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Combining ability analysis in intraspecific (G*ossypium hirsutum*) cotton hybrids

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Abstract

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The aim of this research was to study heterosis, combining ability and gene action for four economic most important traits in 24 F_1 hybrids derived from 8 × 3 line × tester crosses. It was found that additive and non-additive gene effects were involved in the inheritance of studied traits. Non-additive variance was predominant over additive one indicating greater importance of non-additive gene action, which means that selection will be more effective in later hybrid generations. From the female parents, as good general combiners were found: Viki and Denitsa for productivity per plant and boll weight; Avangard-264, Natalia, Colorit and Boyana for fiber length; Rumi, Viki and Denitsa for lint percentage, showed positive and high GCA for the relivent traits. The Turkish cultivar Nazili 954 was found as a good male parent for productivity, while the Greek Millennium and the Spanish FR-H-1001 cultivars were determined as the best male parents for lint percentage, and Millennium for boll weight. Some parents were identified as good general combiners for two or three traits.

The Bulgarian Viki and Denitsa varieties were found as good combiners for three traits – productivity, boll weight and lint percentage, the Greek cultivar Millennium for two traits – productivity and boll weight. Some of parents having high GCA had low SCA variances, while others had high SCA variances. All parents having low or high SCA variances could be used in recombinant selection to create new breeding material. The crosses Viki × Nazili 954, Denitsa × Nazili 954 and Boyana × Nazili 954 were the best to improve productivity exhibited high mean performance with positive SCA effects and heterosis of 10.8 – 34.3%. The crosses Nelina × Millennium, Denitsa × Millennium and Avangard-264 × Millennium were the best for lint percentage, while Avangard-264 × Nazili 954, Avangard-264 × FR-H-1001, Natalia × Millennium and Boyana × Millennium were the best for inproving fiber length, showed high mean values with positive SCA effects for the relevant traits. All these crosses are very valuable for breeding programs to create new more productive and better quality cotton varieties.

*Keywords***:** cotton; variance components; heterosis, line × tester analysis; productivity; fiber length

Introduction

Cotton is the most important fibre crop of great importance for the economy of many countries. In the most cases cotton fibre is irreplaceable by the artificial fibres. Greece and Spain are the two biggest cotton producing countries in Europe. In the European Union cotton fiber is not enough and cotton growing is of increasing importance for Bulgaria. Cotton is a crop tolerant to drought and takes an important place in the field crop rotations. In Bulgaria there are 0-1 insecticide treatments on the cotton areas, which is a great advantage for ecologically directed agriculture.

Bulgarian cotton varieties establish a particular ecological group (*Proles Bulgaricum*) and stand out with high earliness. The aim of cotton breeding is to create high yielding varieties with improved fiber quality and resistant to stress factors as low temperatures in May and June and prolonged drought during the summer months.

In recent years, achievements of cotton breeding in our country are new varieties Sirius, Tsvetelina, Pirin, Perun (Valkova, 2017; Koleva & Valkova, 2019; 2023), Aida, Anabel, Tiara and Melani (Dimitrova, 2022a, b; 2023) combining a complex of valuable qualities. They are very early maturing and have higher productivity than the standard varieties, Anabel and Melani varieties have improved fiber quality characteristics.

Constant task of cotton breeding in our country is to increase seed cotton yield and fiber yield and to improve fiber quality of new varieties. Improving productivity and fiber quality are the primary objectives of any breeding program with cotton (Ashokkumar, 2010; Sudha et al., 2020; Chapara & Madugula, 2021). Over the years, as a result of intensive selection and improvement work with cotton, yields and fiber quality have improved (Dimitrova et al., 2022). Breeding methods include intra- and interspecific hybridization and experimental mutagenesis. Biotechnology including marker-assisted selection is a new direction (Hadzhiivanova & Bozhanova, 2009; Sabev et al., 2020).

Different breeding methods and techniques are applied for the genetic and selection improvement of productivity and fiber quality of cotton. Different crossing schemes and different types of crosses are applied. Diallel and line × tester crosses are most preferred and used. Both analyses, corresponding to the two crossing schemes, provide very useful information on the genetic control in the inheritance of traits and the selection value of parental components.

Line × tester crossing gives very useful information about both maternal and paternal forms (Dabholcar, 1992). Line × tester analysis could be used to find information about combining ability and provide information about parents and their F_1 crosses which is useful for breeding programs (Shakeel et al., 2012; Ali et al., 2013; Ali et al., 2014). Sivia et al. (2017) emphasize the advantages of this method, the line × tester analysis is one of the simplest and efficient methods of evaluating large number of inbreds/parents for their combining ability.

When using the hybridization method, the selection of parents based on their combining ability is of great importance to the success of hybridization programs. Zhang et al. (2016) noted that the ability to combine yield with fiber quality in F_1 interspecific crosses (*G. hirsutum* L. × *G. barbadense* L.) depends on the genetic potential and combining ability of parents. According to Sivia et al. (2017) the concept of combining ability plays an important role in the identification of parents and development of superior lines or hybrids. Combining ability analysis helps in selecting parents which when crossed would produce more desirable segregants (Nimbal et al., 2019).

Gene action is one of the most important factors in cotton breeding. Studying gene action and genetic variation is important for the success of breeding programs. According to Patel et al. (2014) the nature and magnitude of gene action controlling yield, yield components and fibre quality are very useful for development of the breeding procedures to be followed for cotton improvement. Type of gene action is one of the most important criteria of selection in cotton. Additivity, genetic advance, heritability, dominance, GCA, SCA, heterosis and hertobeltiosis are some of the important statistical approaches to improve yield and quality of cotton fibre (Sajjad et al., 2015).

A number of previous studies on line × tester crosses have shown that additive and non-additive genes controled the variation in seed cotton yield and its related components in Upland cotton (Rauf et al., 2006; Neelima & Raddy, 2008; Panhwar et al., 2008; Ashokkumar et al., 2010). Patil et al. (2011) noted that in 3 × 10 line × tester hybrids additive and non-additive effects were important for the inheritance of seed cotton yield and fiber qualities. Karademir et al. (2009) reported that in 7 × 3 line × tester crosses in Upland cotton fiber length was strongly affected by additive gene action, while seed cotton yield was affected by non-additive gene action. Presence of non-additive gene action in the expression of many traits related to yield and fiber quality parameters was reported by Shakeel et al. (2012), Ali et al. (2016a,b), Karademir et al. (2016), Sajjad et al. (2016), Sivia et al. (2017). Other researchers point to a greater importance of additive gene effects. Jatoi et al. (2011) in 5 × 3 line × tester found greater importance of additive gene action for number of bolls per plant, sympodial branches, ginning outturn and fiber yield. Usharani et al. (2014) also found predominance of additive gene action for yield and its components, except number of bolls, in 72 diallel crosses with 9 parental forms. Based on diallel analysis, Akiscan & Çencer (2014), Latif et al. (2014) in diallel crosses in Upland cotton reported similar results demonstrating predominance of additive gene effects for all studied traits.

The objectives of this research were to study the genetic control of productivity per plant, boll weight, lint percentage and fiber length in 8 × 3 line × tester crosses, in view of the selection strategy to be followed when working with hybrid generations, to identify potential parents based on their combining ability to improve the studied traits, and to select the best hybrid combinations for breeding programs.

Material and Methods

Eight Bulgarian varieties Avangard-264, Natalia, Colorit, Rumi, Nelina, Boyana, Viki and Denitsa, used as female parents, were crossed with three foreign cultivars Nazili 954 (Turkish), FR-H-1001 (Spanish) and Millennium (Greek), used as male parents, to produced 24 hybrid combinations. The selected genotypes were crossed followed line × tester design mating system by applying the experimental method I (without reciprocals) of Savchenko (1984).

The trial was carried out at the Field Crops Institute in Chirpan, in a randomized complete block design with six replications. Each plot with parents and hybrids consisted of one row 2.4 m long with a distance of 0.60 m between rows and 0.20 m within row. Normal cotton growing practices in our country were applied during the growing season. The traits under study were productivity per plant (yield of seed cotton plant^{-1}), boll weight, lint percentage and mean fiber length. For each genotype, five sequentially selected plants from each replication were observed.

Methodology of Savchenko (1984) was applied to evaluate the general combining ability (GCA) and specific combining ability (SCA). The hybrid sum of squares was subdivided into variation due to females, males and the female × male interaction. The main effects of females and males are equivalent to GCA, and the female × male interaction represents SCA (Hallauer & Miranda, 1981).

Heterosis was calculated relative to the better parent:

$$HP = (F_1 – HP)/HP*100\%,$$

where:

HP – High parent (better parent) heterosis (heterobeltiosis);

F_1 – Mean of F_1 hybrids.

Results and Discussion

Analysis of variance showed that the mean squares of crosses were significant for all traits under study indicating the presence of variability among hybrids (Table 1).

GCA of female parents and GCA of male parents were significant for all traits, except for GCA of male parents for fiber length. SCA effects were also significant for all traits. Conseguently, additive and non-additive gene effects were important for the inheritance of studied traits which supports the conclusions of other researchers (Ashokkumar et al., 2010; Azam et al., 2013; Swami et al., 2013; Memon et al., 2017) that in line × tester analyses both additive variance and non-additive variance were important and involved in the control of seed cotton yield and its components.

Calculated variances of GCA and SCA for productivity per plant were: σ^2_{GCA}= 0.201; σ^2_{SCA}= 2.39. Preponderance of non-additive variance over additive variance $\sigma^2_{GCA} < \sigma^2_{SCA}$ revealed that non-additive genetic variance was more important in the inheritance of productivity per plant. Our results were similar to those of Basal et al. (2009), Senthilkumar et al. (2010), Karademir et al. (2016), Sajjad et al. (2016), Sivia et al. (2017), Munir et al. (2017), Çoban & Ünay (2017), Roy et al. (2018), Ali et al. (2018) who also have reported predominance of non-additive gene effects for seed cotton yield in interspecific (*G. hirsutum* × *G. barbadense*) and intraspecific line × tester crosses. Khan (2013), Baloch (2014), Usharani et al. (2014) have reported similar results seed cotton yield was more strongly influenced by non-additive gene effects in diallel crosses.

The contribution of σ^2_{GCA} and σ^2_{SCA} to the genetic variance of boll weight, lint percentage and fiber length reveals that non-additive gene effects were also of greater importance in the inheritance of these traits, $\sigma^2_{GCA} < \sigma^2_{SCA}$ confirming non-additive type of gene action.

In research conducted by Baloch (2014) GCA was non-significant for boll weight, lint percentage and staple length. SCA was significant for all traits revealing a greater role of non-additive gene action than additive one in inheritance of these traits in diallel crosses, which is consistent with our results. Non-additive type of gene action for boll weight was reported in a previous study by Khan & Hassan (2011) in diallel crosses. Rasheed et al. (2014) reported non-additive type of gene action for lint percentage also in diallel crosses. Khan et al. (2017) reported greater importance of non-additive gene effects for fiber length in diallel crosses, Çoban & Ünay (2017), Roy et al. (2018) in *G. hirsutum* × *G. barbadense* crosses. Patel et al. (2014) (in *G. hirsutum* × *G. barbadense* crosses), Bölek et al. (2014), Munir et al. (2018) (in intra- and interspecific crosses), Ali et al. (2018) (in 8 × 3 line × tester) reported non-additive gene action in the inheritance of fiber length and lint percentage.

The results of our study differed from those of other authors who found that additive effects were more important for the inheritance of studied traits. Preponderance of additive effects in the inheritance of seed cotton yield and boll weight was reported by Patel et al. (2014) in interspecific *G. hirsutum* L. and *G. barbadense* L. crosses, Chapepa et al. (2015) in diallel crosses. Other researchers Akiscan & Gencer (2014), Rasheed et al. (2014) (in diallel crosses), De Carvalho et al. (2018), Ekinci & Basbag (2018) (in *G. hirsutum* L. × *G. barbadense* crosses) have reported that additive genetic effects were predominant in the inheritance of fiber length. Studies of Vasconcelos et al. (2018) demonstrated predominance of additive gene action for seed cotton yield, boll weight and lint percentage in diallel analysis in *G. hirsutum* crosses.

The SCA is important for hybrid crop exploitation while the GCA is practicable for hybridization and selection programs (Samreen et al., 2008; Jatoi et al., 2011; Sajjad et al., 2016).

Estimates of GCA effects for female parents and male parents are given in Table 2. Among females Viki and Denitsa varieries showed high GCA for productivity per plant. Rumi variety having the highest productivity had non-significant negative GCA. Boyana variety having the highest boll weight had the highest GCA for this trait. Vicky and Denitsa varieties also had positive GCA for boll weight. Viki variety had the highest GCA for lint percentage. Denitsa and Rumi varieties, the second one with the highest value, also had positive GCA for this trait. Avangard-264, Natalia, Col-

Table 1. Analysis of combining ability variance for productivity per plant, boll weight, fiber length and lint percentage in F_1 hybrids of 8 Bulgarian (females) and 3 foreign (males) cotton varieties

Source of variation	Degree of freedom	Sum of squares	Mean square	F-experienced
		Productivity /plant, g		
Crosses	23	1189.37	51.71	24.87**
Errors	72	149.68	2.078	
GCA – females	7	68.043	9.720	28.054**
GCA – males	2	24.850	12.425	35.860**
SCA	14	105.338	7.524	21.715**
Error	24		0.346	
Variance components	σ^2_{GCA}= 0.201; σ^2_{SCA}=2.393			
	F= 0 σ^2_A *= 0.804,* σ^2_D *= 9.572; F = 1* σ^2_A *= 0.402,* σ^2_D *= 2.393*			
Boll weight, g				
Crosses	23	15.44	0.671	14.011**
Errors	72	3.45	0.048	
GCA – females	7	1.423	0.203	25.452**
GCA – males	2	0.162	0.081	10.176**
SCA	14	0.988	0.070	8.836**
Error	24		0.007	
Variance components	σ^2_{GCA}= 0.008; σ^2_{SCA}= 0.021			
	F = 0 σ^2_A *= 0.032,* σ^2_D *= 0.084; F = 1* σ^2_A *= 0.016,* σ^2_D *= 0.021*			
Lint percentage, %				
Crosses	23	236.86	10.298	54.987**
Errors	72	13.48	0.187	
GCA – females	7	7.320	1.046	33.503**
GCA – males	2	15.910	7.955	254.857**
SCA	14	16.223	1.159	37.123**
Error	24		0.031	
Variance components	σ^2_{GCA}= 0.102; σ^2_{SCA}= 0.376			
	F = 0 σ^2_A *= 0.408,* σ^2_D *= 1.504; F = 1* σ^2_A *= 0.204,* σ^2_D *= 0.376*			
Fiber length, mm				
Crosses	23	56.28	2.447	7.242**
Errors	72	24.33	0.338	
GCA – females	7	5.303	0.757	13.452**
GCA – males	2	0.162	0.081	1.439ns
SCA	14	3.908	0.279	4.957**
Error	24		0.056	
Variance components	σ^2_{GCA}= 0.024; σ^2_{SCA}= 0.074			
	F = 0 σ^2_A *= 0.096,* σ^2_D *= 0.296; F = 1* σ^2_A *= 0.048,* σ^2_D *= 0.074*			

P > 0.05 – non significant; P < 0.05 – *; P < 0.01 – **

orit and Boyana varieties had positive and significant GCA effects for fiber length, the largest for the first two varieties. From the specialized literature is known that GCA is due to additive gene action, while SCA is due to non-additive dominant and epistatic genes controlling traits (Baloch et al., 2014; Sajjad et al., 2015). Additive effects of genes are more important than non-additive effects for the genetic improvement of traits, so varieties having high GCA are considered to have most additive genes and in case of high mean performance they are most valuable for hybridization and pedigree breeding. In the presence of high GCA effects the trait is inherited more stably and the selection can be applied in the earlier hybrid generations.

Boyana variety had positive GCA for two traits – boll weight and fiber length, Viki and Denitsa varieties had positive GCA for three traits – productivity per plant, boll weight and lint percentage. These varieties could be used as potential parents in hybridization programs for simultaneous improvement of two and three traits, respectively.

Of the male parents, the Turkish cultivar Nazili 954, having the highest productivity per plant, had positive GCA for this trait. The other two cultivars the Spanish FR-H-1001 and the Greek Millennium, having high lint percentage had positive and high GCA for it. The cultivar Millennium had the highest GCA for lint percentage and boll weight and positive but non-significant for fiber length.

Estimates of SCA for each individual cross are given in Table 3. Positive SCA effects on productivity per plant were found in 8 crosses. The hybrids Avangard-264 × FR-H-1001 had the largest positive SCA and the highest better parent heterosis of 50%, but in productiwity per plant they ware inferior to some crosses. Hybrids Denitsa × Nazili 954, Viki × Nazili 954 and Boyana × Nazili 954 having the highest productivity per plant had lower positive SCA effects and exhibited heterosis of 10.8–34.3%. Heterosis over better parent was accounted for in 13 crosses (54.2%) and it ranged from 10.8% to 50.3% and was commensurate with this one reported by other authors in interspecific hybrids.

Patel et al. (2014) in interspecific hybridization of the two tetraploid species *G. hirsutum* and *G. barbadense* reported heterobeltiosis (better parent heterosis) up to 35.49% for seed cotton yield. Positive mid parent heterosis (heterosis over mid parent) for seed cotton yield in this hybridization was reported by Adsare et al. (2017), Rajeev et al. (2018), Tian et al. (2019). Borzan & Guvercin (2021) noted that F_1 hybrids can be more superior from mean of parents (mid parent heterosis) and superior parent (heterobeltiosis) because of the influence of dominant genes.

The best hybrids for productivity were obtained from the crosses of Viki, Denitsa and Boyana varieties as female parents with the cultivar Nazili 954 as male parent, all having high GCA effects for productivity per plant. The hybrids Viki × Nazili 954, Denitsa × Nazili 954 and Boyana × Nazili 954 exhibited high mean performance with positive SCA effects and heterosis over better parent 10.8–34.3%.

Viki and Denitsa varieties having high GCA for productivity per plant had relatively low variances of SCA ($\sigma^2 s_i$), which means that their high GCA effects were mainly due to additive gene action and they are suitable for recombinant selection. The cultivar Nazili 954 had high SCA variances

Table 2. Evaluation of GCA effects on productivity per plant, boll weight, fiber length and lint percentage in F_1 hybrids of 8 Bulgarian (females) and 3 foreign (males) cotton varieties

Parent forms	Productivity per plant		Boll weight		Lint percentage		Fiber length	
	Mean g	GCA	Mean g	GCA	Mean %	GCA	Mean mm	GCA
Females	Females							
Avanfard-264	18.3	-1.816	5.2	-0.182	37.1	0.103	26.7	0.711
Natalia	18.2	-0.466	5.1	-0.126	39.3	-0.714	26.1	0.511
Colorit	22.9	-2.121	5.0	-0.249	37.6	-0.403	25.4	0.200
Rumi	33.5	-0.010	5.0	-0.171	39.4	0.175	26.2	-0.089
Nelina	21.5	0.401	4.8	-0.009	38.5	-0.069	26.0	-0.400
Boyna	23.4	-1.044	5.4	0.529	38.9	-0.514	27.3	0.267
Viki	28.7	1.967	5.1	0.185	37.5	1.186	26.1	-0.622
Denitsa	23.9	3.089	5.1	0.107	38.6	0.208	26.1	-0.578
Standard error		0.481		0.073		0.144		0.194
Males	Males							
Nazili 954	18.8	1.439	5.3	0.003	38.7	-1.071	25.9	-0.003
FR-H-1001	12.5	-0.738	5.1	0.008	40.5	0.169	25.5	-0.099
Millennium	17.8	-0.701	4.9	0.114	40.8	0.902	26.3	0.101
Standard error		0.294		0.045		0.088		0.119

Table 3. Estimation of SCA effects ($_{Sij}$) and variances ($\sigma^2 s_i$; $\sigma^2 s_j$) for productivity per plant, boll weight, lint percentage and fiber length in F_1 hybrids of 8 Bulgarian (females) and 3 foreign (males) cotton varieties

Male parents	Nazili954			FR-H-1001			Millennium			σ^2_{Si}
Female parents	Mean	SCA	HP%	Mean	SCA	HP%	Mean	SCA	HP%	
	Productivity per plant									
Avangard	20.5	-4.861	109.0	27.5	4.332	150.3	23.7	0.528	129.5	21.139
Natalia	25.8	-0.861	137.2	23.2	-1.317	127.5	26.7	2.178	146.7	3.409
Colorit	24.4	-0.605	106.6	23.9	1.004	104.4	22.5	-0.399	98.3	0.565
Rumi	26.6	-0.550	79.4	25.5	0.560	76.1	25.0	-0.010	74.6	0.106
Nelina	26.9	-0.694	125.1	26.9	1.516	125.1	24.6	-0.821	114.4	1.525
Boyna	29.2	3.050	124.8	19.3	-4.606	82.5	25.5	1.556	109.0	16.269
Viki	31.8	2.672	110.8	25.7	-1.286	89.5	25.6	-1.388	89.2	5.156
Denitsa	32.1	1.850	134.3	27.9	-0.206	116.7	26.5	-1.643	110.9	2.881
MD		0.613			0.613			0.613		
σ^2_{Sj}		6.282			6.517			1.642		
	Boll weight									
Avangard	5.1	0.019	96.2	5.2	0.011	100.0	4.9	-0.031	94.2	-0.003
Natalia	5.2	0.030	98.1	5.2	0.022	102.0	5.0	-0.052	98.0	-0.002
Colorit	5.1	0.019	96.2	5.1	0.044	100.0	4.8	-0.063	96.0	-0.001
Rumi	5.3	0.175	100.0	5.1	-0.033	100.0	4.8	-0.142	96.0	0.021
Nelina	5.1	-0.036	96.2	5.3	0.022	103.9	5.2	0.114	106.1	0.011
Boyna	5.9	0.075	109.3	5.4	-0.433	100.0	6.0	0.358	111.1	0.156
Viki	5.0	-0.445	94.3	6.0	0.511	117.6	5.3	-0.064	103.9	0.228
Denitsa	5.5	0.262	103.8	5.3	0.144	103.9	5.1	0.115	100.0	0.048
MD		0.093			0.093			0.093		
σ^2_{Sj}		0.142			0.061			0.022		
	Lint percentage									
Avangard	37.4	-0.718	96.6	40.0	0.676	98.8	41.0	0.042	98.3	0.469
Natalia	37.0	-0.307	34.1	38.2	-0.280	94.3	39.8	0.581	97.5	0.240
Colorit	37.4	-0.185	96.6	38.3	-0.524	94.6	40.3	0.709	98.8	0.388
Rumi	39.7	1.504	100.8	39.4	-0.019	97.3	38.7	-1.485	94.9	2.216
Nelina	37.7	-0.251	97.4	38.1	-1.058	94.1	41.2	1.309	101.0	1.429
Boyna	37.3	-0.174	95.9	39.9	1.153	98.5	38.5	-0.980	94.4	1.142
Viki	40.2	1.060	103.9	40.5	0.087	100.0	40.0	-1.146	98.0	1.204
Denitsa	37.3	-0.929	96.4	39.4	-0.035	97.3	41.1	0.964	100.7	0.879
MD		0.184			0.184			0.184		
σ^2_{Sj}		0.694			0.449			1.121		
	Fiber length									
Avangard	27.6	0.481	103.4	27.5	0.476	103.0	26.3	-0.957	98.5	0.654
Natalia	26.8	-0.119	102.7	26.5	-0.324	101.5	27.5	0.443	104.6	0.125
Colorit	26.6	0.025	102.7	26.3	-0.213	103.1	26.9	0.187	102.3	0.007
Rumi	26.4	0.114	100.8	26.1	-0.090	99.6	26.4	-0.024	100.4	-0.002
Nelina	25.1	-0.542	96.5	26.6	0.721	102.3	25.9	-0.179	98.5	0.390
Boyna	26.5	-0.208	97.1	26.5	-0.113	97.1	27.1	0.321	99.3	0.046
Viki	26.1	0.347	100.0	25.8	0.110	98.9	25.4	-0.457	96.6	0.138
Denitsa	25.7	-0.097	98.5	25.2	-0.568	96.6	26.3	0.665	100.0	0.355
MD		0.247			0.247			0.247		
σ^2_{Sj}		0.071			0.146			0.243		

($\sigma^2 s_j$), which means that its high GCA effects were due to both additive gene effects and non-additive specific interaction of genes and it can be recommended for heterosis selection.

Parents having high GCA with high or low SCA variances can be used as donors in recombinant selection. Dominant effects decrease in generations with increasing the homozygosity moreover, in crosses with high SCA effects occurrence of transgressive variability is possible, very useful for accelerating the selection process.

Positive SCA effects on boll weight were found in 8 crosses. The hybrids Boyana × Nazili 954, Viki × FR-H-1001 and Boyana × Millennium were the best showed high mean values with high SCA effects and heterosis of 9.3% to 17.6%. From the parent forms, Viki variety and the cultivar Nazili 954 had high GCA with high SCA variances, which means they are suitable for heterosis selection.

Positive SCA effects on lint percentage were found in 9 crosses. Heterosis of 3.9% was found only in one cross, which is consistent with that by Karademir & Gencer (2010) who reported heterosis level of 5.52% in only one cross among studied diallel crosses.

In hybrids having high lint percentage with high and positive SCA effects only one or both parents had high and positive GCA. In the crosses Viki × Millennium and Denitsa × Millennium both parents had high GCA, while in the others Rumi × Nazili 954, Viki × Nazili 954, Avangard-264 × FR-H-1001, Boyana × FR-H-1001, Natalia × Millennium and Colorit × Millennium only one of the parents had high GCA. Similar results have been reported by Sivia et al. (2017), Vasconcelos et al. (2018), Roy et al. (2018) that cross combinations with significant SCA involved at least one parent with high or average GCA effects for a particular trait.

Viki variety and the cultivar FR-H-1001 having high GCA for lint percentage had low SCA variances and they are very suitable for synthetic selection. Rumi variety and the cultivar Millennium having high GCA for this trait had high variances of SCA and they are more suitable for heterosis selection.

The crosses Nelina × Millennium, Denitsa × Millennium and Avangard-264 × Millennium were the best for lint percentage exhibited high mean values with high and positive SCA effects.

Avangard-264, Natalia and Colorit varieties were created by interspecific hybridization of *G. hirsutum* × *G. barbadense* and had low lint percentage, inherited from the *G. barbadense* species. The crosses Avangard-264 × FR-H-1001, Avangard-264 × Millennium, Natalia × Millennium and Colorit × Millennium had comparatively high lint percentage. Consequently, cultivars developed from the interspecific *G. hirsutum* × G. *barbadense* hybridization when cross with good combiners for lint percentage it may result in strong improvement of this trait.

Positive SCA effects on fiber length were found in 9 crosses, of which three crosses Avangard-264 × Nazili 954, Avangard-264 × FR-H-1001, Natalia × Millennium exhibited weak heterosis of 2.3–4.6% and had higher mean values. In these crosses female forms had high GCA for this trait.

Positive heterosis for fiber length was reported by Bölek et al. (2014), Patel et al. (2014), Roy et al. (2018) in interspecific *G. hirsutum* × *G. barbadense* crosses. Çoban et al. (2015), Çoban & Ünay (2017) in *G. hirsutum* × *G. barbadense* crosses reported mid parent heterosis for fiber length in all cross combinations and it ranged between 2.05% to 16.99%. Usharani et al. (2015) noted maximum positive relative heterosis of 34.82%, heterobeltiosis of 27.41% for 2.5% staple length, in diallel crosses. In heterosis studies conducted by Ekinci & Basbag (2018) among the studied crosses the determined heterosis (Ht) values for fiber length varied from -1.77 to 3.81%, the estimated heterobeltiosis (Hb) values for this trait varied from -7.87% to -0.03%. Heterobeltiosis manifestations for fiber length were reported by Ünay et al. (2018) in interspecific crosses of *G. hirsutum* × *G. barabadense*. Chapara & Madugula (2021) reported heterosis for Upper Half Mean Length (UHML) and mean length in intraspecific line × tester crosses and the highest values were 21.34% and 25.37%, heterobeltiosis for UHML ranged between 7.53 to 20.73%.

Our results showed low level of the estimated heterobeltiosis for fiber length compared to these reported by other authors. In addition to the genotype, the scanty rainfall and and prolonged droughts during the summer months of July and early August, a period of flowering and fruiting, negatively affect fiber length formation under our conditions.

Avangard-264 and Natalia varieties, from the female parents, the cultivars FR-H-1001 and Millennium, from the male parents, having high GCA for fiber length had high SCA variances, which means that they are very suitable for heterosis selection.

The hybrids Avangard-264 × Nazili 954, Avangard-264 × FR-H-1001, Natalia × Millennium, Boyana × Millennium were the best in fiber length having high mean values and high SCA effects.

Some cross combinations exhibited positive SCA effects on two or three traits. The hybrids Viki × Nazili 954 and Avangard-246 × FR-H-1001 had positive SCA effects on productivity per plant, lint percentage and fiber length. Particularly valuable for selection were the hybrids Viki × Nazili 954, Avangard-264 × FR-H-1001, Natalia × Millennium, Colorit × Millennium and Denitsa × Millennium having positive SCA effects on lint percentage and fiber length, which is of great importance for a better combination of the two traits in one genotype.

Research results show that additive gene effects and non-additive gene effects were involved in the inheritance of studied traits. Non-additive variance was predominant over additive variance indicating greater importance of non-additive gene action, which means that selection for these traits will be more effective in later hybrid generations. From the female parents, Viki and Denitsa varieties were identified as good general combiners for productivity per plant and boll weight, Avangard-264, Natalia and Colorit varieties – for fiber length, Rumi, Viki and Denitsa – for lint percentage, showed positive GCA effects for the relivent traits. From the male parents, Nazili 954 was good combiner for productivity per plant, while FR-H-1001 and Millennium were very good general combiners for lint percentage, Millennium was and for boll weight. Eight hybrid combinations exhibited significant positive SCA effects on productivity per plant, six for boll weight, nine for lint percentage and nine for fiber length. All parents having positive GCA and hybrid combinations exhibited positive SCA are very valuable for breeding programs to create new breeding material and new more productive and better quality cotton varieties.

Conclusions

Additive gene effects and non-additive gene effects were involved in the inheritance of studied traits. The major variance was of non-additive type and the selection in later hybrid generations is more efficient.

Among the female parents, Viki and Denitsa varieties were identified as best general combiners for productivity per plant, Boyana variety for boll weight, Viki variety for lint percentage, Avangard 264 and Natalia varieties for fiber length. All these varieties had high and positive GCA effects on the relivent traits. From the male parents, the Spanish cultivar FR-H-1001 and the Greek cultivar Millennium were identified as best general combiners for lint percentage.

The Bulgarian varieties Viki and Denitsa were determined as good combiners for three traites – productivity per plant, boll weight and lint percentage, the Greek cultivar Millennium – for two traits – productivity per plant and boll weight.

Some parents having high GCA effects had low SCA variances and are more suitable for synthetic selection, others had high SCA variances and are more suitable for heterosis selection. All parental forms having high GCA with low or high SCA variances could be used in synthetic selection.

The best hybrids for enhancing productivity per plant were Viki × Nazili 954, Denitsa × Nazili 954 and Boyana × Nazili 954 showed high mean performance with positive SCA effects and heterosis of 10.8–34.3%.

Hybrid combinations Nelina × Millennium, Denitsa × Millennium and Avangard-264 × Millennium were the best to increase lint percentage, while Avangard-264 × Nazili 954, Avangard-264 × FR-H-1001, Natalia × Millennium, Boyana × Millennium were the best to improved fiber length, exhibiting high mean values and high SCA effects on the relevant trait.

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