y..)2}{ge}$	$\frac{SSG \times E}{(g-1)(e-1)}$
E × G × E	G(e – 1)	SS(E) + ss (G + E)	$\frac{SSE + G \times E}{g(g-1)}$
E linear	1	rSxx	$\frac{SS\ e\ linear}{1}$
G × E linear	g - 1	$\Sigma ssR(xi) - ss(E\ linear)$	$\frac{SSG\ x\ E\ linear}{(g-1)}$
Pooled deviation	g(e – 2)	$\Sigma see(xi)$	$\frac{SS\ pooled\ deviation}{g(e-2)}$
Pooled error	Eg(r – 1)	SSr + SSe	$\frac{ssr + Ssr}{eg(r-1)}$

F- Test was used to testing of hypothesis as:

Ho: E linear $F = \frac{Ms(E\ linear)}{Ms\ pooled\ deviation}$

Ho: (G x E) linear = $F = \frac{Ms(GXE)linear}{Ms\ pooled\ deviation}$

Ho: Ms pooled deviation = 0 $F = \frac{Ms\ pooled\ diviation}{Ms\ pooled\ error}$

Ho: $S^2d = 0$ $F = \frac{Ms(Xi)gi}{Ms\ pooled\ error}$

Ho: Bi = 1 $1 = \frac{Bi-1}{SBi}$, $SBi = \frac{Ms(Xi)gi}{Sxx}$

Result and Discussion

According to analysis of variance, environments and F_1 hybrids revealed significant ($p \leq 0.01$) differences for almost all the traits while significant ($p \leq 0.05$) for harvest index (Table 3). The interactions between F_1 hybrids and environments were also significant ($p \leq 0.01$) for all the traits except grain yield and harvest index which were merely significant ($p \leq 0.05$). The same table indicates that mean squares due to GCA and SCA were also significant ($p \leq 0.01$) for all studied characters except harvest index ($p \leq 0.05$), indicating the imperative role of both additive and non-additive gene effects for inheritance of the studied variables. In plant breeding programs, the magnitude of genetic variation among populations is very useful which play an important role in selecting the desirable genotypes for agronomic traits. Past studies revealed that significant differences were observed among genotypes, environments, genotype-environment interactions and in mean squares due to GCA and SCA with greater genetic variability for earliness and yield traits in durum and bread wheat (Josephides, 1992; Bahlouli *et al*., 2005; Akinci, 2009; Jains & Sastry, 2012; Yousif & Al-Hayali, 2018). Combining ability studies confirmed significant variability among the parent cultivars and their F_1 genotypes for various agronomic parameters in wheat (Akram *et al*.,2011 Afridi, 2016; Aslam *et al*., 2014; Abro *et al*., 2016). For GCA and SCA effects in parental genotypes and F_1 hybrids, respectively, the positive and increased effects are considered important and desirable for those variables where maximum mean values are of the breeder 's interest. However, for traits like earliness and plant height where minimum mean values are desired, then negative and minimum effects of GCA and SCA are more desirable.

Genetic variability among wheat populations: Genotypes and environments observed with highly significant differences for all the studied traits and revealed greater genetic variability (Table 4). Past studies revealed relatively high variance among the wheat genotypes for studied characters grown under various environmental conditions which reflects variable response of the genotypes in different environments (Ali & Sadallah, 2008; Ali & Hussain, 2014). The environment - linear was highly significant for all studied characters which revealed the genetic effect of genotypes response to environments, while the G × E interactions linear type vs. pooled deviation were highly significant for all traits except spikes plant^{-1} , grains spike^{-1}, grain yield plant^{-1} and harvest index, reflecting high genetic variation among genotypes and their response to different environments. (Ahmed & Al-Naaimi (2011;Sajjad et al.,2020), Among parental genotypes, cultivar Duma–1 showed significant ($p \leq 0.01$) variation for days to 50% flowering, biological yield plant^{-1}, and seed index followed by two other parental genotypes Sham–7 and Haurani. However, the cross Syrian–4 × Duma–1 revealed significant ($p \leq 0.01$) variation for four traits followed by F_1 population Sham–7 × Yousef–1 for days to 50% flowering, spikes plant^{-1} and harvest index. The results were in line with Mohammadi and Amri (2008) and Ali & Hussain (2014).

Table 3. Analysis of variance in half diallel crosses of durum wheat for various traits.

Source of variation	d.f.	Days 50% flowering	Plant height	Biological yield plant^{-1}	Spikes plant^{-1}	Grains spike^{-1}	Grain yield plant^{-1}	Seed index	Harvest index
Environment	3	165.192**	287**	353.412**	13.370**	194.079**	254.262**	92.251**	72137.663*
Rep (Env.)	8	1.650*	3.968*	6.059*	0.800*	3.2111*	38.593*	4.924*	55325.461*
Hybrids	14	207.629**	551.239**	829.820**	24.029**	561.946**	232.630**	271.407**	74346.778*
Env. × Hybrid	42	47.641**	38.816**	87.767**	1.294**	49.305**	47.176*	24.485**	72909.638*
GCA	4	357.347**	1139.759**	968.401**	23.420**	901.420**	443.845**	62.717**	54103.704*
SCA	10	147.742**	316.000**	774.388**	24.273**	426.156**	148.144**	354.883**	82444.008*
GCA × Env.	4	2.650*	9.807**	11.349**	0.614*	22.535**	41.827	6.619*	93218.573*
SCA × Env.	10	3.688*	9.570**	60.601**	1.569**	9.685**	69.806	19.398**	169606.439**

*, ** Significant at p0.05 and p0.01, respectively

Table 4. Combine analysis of variance in diallel crosses of durum wheat across environments.

Source of variation	d.f.	Days to 50% flowering	Plant height	Biological yield plant^{-1}	Spikes plant^{-1}	Grains spike^{-1}	Grain yield plant^{-1}	Seed index	Harvest index
Genotypes (G)	14	69.20**	183.78**	276.60**	8.00**	187.31**	77.54**	90.46**	143.23**
E + (G × E)	45	18.49**	18.46**	35.15**	0.7**	19.65**	20.32**	9.66**	33.63**
E (Linear)	1	165.19**	287.44**	353.41**	13.37**	194.07**	254.26**	92.25**	660.81**
G × E (Linear)	14	11.28**	25.76**	62.52**	0.33	13.18	5.31	17.89	13.72
Pooled dev.	30	16.96**	6.08*	11.78**	0.44	16.85	19.53	3.07**	22.02
Syrian–4	2	11.42**	0.34	128.37**	0.05	140.17	34.81	15.64**	0.57
Duma–1	2	15.47**	1.56	0.52	0.26	51.90**	0.57	11.52*	5.40
Sham–7	2	1.49**	4.28*	2.29	0.14	2.47	3.46	5.22	14.10**
Yousef–1	2	51.65**	2.82	59.44**	0.12	0.87	11.89	0.21	21.02**
Haurani	2	0.20	6.03**	0.16	0.14	4.72**	3.26	6.40	17.69**
Syrian–4 × Duma–1	2	10.59**	20.76**	10.26**	0.01	1.46	3.44	21.58**	3.79
Syrian–4 × Sham–7	2	39.34**	0.78	0.99	0.15	0.36	1.45	2.64	7.61
Syrian–4 × Yousef–1	2	0.61	17.28**	25.73**	0.14	2.99	0.16	2.45	3.86
Syrian–4 × Haurani	2	7.72**	0.55	158.85**	0.85*	2.7	5.26	2.58	2.5
Duma–1 × Sham–7	2	93.95**	24.94**	0.66	0.180	2.83	1.73	7.59	7.74
Duma–1 × Yousef–1	2	5.70**	1.85	0.10	0.193	1.12	0.30	1.39	3.09
Duma–1 × Haurani	2	0.29	0.04	1.27	0.33	22.55**	9.95	6.07	56.5**
Sham–7 × Yousef–1	2	2.31**	9.11**	2.69	1.06**	8.53**	11.81	0.70	68.67**
Sham–7 × Haurani	2	7.51**	0.30	3.55**	0.08	0.64	204.40**	1.87	5.86
Yousef–1 × Haurani	2	6.17**	0.61	10.24**	0.05	9.36**	0.50	6.68	5.77
Pooled error	120	0.30	0.92	0.88	0.20	0.95	9.76	2.42	3.15

For days to 50% flowering, the parental genotypes, environments and F_1 populations ranged from 101.50 to 117.25, 109.35 to 113.11, and 98.66 to 119.66 days, respectively (Table 5). In genotypes, the minimum days to flowering were observed in Sham–7 (101.50 days), followed by F_1 population Syrian–4 × Sham–7 (108.75 days) and cultivar Yousef–1 (109.58 days). However, highest number of days to 50% flowering were exhibited by F_1 populations Sham–7 × Yousef–1, Duma–1 × Yousef–1 and Duma–1 ranged from 116.00 to 117.25 days. In environment means over genotypes, the late sowing at both locations i.e., E–2 (109.35 days), followed by E–4 (111.91 days) took less days while two other environments with early sowing i.e., E–1 and E–3 showed maximum days 50% flowering i.e., 113.11 and 113.00 days, respectively. In genotype by environments, the minimum days to 50% flowering were noted in parental genotypes Sham–7 with E–2 (98.66 days), E–4 (101.50 days), and E–1 (101.66 days), and Yousef–1 with E–2 (101.33 days). However, in G × E interactions, the maximum days to 50% flowering were achieved with early sowing at both locations by F_1 populations i.e., Sham–7 × Yousef–1 with E–1 (119.66 days) and Syrian–4 × Duma–1 with E–3 (119.33 days).

In parental cultivars, the mean values for spikes per plant ranged from 4.00 to 8.08, environments ranged from 5.48 to 6.75, while in interaction between genotypes and environment the mean values ranged from 2.33 to 8.66 (Table 5). On average, maximum number of spikes per plant was observed for genotype Haurani (8.08), followed by F_1 hybrids Sham–7 × Haurani, Syrian–4 × Sham–7, and Sham–7 × Yousef–1 ranged from 7.00 to 7.83. However, minimum spikes per plant were recorded for genotype Syrian–4 × Haurani (3.33), followed by Duma–1 (4.00). In environment means over genotypes, the E–3, E–4 and E–1 showed maximum spikes per plant ranged from 6.06 to 6.75 while minimum spikes were observed in E–2 (5.48). In G x E interaction effects, maximum and at par spikes per plant were observed for genotype Haurani with E–4 (8.66) and E–3 (8.33), Sham–7 × Haurani with E–4 (8.33) and E–3 (8.00), and Sham–7 × Yousef–1 with E–3 (8.00). Minimum number of spikes per plant was recorded for F_1 hybrid Syrian–4 × Haurani with E–2 (2.33), followed by Syrian–4 (3.33) and Duma–1 (3.33) with E–2.

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Table 5. Mean performance of durum wheat genotypes for days to 50% flowering and spikes per plant across environments.

Genotypes	Days to 50% flowering (days)					Spikes plant^{-1}				
	Sumel		Amedi		Means	Sumel		Amedi		Means
	E1	E2	E3	E4		E1	E2	E3	E4	
Syrian–4	109.66	107.66	116.66	113.33	111.83	4.33	3.33	6.33	5.66	4.91
Duma–1	115.33	110.33	121.66	120.33	116.91	4.33	3.33	4.66	3.66	4.00
Sham–7	101.66	98.66	104.66	101.00	101.50	6.66	5.66	7.00	7.33	6.66
Yousef–1	105.00	101.33	116.33	115.66	109.58	6.33	5.66	7.66	7.66	6.83
Haurani	111.66	106.66	111.66	110.33	110.08	7.66	7.66	8.33	8.66	8.08
Syrian–4 × Duma–1	113.66	109.66	119.33	117.66	115.08	5.66	4.66	7.33	6.66	6.08
Syrian–4 × Sham–7	114.66	110.66	107.00	102.66	108.75	7.33	5.66	8.33	8.33	7.41
Syrian–4 × Yousef–1	115.66	112.66	115.66	113.33	114.33	6.66	7.66	6.33	6.00	6.66
Syrian–4 × Haurani	111.33	105.33	114.66	114.33	111.41	4.33	2.33	3.66	3.00	3.33
Duma–1 × Sham–7	120.00	116.33	105.66	103.00	111.25	4.33	4.66	5.33	5.33	4.91
Duma–1 × Yousef–1	117.66	114.00	112.00	120.33	116.00	7.00	5.66	7.00	6.66	6.58
Duma–1 × Haurani	112.33	107.66	112.33	111.33	110.91	7.66	7.33	7.66	6.66	7.33
Sham–7 × Yousef–1	119.66	115.66	117.33	116.33	117.25	5.66	7.00	8.00	7.33	7.00
Sham–7 × Haurani	113.66	114.00	109.33	109.33	111.58	7.66	7.33	8.00	8.33	7.83
Yousef–1 × Haurani	114.66	109.66	110.66	109.66	111.16	5.33	4.33	5.66	5.33	5.16
Means	113.11	109.35	113.00	111.91	-	6.06	5.48	6.75	6.44	-

E1 = Early sowing at Sumel - Duhok University, E2 = Late sowing at Sumel - Duhok University, E3 = Early sowing at Amedi Duhok city, E4 = Late sowing at Amedi - Duhok city

Table 6. Mean performance of durum wheat genotypes for grains per spike and grain yield per plant across environments.

Genotypes	Grains spike^{-1}					Grain yield plant^{-1}				
	Sumel		Amedi		Means	Sumel		Amedi		Means
	E1	E2	E3	E4		E1	E2	E3	E4	
Syrian–4	39.66	33.33	59.33	55.66	47.00	6.29	4.60	20.60	13.40	11.22
Duma–1	47.00	42.66	37.00	33.66	40.08	9.50	6.48	11.27	7.30	8.64
Sham–7	53.33	51.33	51.00	50.33	51.50	15.58	12.21	17.41	17.53	15.68
Yousef–1	43.00	42.33	47.00	42.66	43.75	10.93	10.13	20.26	12.86	13.55
Haurani	53.33	49.33	50.33	49.33	50.58	19.06	17.63	19.83	21.56	19.52
Syrian–4 × Duma–1	32.00	29.66	37.66	32.00	32.83	9.01	6.81	14.06	10.88	10.19
Syrian–4 × Sham–7	50.00	46.66	52.00	48.66	49.33	16.58	11.56	19.70	16.94	16.20
Syrian–4 × Yousef–1	54.33	49.00	54.66	49.33	51.83	16.60	13.58	17.96	14.86	15.75
Syrian–4 × Haurani	56.33	50.66	56.66	53.66	54.33	13.80	6.48	11.76	8.46	10.13
Duma–1 × Sham–7	36.00	36.66	39.33	34.33	36.58	8.51	9.50	11.33	9.03	9.59
Duma–1 × Yousef–1	49.33	50.66	51.66	50.00	50.41	15.76	12.97	17.21	15.73	15.42
Duma–1 × Haurani	56.00	56.66	60.66	48.66	55.50	18.12	16.33	18.49	12.19	16.28
Sham–7 × Yousef–1	48.00	50.66	51.33	45.66	48.91	14.03	17.72	21.16	16.70	17.40
Sham–7 × Haurani	53.33	53.33	54.33	54.66	53.91	23.54	18.41	19.30	20.55	20.45
Yousef–1 × Haurani	54.33	48.00	59.33	55.66	54.33	15.84	11.06	19.73	15.08	15.43
Means	48.40	46.06	50.82	46.95		15.54	11.70	17.34	14.20	

E1 = Early sowing at Sumel - Duhok University, E2 = Late sowing at Sumel - Duhok University, E3 = Early sowing at Amedi Duhok city, E4 = Late sowing at Amedi - Duhok city

Grains per spike ranged from 32.83 to 55.50, 46.06 to 50.84, and 29.66 to 60.66 among the parental cultivars, environments and genotype by environment interaction, respectively (Table 6). In cultivar means, the highest number of seeds per spike was observed for F_1 hybrid Duma–1 × Haurani (55.50), followed by same number of grains (54.33) obtained by F_1 populations Syrian–4 × Haurani and Yousef–1 × Haurani. Minimum number of grains per spike was recorded for F_1 hybrid Syrian–4 × Duma–1 (32.83). In environment means over genotypes, maximum grains per spike were recorded with early sowing in E–3 (50.82), followed by E–1 (48.40). In genotype × environment interaction means, maximum grains per spike were recorded for F_1 hybrid Duma–1 × Haurani with E–3 (60.66), E–2 (56.66) and E–1 (50.66) and Syrian–4 × Haurani with E–3 (56.66). However, minimum grains per spike were recorded for F_1 hybrid Syrian–4 × Duma–1 with E–2 (29.66), followed by same genotype in E–1 and E–2 with equal number of grains per spike (32.00).

For grain yield, on an average the genotypes ranged from 8.64 to 20.45 g, environments varied from 11.70 to 17.34 g, whereas genotype by environment interaction effects ranged from 4.60 to 23.54 g (Table 6). The F_1 hybrid Sham–7 × Haurani showed maximum grain yield (20.45 g), followed by cultivar Haurani (19.52 g). However, least grain yield was noted for parental genotype Duma–1 (8.64 g) and F_1 hybrid Duma–1 × Sham–7 (9.59 g). In environment means over genotypes, highest seed yield was recorded with early sowing at both locations i.e., E–3 (17.34 g) and E–1 (15.54 g). In genotype by environment interactions, highest grain yield was observed for F_1 hybrid Sham–7 × Haurani with E–1 (23.54 g), followed by cultivar Haurani (21.56 g) and hybrid Sham–7 × Yousef–1 with E–3 (21.16 g). However, in G x E interactions the minimum grain yield was observed for parental genotype Syrian–4 with E–2 (4.60 g) and E–1 (6.29 g). Earlier studies revealed that F_1 hybrids with increased spike length and spikelets were found more productive and also have greater grain yield than their parental genotypes in wheat (Afridi, 2016; Afridi *et al*., 2017; Ali *et al*.,2018). Seed index is an important yield component which has direct positive impact on grain yield and genotypes with maximum 1000-grain weight significantly enhanced the grain yield (Mandal and Madhuri, 2016; Murugan and Kannan, 2017). Earlier studies about combining ability revealed similar pattern of significance and inheritance for yield variables in wheat (Tabassum and Prasad., 2017; Parveen *et al*., 2019).

General combining ability effects: For days to flowering, the GCA effects among parental genotypes ranged from -2.89 to 2.50 (Table 7). Two genotypes i.e., Sham–7 and Haurani showed negative and desirable GCA effects while three genotypes Syrian–4, Duma–1 and Yousef–1 revealed positive GCA effects. Significant (p≤0.01) negative GCA effects were observed in parental genotype Sham–7 (-2.89), followed by Haurani (-0.97). However, significant (p≤0.01) positive GCA effects were observed in parental genotype Duma–1 (2.50), followed by Yousef–1 (1.19) while significant (p≤0.05) by Syrian–4 (0.69). Overall in parental genotypes, the highest negative and desirable GCA effects were recorded in parental cultivars Sham–7 and Yousef–1, and were identified as best general combiners for earliness.

For plant height, the GCA values among parental cultivars varied from -4.42 to 3.75 (Table 7). Two cultivars i.e., Syrian–4 and Haurani revealed negative and desirable GCA values while the remaining three genotypes i.e., Duma–1, Sham–7, and Yousef–1 enunciated positive GCA values. The utmost and significant (p≤0.01) negative GCA estimates were attained in genotype Syrian–4 (-4.42), followed by Haurani (-1.92). However, the highest and significant (p≤0.01) positive GCA values were exhibited by cultivars i.e., Duma–1 (3.75), Sham–7 (2.39), and Yousef–1 (1.20). Overall, the highest negative GCA values were recorded in parental genotypes Syrian–4 and Duma–1 and were believed to be the best general combiners for the said variable.

For biological yield, the genotypes GCA values varied from -5.16 to 3.15 (Table 7). Three lines i.e., Sham–7, Haurani, and Yousef–1 were recorded with positive GCA effects while the other two parental cultivars i.e., Syrian–4 and Duma–1 manifested negative GCA values. The significant (p≤0.01) and maximum positive GCA values were owned by genotypes Sham–7 (3.15), Haurani (2.38), and Yousef–1 (1.20). However, the utmost and significant (p≤0.01) negative GCA estimates were attained by parental genotypes Syrian–4 (-5.16) and Duma–1 (-1.57). Overall, significant positive GCA estimations were achieved by parental cultivars Sham–7, and Haurani, and believed to be prominent general genotypes and to use in future breeding for improving the biological yield.

For spikes per plant, among cultivars the GCA effects ranged in between -0.60 and 0.48 (Table 7). Three genotypes viz., Sham–7, Yousef–1, and Haurani showed positive GCA effects while the other two parental cultivars i.e., Syrian–4 and Duma–1 showed negative GCA effects for spikes per plant. Significant (p≤0.01) positive GCA effects were observed in cultivars Sham–7 (0.48), Haurani (0.39), and Yousef–1 (0.28). However, maximum and significant (p≤0.01) negative GCA effects were recorded in two genotypes Duma–1 (-0.60) and Syrian–4 (-0.54). Overall, among parental genotypes, the highest and desirable GCA effects were recorded in genotypes Sham–7 and Haurani, followed by Yousef–1 and were identified as best general combiners for spikes per plant and spike traits.

Table 7. Estimation of GCA and SCA effects among parental genotypes and F_1 hybrids for various traits.

Parental genotypes & F_1 populations	Days 50% flowering	Plant height	Biological yield plant^{-1}	Spikes plant $^{-1}$	Grains spike^{-1}	Grain yield plant^{-1}	Seed index	Harvest index
	GCA effects in parental genotypes							
Syrian–4	0.690*	- 4.419**	- 5.160**	- 0.542**	- 0.861**	- 1.920**	- 1.130**	- 17.136
Duma–1	2.502**	3.745**	- 1.569**	- 0.602**	- 4.695**	- 2.775**	- 0.427	- 21.414
Sham–7	-2.890**	2.394**	3.151**	0.480**	0.483**	1.688**	0.426	-16.887
Yousef–1	1.192**	1.203**	1.202**	0.278**	0.661**	0.415**	- 0.027**	26.684
Haurani	-0.973**	- 1.924**	2.375**	0.385**	4.411**	2.592	1.159*	28.753
	SCA effects F_1 populations							
Syrian–4 × Duma–1	0.400*	- 1.182**	- 9.574**	1.039**	- 9.670**	0.190	1.218**	23.489
Syrian–4 × Sham–7	-0.539 *	1.709**	11.129**	1.289**	1.650**	1.728	- 2.214**	11.103
Syrian–4 × Yousef–1	0.960 **	4.691**	4.898**	0.742**	3.972**	2.557*	4.398	- 27.065
Syrian–4 × Haurani	- 0.305	- 5.091**	- 6.489**	- 2.884**	3.384**	- 4.860**	1.188*	- 20.868
Duma–1 × Sham–7	- 0.373	11.203**	6.595**	- 1.150**	- 7.265**	- 4.019**	5.794**	2.919
Duma–1 × Yousef–1	2.793 **	- 2.580**	6.707**	0.718**	6.389**	3.080*	- 0.213	- 28.043
Duma–1 × Haurani	- 2.722 **	- 3.555**	3.378**	0.376*	9.134**	1.259	- 7.693**	- 14.494
Sham–7 × Yousef–1	6.936 **	0.153	0.063	0.051	- 0.289	0.602	3.587**	- 25.811
Sham–7 × Haurani	- 1.293**	- 6.046**	- 8.575**	0.293	3.432**	4.080**	- 4.792**	- 6.800
Yousef–1 × Haurani	- 5.876 **	- 2.317**	- 6.855 **	- 1.599*	-4.436**	- 4.256**	- 0.900	154.59*

*, ** Significant at p0.05 and p0.01, respectively

For grains per spike, the GCA effects among parental genotypes ranged from -4.70 to 4.41 (Table 7). Three genotypes i.e., Sham–7, Yousef–1, and Haurani showed positive GCA effects while the other two cultivars (Syrian–4 and Duma–1) revealed negative GCA effects. Significant ($p \leq 0.01$) positive GCA effects were observed in genotypes Haurani (4.41), Sham–7 (0.48), and Yousef–1 (0.66). However, the highest and significant ($p \leq 0.01$) negative GCA effects were noted in parental cultivars i.e., Duma–1 (-4.70) and Syrian–4 (-0.86). Overall, in parental genotypes the desirable GCA effects were observed in parental cultivars Haurani and Sham–7, followed by Yousef–1, and were considered as best general combiners for grains per spike.

For seed index, among parental cultivars the GCA values varied from -1.13 to 1.16 (Table 7). Two genotypes i.e., Sham–7 and Haurani showed positive GCA estimates while the remaining three parental cultivars (Syrian–4, Duma–1, and Yousef–1) exhibited negative GCA values. The highest and significant ($p \leq 0.05$) positive GCA values were recorded in cultivar (1.16) and nonsignificant positive GCA effects were noted genotype Sham–7 (0.43) for seed index. However, the lowest and significant ($p \leq 0.01$) negative GCA values were attained by cultivars Syrian–4 (-1.13) and Yousef–1 (-0.03), and nonsignificant negative by genotype Duma–1 (-0.43). Overall, the parental genotypes Haurani and Sham–7 showed the highest positive GCA values, and were deemed as best general combiners for seed index.

For grain yield per plant, the genotypes GCA effects varied from -2.78 to 2.59 (Table 7). Three genotypes i.e., Sham–7, Yousef–1, and Haurani exhibited positive GCA effects while remaining two cultivars (Syrian–4 and Duma–1) showed negative GCA effects. Significant ($p \leq 0.01$) positive GCA effects were observed in genotypes Sham–7 (1.69) and Yousef–1 (0.42) and nonsignificant positive in Haurani (2.59). However, maximum negative GCA effects were observed in two cultivars Duma–1 (-2.78) and Syrian–4 (-1.9). Overall, in parental genotypes, the maximum positive and desirable GCA effects were recorded in genotypes Sham–7, and Yousef–1, followed by Haurani, and were identified as best general combiners for grain yield per plant.

In case of harvest index, the genotypes GCA values varied from -21.41 to 28.75 (Table 7). Two parental genotypes i.e., Yousef–1 and Haurani exhibited positive GCA values whereas the three other cultivars i.e., Syrian–4, Duma–1, and Sham–7 revealed the negative GCA values. The highest positive GCA values were attained by cultivars Haurani (28.75) and Yousef–1 (26.68) while the utmost negative GCA values were recorded in three genotypes i.e., Duma–1 (-21.41), Syrian–4 (-17.14), and Sham–7 (-16.89). Overall, the highest positive and desirable GCA estimates were owned by parental genotype Haurani, followed by Yousef–1, and were regarded as best general combiners for harvest index.

Based on GCA effects, the results indicated that parental lines i.e., Sham–7 and Yousef–1 proved to be the best general combiners for biological yield plant^{-1}, spikes plant^{-1}, grains spike^{-1} and grain yield plant^{-1}. However, the former genotype Sham–7 also revealed negative and desirable GCA effects for days to 50% flowering indicating decreased number of days. Parental genotype Haurani recorded with highly significant but negative GCA value for biological yield, spikes plant^{-1}, grains spike^{-1} and non-significant for grain yield plant^{-1}, harvest index and seed index). Parental genotypes Syrian–4 and Duma–1 exhibited significant negative GCA values for all the traits except days to 50% flowering and plant height for which owned positive values. Results concluded that parental genotypes Sham–7 and Haurani were found as the best general combiners for the studied characters. The crosses involving these general combiners produced promising hybrids with best performance for majority of the traits. Wheat genotypes with minimum days to flowering and maturity were more preferable from farmer and end user point of view (Akram *et al*., 2009; Akram *et al*.,2011;Afridi *et al*., 2018). The F_1 populations with desirable GCA and SCA effects were suggested as best general and specific combiners for yield related traits in wheat (Araus and Cairns, 2016). Past studies identified the genotypes with significant negative GCA effects for earliness traits and significant positive GCA values for yield related traits, and recognized the best general combiners for various traits in durum and bread wheat over varied environments (Kruvadi, 1991; Ismail, 2015; Jains and Sastry, 2012; Rizkalla *et al*., 2012; Tiwari *et al*., 2017).

Specific combining ability effects: For days to 50% flowering, the specific combining ability values among the F_1 hybrids ranged from -5.88 to 6.94 (Table 7). More than half of the F_1 populations revealed negative and desirable SCA values ranging from -0.30 to -5.88 while the other half revealed positive SCA values (0.40 to 6.94). Highly significant ($p \leq 0.01$) and negative SCA values were owned by F_1 hybrids Yousef–1 × Haurani (-5.88), Duma–1 × Haurani (-2.72), Sham–7 × Haurani (-1.29), and Syrian–4 × Sham–7 (-0.54). However, the hybrids Sham–7 × 4, Duma–1 × Yousef–1, and Syrian–4 × Yousef–1 revealed significant ($p \leq 0.01$) and maximum positive SCA values ranging from 0.96 to 6.94 for days to 50% flowering. Genotypes with significant negative SCA values are preferred to be utilized in the development of early maturing genotypes which can escape from the late-season biotic and abiotic stresses. Therefore, the F_1 populations i.e., Yousef–1 × Haurani, Duma–1 × Haurani, Sham–7 × Haurani, and Syrian–4 × Sham–7 were identified as dependable specific combinations for future breeding. Results further depicted that high × low, low × high and high × high GCA parents were engaged in the presentation of these promising F_1 populations.

For plant height, the SCA estimates among F_1 populations varied from -6.05 to 11.20 (Table 7). Six F_1 populations were found with negative SCA values ranging from -1.18 to -6.05 while the other four F_1 hybrids showed positive SCA values (0.15 to 11.20). The F_1 populations i.e., Sham–7 × Haurani (-6.05), Syrian–4 × Haurani (-5.09), and Duma–1 × Haurani (-3.56) possessed utmost and significant ($p \leq 0.01$) negative SCA values, followed by three other F_1 hybrids. However, the F_1 populations i.e., Duma–1 × Sham–7 (11.20) and Syrian–4 × Yousef–1 (4.69), and Syrian–4 × Sham–7 (1.71) revealed maximum and significant ($p \leq 0.01$) positive SCA values. In wheat, the negative specific combining ability is favored for plant height because the short stature genotypes have fewer chances of lodging and more responsive to fertilizers. Therefore, the F_1 populations Sham–7 × Haurani, Syrian–4 × Haurani, and Duma–1 × Haurani were considered as best specific combiners for plant height which can be utilized in breeding as dwarfing gene sources. Present investigations highlighted that low × high and high × high general combiners were more important in these F_1 populations with desirable SCA and paramount mean performance.

For biological yield per plant, the SCA effects in F_1 populations ranged from -9.57 to 11.13 (Table 7). Six F_1 hybrids showed positive and desirable SCA effects (0.06 to 11.13) while the four other hybrids showed negative SCA effects (-6.60 to -9.57). The F_1 populations Syrian–4 × Sham–7 (11.13), Duma–1 × Yousef–1 (6.71), Duma–1 × Sham–7 (6.60), and Syrian–4 × Yousef–1 (4.90) showed significant ($p \leq 0.01$) positive SCA effects, and were identified as best specific combiners for biological yield. However, F_1 hybrids Syrian–4 × Duma–1, Sham–7 × Haurani, Yousef–1 × Haurani, and Syrian–4 × Haurani revealed significant negative SCA effects ranging from -6.49 to -9.57. Results further revealed that low × high, and high × high general combiners were occupied in the F_1 populations with promising SCA.

For spikes per plant, the SCA effects among F_1 populations ranged from -2.88 to 1.29 (Table 7). Seven F_1 hybrids revealed positive and desirable SCA effects ranging from 0.05 to 1.29, while three other populations showed negative SCA effects (-1.15 to -2.88). Significant ($p \leq 0.01$) positive SCA effects were observed in F_1 populations Syrian–4 × Sham–7 (1.29), Syrian–4 × Yousef–1 (0.74), Duma–1 × Yousef–1 (0.72), followed by Duma–1 × Haurani (0.38), and were considered as best specific cross combinations for spikes per plant. However, the maximum and significant ($p \leq 0.01$) negative SCA effects were found in F_1 populations Syrian–4 × Haurani, Yousef–1 × Haurani, and Duma–1 × Sham–7 ranging from -1.15 to -2.88. Results further revealed that low × low and low × high general combiners were engaged in the F_1 populations with promising SCA for spikes per plant.

For grains per spike, in F_1 populations the SCA effects ranged from -9.67 to 9.13 (Table 7). Six out of ten F_1 populations revealed positive and desirable SCA effects ranging from 1.65 to 9.13 while the other four hybrids exhibited negative SCA effects (-0.29 to -9.67) for grains per spike. Significant ($p \leq 0.01$) positive SCA effects were observed in F_1 populations Duma–1 × Haurani (9.13), Duma–1 × Yousef–1 (6.39), Syrian–4 × Yousef–1 (3.97), Sham–7 × Haurani (3.43), and Syrian–4 × Haurani (3.38). However, maximum and significant ($p \leq 0.01$) negative SCA effects were observed in F_1 populations Syrian–4 × Duma–1, Duma–1 × Sham–7, and Yousef–1 × Haurani ranged from -4.44 to -9.67. Grains per spike are significantly positively correlated with grain yield, and therefore, genotypes with positive combining ability effects are preferred for further selection. Therefore, the F_1 populations Duma–1 × Haurani, Duma–1 × Yousef–1, Syrian–4 × Yousef–1, and Sham–7 × Haurani were considered as best specific combiners for grains per spike. Results further revealed that low × high and high × high general combiners were involved in the management of best F_1 populations with promising SCA for the said trait.

For seed index, among F_1 populations the SCA effects ranged from -7.69 to 5.79 (Table 7). Half of the F_1 populations showed positive SCA effects ranging from 1.18 to 5.79, while the other half showed negative SCA effects (-0.90 to -7.69). Significant ($p \leq 0.01$) positive SCA effects were recorded in F_1 populations i.e., Duma–1 × Sham–7 (5.79), Duma–1 × Haurani (3.59), and Syrian–4 × Duma–1 (1.22). However, maximum and significant ($p \leq 0.01$) negative SCA effects were found in F_1 populations i.e., Duma–1 × Haurani (-7.69), Sham–7 × Haurani (-4.79), and Syrian–4 × Sham–7 (-2.21). The positive combining ability is more important for seed index because of its significant positive association with grain yield and it can be used as selection criteria in wheat breeding program. Present results revealed that hybrids i.e., Duma–1 × Sham–7, Duma–1 × Haurani, and Syrian–4 × Duma–1 could be used as best specific combiners for improvement in seed index in future wheat breeding program. Results further revealed that low × high and high × low general combiners were involved in the F_1 populations with promising SCA for the said trait.

For grain yield per plant, among F_1 populations the SCA effects ranged from -4.86 to 4.08 (Table 7). Seven F_1 populations were found with positive and desirable SCA effects ranging from 0.19 to 4.08 while the three hybrid populations exhibited negative SCA effects (-4.02 to -4.86). Significant ($p \leq 0.01$) positive SCA effects were found in F_1 population Sham–7 × Haurani (4.08), followed by two other F_1 hybrids Duma–1 × Yousef–1 (3.08), and Syrian–4 × Yousef–1 (2.56). However, maximum negative SCA effects were observed in F_1 populations Syrian–4 × Haurani, Duma–1 × Sham–7, and Yousef–1 × Haurani ranging from -4.02 to -4.86. These promising genotypes could be further studied and utilized as best specific combiners for improving the grain yield in wheat. Results further revealed that low × high and high × high general combiners were implied in the F_1 populations with promising SCA.

In F_1 populations, the SCA values varied from -28.04 to 154.59 for harvest index (Table 7). Four F_1 populations recorded with positive SCA values ranging from 2.92 to 154.59, while the six hybrids showed negative SCA estimates (-6.80 to -28.04) for harvest index. The highest positive and significant ($p \leq 0.01$) SCA values revealed by F_1 population Yousef–1 × Haurani (154.59), persuaded by three other F_1 populations with positive SCA effects i.e., Syrian–4 × Duma–1, Syrian–4 × Sham–7, and Duma–1 × Sham–7 ranging from 2.92 to 23.49 for harvest index. The highest negative SCA values were noted in F_1 populations i.e., Duma–1 × Yousef–1, Syrian–4 × Yousef–1, Sham–7 × Yousef–1, and Syrian–4 × Haurani ranging from -20.86 to -28.04. Results further indicated that F_1 populations i.e., Yousef–1 × Haurani, Syrian–4 × Duma–1, Syrian–4 × Sham–7, and Duma–1 × Sham–7 were recognized as most promising genotypes which can be employed in future breeding for improvement in harvest index and eventually the grain yield. Present findings also confirmed that high × high and low × low GCA parents were occupied in presentation of capable F_1 populations with promising SCA and best mean performance.

In conclusion, the hybrid Syrian–4 × Sham–7 revealed desirable SCA effects for days to flowering, biological yields, spikes plant^{-1} and grains spike^{-1}, followed by hybrid Sham–7 × Haurani for days to flowering, plant height, grains spike^{-1} and grain yield plant^{-1}. The hybrid Yousef–1 × Haurani has promising SCA for flowering, plant height, seed index and harvest index. The cross Duma–1 × Haurani had a good SCA for flowering, plant height, biological yield, grain spike^{-1}. Past studies revealed that significant mean squares were reported due to GCA and SCA with greater genetic variability for earliness and yield traits in wheat (Akinci, 2009; Jains & Sastry, 2012). In the past combining ability studies of wheat the best specific combinations were identified based on significant and desirable SCA effects for various earliness and yield related traits in *T. aestivum* L. and *T. durum Desf.* (Joshi *et al*., 2004; Rizkalla *et al*., 2012; Ismail, 2015; Afridi, 2016; Yousif & Al-Hayali, 2018).

Stability analysis

The stability analysis regarding regression coefficient (Bi) and variance deviation from regression (S^2d) are provided in Tables 8 and 9. For days to 50% flowering, the parental cultivars (except Haurani) showed the significant values for Bi and S^2d, and the Bi value was more than unity indicated as unstable parental genotypes across different environments, while parental genotype Haurani responded well to good environment (Table 8). Among F_1 hybrids for days 50% flowering, the hybrids Syrian–4 × Yousef–1 and Duma-1 × Haurani had greatest stability due to non-significant value of Bi, S^2d with high mean values (114.3, and 110.9), respectively, However, F_1 hybrids Syrian–4 × Sham–7, Duma-1 × Sham–7, and Sham–7 × Haurani were found as unstable and sensitive across environment for days to 50% flowering.

According to plant height, the parental cultivars Syrian–4 and Duma–1 revealed significant values for Bi and less than unity with non-significant value of S^2d, revealed that these parental cultivars responded only to good environments (Table 8). Both stability parameters (Bi and S^2d) were non-significant for parental cultivar Yousef–1 indicating the high stability value with maximum mean (91.32 cm) and showed better response to various environments. However, parental genotype Haurani was found unstable across various environments because of the significant S^2d and non-significant value of Bi for plant height. Among F_1 hybrids, hybrid Duma-1 × Haurani exhibited high stability and best response to various environmental conditions due to non-significant values of stability parameters (Bi, S^2d) with high mean value (91.05 cm) for plant height. Hybrids Syrian–4 × Sham–7, Syrian–4 × Haurani, Duma-1 × Yousef–1, and Yousef–1 × Haurani were found with unstable response to the best environments.

Parental cultivars Syrian–4 and Yousef–1 exhibited significant values for Bi and S^2d, and the Bi value was more than unity referring as unstable cultivars to various environments for biological yield plant^{-1} (Table 8). Cultivars Duma–1 and Sham–7 observed with significant value of regression coefficient Bi and also less than unity while S^2d was non-significant revealing their response to good environments. Parental genotype Haurani had greater stability due to non-significant value of Bi and S^2d with mean value (45.23 g) for biological yield plant^{-1}.

For spikes per plant, all the five parental genotypes responded well to good environment due to non-significant values of S^2d with significant value of Bi (Table 8). Among F_1 hybrids concerning spikes plant^{-1}, the hybrids Duma–1 × Sham–7 and Sham–7 × Haurani showed high stability with highest mean values (4.91, 7.83), respectively indicating their better response to various environmental conditions. However, hybrids Syrian–4 × Yousef–1 and Duma–1 × Haurani revealed unstable response to unsuitable environmental conditions due to negative value of Bi with non-significant value of S^2d.

Parental cultivars Sham–7 and Yousef–1 exhibited high stability for grains spike^{-1} due to non-significant values of Bi and S^2d with high mean values (51.50, 43.73), respectively indicating that these genotypes had good response to different environments (Table 9). The F_1 hybrids i.e., Syrian–4 × Sham–7, Duma–1 × Sham–7, Duma–1 × Yousef–1, and Sham–7 × Haurani showed high stability by having nonsignificant values of Bi, S^2d with high mean value (49.33, 36.58, 50.41, and 53.91), respectively and exhibited best response to various environments for grains per spike. However, hybrids Syrian–4 × Duma–1 and Syrian–4 × Yousef–1 responded to good environments only and found unstable across various environments for grains per spike.

According to grain yield plant^{-1}, parental cultivars Sham–7 and Haurani demonstrated high stability due to non-significant values of Bi, S^2d with highest mean values (15.68 and 19.52 g), respectively referring their best response to various environments (Table 9). The F_1 hybrids Syrian–4 × Yousef–1, Duma–1 × Sham–7, Duma–1 × Yousef–1 and Duma–1 × Haurani had high stability and better response to different environments due to nonsignificant values of Bi and S^2d with high mean values (15.25, 9.59, 15.42, and 16.28 g), respectively for grain yield. However, F_1 hybrids Sham–7 × Yousef–1, Sham–7 × Haurani and Yousef–1 × Haurani were identified with unstable response to good environments for grain yield.

For seed index, the parental cultivar Yousef–1 revealed high stability and good response to various environmental conditions due to non-significant values of Bi and S^2d (Table 9). Among F_1 hybrids, the F_1 populations i.e., Syrian–4 × Yousef–1, Duma–1 × Haurani, and Sham–7 × Yousef–1 had high stability with high mean values (49.90, 38.8, and 50.65 g), respectively referring to their best response to different environmental conditions for seed index. However, F_1 hybrids viz., Duma–1 × Sham–7 and Sham–7 × Haurani were recognized as unstable hybrids for seed index due to non-significant value of S^2d with negative value of Bi which had adaptability to unsuitable environments.

In case of harvest index, parental cultivars Syrian–4 and Duma–1 responded well to best environments as compared to parental genotype Yousef–1 by having significant values of Bi and S^2d that certified as unstable parent across various environment (Table 9). The F_1 hybrids i.e., Duma–1 × Sham–7 and Duma–1 × Yousef–1 were found stable due to non-significant values of Bi and S^2d indicating best response across environments.

Table 8. Stability parameters for the studied traits in durum wheat across environments.

Genotypes	Days to 50% flowering			Plant height (cm)			Biological yield plant^{-1} (g)			Spikes plant^{-1}		
	Bi	S^2d	Means	Bi	S^2d	Means	Bi	S^2d	Means	Bi	S^2d	Means
Syrian–4	1.501248*	22.84654**	111.83	2.432522*	0.680155	77.94	4.130163*	256.7435**	31.47	2.439087*	0.113847	4.91
Duma–1	2.112353*	30.94368**	116.91	1.870966*	3.134359	92.51	0.821321*	1.058129	31.51	0.806073*	0.531947	4.00
Sham–7	1.18044	2.987609**	101.5	1.489185*	8.571468*	86.67	0.752903*	4.58537	38.85	1.188411*	0.296671	6.66
Yousef–1	2.491002*	103.3032**	109.58	0.492986	5.65832	91.36	2.464516*	118.8906**	39.35	1.753504*	0.259273	6.83
Haurani	1.21776*	0.418615	110.08	0.139906	12.07241**	88.07	0.033063	0.324799	45.23	0.710601*	0.299905	8.08
Syrian–4 × Duma–1	1.780013*	21.18973**	115.08	2.768015*	41.53729**	86.05	1.313919*	20.52469**	25.45	2.131579*	0.033333	6.08
Syrian–4 × Sham–7	-0.07909	78.68111**	108.75	0.686903*	1.572466	87.59	0.652142	1.983932	50.87	2.231314*	0.312139	7.41
Syrian–4 × Yousef–1	0.744585	1.227733	114.33	-0.08167	34.57108**	89.38	-0.20572	51.46286**	42.7	-1.1883	0.296909	6.66
Syrian–4 × Haurani	1.920667*	15.45738**	111.41	2.307436*	1.107666	76.6	0.566025	317.7152**	32.44	0.764564*	1.701172*	3.33
Duma–1 × Sham–7	-1.11624	187.9169**	111.25	-1.2089	49.89122**	106.25	1.035448*	1.330526	49.93	0.660677	0.360927	4.91
Duma–1 × Yousef–1	1.511327*	11.40103**	118.5	0.824722*	3.709155	91.27	0.604775	0.202555	48.1	0.951582*	0.387313	6.58
Duma–1 × Haurani	1.134312	0.58017	110.91	0.087409	0.088124	91.05	1.396174*	2.55197	53.05	-0.02491	0.666114	7.33
Sham–7 × Yousef–1	0.643976	4.627369**	117.25	2.061021*	18.22969**	92.65	1.346982*	5.3997	46.17	0.91815*	2.137475**	7.00
Sham–7 × Haurani	-0.69246	15.02482**	111.58	-0.28033	0.615155	90.35	0.619758	7.115926**	47.92	0.664828	0.161578	7.83
Yousef–1 × Haurani	0.649696	12.35142**	111.16	1.409917*	1.236862	85.81	-0.53135	20.49048**	43.29	0.997242*	0.113551	5.16
S.E. (B)	1.241	-	-	0.564	-	-	0.707	-	-	0.707	-	-
Overall means	-	-	112.01	-	-	88.90	-	-	41.76	-	-	6.18

Table 9. Stability parameters for the studied traits in durum wheat across environments.

Genotypes	Grains spike^{-1}			Grain yield plant^{-1} (g)			Seed index (g)			Harvest index (%)		
	Bi	S^2d	Means	Bi	S^2d	Means	Bi	S^2d	Means	Bi	S^2d	Means
Syrian–4	3.805987*	280.3546	47	2.337876*	69.62769	11.24	2.344299*	31.28813	39.81	2.157825*	1.157972	33.64
Duma–1	-0.32675	103.813**	40.08	0.87559	1.157304	8.63	2.595386*	23.05177	46.7	1.133254*	10.80733	27.87
Sham–7	0.066699	4.942438	51.5	0.825386	6.930524	15.68	1.357465*	10.45526	45.14	0.785844*	28.21586**	39.38
Yousef–1	0.984848	1.756027	43.75	1.542105*	23.79049	13.55	0.233054	0.420616	39.73	1.27812*	42.04489**	34.27
Haurani	0.318171	9.440186**	50.58	0.299985	6.524475	19.52	1.430976*	12.81209	48.61	0.295588	35.38425**	43.06
Syrian–4 × Duma–1	1.568944*	2.928222	32.83	1.122952*	6.897688	10.19	-1.13204	43.17577**	46.32	1.639059*	7.592439	39.51
Syrian–4 × Sham–7	1.054547	0.722456	49.33	1.363353*	2.902653	16.19	0.947811*	5.292548	43.74	1.341337*	15.23117	31.65
Syrian–4 × Yousef–1	1.320479*	5.994914	51.83	0.796361	0.331223	15.75	0.525799	4.905913	49.9	1.356432*	7.723108	37.05
Syrian–4 × Haurani	1.172488*	5.546224	54.33	1.13245*	10.52061	10.12	3.612773*	5.161151	52.47	1.658331*	5.138466	31.98
Duma–1 × Sham–7	0.750998	5.674845	36.58	0.250371	3.460946	9.59	-0.69624	15.19073	52.45	0.239975	15.48507	19.19
Duma–1 × Yousef–1	0.235442	2.254995	50.41	*0.719904	0.605258	15.42	1.289986*	2.792773	45.99	0.625906	6.192057	31.8
Duma–1 × Haurani	1.519711*	45.11792**	55.5	0.546993	19.91353	16.28	0.09743	12.14463	38.8	-0.06133	113.0644**	31.29
Sham–7 × Yousef–1	0.499651	17.07541**	48.91	0.382517	23.63851**	17.4	0.440369	1.401246	50.65	0.202953	137.3596**	38.56
Sham–7 × Haurani	0.099469	1.288649	53.91	1.329844*	408.8122	25.45	-0.55351	3.742477	45.83	-0.16355	11.72874	41.05
Yousef–1 × Haurani	1.929329*	18.72724**	54.33	1.474262*	1.006571	15.43	2.505907*	13.37378	53.76	2.510116*	11.54352	35.95
S.E. (B)	1.141	-	-	1.074	-	-	0.707	-	-	0.707	-	-
Overall means	-	-	48.05	-	-	14.70	-	-	46.66	-	-	34.42

Results further revealed that parental genotype Sham–7 was found stable for grains spike^{-1} and grain yield plant^{-1}, parental cultivars Yousef–1 for plant height, grains spike^{-1} and seed index, and Haurani for biological yield and grain yield plant^{-1}. The two parental cultivars Sham–7 and Haurani had the best stability for grain yield and its components based on stability parameters. Due to high mean values, these promising genotypes were recommended to test and improve through future breeding program, and then to cultivate in a wide range of environments.

Present results authenticated that F_1 hybrid Duma–1 × Haurani was found as stable for days to 50% flowering, plant height, grain yield plant^{-1}, and seed index, Sham–7 × Haurani for spikes plant^{-1} and grains spike, Duma–1 × Sham–7 was stable for spikes plant^{-1} , grains spike plant^{-1}, grain yield plant^{-1} and harvest index, and F_1 hybrid Duma-1 × Yousef–1 was found promising and stable for biological yield plant^{-1}, grains spike^{-1}, grain yield plant^{-1}, and harvest index.

Past findings demonstrated that stability parameters were found suitable in selecting superior cultivars with good performance, and the stable durum wheat genotypes should be recommended for cultivation in varying environments (Mohammadi and Amri, 2008; Hamam & Abdel-Sabour, 2009). In the past studies, high adaptability was reported in durum wheat genotypes across various environments with various stability parameters (Josephides, 1992). For stability the different parameters were used and obtained high stable genotypes of durum wheat across diverse environments (Bahlouli *et al*., 2005). High yielding and stable genotypes were identified in the study of durum wheat genotypes in varied environmental conditions (Oku-Yama *et al*., 2005). Linear regression coefficient showed significant influence of genotypes and environments with varied values of Bi in durum wheat (Ulker *et al*., 2006; Sharma *et al*., 2012).

Conclusion

Parental genotypes Sham–7 and Haurani were found as the best general combiners for the studied characters. The F_1 hybrids i.e., Syrian–4 × Sham–7, Sham–7 × Haurani and Duma–1 × Haurani, involving these general combiners produced promising hybrids with best performance for majority of the traits. According to stability parameters, the parental genotypes Sham–7, and Haurani, and F_1 hybrids Duma–1 × Sham–7, Duma–1 × Yousef–1, Duma–1 × Haurani, and Sham–7 × Haurani were found as the most stable genotypes indicating wide adaptability across varied environmental conditions.

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References

Abro, S.A., A.W. Baloch, M. Baloch, G.A. Baloch, T.A. Baloch, A.A. Soomro, Q. Jogi and M. Ali. 2016. Line × tester analysis for estimating combining ability in F_1 hybrids of bread wheat. *Pure Appl. Biol. Sci*., 5(3): 647-652.

Afridi, K. 2016. Inheritance of yellow rust resistance and glutenin content in wheat. Ph.D Dissertation, Department of Plant Breeding and Genetics. The University of Agriculture, Peshawar, Pakistan.

Afridi, K., N.U. Khan, F. Mohammad, S.J.A. Shah, S. Gul, I.A. Khalil, M. Sajjad, S. Ali, I. Ali and S.M. Khan. 2017. Inheritance pattern of earliness and yield traits in half diallel crosses of spring wheat. *Can. J. Plant Sci*., 97: 865-880.

Afridi, K., N.U. Khan, Z. Bibi, S. Gul, R. Gul, S. Ali, N. Ali, I.A. Khalil, F. Uddin and G. Ahmad. 2018. Assessment of genetic effects for earliness and yield traits in F_1 and F_2 half diallel populations of wheat. *Int. J. Agri. Biol*., 20: 2785-2796.

Ahmed, A.A. and A.T. Al-Naaimi. 2011. Estimation of genetic parameters and stability analysis for durum wheat entries (*T. durum* Desf.). *Mesopotamia J. Agri. Sci*., 22(1): 37-48.

Akinci, C. 2009. Heterosis and combining ability estimates in 6 x 6 half diallel cross of durum wheat (*T. durum* Desf.). *Bulg. J. Agri. Sci*., 15(3): 214-221.

Akram, Z., S.U. Ajmal, K.S. Khan, R. Qureshi and M. Zubair. 2011. Combining ability estimates of some yield and quality related traits in spring wheat (*Triticum aestivum* L.). *Pak. J. Bot*, 43(1): 221-231.

Akram, Z., S.U. Ajmal, G. Shabbir, M. Munier and N.M. Cheema. 2009. Inheritance mechanism of some yield component in bread wheat. *Pak. J. Agri. Res*., 22: 1-8.

Al-Doss, A.A., A.A. Elshafei, K.A. Moustafa, M. Saleh and M.N. Barakat. 2011. Comparative analysis of diversity based on morpho-agronomic traits and molecular markers in durum wheat under heat stress. *Afr. J. Biotechnol*., 10(19): 3671-3681.

Ali, S., N.U. Khan, S. Gul, R. Goher, I. Naz, S.A. Khan, N. Ali, M. Saeed, I. Hussain, S.M. Khan and I. Ali. 2019. Heterotic effects for yield related attributes in F_1 populations of maize. *Pak. J. Bot*., 51: 1675-1686.

Ali, S., N.U. Khan, R. Gul, I. Naz, R. Goher, N. Ali, S.A. Khan, I. Hussain, M. Saeed and M. Saeed. 2018. Genetic analysis for earliness and yield traits in maize. *Pak. J. Bot*., 50(4): 1395-1405.

Ali, I.H. and H.A. Sadallah. 2008. Genetic stability in seven varieties of durum wheat. *Zanco J*., 20(1): 85-94.

Ali, I.H. and M.A. Hussain. 2014. Genetic stability in some bread wheat cultivars. *Jord. J. Agri. Sci*., 10(2): 225-236.

Al-Zubaidy K.M.D and M.A.H. Al-Falahy. 2016. Principles and procedures of statistic and experimental designs. Higher Education Press, Duhok University, Iraq.

Araus, J.L. and J.E. Cairns. 2016. Analysis of general combing ability for yield and yield related associated traits. *Univers. J. Plant Sci*., 19(1): 52-61.

Aslam, R., M. Munawar and A. Salam. 2014. Genetic architecture of yield components accessed through line × tester analysis in wheat (*T. aestivum* L.). *Univers. J. Plant. Sci*., 2(5): 93-96.

Bahlouli, F., H. Bouzerzour, A. Benmahammed and K.L. Hassous. 2005. Selection for high yielding and risk efficient durum wheat (*T. durum* Desf.) cultivars under semi-arid conditions. *J. Agron*., 4(4): 360-365.

Becher, H. and J. Leon. 1988. Stability analysis in plant breeding. *Plant Breed*., 101: 1-23.

Dexter, J.E., R.R. Matsuo and J.E. Kruger. 1990. The spaghetti making quality of commercial durum wheat samples with variable alpha-amylase activity. *Cereal Chem*. 67(5): 405-412.

Eberhart, S.A. and W.A. Russell. 1966. Stability parameters for comparing varieties. *Crop Sci*., 6: 36-40.

El-Shazly, M.S., M.A. El-Ashry, M.M. Nachit and A.S. El-Sebae. 2000. Performance of selected durum wheat genotypes under different environmental conditions in Eastern Egypt. In: (Eds.): C. Royo, M. Nachit, N.D. Fonzo, J.L. Araus. Proceed. Durum wheat improvement in the

Mediterranean region: New challenges, Zaragoza, Spain: CIHEAM, pp. 595-600.

Fehr, W.R. 1993. Principles of cultivar developments. Mac. Millan Publications Co. New York, pp. 342.

Finlay, K.W. and G.N. Wilkinson. 1965. The analysis of adaptation in a plant-breeding program. *Aust. J. Agri. Res*., 14: 742-754.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing system. *Aust. J. Biol. Sci*., 9(4): 463-493.

Hamam, K.A. and G.A. Abdel-Sabour. 2009. Stability of wheat genotypes under different environments and their evaluation under sowing dates and nitrogen fertilizer levels. *Aust. J. Basic & Appl. Sci*., 3(1): 206-217.

Ismail, S.K.A. 2015. Heterosis combining ability analysis for yield and its components in bread wheat (*T. durum* L.). *Int. J. Curr. Microbiol. Appl. Sci*., 4(8): 1-9.

Jains, S.K. and E.V.D. Sastry. 2012. Heterosis and combining ability for grain yield and its contributing traits in bread wheat. *J. Agri. Allied Sci*., 1: 17-22.

Johansson, E. and G. Svensson. 1998. Variation in bread-making quality effects of weather parameters on protein concentration and quality in some Swedish wheat-cultivars grown during the period 1975-1966. *J. Sci. Food Agri*., 78: 109-118.

Josephides, C.M. 1992. Analysis of adaptation of barley, triticale, durum and bread wheat under Mediterranean conditions. *Euphytica*, 65(1): 1-8.

Joshi, S.K., S.N. Sharma, D.L. Singhania and R.S. Jain. 2004. Combining ability in F_1 and F_2 generation of diallel cross in hexaploid wheat (*T. aestivum* L. em Thell). *Hereditas*, 141(2): 115-121.

Karimizadeh, R. and M. Mohammadi. 2010. AMMI adjustment for rainfall lentil yield trials in Iran. *Bulg. J. Agri. Sci*., 16(1): 66-73.

Karimizadeh, R., M. Mohammadi, M.M. Sheikh, V. Bavi, T. Hosseinpour, H. Khanzadeh, H. Ghojogh and M. Armioun. 2011. Application of multivariate methods in determining grain yield stability in durum wheat genotypes in semi warm dry land areas of Iraq. *Modern Genet. J*., 6(2): 33-48.

Korkut, K.Z., O. Bilgin, I. Baser and N. Saglam. 2007. Stability of grain vitreousness in durum wheat (*T. durum* Desf.) genotypes in North-Western region of Turkey. *Turk. J. Agri. For.*, 31: 313-318.

Kruvadi, S. 1991. Diallel analysis and heterosis for yield and associated characters in durum wheat under upland conditions. *Turrialba Publ. Canada* 41(3): 335-338.

Mandal, A.B. and G. Madhuri. 2016. Combining ability analysis for morphological and yield traits in wheat (*T. aestivum* L.). *J. Plant Sci. Res.,* 3(2): 157-162.

Mather, K. and J.L. Jinks. 1982. Biometrical Genetics, 3rd edition, Chapman and Hall, London.

Mohammadi, R. and A. Amri. 2008. Comparison of parametric and non-parametric methods for selecting stable and adapted durum wheat genotypes in variable environments *Euphytica*, 159: 419-432.

Murugan, A. and R. Kannan. 2017. Heterosis and combining ability analysis for yield traits of Indian hexaploid wheat (*T. aestivum* L.). *Int. J. Recent Sci. Res*., 8(7): 18242-18246.

Oku-Yama, L.A., L.C. Federizz and J.F.B. Neto. 2005. Grain yield stability of wheat genotypes under irrigated and non-irrigated conditions. *Brazilian Arch. Biol. Technol*., 48(5): 697-704.

Parveen, N., M. Iqbal, M. Tahir, S. Aleem, R. Aslam, E. Amin, K.L. Cheema and A.S. Khan. 2019. Assessment of heritable variation and best combining genotypes for grain yield and its attributes in bread wheat. *Amer. J. Agri. Res*., 4(31): 1-9.

Rizkalla, A., B.A. Hussien, A.M.F. Al-Ansary, J.E. Nasseef and M.H.A. Hussien. 2012. Combining ability and heterosis relative to raped marker in cultivated and newly hexaploid wheat varieties. *Aust . J. Basic Appl. Sci*., 6(5): 215-224.

Sajjad, M., Khan, N. U., Gul, S., Khan, S. U., Bibi, Z., Ali, S., ... & Khan, S. A. (2020). Maize improvement through selfed progeny recurrent selection across different environments. *Pakistan Journal Of Botany*, *52*(2), 541-549.

Sharma, R.C., A.I. Morgounov, H.J. Braum, B. Akin, M. Keser, Y. Kaya, Z. Khalikulov, M.V. Ginkel, A. Yahyaoui and S. Rajaram. 2012. Yield stability analysis of winter wheat genotypes targeted to semi-arid environments in the international winter wheat improvement program. *Int. J. Plant Breed*., 6: 7-13.

Srivastava, J.P., A.B. Damania and L. Pecetti. 1988. Landraces, primitive forms and wild progenitors of macaroni wheat, *T. durum*: their use in dry land Agriculture. Proceed. 7th International Wheat Genetics Symposium. (Eds.): E.T. Miller and R.M.D. Koebner, Cambridge, England, pp. 153-158.

Tabassum, A. Kumar and B. Prasad. 2017. Study of combining ability and nature of gene action for yield and its contributing traits in bread wheat (*T. aestivum* L. em Thell). *Int. J. Curr. Microbiol. Appl. Sci*., 6(10): 3562-3573.

Tiwari, R., S. Markea and D.R. Meghwal. 2017. Combining ability estimates for spike characters in F_1 hybrids developed through diallel crosses among macaroni wheat (*T. durum* Desf.) genotypes. *J. Pharm. Phytochem*., 6(2): 237-241.

Ulker, M., F. Sonmez, V. Ciftci, N. Yilmaz and R. Apak. 2006. Adaptation and stability analysis in selected lines of wheat. *Pak. J. Bot*., 38(4): 117-1183.

Von-Buren, M. 2001. Polymorphism in two homeologous gamma-gliadin genes and the evolution of cultivated wheat. *Genet. Res. Crop Evol*. 48(2): 205-220.

Yousif, N.K. and M.A.M. Al-Hayali. 2018. Estimates of combining ability by complete diallel crosses analysis in hexapolid wheat - *T. aestivum* L. *Mesopotamia J. Agri. Sci*., 46(4): 73-84.

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