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Diallel analysis of some important morpho-phenological traits in bread wheat *(Triticum aestivum* L.) crosses

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Abstract

Wheat (*Triticum aestivum* L.) is the most important food crop. It offers a great wealth of material for genetic studies due to its wide ecological distribution. The effects of GCA and SCA of morpho-phenological traits i.e. days to emergence, days to flowering, days to maturity, flag leaf length, grain filling duration, spike weight per plant, stem weight and grain yield were studied utilizing an 8×8 half diallel cross according to Griffing's method II of Fixed model (I). Kouhdasht, Mehregan, Karim, Line 17, N-80-19, Atrak, N-92-9 and Ehsan cultivars were evaluated based on a randomized complete block design (RCBD) with two replications at the research farm of Gonbad Kavous University during fall 2017-2018. The analysis of variance and effect of SCA were significant for all the characters which showed a significant variability among their parents for all studied traits. The analysis of variance indicated that the effect of GCA was significant for all traits except for days to maturity and grain filling duration ($p \leq 0.05$). The obtained results from the mean square ratio of GCA to SCA showed that non-additive genetic variance played a predominant role in the inheritance of most traits. Based on GCA and SCA effects obtained from biplot analysis on 8 parents, N-92-9×Ehsan, N-92-9×Kouhdasht, Mehregan×Atrak, Ehsan×Line 17, N-80-19×Mehregan and Karim×Karim were detected as the best hybrids for grain yield. Further studies in relation to the agronomic traits, can improve our knowledge about the wheat cultivars used in the present study and can direct future breeding programs.

Key words: Biplot, Diallel analysis, Gene action, Wheat (*Triticum aestivum* L.), Yield.

ABBREVIATIONS

GCA (General Combining Ability), SCA (Specific Combining Ability), CRBD (Randomized Complete Block Design), DE (Day to Emergence), DF (Day to Flowering), DM (Day to Maturity), GFD (Grain Filling Duration), SWP (Spike Weight per Plant), SW (Stem Weight), FLL (Flag Leaf Length), YLD (Grain Yield).

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the first domesticated food crops that accounts for approximately one-sixth of the world's total land area. This was the highest amount of grain needed for food, which led to higher wheat production than all crops, including rice, corn and potatoes (Khokhar, 2019). Wheat is the main source of food for more than a third of the world's population due to its nutritional importance, scope of use, and storage quality. The nutritional value of wheat flour plays an important role in the diet (Rasaei *et al.,* 2017). Wheat seeds contain 70, 22, 12, 12, 2 and 1% carbohydrates crude fibers, protein, water, fat, and minerals, respectively (Yadav *et al.,* 2017). Wheat as a main food, provide calorie needs of growing populations (Kandhare, 2014), so that 4.5 billion people from 94 developing countries, consume wheat as the main source of food calories (21%) and protein (20%) as reported by Braun *et al*. (2010). FAO lowered its forecast for global cereal production in 2019 by 2.2 million tons, pegging the world cereal output at 2706 million tons, but still up 53 million tons (2.0 percent) from the outturn in 2018. Global wheat production is pegged at 766 million tons, down nearly 1 million tons from last month's forecast, though it is still a high record (FAO, 2019). According to statistics of the Iran ministry of agriculture, the area under cultivation, yield per unit area and total wheat production in 2016/17 were 6 million hectares, 1400 kg ha^{-1} for rain fed cultivation, and 4200 kg ha^{-1} for irrigation and 14 million tons, respectively (Golestan Agricultural Jihad Organization, 2018). To feed growing population of world, there is a terrible need to develop wheat genotypes having high yield potential (Jaiswal *et al.,* 2018). Breeders like to introduce new varieties with desirable traits, while crossing is one of the methods that is commonly used by breeders in recent years (Khahani *et al.,* 2018). The concept of hybrid vigor or heterosis is one of the most important achievements of a plant breeding program first observed by Freeman when studied heading time, plant height and leaf width in wheat (Freeman, 1919). Exploitation of heterosis approach in wheat is much more efficient than conventional breeding methods because using heterosis can produce high-yielding hybrids in various crops and plants. Increase in growth, yield and other plant traits are known as hybrid vigor or heterosis. Yield increase from heterotic hybrids due to the expression of heterosis is up to 30% superior to conventional varieties (Briggle, 1963; Singh, 2004). It is well known that heterosis occurs with the right combination of parents (Kalhoro, 2015). Hybridization is a potential technique in an effort to increase the yield of a commodity with the desired character. Superior hybrid varieties are typically characterized by high yielding (Dwitama *et al.,* 2018). High yields can be achieved if the derivatives of the crossed combinations have high combining ability (Sujiprihati *et al.,* 2007). Therefore, the estimation of available genetic variances in the early breeds of hybrids may be helpful for breeders. Diallel is a mating system that includes all possible crosses in a group of parents, often used to estimate heritability of quantitative traits. Among various diallel forms, the half diallel methods have certain advantages over others, giving maximum information about genetic architecture of a trait, parents and allelic frequency (El-Maghraby, 2005; Iqbal, 2007). Based on the combining ability in diallel cross, higher SCA displays the dominance gene effects, while higher GCA shows the additive gene effects. In addition, the diallel cross is commonly used to select inbred lines in hybrid programs (Farshadfar *et al.,* 2008; Nouri *et al.,* 2011). Griffing (1956), Hayman (1954) and Jinks (1954) models provide information on the importance and role of additive or non-additive gene actions in F_1 hybrids. The GCA and SCA effects help to detect parents and hybrids that show a particular type of gene action (Faraji *et al*., 2011; Ali, 2018). This information is used for a variety of genetic variations in traits, and will be useful for quick evaluation of plant production capacity by identifying hybrids in form of superior genotypes (Ejaz-ul-Hassan & Khaliq, 2008).

The selection of the best general combining ability can be effective in increasing yield through hybridization; and superior hybrids may be developed by selecting the best combining. The present study aimed to estimate GCA of cultivars and also SCA of crosses, and determine type of action of genes that control traits in crosses of F_1 hybrids to select the best individuals.

Ali *et al*. (2018) reported that the heritability of plant height, days to emergence, days to flowering, days to maturity, grain filling duration, grain per spike and 1000-grain weight are all affected by additive gene action. Kumar *et al*. (2019) showed that grain yield in both generations was controlled by non-additive effects. Nagar *et al*. (2018) recorded non-additive gene action for yield and related traits in both $F_1$and F_2. Rashid *et al*. (2012) reported that additive effects and relative dominance effects were able to control traits such as tillers per plant, spike length, number of grains per plant, whereas thousand grain weight were controlled by genes with over dominance effects. Hama Amin and Towfiq (2019) observed that the mean square of genotypes was highly significant for yield and yield components; and their heritability was influenced by non-additive effects of genes. The dominant type of gene action in the heritability of grain yield was explained by Patial *et al*. (2018).

The aim of this study was to evaluate the general combining abilities of cultivars and specific combining abilities of crosses to determine the type of action of genes controlling traits in F_1 crosses for the selection of superior progeny.

MATERIALS AND METHODS

The present research was conducted at Gonbad Kavous University, College of Agriculture, research farm located at longitude E 55° 12', latitude N 37° 16' and 46 meters' above the sea level with a warm, semi-dry Mediterranean climate (Based on koppen's climate classification). The mean rainfall was 457 mm during season 2017-

2018. Eight cultivars (Parents) as well as 28 crosses (F_1 progenies) were planted based on a randomized complete block design with two replications. Soil texture of the research farm was silty clay loam with a pH of 7.8, the electrical conductivity of 1 $dS.m^{-1}$ and 1.5% of organic matters, and 18 to 19% of lime.

Plant materials included 28 F_1 hybrids of wheat resulted from crossing between eight cultivars and lines i.e. Atrak, Ehsan, Karim, Kouhdasht, Line 17, Mehregan, N-80-19 and N-92-9. Most cultivars used in present study were high yielding Iranian cultivated varieties. Pedigree of these cultivars is shown in Table 1. The crosses were carried out at Golestan Agricultural and Natural Resources Research and Education Center.

DE, DF, DM, GFD, SWP, SW, FLL and YLD traits were evaluated for fifteen plants in each experimental unit (plot). Also, days to spike emergence and days to physiological maturity were measured by counting the number of days to emergence at cultivation time until 50% of flowering occurred per plot.

The analysis of variance for each trait was performed based on a randomized complete block design with 36 genotypes and two replications.

After finding significant differences between genotypes, MSGCA/MSSCA were used to determine the general and specific combining ability of the studied parents in the genetic model (model I and method II) and to determine the contribution of additive variance in genetically controlling the studied traits using Baker's ratios (Baker, 1978). AGD-R program (2015) was used to perform the statistical and genetic data analyses of diallel design (Francisco Rodríguez, 2015). Graphic analyses were carried out by GGE Bi-plot software based on the method proposed by (Yan and Hunt, 2002).

RESULTS AND DISCUSSION

The analysis of variance on combining ability revealed that the variances were highly significant at 1% probability level, for GCA and SCA for most traits in F_1. DE, DF, DM, FLL, SWP and YLD (Table 2) indicating the existence of sufficient diversity and possibility of selection between examined parents and F_1 crosses (Table 3).

Days to emergence (DE)

The results revealed significant specific combining ability effects for DE (Table 2). Dominance effect was the major gene action for most of the traits, suggesting that heterosis can be utilized in future breeding programs of those traits; and the selection of superior plants should be postponed to the next breeds to assess superior varieties. Our results are consistent with those of Heidari *et al*. (2006), Zare-kohan and Heidari (2012) and Heidari and Sepahi (2017). N-92-9 showed the best GCAs for DE (-2.535) (Table 4). Heterosis breeding can be used in the crosses of Kouhdasht×line17, N-80-19×Ehsan and N-80-19×N-92-9 for DE (Table 5). The MSGCA/MSSCA results showed a high contribution of non-additive effects of genes.

Days to flowering and physiological maturity

Significant ratio of MSGCA/MSSCA displayed the relative importance of additive gene action for DF and DM. Due to the high accuracy of the MSGCA/MSSCA ratio, hence, the pedigree method of selection can be used for DF and DM improvement (Table 3). Ehsan showed the best GCAs for DF (-3.06) (Table 4). Kouhdasht×Ehsan, Kouhdasht×Mehregan, Kouhdasht×Atrak, Ehsan× Karim, Ehsan×Mehregan, Line 17×Atrak, and Line N-92-9×Atrak were the best combinations for DF; and Kouhdasht×Line 17, Kouhdasht×N-92-9, N-80-19×Atrak, Line17×Mehregan were the best combinations for DM (-3.596, -2.310, -2.553 and -1.987) and are recommended for early maturity in hybrid production (Table 5). Loss and Siddique (1994) stated that early flowering had a positive effect on grain yield in durum and wheat cultivars. Motzo and Giunta (2007) also stated that the stresses of season end in Mediterranean regions led to improved pollination and

Table 1. Characteristics and pedigree of parents.

Cultivar	Characteristics	Pedigree
N-80-19	Late-stage, spring, high yield, susceptible to drought	SW89.3064.STAR…
KOHDASHT	Early-stage, spring, drought resistant	TR8010200
ATRAK	Spring, short, high tillers	Kauz″s″
EHSAN	Late-stage, spring, high yield, susceptible to drought	SABUF.7.ALTAR…
N-92-9	Spring, drought resistant	KLCQ.ER2000..WBLL1
MEHREGAN	Spring, high yield	OASIS.SKAUZ..4*BCN.3.2*PASTOR
KARIM	Spring, suitable for rainy season	Hamam-4
LINE17	Early-stage, short	Jup.alds..att"s".vee"s".3.…

Table 2. Analysis of variance of studied traits based on Griffing method (1956).

Source of variation	df	Mean of square							
		DE	DF	DM	FLL	GFD	SW	SWP	YLD
REP	1	1.389	4.104*	4.5*	1.598	17.014*	0.439**	22.22	36.399
Cross	35	4.474**	5.795**	2.612**	8.547**	15.062**	0.095*	33886.47**	12404.53**
GCA	7	4.614**	2.825**	1.214	19.742**	5.968	0.129*	58860.71**	17236.07**
SCA	28	4.440**	6.537**	2.962**	5.748**	17.335**	0.086*	27642.86**	11196.65**
Residuals	35	1.388	0.842	0.928	1.183	3.414	0.048	9964.365	1946.97
Coefficient of variation (%)	-	11.370	0.856	0.002	0.003	0.002	0.01	0.022	0.014

*, **: Significant at 5% and 1% probability levels, respectively.
DE: Days to emergence, DF: Days to flowering, DM: Days to maturity, FLL: Flag leaf length, GCA: General combining ability, GFD: Grain filling duration, SCA: Specific combining ability, SW: Stem weight, SWP: Spike weight per plant, YLD: Yield.

Table 3. The values of GCA, SCA, GCA/SCA and Baker's ratio related to evaluated traits.

Statistics	DE	DF	DM	FLL	GFD	SW	SWP	YLD
GCA	0.161	0.099	0.014**	0.927	0.127	0.004**	2444.817	764.454
SCA	1.125	2.847	1.016	2.282	6.960	0.018**	8839.246	4624.838
GCA/SCA	0.143	0.034*	0.014**	0.406	0.018**	0.212	0.276	0.165
Baker's ratio = $\frac{2MS_{GCA}}{2MS_{GCAsa}+2MS_{SCA}}$	0.509	0.301	0.290	0.774	0.256	0.6	0.680	0.606
δ2p	3.236	3.888	1.974	5.321	10.629	0.075	23693.25	8100.717

*, **: Significant at 5% and 1% probability levels, respectively.
DE: Days to emergence, DF: Days to flowering, DM: Days to maturity, FLL: Flag leaf length, GFD: Grain filling duration, GCA: General combining ability, SCA: Specific combining ability, GCA/SCA: Additive to non-additive variance ratio, and δ2p: Phenotypic variance, SW: Stem weight, SWP: Spike weight per plant, YLD: Yield.

fertilization and, consequently, increased yield by early flowering.

Flag leaf length (FLL)

Specific combing ability variance was greater than general combining variance, so non additive type of gene action was more important for FLL trait. Therefore, late segregating generations of these crosses and heterosis breeding method is suggested by selection (Table 3). The result was consistent with studies reported by Mohammadi *et al*. (2007), Sadeghi *et al*. (2002) and Bagheri *et al*. (2009). N-80-19, Kouhdasht and Ehsan cultivars had the highest significant and positive GCA, (Table 4). The highest significant positive effects of SCA were related to Kouhdasht×Line17, Kouhdasht×N-92-9, N-80-19×Ehsan, Ehsan×Line17, Karim×N-92-9, and Atrak×N-92-9 (Table 5).

Grain filling duration (GFD)

The ratio of MSGCA/MSSCA displayed the relative importance of additive gene action. Hence, the pedigree method of selection can be used for GFD improvement (Table 3). Since the ultimate goal is to increase the yield, and there is a high correlation between grain filling rates and grain filling duration with yield, this correlation can be used to select the cultivars with the maximum yield (Darroch and Baker, 2006). Grain filling rate and duration are two important physiological traits playing significant roles in determining the yield (Banyai *et al*., 2014). Given the early maturity of cultivars, the selection of plants with the least grain filling durations can be effective in the relative success of yield. Due to the late maturity of Karim cultivar (Table 4), its late maturity and pollination face the late season heat stress and a longer reduction in the GFD. Radmehr *et al*. (2005), Tewolde *et al*. (2006), Lack and Modhej (2011) concluded that the effective GFD in the late flowering cultivars was lower than the earlier flowering ones under unfavorable environmental conditions, such as the late season heat stress. The most significant SCA belonged to Kouhdasht×Ehsan, Kouhdasht×Mehregan, Ehsan×Karim, Line17×Atrak, and N-92-9×Atrak crosses that can be proposed for application in hybrid production with shorter GFD and higher yield (Table 5).

Spike Weight per Plant (SWP)

The mean squares obtained from analysis of variance on hybrids were significantly different for this trait. This result showed that this datum can be processed for further analysis in order to evaluate heterotic effects in F_1 hybrids (Table 2). Due to the significance of the variance of specific combining ability (Table 3), SWP trait is influenced by the dominance effect, and the

Table 4. General combining ability of parents for the studied traits.

Parents	DE	DF	DM	FLL	GFD	SW	SWP	YLD
Kouhdasht	-0.507	0.325	-0.248	4.524**	0.291	-0.932	-1.496	1.658
N-80-19	-0.507	0.065	-0.744	6.805**	0.420	0.276	2.969*	3.433**
Ehsan	3.549**	-3.060**	0.248	3.744**	-1.649	2.835*	3.484**	4.331**
Line-17	1.926	-0.796	-0.248	-0.840	-0.355	-2.285*	-1.625	-2.945*
Karim	-0.507	-1.757	2.728*	-4.108**	-2.296*	0.087	-4.358**	-5.104**
Mehregan	-1.724	2.929*	0.001**	-3.946**	1.455	-1.431	-0.706	-1.630
N-92-9	-2.535*	2.148	-1.488	-2.601*	1.843	2.107	0.502	-0.091
Atrak	0.304	0.325	-0.248	-3.577**	0.291	-0.657	1.257	0.348

*, **: Significant at 5% and 1% probability levels, respectively.
DE: Days to emergence, DF: Days to flowering, DM: Days to maturity, and FLL: Flag leaf length, GFD: Grain filling duration, SW: Stem weight, SWP: Spike weight per plant, YLD: Yield.

Table 5. Specific combining ability of parents for the studied traits.

Cross		DE	DF	DM	FLL	GFD	SW	SWP	YLD
Kouhdasht	N-80-19	1.176	1.406	-0.935	-2.568**	1.186	0.346	0.821	-0.106
Kouhdasht	Ehsan	1.176	-4.370**	3.596**	-2.243*	-4.047**	-1.02	-1.729	-3.555**
Kouhdasht	Line17	-2.264*	4.295**	-3.524**	2.794**	3.971**	0.227	-0.287	-1.446
Kouhdasht	Karim	-1.470	1.151	1.168	1.329	-0.037	-0.613	1.884	1.623
Kouhdasht	Mehregan	2.896**	-5.475**	2.059*	-2.985**	-3.793**	-1.255	-0.635	-1.771
Kouhdasht	N-92-9	-0.808	2.426*	-2.310*	3.244**	2.410*	0.403	2.133*	1.372
Kouhdasht	Atrak	2.235*	-2.076*	0.521	0.252	-1.303	2.508**	0.364	-0.751
N-80-19	Ehsan	-2.793**	2.511**	-1.096	2.221*	1.819	0.222	-0.764	-1.075
N-80-19	Line17	0.382	-0.717	0.683	-3.501**	-0.712	1.304	-0.065	0.171
N-80-19	Karim	2.499**	-1.312	-0.287	1.513	-0.501	-1.836	-0.432	0.111
N-80-19	Mehregan	-1.073	2.256*	-1.016	-0.559	1.650	1.398	1.657	2.410*
N-80-19	N-92-9	-3.455**	-1.736	0.278	-1.764	-1.008	0.364	-0.494	-0.620
N-80-19	Atrak	-1.735	4.804**	-2.553**	1.463	3.718**	1.367	-0.623	-0.961
Ehsan	Line17	0.382	0.302	-0.449	4.380**	0.384	1.187	2.696**	4.478**
Ehsan	Karim	1.176	-3.691**	2.625**	-4.249**	-3.202**	-1.903	-1.772	-2.904**
Ehsan	Mehregan	1.573	-2.671**	1.087	0.221	-1.894	1.376	-0.697	-0.631
Ehsan	N-92-9	1.838	-0.717	-0.044	-0.003	-0.332	1.405	2.305*	2.939**
Ehsan	Atrak	-0.411	1.576	-1.258	1.377	1.439	1.456	-1.846	-2.316*
Line17	Karim	1.705	-1.821	0.359	-2.125*	-1.092	1.096	-0.252	-0.858
Line17	Mehregan	-1.867	3.445**	-1.987*	-1.102	2.748**	0.175	-1.014	-1.253
Line17	N-92-9	-1.602	3.700**	-1.501	-1.023	2.621**	-1.104	-3.244**	-4.645**
Line17	Atrak	1.441	-3.351**	2.140*	-1.904	-2.780**	-1.023	0.688	1.685
Karim	Mehregan	-1.073	2.001*	-1.339	1.523	1.692	1.902	-2.397*	-4.289**
Karim	N-92-9	1.838	0.556	-1.663	4.522**	1.144	2.647**	-2.869**	-5.078**
Karim	Atrak	-1.735	1.151	-1.258	-1.142	1.228	-0.779	-2.217*	0.478
Mehregan	N-92-9	-0.411	2.426*	-1.582	-1.334	2.030*	-0.835	0.274	0.502
Mehregan	Atrak	1.308	0.472	-1.177	1.477	0.848	-0.123	-0.088	0.878
N-92-9	Atrak	2.896**	-5.220**	2.544**	1.980*	-3.920**	0.741	-0.443	0.427

*, **: Significant at 5% and 1% probability levels, respectively.

DE: Days to emergence, DF: Days to flowering, DM: Days to maturity, FLL: Flag leaf length, GFD: Grain filling duration, SW: Stem weight, SWP: Spike weight per plant, YLD: Yield.

heterozygous breeding method is suitable for breeding this trait. However, the selection of superior plants should be carried out in subsequent breeds and direct selection is not effective in obtaining superior varieties with a greater number of spikes (Table 3). The highest significant and positive effects of GCA belonged to Ehsan and N-80-19 cultivars. They can improve plant yield and can achieve desirable results in plant breeding programs (Table 4). Effects of specific combination of Ehsan×Line17, Ehsan×N-92-9 and Kouhdasht×N-92-9 crosses leading to the highest spike weight with the positive and significant combining ability are presented in Table 5. The negative combining effects belonged to Karim×Mehregan, Karim×N-92-9 and Karim×Atrak crosses.

Stem weight (SW)

Our findings indicated that general and specific combining values were significant for SW (P≤0.05), indicating the combined roles of additive and non-additive effects in the genetic control of this trait (Table 2). Genetic variance components i.e. the reduced additive variance ratio (GCA) and dominant variance (SCA) indicated that the non-additive effects of genes were much greater than the additive contributions; hence, heterosis can be utilized in future breeding programs for this trait. The selection of superior plants with higher SW should be postponed to the next generation to achieve high yielding cultivars (Table 3). The highest significant and positive effect of general combining ability belonged to Ehsan parent; hence, it can be used in breeding programs to create plants with higher stem weights (Table 4). Furthermore, Kouhdasht×Atrak and Karim×N-92-9 hybrids are suggested for application in hybrid production, and Ehsan×Mehregan, Ehsan×N-92-9 and Ehsan×Atrak hybrids can be used in recombination breeding, because at least one of their parents has a positive and significant GCA effect (Table 5).

Grain yield (YLD)

Mean square of the genotypes was partitioned into general and specific combining abilities (GCA and SCA) (Table 2). Mean squares of GCA and SCA were significant for yield indicating the involvement of additive and non-additive gene action in its inheritance. Considering the insignificance of the mean squared ratio GCA/SCA (Table 3), it can be concluded that the role of non-additive effects in controlling this trait is greater than additive effects. Ehsan×Line 17, Ehsan×N-92-9 and N-80-19×Mehregan are suggested for hybrid production projects due to their positive and significant SCA effects (Table 5) because, their parents (Ehsan and N-80-19) showed the best GCA for this trait (Table 4). N80-19×Line 17 and N80-19×Karim hybrids could be used in heterosis breeding since there is at least a parent with positive and significant GCA effect. Mehregan×Atrak, N-80-19×Mehregan, Ehsan×line 17, Ehsan×N-92-9, N-92-9×Kouhdasht hybrids are suitable for hybridization breeding, however, since their SCA effects were not significant (lack of dominance), the selection of superior plants should be postponed until subsequent generations (Table 5).

Since there was a greate contribution of non-additive effects on grain yield control, YLD is predominantly controlled by non-additive (dominance and epistasis) gene action. Shabbir *et al.* (2011), found similar results in the study of this trait. The improvement of such characters warrants a breeding methodology which capitalizes on additive as well as non-additive genetic variance, so it may be necessary to resort heterosis breeding and the selection of superior plants is postponed to subsequent generations (Zahid, 2011).

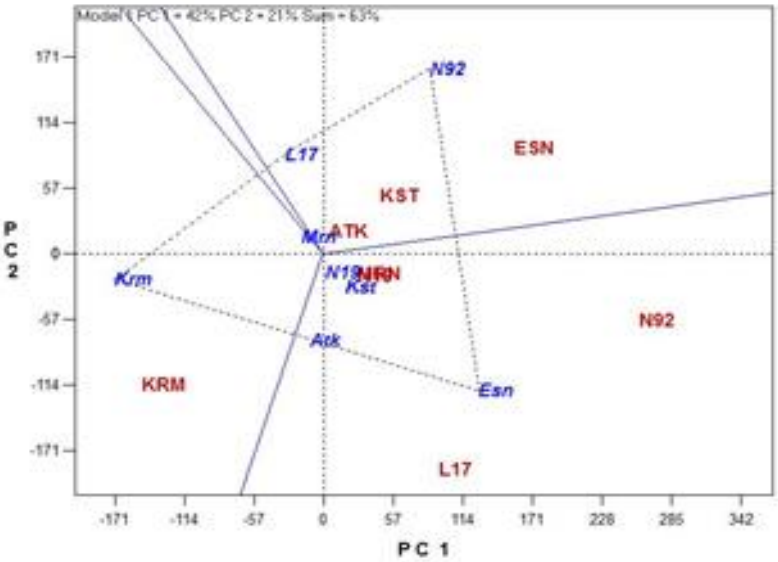
Detection of heterotic hybrids using biplot analysis

The graphical demonstration presented by the biplot analysis provided a mean performance in crosses, grouping similar genotypes on the basis of heterosis and provided an opportunity for assessing the interrelationship among the genotypes.

According to Figure 1, GGE Bi-plot is responsible for 63% of data variation for the grain yield (42% and 21% by PC1 and PC2 from the total variation). N-92-9 line and Ehsan tester are on one angle and Ehsan line and N-92-9 tester are on the other angle. This means that there are many combining abilities between genotypes N-92-9 and Ehsan and their hybrid is heterotic. Ehsan line showed a high combining ability with line 17 tester. On the other hand, N-92-9 line with Kouhdasht tester, Kouhdasht and N-80-19 lines with Mehregan tester and Mehregan line with Atrak tester were suitable pairs for cross. Karim tester was beside Karim line indicating that these genotypes should be better than all crosses related to Karim and as a result, heterosis between Karim and any other parent would not be possible. Kouhdasht and Atrak testers, on one side, and Kouhdasht and Atrak lines, on the other side, illustrated the low combining ability. In general, hybrids N-92-9×Ehsan, N-92-9×Kouhdasht, Mehregan×Atrak, Ehsan×Line 17, N-80-19×Mehregan and Karim×Karim were highly heterotic.

Baker's ratio

Finally, Baker's ratio (Baker, 1978) was calculated for each of the traits in order to compare the results of the mean genetic variance. The closer the Baker's ratio to



Tester-focused Scaling

Figure 1. 2D diagram of diallel data for grain yield per m^2 for 8 genotypes of bread wheat. Polygon display and genotypes and testers positions. The lowercase letters indicate the genotypes and the capital letter indicate the testers.

the unit value (1), the more important the additive effect of the genes. This can be attributed to environmental conditions and genotypes studied.

For all traits studied in this study, Baker's ratio was significantly different and confirmed the effect of non-additive genes on DE, FLL, SWP, SW and YLD traits (Table 3).

CONCLUSION

The results of this study showed that in crosses of resistant and susceptible cultivars of Iranian wheat varieties with high yields, there was a great variation in morpho-phenological characteristics and there was the effect of both additive and non-additive genes on the regulation of grain yield and component traits in this set of breeding material. Inclusion of F_1 hybrids that show high SCA and having parents with good GCA in multiple crosses can also be a valuable approach to improve grain yield in bread wheat. Given the higher role of non-additive gene action in controlling most traits, due to the low heritability, their direct selection may not be useful in early breeds and therefore, it should be postponed to advanced breeds of breeding programs. However, given the high heritability and higher role of additive gene action in controlling DF, DM and GFD, direct selection in early generations may be useful. Also, based on the graphical and griffing results, the maximum value of heterosis for higher grain yield was introduced by N-92-9×Ehsan, Ehsan×Line 17 and N-80-19×Mehregan crosses, parents with high GCA. In general, the applied germ plasms in breeding programs should be taken into account by researchers and have the above traits in order to obtain high-yielding genotypes.

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