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Original scientific paper

GENETIC ANALYSIS OF SPIKE TRAITS IN WHEAT (*Triticum aestivum* L.)

Ensieh Es'haghi SHAMSABADI[1], Hossein SABOURI[1*], Habibollah SOUGHI[2], Seyed Javad SAJADI[1]

[1]Department of Plant Production, Collage of Agriculture Science and Natural Resources, Gonbad Kavous University, Gonbad, Golestan, Iran.
[2]Horticulture and Agronomy Department, Golestan Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Gorgan, Iran

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An 8×8 half diallel cross design was carried out by the Griffing method II of fixed model (I) in a Complete Randomized Block Design using Kouhdasht, Mehregan, Karim, Line17, N80-19, Atrak, N-92-9 and Ehsan cultivars in two replications at the research field of Gonbad Kavous University in 2017. In order to study the impact of general combining ability (GCA) and specific combining ability (SCA) of traits of wheat maturity including spike length, spike weight, number of grains per spike, grain weight per spike, awn length, and grain yield. The mean square of general combining ability (GCA) and specific combining ability (SCA) was significant for all traits at 1% probability level due to the importance of both additive gene action and non-additive gene action on the inheritance of the traits. The obtained results from the ratio of mean square of GCA to SCA indicated that the contribution of dominance was greater than the additive gene in controlling the spike weight and grain yield, while the additive gene effect played a decisive role in the number of grain per spike, length of awn, spike length and weight of spike grain due to the significant ratio of SCA to GCA. According to results number of grains per spike, length of awn, spike length and weight of spike seeds largely had the additive gene variance and had the ability of responsive selection.

Keywords: General combining ability (GCA), Specific combining ability (SCA), Wheat, Yield.

INTRODUCTION

Wheat (*Triticum aestivum* L.) as a main and the most important crop, has a special place in Iran and constitutes a major part of starch in diet of people around the world; and the global demand for increases every year (BAKHSHANDE *et al*., 2010). The world's population is now around 7.2 billion and is expected to increase to 9 billion people by 2050 (ISNA, 2019). The latest FAO report on human and livestock consumption of grains also indicated a new record of 2,626

Corresponding authors*:* Hossein Sabouri. Department of Plant Production, Collage of Agriculture Science and Natural Resources, Gonbad Kavous University, Gonbad, Golestan, Iran. Phone: +98 09 111 438 917, Email: Hossein.sabouri@gonbad.ac.ir

million tons. Therefore, the global reserves of grains were expected to decrease by 2.7% at the end of agricultural season until 2019, and the ratio of reserves to global grain consumption also decrease to 27.2%. This ratio reached the highest level of 28.8% in 16 years in 2017-2018 (FAO, 2019). According to prediction of global organizations, the population of Iran will reach 92.2 million in 2050. From 1980 to 2011, the world's population grew by about 40 percent, while an increase in cultivation area was less than 5 percent (HEJJARPOOR *et al*., 2017). Decrease in yield gap is a way to increase wheat production. The yield gap is a difference between actual yields with obtained yield under optimum managerial conditions. There are many ways to meet the increasing human demand for food in the world including the increase in cultivation area and increase in yield per unit area. Therefore, the increased yield per unit area is emphasized more than increase in cultivation area (AGRICULTURE ORGANIZATION OF GOLESTAN PROVINCE, 2018).

The indirect selection of first breeding generations is an important strategy in plants, and thus traits, which have positive and significant correlation with grain yield and also have greater heritability than grain yield, are selected; hence, the knowledge about the inheritance and the genetic control of different traits are particularly important in breeding programs.

The production of new and adaptable cultivars in different environments is an important goal of breeders. Crosses of new cultivars and the selection of superiority of each genotype in terms of favorable traits among their results is a technique that is always utilized by breeders. Various methods have been developed by a large number of researchers to estimate the general and specific combining ability of parents and crosses; and the analysis of diallel crosses is an important method in this field (GRIFFING, 1956).

AFRIDI *et al*. (2019) studied genetic structures of traits of yield and stripe rust resistance in six wheat cultivars in two generations, F1 and F2, using the diallel cross analysis, and found that all traits except for the grain yield in the F1 generation and flag leaf area in the F2 generation were under control of additive gene action.

According to review of eight wheat families with 28 hybrids of F1 and F2 in India to study the combining ability, amount of SCA variance were greater than GCA variance for most of the traits in both the generations indicated that non additive type of gene effects were more pronounced than those of additive gene effect showed significant GCA effects for grain yield per plant (KUMAR *et al*., 2018).

PATEL *et al*. (2018) conducted a 7×7 diallel design of wheat in the study of yield and resistance to leaf spot disease and reported that variance of SCA was greater than variance of GCA in all traits except for number of productive tillers per plant and 1000 grain weight and it was a sign of greater role of non-additive effects than additive gene action.

JYOTI *et al*. (2017) used a half diallel of ten parents for Combining ability yield and its components in bread wheat (*Triticum aestivum* L. em. Thell.). The ratio of δ2GCA/ δs2SCA revealed preponderance of non-additive gene actions in almost all the traits.

SEPAHI and HEIDARI (2017) utilized half diallel crosses of 5 wheat genotypes to estimate genetic parameters and heritability of some traits such as morphology and yield components of wheat. Based on their results, effects of general combining ability (GCA) and specific combining ability (SCA) of genotypes were statistically significant for all traits; hence, they found the general and specific combining ability for all traits. They also stated that roles of both additive and non-additive gene action were important in their genetic incidence, so that the selection efficiency can increase in wheat breeding programs for grain yield according to obtained results from crosses with suitable SCA.

Five varieties of bread wheat (*Triticum aestivum* L.) were used to analyze the grain yield of wheat and its components by half diallel crosses. The result of the analysis of variance indicated that the mean square of genotypes, GCA and SCA were highly significant for all studied characters. GCA to SCA ratio was less than 1 for all studied traits except plant height that indicated the dominance gene effects is more important for determining these traits (AYOOB, 2020).

Investigating some quantitative traits of wheat under drought stress, GOLPARVAR *et al*. (2011) found very significant mean square of general combining ability for all traits, and also mean square of specific combining ability for all traits except for number of grains per spike indicating the importance of both additive gene action and dominance of genes in heredity of these traits under stress. The grain per spike trait is controlled by additive gene action and has higher heritability. The use of this trait can be used as an indirect selection criterion for genetic improvement of grain yield.

Since the yield prediction is the most important part of breeding programs, the present study used field data of results to detect of the best hybrid among crosses.

MATERIALS AND METHODS

The present research was conducted at the research farm of Gonbad Kavous Agricultural College located in 100 kilometers northeast of Gorgan, at 55° 12' E longitude and 37° 16' N latitude in a randomized complete block design with two replications. Each genotype was cultivated in two 1 m^2. The average precipitation was 457 mm in the year. The research was carried out on a silty clay-loam soil with EC 1 $dS \cdot m^{-1}$, pH 7.8, organic matters 1.5% and 18-19% of lime, which was ploughed and disked prior to planting on 5 December 2017.

The studied wheat population included 28 generations of F1 (half diallel crosses) obtained from crosses of eight cultivars namely Kouhdasht, Mehregan, Karim, Line17, N80-19, Atrak, N-92-9 and Ehsan. The crosses were conducted at the Agricultural and Natural Resources Research Institute of Golestan Province. Each family was cultivated in 1 m^2.

Fifteen plants were randomly selected from each unit; and then we measured traits of spike length (SL), Spike weight (SW), number of grains per spike (GNS), grains weight per spike (GWP), grain yield (YLD) and awn length (LAW).

Analysis of variance of each trait was done based on the Randomized Completed Block Design with 36 genotypes and two replications. The second method of fixed model (I) by GRIFFING (1956b) was used to estimate variance of analysis of diallel crosses in order to obtain additive gene action and dominance as well as effects of general combining ability of parents and specific combining ability of crosses of F1 generation.

AGD-R was used to perform the statistical and genetic data analysis (RODRÍGUEZ *et al*. (2015).

RESULTS AND DISCUSSION

Spike length, spike weight, number of grain per spike, weight of spike seeds, grain yield and awn length had a significant difference at 1% probability level (Table 1). The same results mentioned by other researchers (RASHID *et al*., 2012; ZARE-KOHAN and HEIDARI, 2014; YILDIRNM *et al*., 1995; GOLPARVAR *et al*., 2011; RIAZ and CHOWDHRY, 2003). It suggests genetic differences between cultivars and wheat hybrids in terms of traits; hence, genetic variation between genotypes can be divided into additive and non-additive variance. In other words, differences of genotypes are due to additive and non-additive gene action (Table 2).

The existence of additive and non-additive gene action in the genetic control of yield and grain yield components in wheat is consistent with findings by other researchers (SINGH *et al*., 2013; KAPOOR *et al*., 2011; KHALILZADEH, 2017; SEPAHI and HEIDARI, 2017; ZARE KOHAN and HEIDARI, 2014; SHARMA *et al*., 2002; HEIDARI *et al*., 2006; GOLPARVAR *et al*., 2011).

The significance of parents' combining ability (gi) in traits (Table 3) indicates that parents have high or low heritability of each trait, so that positive values (gi) should be taken into account in cases where trait value is going to increase.

Table 1. Analysis of variance for studied traits based on randomized completed block design with Griffing method in diallel crosses (8 parents and 28 crosses)

Source of variation	df	SL	SW	GWP	GNS	YLD	LAW
REP	1	0.066	0.096	0.039	0.129	36.399	0.107
Cross	35	2.004**	0.386**	0.185**	66.094**	12404.53**	1.883**
GCA	7	7.853**	1.127**	0.625**	213.301**	17236.07**	6.913**
SCA	28	0.542**	0.200**	0.075**	29.292**	11196.65**	0.626**
Residuals	35	0.214	0.061	0.021	13.344	1946.97	0.275

*, **: significant at 5% and 1% probability levels, respectively; spike length (SL), spike weight (SW), grain number per spike (GNS), grain weight per spike (GWP), awn length (LAW), grain yield (YLD), general combining ability (GCA), specific combining ability (SCA).

Spike length

The mean squares of specific and general combining ability were significant for the trait at a probability level of 1%, hence, it was possible to separate genetic variance among genotypes to effects of additive and non-additive gene action (Table 1). Since the ratio of additive to non-additive variance was greater than unit (1), the spike length trait was influenced by the additive gene action, and thus it allowed direct selection of superior plants for the trait in studied cultivars (Table 2). The greatest positive and significant effects of general combining ability belonged to N80-19, Kouhdasht and Ehsan. It can be expected that desirable genotypes may be selected for improving spike length from results of crosses of these cultivars (Table 3). The highest and lowest spike length were recorded for Ehsan× Line17 and Ehsan× Kouhdasht respectively (Table 4). Crosses N80-19 × Ehsan, N80-19 × Mehregan, N80-19× N-92-9, N80-19× Atrak, Ehsan× N-92-9, Ehsan× Atrak and Kouhdasht× N80-19 (no significant effects of SCA) can be used in hybridization breeding because at least one parent has positive and significant GCA effects, and the other parent lacks it. The results of the present study were in line with the findings of KANDIL *et al*. (2016), SHAHID *et al*. (2015) and KHIABANI *et al*. (2015).

Table 2. Components of genetic variance

	SL	SW	GWP	GNS	YLD	LAW
GCA	0.381	0.053*	0.030*	9.997	764.454	0.331
SCA	0.163	0.069	0.027*	7.973	4624.838	0.175
GCA/SCA	2.331	0.765	1.117	1.253	0.165	1.889
δ2p	1.142	0.237	0.109	41.313	8100.717	1.114
Narrow-heritability	0.668	0.447	0.553	0.483	0.188	0.595
Broad-heritability	0.812	0.740	0.801	0.677	0.759	0.753

*, **: significant at 5% and 1% probability levels, respectively; spike length (SL), spike weight (SW), grain number per spike (GNS), grain weight per spike (GWP), awn length (LAW), grain yield (YLD), general combining ability (GCA), specific combining ability (SCA), additive to non-additive variance ratio (GCA/SCA), phenotypic variance (2δp)

Spike weight

Since the additive to non-additive variance ratio (GCA/SCA) is less than unit, spike weight is influenced by the dominance activity of gene; hence, the heterosis breeding method is ideal for breeding this trait and there is no possibility of direct superior plant selection and it should be postponed until subsequent generations (Table 2). Ehsan, Karim and N80-19 cultivars had the greatest positive general combining ability and could produce superior results in terms of spikes with more and heavier grains (Table 3). N80-19× Mehregan, Karim× Mehregan, Karim× N-92-9 and Karim× Atrak hybrids are suggested for hybrid production projects because of significant SCA effects. Also, N80-19× N-92-9, Ehsan× Line17, Ehsan× Karim, Ehsan× N-92-9 and Ehsan× Atrak hybrids can be used in recombination breeding (Table 4).

Table 3. Parental general combinability values for the traits studied

Parent	SL	SW	GWP	GNS	YLD	LAW
Kouhdasht	8.373**	-2.963*	-2.502*	-1.034	1.658	-3.759**
N80-19	6.589**	3.600**	4.095**	2.889*	3.433**	1.046
Ehsan	7.584**	4.300**	1.154	-5.739**	4.331**	10.893**
Line-17	-7.148**	-4.146**	-3.272**	4.534**	-2.945*	-1.282
Karim	-2.001	7.823**	12.184**	4.415**	-5.104**	3.503**
Mehregan	-6.148**	-3.156**	-3.282**	-3.650**	-1.630	-5.733**
N-92-9	-2.447*	-1.565	-3.419**	-4.635**	-0.091	-0.143
Atrak	-4.800**	-3.891**	-4.957**	3.237**	0.348	-4.526**

*, **: significant at 5% and 1% probability levels, respectively, spike length (SL), spike weight (SW), grain number per spike (GNS), grain weight per spike (GWP), awn length (LAW), grain yield (YLD).

Number of grains per spike

Analysis of variance for number of grains per spike was significant at 1% probability level (Table 1). The ratio of variance of GCA to SCA was greater than unit for number of grains per spike. So, it was under the influence of additive gene action (Table 2). Given that the additive gene effect trait plays role in the inheritance, the direct selection of superior wheat varieties is possible in terms of number of grains per spike. Effects of general combining ability of average number of grains per spike for parents varied from 1.034 for Kouhdasht to 5.739 for

Ehsan cultivar. Four parents, N80-19, Line17, Karim and Atrak had positive and significant general combining ability; hence, these parents could be used in breeding programs to increase number of grain per spike which was an important component for increasing yield (Table 3). N-92-9× Kouhdasht and Ehsan× N-92-9 are suggested in hybrid production projects due to their positive and significant SCA effects. Furthermore, N80-19 ×Line17, N80-19× Karim, N80-19 × Atrak and Karim× Atrak hybrids (with parents that have positive and significant GCA effects) are suitable for hybridization breeding, but since their SCA effects were not significant (lack of dominance), the selection of superior plants should be postponed until subsequent generations (Table 4). Hybrids such as Kouhdasht× N80-19, Kouhdasht× Karim, Kouhdasht× Atrak, Ehsan× Line17, Line17× N-92-9 and Mehregan× Atrak (without significant SCA effects) can be used in recombination breeding because at least a parent has positive and significant general combining ability effect. Other crosses, which have parents with positive and significant GCA effects, but their hybrids have significant and negative SCA impact, are useless (Table 4). Confirming the above findings, the results of, ISMAIL (2015), RAJPUT and KANDALKAR (2018), ADEL and ALI (2013) and AWAN *et al*. (2005) recorded the superiority of incremental variance for this trait.

Grain weight per spike

The grain weight per spike was affected by the additive gene action (Table 1 and Table 2). Given that this trait has additive gene effects on the inheritance, the direct selection method is ideal for selection of superior wheat varieties in terms of this trait. The greatest positive and significant general combining effects belonged to Karim and N80-19; hence, the cultivars had the best general combining ability to increase yield. Among obtained results from crosses, we can select genotypes with greater yield (Table 3). Mehregan× N80-19, Karim× Mehregan, and Karim× Atrak hybrids had the greatest positive and significant specific combining gene ability; hence, the selection should be done from results of crosses for genetic improvement of yield (Table 4). Kouhdasht× N80-19, Kouhdasht× Karim, N80-19 ×Line 17, N80-19× N-92-9, N80-19× Atrak, Ehsan× Karim, Line17× Karim, and Karim× N-92-9 (no significant effects of SCA) could be used in recombination breeding because a parent had positive and significant GCA effect. Other crosses had negative and significant effects or their parents had negative general combining ability. So, the use of these crosses would result in undesirable and unpredictable results.

Awn length

The additive gene action played role in the inheritance of awn length. It was possible to directly select of superior wheat varieties in terms of target trait in studied cultivars (Table 2). Karim and Ehsan cultivars had the greatest positive and significant general combining ability than other cultivars; hence, the cultivars could be used in hybrid programs to produce resistant varieties to increase awn length and thus the yield due to the positive effect of awn length in filling grains in stress conditions (Table 3). The greatest positive and significant combining gene ability belonged to Kouhdasht × Line17, N80-19× Atrak, Karim× N-92-9 and Ehsan× N-92-9 crosses that could be used in hybrid production projects (Table 4).

Table 4. Specific combining ability (Sij) values for the traits evaluated

		SL	SW	GWP	GNS	YLD	LAW
N-80-19	Kouhdasht	0.568	1.662	1.706	1.470	-0.106	1.097
Ehsan	Kouhdasht	-0.092	0.376	0.450	0.614	-3.555**	-1.033
Line17	Kouhdasht	-0.956	-0.405	-0.779	-1.505	-1.446	2.204*
Karim	Kouhdasht	2.240*	0.625	0.967	1.892	1.623	-0.343
Mehregan	Kouhdasht	-0.563	-0.590	-0.529	-2.037*	-1.771	-0.666
N-92-9	Kouhdasht	2.640**	1.619	1.635	2.113*	1.372	1.138
Atrak	Kouhdasht	-0.329	0.122	0.114	1.303	-0.751	-0.807
Ehsan	N-80-19	0.633	-0.249	-0.227	-1.523	-1.075	0.004
Line17	N-80-19	-2.327*	-0.030	0.708	0.145	0.171	0.094
Karim	N-80-19	-0.790	-1.144	-2.442*	1.774	0.111	0.298
Mehregan	N-80-19	0.029	2.556**	3.483**	-2.105*	2.410*	-0.439
N-92-9	N-80-19	0.125	0.609	0.449	-0.746	-0.620	-0.383
Atrak	N-80-19	1.166	-0.058	0.857	0.770	-0.961	2.131*
Line17	Ehsan	3.337**	1.282	1.706	0.692	4.478**	1.515
Karim	Ehsan	-0.131	1.030	0.047	-2.946**	-2.904**	-0.252
Mehregan	Ehsan	-0.772	-0.539	-0.376	0.005	-0.631	0.532
N-92-9	Ehsan	0.551	0.616	0.792	2.957**	2.939**	2.001*
Atrak	Ehsan	1.511	0.381	1.393	-2.284*	-2.316*	0.847
Karim	Line17	-0.789	0.987	1.916	-0.603	-0.858	-0.371
Mehregan	Line17	-1.448	1.273	1.276	-0.016	-1.253	-0.355
N-92-9	Line17	-0.165	1.439	1.413	0.986	-4.645**	-0.363
Atrak	Line17	-2.429*	-1.082	-1.017	-1.137	1.685	-0.877
Mehregan	Karim	-0.221	2.155*	2.333*	-0.681	-4.289**	1.178
N-92-9	Karim	1.190	3.087**	1.747	-0.674	-5.078**	4.572**
Atrak	Karim	2.257*	3.712**	3.159**	0.486	0.478	-1.570
N-92-9	Mehregan	-0.514	-0.762	-0.676	-1.009	0.502	-1.628
Atrak	Mehregan	1.567	-0.187	-0.505	0.505	0.878	1.879
Atrak	N-92-9	1.029	0.584	1.151	0.207	0.427	1.129

*, **: significant at 5% and 1% probability levels, respectively, spike length (SL), spike weight (SW), grain number per spike (GNS), grain weight per spike (GWP), awn length (LAW), grain yield (YLD).

Grain yield

For this trait, genotypes showed statistically significant differences at a probability level of 1% (Table 1). The greatest grain weight belonged to Karim cultivar, but the least amount was related to N-92-9 cultivar that ranged from 5.104 g to 0.091 g. The dominance trait played roles in the inheritance, the heterosis method would be ideal for the trait to achieve superior wheat varieties and achieve a greater yield. Two parents, Ehsan and N80-19, can be used in breeding programs with the aim to increase the grain yield of plant due to the greatest positive and significant effect of general combining ability (Table 3). The greatest positive and significant specific combining ability belonged to N80-19 × Mehregan, Line× Ehsan and Ehsan× N-92-9 crosses that are suggested for application in hybrid production projects. According to results, the crosses included the greatest grain weights; and their parents had the best general combining ability in terms of grain yield. These cross combinations showing desirable SCA effects for grain yield per plant, yield component traits and may produce transgressive segregates in succeeding generations, which can be selected and improved for increasing yield. N80-19 ×Line 17 and N80-19× Karim hybrids could be used in heterosis breeding due to at least a parent with positive and significant GCA effect. Kouhdasht× Ehsan, Karim× Mehregan, Ehsan× Atrak and Karim× Ehsan crosses had negative and significant combining effects, and it was predicted that the results would have adverse and unpredictable results (Table 4). The results were in line with the findings of KUMAR *et al*., (2018) and NAGAR *et al*., (2018). SCA variance higher than GCA variance for most of the traits in both the generations indicated that non-additive effects were more pronounced than those of additive effect as well as the significant GCA effects for grain yield per plant.

CONCLUSION

Given the impact of general combining effects of parents and specific combining effects of crosses in traits, spike length (N80-19, Kouhdasht and Ehsan), number of grains per spike (N80-19, Line 17, Karim and Atrak), Spike weight (N80-19, Karim and Ehsan), grain weight per spike (N80-19 and Karim), awn length (Ehsan and Karim) and grain yield (N80-19 and Ehsan), it became clear that a number of crosses with high SCA were resulted from crosses with high general combining ability with the probability of significant value of additive × additive gene interaction. Sometimes crosses of parents with High × Low, GCA or Low × Medium, SCA indicated greater SCA effects; and greater values of this effect could be explained due to increasing additive interactions × dominance or dominance × dominance that was as non-fixed gene state. According to above results, it can be inferred that the selection of parents only based on the GCA is not a good criterion for selection because suitable parents for a trait may show low GCA. Therefore, the parent selection should also be based on both GCA and yield of parent, and the selection of hybrids should be based on the combination of yield of hybrids and GCA of parents. N80-19 × Mehregan, Ehsan × Line17, and Ehsan × N-92-9, which had the best specific combination of grain yield, had at least a parent with GCA resulting in an increase in desirable alleles that provided good conditions for the production of hybrid cultivars. In cultivars, which had low specific hereditary in genetic control of grain yield and its components, it would be better to use advanced breeding generations to achieve the genetic improvement of these traits.

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GENETIČKA ANALIZA OSOBINA KLASA KOD PŠENICE (*Triticum aestivum* L.)

Ensieh Es'haghi SHAMSABADI[1], Hossein SABOURI[1*], Habibollah SOUGHI[2],
Seyed Javad SAJADI[1]

[1]Departman za biljnu proizvodnju, Koledž za poljoprivredne nauke i prirodne resurse, Gonbad Kavous Univerzitet, Gonbad, Golestan, Iran
[2]Departman za hortikulturu i poljoprivredu, Golestan Centar za istraživanje i edukaciju u poljoprivredi i prirodnim resursima, Poljoprivredna istraživačka, obrazovna i savetodavna organizacija (AREEO), Gorgan, Iran

Izvod

Dizajn polu-dialelnog ukrštanja (8 × 8) izveden je Griffing-ovom metodom II fiksnog modela (I) u kompletnom randomiziranom blok dizajnu koristeći Kouhdasht, Mehregan, Karim, Line17, N80-19, Atrak, N-92-9 i Ehsan kultivare u dva ponavljanja na istraživačkom polju Univerziteta Gonbad Kavous 2017. Da bi se proučio uticaj opšte kombinacione sposobnosti (GCA) i specifične kombinacione sposobnosti (SCA) osobina zrelosti pšenice, uključujući dužinu klasa, težinu klasa, broj zrna po klasu, težinu zrna po klasu, dužina osja i prinos zrna.

Srednji kvadrat opšte kombinacione sposobnosti (GCA) i specifična kombinaciona sposobnost (SCA) bili su značajani za sve osobine sa nivoom verovatnoće od 1% zbog važnosti kako aditivnog delovanja gena tako i ne-aditivnog delovanja gena na nasleđivanje osobina. Dobijeni rezultati iz odnosa srednjeg kvadrata GCA prema SCA pokazali su da je doprinos dominacije bio veći od aditivnog efekta gena u kontroli mase klasa i prinosa zrna, dok je efekat aditivnog gena igrao odlučujuću ulogu u broju zrna po klasu, dužini osja, dužini klasa i težina zrna po klasu zbog značajnog odnosa SCA prema GCA. Prema rezultatima, broj zrna po klasu, dužina osja, dužina klasa i težina zrna po klasu u velikoj meri su imali aditivnu varijansu gena i pokazali su mogućnost za ciljanu selekciju na ta svojstva.

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