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Selection for high yield and quality in half-diallel bread wheat F_2 populations (*Triticum aestivum* L.) through heterosis and combining ability analysis

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Abstract
The study was carried out to evaluate the combining ability and heterosis of seven parents and their 21 half-diallel F_2 populations for yield and quality traits during the 2013-14 season in the randomized complete block design with three replications. Significant differences were observed among the genotypes, GCA (general combining ability) and SCA (specific combining ability) effects for all traits, except spike length. The best combiner parents were identified as Esperia and Pehlivan for grain yield, and Flamura85, Aldane and Selimiye for quality traits because of significant GCA and per se performance. The ranges of best parent heterosis were -12.71 to 8.23% for plant height, -15.46 to 8.36% for spike length, -16.62 to 24.80% for number of grains per spike, -23.61 to 36.50% for grain weight per spike, -17.13 to 8.84% for harvest index and -44.26 to 15.83 for grain yield, -17.61 to 8.38% for thousand grain weight, -18.55 to 8.44% for wet gluten content, -33.80 to 24.78% for gluten index, -20.24 to 15.23% for Zeleny sedimentation value, -15.58 to 10.00% for quality index and -8.96 to 6.87 for grain protein content. The three (Slm/Phl, F85/Slm and F85/Esp) and seven (F85/Phl, Sb/Fs, Fs/Slm, Esp/Slm, Fs/Phl, Esp/Sb and Sb/Slm) of F_2 populations are offered a good opportunity in base material for selection of potential because of significant SCA effects and best parent heterosis for grain yield and quality traits respectively.

Keywords
Bread wheat, Combining ability, Heterosis, Grain yield, Quality

Introduction

Wheat is not only called the 'King of Cereals', but also the 'Stuff of Life' due to its worldwide spread, high cultivation area, high productivity and is the most basic food (Sharma et al., 2019). Therefore, it is a staple grain for world food security, poverty reduction and livelihoods (Rahul, 2017).

It is vital to increase wheat production to close the gap between production and consumption in Turkey as well as globally. By diversifying wheat breeding programs and developing new high yielding wheat varieties, large differences in wheat productivity in different regions of the country must be reduced to achieve the anticipated high productivity. In addition, the developed new cultivars should be possessed the functional attributes demanded by producers, processors, and consumers under various agro-climatic conditions. Selection of parents and determination of suitable hybrid combinations are the most important points in the development of new varieties that are superior in terms of yield and quality characteristics in combination breeding. A hybrid that is a cross of two genetically different individuals outstrips the average of the parents (heterosis) or the best parent (heterobelthiosis). This phenomenon has been successfully exploited in fibre, cereals, and oilseed crops (Ahmad et al., 2014). The magnitude of heterosis helps in determining genetic variability and serves as a guide in the selection of desirable parents. Hybrid combinations should have superiority over the best parent, commercial use of heterosis, and high transgressive segregant formation abilities.

Breeders aim to generate populations containing desired genes and gene complexes to select suitable genotypes. Griffing (1956) developed a diallel method for determining the combining ability and explaining the nature and magnitude of gene action. In general, for plant breeding, hybrid combinations with high specific combining ability (SCA) and those with at least one parent with high general combining ability (GCA) are the most sought after (Paini et al., 1996). Combining ability describes the breeding values of parents to produce hybrids. Additive gene action relative to the average performance of a genotype in a series of hybrid combinations refers to GCA (Griffing, 1956; Singh and Chaudhary, 1985). The performance of one parent genotype in crossing combination with another parent genotype is called SCA (Mandal and Madhuri, 2016).

The main objectives of this study were to evaluate the GCA and SCA of parents and F_2 progeny from a half-diallel crosses and was to examine the heterobeltiosis for yield and quality traits and also to identify the heterotic combination which may be further exploited through heterosis breeding programme.

Material and Methods

Plant material

The genetic material, environment characteristics, field trial procedure and set-up of the experiments, are fully described by Yazıcı and Bilgin (2019). The experiment was set up with twenty-one F_2 combinations and their 7 parents (6 widely used commercial bread wheat cultivars and one advanced line) in randomized complete block design with three replicated in 2013-2014 growing year in Tekirdağ Namık Kemal University, Agricultural Faculty, Field Crops Department research area in Tekirdağ Province of Trakya Region where is located North Part of Turkey. It lies at an altitude of 10m above sea level and at 27^o 34’ East and 40^o 59’ North. The Thrace region, a peninsula, is under the typical continental climate. Average rainfall of 476mm was lower than the last fifty-year average of 521mm, most of which falls between November and June. The relatively low rainfall (0.2mm) received in June was a negative effect on the filling period. But irregularities in rainfall amounts according to the month are the most characteristic feature of the region. Temperature in summer rise to the maximum of 28.4 ^{o}C, while winter temperature may reach as low as -0.3 ^{o}C. It has a clayey loamy texture and enters the weak soil group according to soil analysis. Grain yield (GY) and some attributes characteristics such as plant height (PH), spike length (SL), number of grains per spike (NGS), grain weight per spike (GWS), harvest index (HI), and grain quality characters such as thousand grain weight (TGW), wet gluten content (WGC), Zeleny sedimentation value (ZSV), quality index (QI) (expressed as ZSV/GPC) and grain protein content (GPC) (for methods see Yazıcı and Bilgin, 2019) were evaluated in half-diallel crosses F_2 combinations and their parents.

Statistical analysis

The data after compilation were subjected to a simple analysis of variance technique (Steel and Torrie, 1980) using the statistical package ‘MSTATC’ to see whether significant differences existed among the wheat genotypes for further analysis. An ANOVA was done on the F_2 generation for each characteristic evaluated. For features where significant differences were identified, the combining ability analysis was performed in Method 2, Model 1 as proposed by Griffing (1956) using computer software ‘AGD-R (2015) Version 2.0’ developed by Rodriguez et al. (2015). General combining ability is used to indicate the average performance of a genotype in a hybrid combination, while SCA is used to identify situations where certain combinations perform relatively better or worse than expected, based on the average performance of the genotype concerned (Sprague and Tatum, 1942). The heterosis analysis were performed on the characters showing significant differences. The per cent increase (+) or decrease (-) of F_2 hybrids over mid as well as a best parent was calculated to estimate possible heterotic effects for the characters by using the formula of Fonseca and Patterson (1968) as:

$$Ht(\%)= \frac{F_2 - MP}{MP} x100$$

$$Hb(\%)= \frac{F_2 - BP}{BP} x100$$

Where,

Ht=Heterosis, Hbt=Heterobelthiosis, MP=Mid parent and BP=Best parent value. The “t” test was computed to determine whether F_2 hybrid means were statistically significant from mid parent and best parent means as follows (Wynne et al., 1970).

$$tij= F_2ij - MPij \Big/ \sqrt{\frac{3}{8} EMS}$$

$$tij= F_2ij - BPij \Big/ \sqrt{\frac{1}{2} EMS}$$

Where,

F_2ij=The mean of the ijth F_2 cross, MPij=The mid parent for ijth cross, BPij=The best parent value for ijth cross, EMS=Error mean square.

Results and Discussion

The results of preliminary, GCA and SCA of ANOVA are given in Table 1. The preliminary analysis results revealed that significant (p≤0.01) differences were observed among the parental genotypes and their F_2 populations for all the traits. While the GCA mean squares of the genotypes were very important for all traits examined, the SCA mean squares were found to be insignificant only for the spike length (Table 1). The extensive genetic variation of the breeding material allows for further evaluation for GCA and SCA effects (Kempthorne, 1957). Singh et al. (2013), Verma et al. (2016) and Rajput and Kandalkar (2018) reported similar results.

Table 1. Preliminary analysis of variance of yield and quality traits for parents and F_2 progeny

SOV	Replication (2)	Genotype (27)	Error (54)	σ^2_{GCA}	σ^2_{SCA}	$\sigma^2_{GCA}/\sigma^2_{SCA}$
PH	1.17	307.66**	44.48	24.25**	1.97**	12.31
SL	0.40	1.14**	0.49	6.07**	1.23	4.94
NGS	23.89	85.80**	28.62	7.21**	1.79*	4.03
GWS	0.03	0.32**	0.09	9.01**	1.82*	4.95
HI	9.51*	64.3**	4.80	76.96**	3.84**	20.04
GY	590.08	9787.85**	1192.45	24.45**	3.57**	6.85
TGW	0.84	65.31**	6.14	39.94**	2.28**	17.52
WG	0.26	20.11**	3.26	19.50**	2.36**	8.26
GI	14.71	524.77**	14.15	117.33**	14.17**	8.28
ZSV	5.14	145.11**	7.76	76.96**	3.84**	20.04
QI	0.07	0.57**	0.04	51.51**	3.00**	17.17
GPC	0.11	0.89**	0.11	24.92**	3.81**	6.54

*significant at the %5 level, **significant at the 1% level

The genetic component of the variances can be explained through estimates of the GCA and SCA variances. It is assumed that the additive genetic variance is equal to the GCA variance and the SCA variance is the dominance variance. In our study, the magnitudes of the genetic component, the total components of the variances for all characters were found to be higher than the dominance components of the variances.

The ratio of genetic components "σ^2gca/σ^2sca" also showed more than one, indicating a predominance of additive variances for almost all characters (Table 1). The present finding is confirmed by Kandil et al. (2016), Rahul (2017) and Ali et al. (2018), were recorded the predominance of additive variances for all the traits.

Combining ability

The combining abilities of parents play a key role in the evaluation of breeding traits and assist in deciding the effective breeding method in segregation generations (Griffing, 1956; Singh and Chaudhary, 1985)

Mean performance of parents and General combining ability effects

Evaluation of GCA effects for yield components and quality traits together with average performances is of great importance in selecting parents for yield and quality improvement. The evaluated parental genotypes and their F_2 crosses exhibited a wide variation for all assessed traits. The parents' Esperia and Pehlivan exhibited the good yielding characteristics, while Flamura85, Aldane and Selimiye have been involved as a parent in most of the best performing for quality traits F_2 combinations (Table 2). Estimates of GCA effects for each parent are presented in Table 2.

The results indicated that advanced line Fs showed significant negative GCA for all studied characters except GPC. This means that Fs can be a good combiner for the sole purpose of shortening PH. Another parent that could be a good combiner for shortening PH was Saraybosna. Flamura85 showed also positive GCA for SL, TGW, GI, ZSV and QI. Esperia showed significant GCA effects for NGS and heavy GWS and TGW and more GY. Moreover, the cultivar Pehlivan showed positive GCA effects for PH, SL, GWS, HI, GY and TGW. Aldane cultivar showed significant GCA effects for grain quality traits such as TGW, GI, ZSV, QI and GPC, while these effects were negative for grain yield traits other than PH. Parental genotypes with desirable GCA effects are considered to be the best parental genotypes and good general combiners that can be exploited to improve the trait in wheat breeding (Afridi et al., 2017; Parveen et al., 2019).

Table 2. The averages and GCA effects of the parental genotypes

Crosses	Flamura85 (F85)		Esperia (Esp)		Saraybosna (Sb)		Aldane (Ald)	
	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA
PH	86.4	-0.18	82.5	-1. 28	82.3	-7. 26**	102.7	6. 25**
SL	8.37	0.33*	8.42	-0.27*	8.68	-0.04	8.81	-0.07
NGS	36.3	0.46	45.3	2.39*	50.1	2.98**	39.2	-5.13**
GWS	1.78	0.05	2.35	0.17**	2.43	0.08	1.95	-0.30**
HI	38.00	-1.68**	44.33	0.58	43.33	2.18**	36.33	-3.38**
GY	405	-22.39**	638	12.50*	453	-8.06	553	-1.10
TGW	48.03	1.84**	48.77	0.99*	40.33	-3.25**	48.47	1.12*
GI	92.67	4.60**	85.33	7.64**	55.33	-8.51**	88.67	9.19**
ZSV	55.33	1.69**	44.00	-3.27**	43.33	-2.01**	67.67	8.66**
QI	4.18	0.15**	3.51	-0.10**	3.37	-0.18**	4.66	0.49**
GPC	13.23	-0.07	12.53	-0.53**	12.87	0.11	14.53	0.51**

PH: plant height, SL: spike length, NGS: number of grain per spike, GWS: grain weight per spike, HI: harvest index, GY: grain yield, TGW: thousand grain weight, GI: gluten index, ZSV: Zeleny sedimentation value, QI: quality index, GPC: grain protein content

Table 2. The averages and GCA effects of the parental genotypes (continuation)

Crosses	F/S (Fs)		Selimiye (Slm)		Pehlivan (Phl)	
	Mean	GCA	Mean	GCA	Mean	GCA
PH	83.3	-8. 98**	103.5	5. 61**	100.4	5.84**
SL	9.08	-0.51**	9.06	0.12	8.66	0.45**
NGS	38.7	-1.38	44.3	1.50	42.6	-0.81
GWS	1.95	-0.20**	2.58	0.13*	2.23	0.07
HI	39.67	2.21**	40.33	-0.49	43.67	0.58
GY	325	-49.13**	685	11.53	645	56.65**
TGW	35.53	-5.27**	51.10	2.03**	50.13	2.53**
GI	59.33	-7.88**	84.00	2.86**	58.67	-7.88**
ZSV	43.33	-2.86**	53.67	2.25**	43.33	-4.46**
QI	3.30	-0.24**	4.06	0.17**	3.22	-0.30**
GPC	13.14	0.10	13.23	0.01	13.50	-0.13*

PH: plant height, SL: spike length, NGS: number of grain per spike, GWS: grain weight per spike, HI: harvest index, GY: grain yield, TGW: thousand grain weight, GI: gluten index, ZSV: Zeleny sedimentation value, QI: quality index, GPC: grain protein content

These results show that Esperia and Pehlivan varieties were found to be good combiners, while Selimiye and Flamura85 were average and Saraybosna, Aldane and Fs were poor combiners to increase grain yield. Although Flamura85, Aldane and Selimiye varieties are appropriate parents that can be used to increase grain quality, Esperia, Saraybosna, Fs and Pehlivan were poor combiners to increase grain quality. Consequently, our results on average performance and GCA effects for the respective characters are in agreement with those reported by Ismail (2015), Joshi et al (2020), and Abro et al (2021).

Specific Combining Ability Effects and Heterotic Performances

The SCA effect is an indication of the heterosis (interaction) for a specific trait. Heterosis is the process by which the performance of an F_1 is superior to that of the mean of the crossed parents. Generally, heterosis is manifested in a positive direction for some characters such as adaptation, yield, quality, and general vigour over its parents and in some cases it is in a negative direction for some characters such as plant height, maturity duration, earliness and toxic substances which is also desirable (Chaudhary et al., 2018). Heterosis helps the plant breeders eliminate unproductive crosses in early generations and is of considerable importance to evaluate as means of increasing the productivity of crop plants. On the other hand, Singh et al. (2004) and Zaazaa et al. (2012) especially emphasized that the superiority of heterosis hybrids over the high parent is more appropriate for commercial use, and explained that the parent combinations achieve the ability to produce the highest level of transgressive segregants in this case.

Tables 3 and 4 give the SCA effects and heterosis estimates of the grain yield and quality traits for all the crosses. Although Paroda and Joshi (1970) and Morojele and Labuschagne (2013) stated that a marked decrease in the magnitude of the SCA in the F_2 population was found, good results could still be obtained in F_2. The results of SCA effects (Tables 3 and 4) of different crosses revealed that none of the crosses showed consistently significant positive or negative and desirable SCA effects for all the characters. Data presented in Table 3 revealed that SCA effects of F_2 hybrids ranged between -7.196 and 7.537 for PH, -0.592 and 0.551 for SL, -6.603 and 5.797 for NGS, -0.311 and 0.324 for GWS, -3.213 and 3.157 for HI and -65.694 and 54.417 for GY, and 14 crosses showed a, thereby, indicating good specific combinations for grain yield and other attributing traits. SCA effect of SL were not found significant. Crosses viz., Esp/Slm, Slm/Phl and Esp/Phl registered the best specific combiner for grain yield characteristics because these crosses were the results of good x good general combiners and reported significant positive SCA effects. Crosses Esp/Ald, Esp/Fs, Esp/Sb, F85/Esp, F85/Phl, F85/Slm, Fs/Phl and Sb/Slm were the result of good x poor general combiner and also reported significant positive SCA effect for grain yield characters. The rest of the crosses viz., Sb/Fs, Ald/Fs and Sb/Ald were the result of poor x poor general combiner but exhibited significant positive SCA effect for grain/yield, thereby, suggesting good specific combiner for these traits. The estimated value of heterosis showed that the degree and direction of heterosis varied not from trait to trait but also from cross to cross. The ranges of best parent heterosis were -12.71 to 8.23% for PH, -15.46 to 8.36% for SL, -16.62 to 24.80% for NGS, -23.61 to 36.50% for GWS, -17.13 to 8.84% for HI and -45.65 to 15.83 for GY (Table 3).

Shah et al (2018), as a result of their study, emphasized that 10.0 per cent or more heterosis over the best parent in F_2 can be considered good for all of the characteristics they examined in wheat (except for the maturity characteristics of 5.0 per cent or more). There is a possibility of obtaining a low heterosis cross from high performing parents, as well as a high heterosis percentage crossing from low per se performing parents (Kumar et al., 2015). Since the SCA effect is accepted as an indicator of heterosis (interaction) for a particular trait, examining them together will allow more appropriate inferences to be made (Ceyhan and Avci, 2005). A comparative study of promising crosses identified based on heterosis and combining ability (Table 3) revealed that hybrid viz., Slm/Phl, F85/Slm and F85/Esp showed positive significant heterosis and heterobelthiosis for NGS, GWS, HI and GY. None of the crosses exhibited significant positive heterosis over the best parent for PH and SL. These results are in accordance with those recounted by Patel et al. (2019), Sharma and Jaiswal (2020), Fleitas et al. (2020) and Abro et al. (2021). The crosses with SCA effects and heterotic performance for seed quality traits have been depicted in Table 4. The crosses having higher SCA effects in a desirable direction for different traits can be utilized to produce superior transgressive segregants for these traits. The involvement of parents with good GCA for specific traits in certain crosses can be attributed to superior SCA effects of these crosses for these traits. The mean of SCA effects changed from -2.708 to 4.962 for TGW, -2.801 to 2.910 for WGC, -17.426 to 11.982 for GI, -4.556 to 7.333 for ZSV, -0.274 to 0.491 for QI and -0.380 to 0.657 for GPC in F_2 hybrids. A total of 14 crosses showed good specific combinations for grain quality traits.

Table 3. SCA effects, heterosis and heterobelthiosis estimates for grain yield associated characters

Crosses	PH			SL			NGS		
	SCA	H_t (%)	H_b (%)	SCA	H_t (%)	H_b (%)	SCA	H_t (%)	H_b (%)
F85/Esp	-7.196**	-4.51	-4.51	0.053	2.80	0.59	1.345	18.27*	12.40
F85/Sb	-1. 422	0.86	-4.75	0.079	3.21	2.84	5.556*	24.93**	14.38
F85/Ald	-5. 467**	11.51*	5.12	0.236	5.89	5.13	2.764	11.36	7.98
F85/Fs	1. 367	8.04	-3.59	0.551	20.77**	8.36	-1.425	4.59	2.65
F85/Slm	6. 948**	13.49**	7.81	0.306	5.96	3.78	1.271	20.38*	19.08
F85/Phl	3. 644**	11.19*	6.70	-0.431	-1.81	-6.48	1.879	14.82	12.40
Esp/Sb	0. 619	1.96	-3.70	-0.275	-6.08	-8.42	5.797*	19.23*	14.61
Esp/Ald	3. 374**	8.04	1.84	0.419	3.07	1.45	-1.862	-1.88	-9.42
Esp/Fs	3. 507**	9.47	-2.32	0.174	4.91	-3.99	0.249	8.46	4.96
Esp/Slm	2. 756**	7.68	2.29	-0.254	-5.73	-9.62	1.312	19.32*	14.88
Esp/Phl	1. 319	7.42	3.08	-0.517	-8.92	-15.02**	4.186	19.69*	16.12
Sb/Ald	-4. 585**	-2.06	-12.49*	-0.592	-8.87	-9.84	-1.384	-3.84	-14.38
Sb/Fs	-4. 585**	-2.77	-8.46	0.113	4.24	-6.76	-1.140	1.71	-5.25
Sb/Slm	7. 130**	11.81*	0.63	-0.218	-4.89	-6.52	4.156	22.71**	13.47
Sb/Phl	2. 393*	7.72	-2.13	0.485	4.07	-0.54	-6.603*	-10.51	-2.91
Ald/Fs	7.537**	15.96**	-1.84	0.203	6.30	-3.99	-0.999	-6.40	-10.87
Ald/Slm	-1. 548	4.64	3.79	-0.148	-3.41	-6.07	-1.569	0.56	-3.49
Ald/Phl	1.615	9.28*	7.27	-0.301	-4.22	-9.40	-3.529	-12.22	-16.62
Fs/Slm	-3. 981**	2.32	-12.71*	-0.530	-4.03	-15.46**	2.908	17.60*	16.97
Fs/Phl	7. 015**	17.43**	0.96	0.320	7.67	7.45	1.582	7.14	6.86
Slm/Phl	1. 363	9.25*	8.23	0.446	3.55	0.64	5.579*	25.79**	24.80*

PH: plant height, SL: spike length, NGS: number of grain per spike, GWS: grain weight per spike, HI: harvest index, GY: grain yield

Table 3. SCA effects, heterosis and heterobelthiosis estimates for grain yield associated characters (continuation)

Crosses	HI			GY		
	SCA	H_t (%)	H_b (%)	SCA	H_t (%)	H_b (%)
F85/Esp	3.083**	12.72**	8.84*	34.120	29.94**	10.59
F85/Sb	0.491	2.36	-7.28*	-18.991	-14.42	-30.73**
F85/Ald	-0.954	-3.20	-4.47	13.713	11.63	-5.56
F85/Fs	-3.213**	-5.47	-13.69**	-28.917	-19.60	-19.60
F85/Slm	0.157	-0.98	-6.92	54.417**	34.31**	11.24
F85/Phl	2.417*	7.10*	0.00	-6.361	-5.10	-32.50**
Esp/Sb	0.231	3.66	-2.99	-39.546*	-21.76*	-25.25**
Esp/Ald	0.787	3.86	-0.98	-9.843	0.00	-0.72
Esp/Fs	-0.139	3.92	-2.17	51.861**	25.35**	6.68
Esp/Slm	-1.435	-2.38	-5.31	30.861	19.72*	15.83
Esp/Phl	3.157**	10.66**	6.86	-17.250	-7.89	-26.23**
Sb/Ald	-2.472*	-7.41*	-17.13**	40.713*	5.85	0.26
Sb/Fs	2.602*	6.47*	5.56	-31.250	-32.86**	-45.65**
Sb/Slm	0.306	-1.55	-5.13	20.750	0.35	-2.52
Sb/Phl	-1.102	-2.65	-5.78	-65.694**	-33.75**	-44.26**
Ald/Fs	2.491*	5.30	-5.00	-5.213	-11.48	-25.11*
Ald/Slm	-0.806	-6.21	-12.93**	-59.880**	-24.58**	-26.51**
Ald/Phl	-1.880	-6.45	-13.72**	9.676	-4.05	-22.73**
Fs/Slm	0.269	-0.89	-3.69	-39.509*	-24.85**	-37.75**
Fs/Phl	-0.472	-0.22	-2.82	-5.954	-14.76	-39.37**
Slm/Phl	-2.435*	-8.04*	-8.46*	7.713	-2.60	-19.96**

PH: plant height, SL: spike length, NGS: number of grain per spike, GWS: grain weight per spike, HI: harvest index, GY: grain yield

Table 4. SCA effects, heterosis and heterobelthiosis estimates for grain quality traits

Crosses	TGW			WGC			GI		
	SCA	H_t (%)	H_b (%)	SCA	H_t (%)	H_b (%)	SCA	H_t (%)	H_b (%)
F85/Esp	-2,708*	-1.86	-2.66	0,429	-0.30	-5.29	2,982	4.61	0.43
F85/Sb	4,962**	15.41**	6.04	-0,345	2.01	-0.56	4,463*	5.95	-15.44**
F85/Ald	1,392	7.26*	7.26	0,888	1.67	-3.69	-9,907**	-9.93**	-11.87**
F85/Fs	-0,419	4.31	-9.37*	-0,645	-1.41	-5.17	2,167	0.92	-17.27**
F85/Slm	0,188	3.83	0.58	0,140	1.67	-3.19	2,093	-1.13	-5.72
F85/Phl	2,581*	10.81**	8.38*	-0,234	-4.12	-10.05**	-13,167**	-18.91**	-33.80**
Esp/Sb	-0,549	0.00	-8.62*	2,166*	7.53*	0.00	0,759	10.38**	-9.02**
Esp/Ald	-0,453	1.03	0.61	-0,568	-4.95	-13.98**	-2,944	5.40	3.38
Esp/Fs	2,203	7.36*	-7.18*	-2,801**	-10.38**	-17.71**	9,797**	20.74**	2.34
Esp/Slm	2,777*	6.41*	3.91	-0,749	-2.93	-11.96**	6,389**	11.82**	10.90**
Esp/Phl	-0,164	2.63	1.19	-1,157	-8.93**	-18.55**	-1,537	5.70	-10.90**
Sb/Ald	0,584	3.38	-5.37	-1,375	-2.17	-5.01	9,204**	21.83**	-1.12
Sb/Fs	-0,360	1.31	-4.71	2,625**	9.94**	8.44*	-7,722**	-6.45	-9.61*
Sb/Slm	-1,319	-1.96	-12.32**	0,977	6.55*	3.72	4,537*	10.05**	-8.80*
Sb/Phl	-2,294	-1.99	-11.57**	-0,231	-1.34	-5.41	-0,389	7.20	4.09
Ald/Fs	-0,631	1.43	-12.19**	-0,108	-1.34	-2.90	6,574**	15.83**	-3.38
Ald/Slm	0,744	3.01	0.19	-0,423	-1.06	-1.58	2,833	7.30**	4.51
Ald/Phl	0,603	4.87	2.99	-0,197	-4.96	-6.18	9,241**	19.97**	-0.33
Fs/Slm	-1,934	-2.77	-17.61**	2,910**	8.89**	7.44*	-17,426**	-22.76**	-34.16**
Fs/Phl	3,692**	12.85**	-3.59	-1,897*	-8.22**	-10.82**	11,982**	25.63**	24.78**
Slm/Phl	0,132	2.76	1.76	-1,445	-6.28*	-7.73*	0,574	2.80	-12.73**

TGW: thousand grain weight, GI: gluten index, ZSV: Zeleny sedimentation value, QI: quality index, GPC: grain protein content

Table 4. SCA effects, heterosis and heterobelthiosis estimates for grain quality traits (continuation)

Crosses	ZSV			QI			GPC		
	SCA	H_t (%)	H_b (%)	SCA	H_t (%)	H_b (%)	SCA	H_t (%)	H_b (%)
F85/Esp	1,482	2.01	-8.32*	0,113	3.64	-4.55	0,057	-0.78	-3.78*
F85/Sb	-1,778	-1.22	-11.93**	-0,085	-1.85	-11.27**	-0,183	0.76	-0.75
F85/Ald	0,222	-0.33	-9.45**	0,018	1.36	-4.07	-0,013	-0.72	-5.51**
F85/Fs	0,074	0.81	-10.13**	-0,079	-2.14	-12.47**	0,294	3.81*	3.03
F85/Slm	0,963	2.20	0.72	0,069	2.18	0.71	0,028	0.00	0.00
F85/Phl	-3,333*	-9.33**	-19.17**	-0,154	-4.60	-15.58**	-0,380*	-4.51**	-5.92**
Esp/Sb	5,185**	16.02**	15.23**	0,265*	10.75**	8.54*	0,443*	5.55**	3.90*
Esp/Ald	-0,815	-1.07	-18.32**	-0,016	2.69	-10.08**	-0,054	-2.22	-8.96**
Esp/Fs	-1,296	-0.92	-1.59	-0,006	2.05	-1.13	-0,380*	-3.12*	-5.34**
Esp/Slm	-4,074**	-6.54	-14.90**	-0,198	-2.38	-8.88*	-0,380*	-3.90*	-6.81**
Esp/Phl	-0,037	-1.60	-2.27	0,070	3.86	-0.56	-0,320	-5.38**	-8.88**
Sb/Ald	-3,407*	-2.70	-20.24**	-0,234*	-2.99	-16.52**	-0,028	1.47	-4.82**
Sb/Fs	-0,889	3.93	3.93	-0,188	-3.60	-4.74	0,513**	8.52**	6.87**
Sb/Slm	7,333**	20.21**	8.57*	0,491**	15.90**	6.17	0,180	3.84*	2.27
Sb/Phl	0,370	3.23	3.23	-0,062	-0.30	0.30	0,339*	3.81*	0.74
Ald/Fs	1,111	3.96	-14.77**	0,142	5.77	-9.65**	-0,183	-0.72	-5.51**
Ald/Slm	3.000*	6.59*	-4.43	0,254*	20.35**	1.50	-0,117	-1.44	-6.20**
Ald/Phl	0,704	0.36	-17.73**	0,098	4.58	-11.80**	-0,091	-3.57*	-6.89**
Fs/Slm	0,519	4.54	-5.59	-0,140	-1.63	-10.86**	0,657**	6.87**	6.06**
Fs/Phl	3,889**	9.24*	9.24*	0,348**	11.69**	10.00*	-0,217	-2.25	-3.70*
Slm/Phl	-4,556**	-9.28*	-18.06**	-0,274*	-5.78	-15.55**	-0,283	-3.75*	-5.18**

TGW: thousand grain weight, GI: gluten index, ZSV: Zeleny sedimentation value, QI: quality index, GPC: grain protein content

Out of the total 21 crosses, 4 (F85/Sb, F85/Phl, Esp/Slm and Fs/Phl), 4 (F85/Sb, F85/Phl, Esp/Slm and Fs/Phl), 8 (F85/Sb, Esp/Fs, Esp/Slm, Sb/Ald, Sb/Slm, Ald/Fs, Ald/Phl and Fs/Phl), 4 (Esp/Sb, Sb/Slm, Ald/Slm and Fs/Phl), 4 (Esp/Sb, Sb/Slm, Ald/Slm and Fs/Phl) and 4 (Esp/Sb, Sb/Fs, Sb/Phl and Fs/Slm) crosses showed significant SCA effects in a desirable direction for TGW, WGC, GI, ZSV, QI and GPC respectively. The GPC is considered one of the most important traits from a breeding point of view as it decides the success of a particular breeding programme. Four crosses namely, Esp/Sb, Sb/Fs, Sb/Phl and Fs/Slm showed significant positive SCA effects for GPC. Crosses with significant and positive SCA effects for

GPC were also identified by Joshi et al. (2020). Cross viz., Ald/Slm registered best good specific combiner for grain quality traits because this cross was the result of good x good general combiners and reported a significant positive SCA effect. Crosses F85/Sb, F85/Phl, Esp/Slm, Sb/Ald, Sb/Slm, Ald/Fs, Ald/Phl and Fs/Slm were the result of good x poor general combiner and also reported significant positive SCA effect for grain quality traits. The rest of the crosses viz., Esp/Sb, Esp/Fs, Sb/Fs, Sb/Phl and Fs/Phl were the result of poor x poor general combiner but exhibited significant positive SCA effect for grain quality traits, thereby, suggesting good specific combiner for these traits. The significant positive and negative estimated value of heterosis over best parent was observed for all quality traits. The ranges of heterosis were -17.61 to 8.38% for TGW, -18.55 to 8.44% for WGC, -34.16 to 24.78% for GI, -20.24 to 15.23% for ZSV, -16.52 to 10.00% for QI and -8.96 to 6.87 for GPC (Table 4). A comparative study of promising crosses identified based on heterosis and combining ability (Table 4) revealed that hybrid viz., F85/Phl, Sb/Fs, Fs/Slm, Esp/Slm, Fs/Phl, Esp/Sb and Sb/Slm showed positive significant heterosis and heterobelthiosis for TGW, WGC, GI, ZSV, QI and GPC. These results, together with significant SCA effect and significant positive heterosis on the best parent, as noted by Singh et al (2004), suggest that commercial use of these hybrids may be more appropriate to improve wheat yield. The present finding is in confirmation by Thorwarth et al. (2018), Boeven and Longin (2019), and Joshi et al. (2020).

Conclusions

The study revealed the existence of a significant amount of variability amongst parental lines and crosses for almost all the traits studied except for SL for which SCA mean squares were insignificant. This shows that the improvement for all the traits except for SL can be achieved through a selection of genotypes with superior traits or by isolation of transgressive segregants. The parents Esperia and Pehlivan exhibited good yielding characteristics and significant positive GCA effects, hence it can be used for the development of lines with high yielding. On the other side, for improvement of grain quality traits such as TGW, WGC, GI, ZSV, QI and GPC, Flamura85, Aldane and Selimiye can be used as one of the parents in the hybridisation programme. A comparative study of promising crosses identified based on heterosis and SCA effects revealed that hybrids namely Slm/Phl, F85/Slm and F85/Esp for yield and yield contributing traits, while F85/Phl, Sb/Fs, Fs/Slm, Esp/Slm, Fs/Phl, Esp/Sb and Sb/Slm were the best hybrids for grain quality traits. These hybrids therefore offer an opportunity for commercial use, either as hybrid varieties or as a base material for the selection of potential homozygous lines from transgressive segregants to improve yield and quality levels of bread wheat.

Compliance with Ethical Standards

Conflict of interest

The authors declared that for this research article, they have no actual, potential or perceived conflict of interest.

Author contribution

The contribution of the authors to the present study is equal.

All the authors read and approved the final manuscript. All the authors verify that the Text, Figures, and Tables are original and that they have not been published before.

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