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Inheritance, heterosis and combinatorial ability in *G. hirsutum* L. × *G. barbadense* L. interspecific crosses

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Abstract

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Five *G. hirsutum* and three *G. barbadense* (FR-B-201, FR-B-202 and FR-B-203) varietis were included in reciprocal crosses to study the inheritance, heterosis and combining ability of the parent forms for productivity/plant, number of bolls, boll weight, lint percentage and fiber lenght. It was found that the inheritance of productivity/plant was mainly with positive overdominance and independenly of crossing direction, with manifested heterosis from 5.2% to 36.1% and 7.2% to 32.7% respectively, in the crosses with *G. hirsutum* female parent and *G. barbadense* female parent. The inheritance of longer fiber of the *G. barbadense* species was incompletely dominant in some cases with positive overdominance. Genetic control was mainly non-additive for the studied traits, except for lint percentage, it was additive or non-additive depending on the direction of crossing. The variety Chirpan-539 (*G. hirsutum*) was idenfied as good general combiner for productivity and lint percentage, the varieties FR-B-102 and FR-B-103 (*G. barbadense*) were identified as good general combiners for fiber length.

Keywords: cotton; interspecific hybridization; genetic control; heterosis; combining ability

Introduction

Cotton (*Gossypium spp.*) is a major fiber-producing and important oil-producing crop of great importance for the economy of many countries in the world. The genus *Gossypium* L. (*Malvaceae*) includes 45 diploid and 6 tetraploid species (Grover et al., 2015). The two diploid species *G. arboreum* L. and *G. herbaceum* L., which belong to the Old World cotton group, and the two tetraploid species *G. hirsutum* L. and *G. barbadense* L., which belong to the New World cotton group, are grown in the world.

Cultivars from the American allotetraploid species (*G. hirsutum* L. and *G. barbadense* L.) predominate worldwide cotton production and have almost displaced cultivars from the Old World diploid species (*G. arboreum* L. and *G. herbaceum* L.) (Chen et al., 2018). The species *G. hirsutum* L., known as "Upland cotton", is the most widely cultivated cotton species in the world, due to its high lint yield and wide adaptability, and is of primary economic importance in modern world cotton production (Chen et al., 2018; Mehboob-ur-Rahman et al., 2012; Zhang et al., 2015).

Bulgarian cotton varieties form a specific ecological group *Proles Bulgaricum* of the species *Gossypium hirsutum* L. and are distinguished by high earlyness and good productivity, but they have a shorter fiber compared to many foreign varieties (Bozhinov & Dimitrova, 1974). For the selection of cotton in our country, with a view to increasing the fiber length, the hybridization of *G. hirsutum* L. × *G. barbadense* L. species is of greatest interest. The two species are closely related and have the greatest economic importance on a global scale. The species *G. hirsutum* L. is early ripening and high-yielding, and the species *G. barbadense* L. with excellent technological fiber qualities.

Upland cotton, *G. hirsutum*, is known for its high yield potential and wide adaptation, while long extra staple cotton, known as Pima cotton (*G. barbadense*) in the USA, has su-

perior fiber quality, but only grown in semiarid areas in the world (Zhang et al., 2016).

G. barbadense species has lower productivity and limited adaptations to most cotton-growing areas. It includes the famous Egyptian cotton the long extra staple cotton called "Sea-Island", which has the longest and technically most valuable fiber, and Pima cotton (Chaudhry & Guitchounts, 2003). In the process of evolution the two species have become highly specialized in terms of productivity, adoptability and fiber quality. *Gossypium hirsutum* L. evolved to produce a higher fiber yield and to better survive in harsh environments than *Gossypium barbadense*, which produces superior-quality fibers (Hu et al., 2019). Introducing germplasm from *G. barbadense* L. can broaden the genetic base of Upland cotton (Zhang et al., 2016).

Hybridization of the two species is being worked on in many countries with developed cotton production. Valuable forms obtained have been reported by a number of authors. Shiming et al. (2011) observed transgressive segregants for lint percentage, fiber uniformity and fiber maturity, fiber number/seed and fiber weight/seed. Zhang (2011) reported that interspecific crossing between Upland and Pima resulted in the development of high-yielding lines with subokra leaf or cleistagamous flowers, and lines with high fiber quality. Zhang et al. (2016) identified introgression lines possessing high breeding potential for yield and fiber quality improvement and for heterotic hybrids, developed from an interspecific crossing of Upland cotton and *G. barbadense,* and backcrossing.

Many researchers studied the nature of inheritance of the individual most strongly expressed traits and their genetic basis in order to combine the useful traits of both species and construction of the selection strategy (Mingbao et al., 2010; Zhang et al., 2014; Çoban & Ünay, 2017). Development of chromosome-substitution lines is one of the methods to transfer agronomically valuable traits from *G. barbadense* into *G. hirsutum* (Zhang et al., 2014; Zhang et al., 2016; Sanamyan et al., 2022). According to Sanamyan et al. (2022) many new traits are associated with the replacement of chromosomes and chromosome segments. Another effective approach for the introgression of desired genes for fiber quality from Pima (*G. barbadense*) to Upland cotton (*G. hirsutum*) is development and use of introgression lines as parental forms through interspecific crossing and backcrossing between Upland and Pima cotton (Yu et al., 2013; Zhang et al., 2016; Borzan & Guvercin, 2021).

Anwar et al. (2022) noted that crossing with *G. barbadense* led to the development of multiple genetic lines in Upland cotton, but in later hybrid generations, reproductive barriers, strong and prolonged hybrid segregation were observed, making difficult and complicating the introgression of new, stably inherited allelic variation, from interspecific hybridization.

In order to obtain high-quality and high yielding hybrids from the crossing of the two species great attention is paid to studying the degree of heterosis, general and specific combining ability (Çoban et al., 2015; Roy et al., 2018; Rajeev et al., 2018; Malathi et al., 2019). Positive heterosis was found for seed cotton yield (Patel et al., 2014; Adsare et al., 2017; Rajeev et al., 2018), fiber length and fiber strength (Çoban et al., 2015; Çoban & Unay, 2017; Unay et al., 2018). Negative heterobeltiosis was reported for fiber fineness (Gungor & Efe, 2017), boll number and boll weight (Malathi et al., 2019). Extensive research conducted by Li et al. (2022) revealed the mechanism of heterosis in early biomass.

Genetic and QTL modeling of interspecific *G. hirsutum* L. × *G. barbadense* L. populations and QTL data for fiber traits demonstrate that positive effects on all fiber traits are obtained from the presence of alleles from both species, usually leading to transgressive segregation (Furong et al., 2011; Chen et al., 2018).

In our country, studies to clarify the character of traits inheritance in this hybridization were also carried out (Stoilova, 1987; Adetunji, 1997). From the crossing of *G. hirsutum* L. × *G. barbadense* L. the variety Avangard-264, with 3 mm longer fiber than the standard variety Beli Izvor, was obtained (Koynov & Stoilova, 1996).

The objectives of the present research were: (i) to study the inheritance and establish the manifestations of heterosis in productivity and fiber length in interspecific crosses of *G. hirsutum* × *G. barbadense;* (ii) to determine the type of gene action controlling the traits under study in connection with the choice of selection strategy and work with the hybrid generations; (iii) to estimate the general combining ability and specific combining ability of the parental forms and to identify the best general combiners for each trait and the best hybrid combinations for the selection programs; iii) establishing the general combinatory ability and specific combinatory ability of the varieties included in crosses and assessing / estiming their perspective / and an assessment of their perspective as parental components for hybridization and to select the best hybrid / cross combinations for the breeding programs.

Materials and Methods

Three Spanish varieties FR-B-201, FR-B-202 and FR-B-203 from the *G. barbadense* L. species were involved in hybridization with the *G. hirsutum* L. species. From the species *G. hirsutum* L. the varieties Chirpan-539, Helius, Natalia,

Darmi and Boyana (Bulgarian selection) were included. The selected cotton genotypes were crossed in 5 × 3 (*G. hirsutum* × *G. barbadense*) and 3 × 4 (*G. barbadense* × *G. hirsutum*) design mating system by applying the experimental method I of Savchenko (1984).

The parental forms of both species were used as maternal and paternal components, with the exception of Darmi variety, in crosses with the *G. barbadense* female parent. The hybrid populations of 15 direct and 12 reciprocals, a total of 27 crosses, were studied. The inheritance of the economically valuable characters and the selection value of the parental forms were studied. The study was carried out at the Field Crop Institute in Chirpan, in randomized complete block design with three 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 the row. Normal cotton growing practices in our country were applied during the growing season. For each genotype, ten consecutively selected plants from each replication were observed. Data were collected for raw cotton yield (g/plant), boll weight (g), fiber yield (%) and fiber length determined by the „butterfly" method (mm).

The degree of dominance (d/a) was determined (Genchev et al., 1975; Ognyanova, 1975). Heterosis was calculated relative to the better parent. Savchenko's methodology (1984) was applied to evaluate the general combinative ability and the specific combinative ability.

Results and Discussion

Inheritance and heterosis

Varieties of the two species differed greatly in productivity per plant. Productivity per plant in *G. hirsutum* varieties varied from 31.8 g in Natalia variety to 35.3 g in Boyana variety, in *G. barbadebse* varieties it varied from 7.3 g in FR-B 202 to 11.3 g in FR-B 202. In the *G. hirsutum* × *G. barbadense* hybrids the inheritance of productivity/plant was mainly overdominant and independent of the crossing direction (Table 1). Complete and incomplete dominance of the more productive *G. hirsutum* parent was observed in 5 crosses – 3 direct and 2 with *G. barbadense* female parent. In some crosses the productivity was higher with female parent *G. hirsutum*, but there was no pronounced regular character. The overdominant type of inheritance caused heterosis from 5.2% to 36.1% in crosses with the *G. hirsutum* female parent and from 7.2% to 32.7% in crosses with the *G. barbadense* female parent.

In the studies of Patel et al. (2014) the better parent heterosis (heterobeltiosis) for seed cotton yield reached 35.49%. A positive heterosis for seed cotton yield was reported by Adsare et al. (2017), Rajeev et al. (2018).

The combining ability of the parent varieties of the two species was of importance for inheritance and degree of heterosis. Boyana variety, with the highest productivity/plant, and the Darmi variety, the heterosis manifestations were less pronounced or absent, and their productivity was lower compared to the hybrids of the Chirpan-539 and Helius varieties.

The highest productivity/plant (40.0-44.5 g) and the highest heterosis effect (20.2-36.1%) were accounted for the crosses Chirpan-539×FR-B-201, Chirpan-539×FR-B-202, FR-B-201×Chirpan-539, FR-B-202×Chirpan-539, FR-B-202×Helius and FR-B-203×Chirpan-539.

Table 1. Inheritance and heterosis for productivity/plant in the F_1 hybrids *G. hirsutum* × G. *barbadense*

Hybrid combination	P_1	P_2	F_1	d/a	HP %
Productivity, g					
Chirpan-539×FR-B-201	32.7	10.7	44.5	2.07	136.1
Chirpan-539× FR-B-202	32.7	7.3	39.3	1.52	120.2
Chirpan-539×FR-B-203	32.7	11.3	37.7	1.47	115.3
Helius×FR-B-201	33.0	10.7	34.7	1.15	105.2
Helius×FR-B-202	33.0	7.3	36.2	1.25	109.7
Helius×FR-B-203	33.0	11.3	37.7	1.43	114.2
Natalia×FR-B-201	31.8	10.7	32.9	1.10	103.5
Natalia×FR-B-202	31.8	7.3	36.8	1.41	115.7
Natalia×FR-B-203	31.8	11.3	36.3	1.46	115.1
Darmi×FR-B-201	32.6	10.7	33.2	1.05	101.8
Darmi×FR-B-202	32.6	7.3	30.3	0.82	92.9
Darmi×FR-B-203	32.6	11.3	33.3	1.07	102.1
Boyana×FR-B-201	35.3	10.7	38.1	1.23	107.9
Boyana×FR-B-202	35.3	7.3	33.0	0.84	93.5
Boyana×FR-B-203	35.3	11.3	32.0	0.73	90.7
FR-B-201×Chirpan-539	10.7	32.7	41.5	1.80	126.9
FR-B-201×Helius	10.7	33.0	35.9	1.26	108.8
FR-B-201×Natalia	10.7	31.8	34.4	1.25	108.2
FR-B-201×Boyana	10.7	35.3	40.0	1.38	113.3
FR-B-202×Chirpan-539	7.3	32.7	43.4	1.84	132.7
FR-B-202×Helius	7.3	33.0	40.0	1.54	121.2
FR-B-202×Natalia	7.3	31.8	34.1	1.19	107.2
FR-B-202×Boyana	7.3	35.3	39.1	1.27	110.8
FR-B-203×Chirpan-539	11.3	32.7	40.2	1.70	122.9
FR-B-203×Helius	11.3	33.0	31.1	0.82	94.2
FR-B-203×Natalia	11.3	31.8	33.5	1.17	105.3
FR-B-203×Boyana	11.3	35.3	35.0	0.98	99.2
GD 5.0 %; 1.0 %; 0.1 %	3.4; 4.5; 5.9				

The high heterotic effect for productivity/plant was associated with a high heterotic effect for the number of set and retained bolls, and respectively with the number of mature bolls/plant. As a result of better fruiting and retention of a

greater number of bolls, compared to the two species, the F_1 hybrids were distinguished by high fertility (Table 2). The inheritance of mature bolls number/plant in 25 of 27 cross combinations was overdominant with a pronounced heterotic effect of up to 70.2% (data not shown here).

Malathi et al. (2019) reported negative heterosis for bolls number and boll weight. Tyagi et al. (2014), in Upland cotton (*G. hirsutum*), found bolls number to be significant for yield heterosis.

Table 2. Inheritance and heterosis for the number of set and retained bolls per plant in the F_1 hybrids *G. hirsutum* × *G. barbadense*

Hybrid combination	P_1	P_2	F_1	d/a	HP %
Total number of bolls per plant					
Chirpan-539×FR-B-201	5.6	8.5	11.2	2.86	131.8
Chirpan-539× FR-B-202	5.6	5.3	10.1	31.00	180.4
Chirpan-539×FR-B-203	5.6	3.9	8.9	4.88	158.9
Helius×FR-B-201	7.4	8.5	9.1	2.09	107.1
Helius×FR-B-202	7.4	5.3	8.6	2.14	116.2
Helius×FR-B-203	7.4	3.9	10.1	2.54	136.5
Natalia×FR-B-201	6.0	8.5	8.9	1.32	104.7
Natalia×FR-B-202	6.0	5.3	7.9	6.43	131.7
Natalia×FR-B-203	6.0	3.9	7.7	2.62	128.3
Darmi×FR-B-201	5.6	8.5	7.4	0.24	87.1
Darmi×FR-B-202	5.6	5.3	8.9	23.00	158.9
Darmi×FR-B-203	5.6	3.9	9.8	5.94	175.0
Boyana×FR-B-201	7.8	8.5	9.7	4.43	114.1
Boyana×FR-B-202	7.8	5.3	8.2	1.32	105.1
Boyana×FR-B-203	7.8	3.9	8.6	1.41	110.3
FR-B-201×Chirpan-539	8.5	5.6	12.0	3.41	141.2
FR-B-201×Helius	8.5	7.4	8.7	1.36	102.4
FR-B-201×Natalia	8.5	6.0	8.6	1.08	101.2
FR-B-201×Boyana	8.5	7.8	9.6	4.14	112.9
FR-B-202×Chirpan-539	5.3	5.6	8.4	19.67	150.0
FR-B-202×Helius	5.3	7.4	11.2	4.62	151.4
FR-B-202×Natalia	5.3	6.0	11.4	16.43	190.0
FR-B-202×Boyana	5.3	7.8	9.5	2.36	121.8
FR-B-203×Chirpan-539	3.9	5.6	7.7	3.47	137.5
FR-B-203×Helius	3.9	7.4	10.2	2.60	137.8
FR-B-203×Natalia	3.9	6.0	7.9	2.81	131.7
FR-B-203×Boyana	3.9	7.8	8.3	1.26	106.4
GD 5.0 %; 1.0 %; 0.1 %	2.5; 3.3; 4.5				

The boll weight is also one of the elements directly related to productivity. The *G. hirsutum* varieties had a boll weight of 5.4–6.0 g, while the *G. barbadense* varieties had a boll weight of 2.4–3.7 g. In most cases hybrids inherited this trait additively and with incomplete dominance of the parent with higher value of the *G. hirsutum* species (Table 3). Incomplete dominance of the smaller boll of the species *G. barbadense* was observed in 4 crosses. In the reciprocal crosses of the Chirpan-539 and Helius cultivars, the boll weight was on average 0.2 g greater in the direct crosses with female parents these cultivars. In other cases differences depending on the crossing direction were not found. The results obtained confirmed the intermediate character of inheritance of this trait (Stoilova, 1987; Adetunji, 1997).

Table 3. Inheritance of boll weight in the F_1 hybrids *G. hirsutum* × *G. barbadense*

Hybrid combination	P_1	P_2	F_1	d/a	HP %
Boll weight. g					
Chirpan-539×FR-B-201	5.4	3.7	5.1	0.65	94.4
Chirpan-539×FR-B-202	5.4	2.4	4.4	0.33	81.5
Chirpan-539×FR-B-203	5.4	2.9	4.7	0.44	87.0
Helius×FR-B-201	5.6	3.7	5.2	0.58	92.9
Helius×FR-B-202	5.6	2.4	4.9	0.56	87.5
Helius×FR-B-203	5.6	2.9	4.6	0.26	82.1
Natalia×FR-B-201	5.6	3.7	4.4	-0.26	78.6
Natalia×FR-B-202	5.6	2.4	4.4	0.44	83.9
Natalia×FR-B-203	5.6	2.9	4.4	0.11	78.6
Darmi×FR-B-201	6.0	3.7	4.6	-0.22	76.7
Darmi×FR-B-202	6.0	2.4	4.6	0.22	76.7
Darmi×FR-B-203	6.0	2.9	4.3	-0.10	71.7
Boyana×FR-B-201	5.9	3.7	4.8	0.00	81.4
Boyana×FR-B-202	5.9	2.4	4.4	0.14	74.6
Boyana×FR-B-203	5.9	2.9	4.6	0.13	78.0
FR-B-201×Chirpan-539	3.7	5.7	4.5	-0.20	78.9
FR-B-201×Helius	3.7	5.6	5.0	0.37	89.3
FR-B-201×Natalia	3.7	5.6	5.0	0.37	89.3
FR-B-201×Boyana	3.7	5.9	4.8	0.00	81.4
FR-B-202×Chirpan-539	2.4	5.4	4.4	0.33	81.5
FR-B-202×Helius	2.4	5.6	4.5	0.31	80.4
FR-B-202×Natalia	2.4	5.6	4.2	0.13	75.0
FR-B-202×Boyana	2.4	5.9	4.8	0.37	81.4
FR-B-203×Chirpan-539	2.9	5.4	4.5	0.28	83.3
FR-B-203×Helius	2.9	5.6	4.5	0.19	80.4
FR-B-203×Natalia	2.9	5.6	4.3	0.04	76.8
FR-B-203×Boyana	2.9	5.9	4.5	0.07	76.3
GD 5.0 %; 1.0 %; 0.1 %	0.4; 0.5; 0.6				

As for lint percentage the inheritance was with negative overdominance in 12 out of 27 crosses, incomplete and complete dominance of the lower lint percentage parent of the *G. barbadense* species – in 3 crosses or of the higher parent of the G. hirsutum species – in 11 crosses, and with positive overdominance in one cross (Table 4). The crossing direction was also of importance for its inheritance. In the hybrids with *G. barbadense* female parent the lint percent-

age was lower, 7 out of 12 crosses (58.3%) showed negative overdominance for this trait. The F_1 hybrids from the crosses Helius×FR-B-201 (39.2%), Chirpan-539×FR-B-203 (38.8%) had the highest lint percentage showing complete and incomplete dominant inheritance of the high parent, and Boyana×FR-B-203 (38.6%) with overdominant inheritance and manifested heterosis of 1.8%.

Table 4. Inheritance and heterosis for lint percentage in the F_1 hybrids *G. hirsutum* × *G. barbadense*

Hybrid combination	P_1	P_2	F_1	d/a	HP %
Lint percentage, %					
Chirpan-539×FR-B-201	39.0	33.6	38.3	0.74	98.2
Chirpan-539× FR-B-202	39.0	33.4	38.4	0.79	98.5
Chirpan-539×FR-B-203	39.0	33.1	38.8	0.93	99.5
Helius×FR-B-201	39.3	33.6	39.2	0.96	99.7
Helius×FR-B-202	39.3	33.4	36.5	0.05	92.9
Helius×FR-B-203	39.3	33.1	37.0	0.26	94.1
Natalia×FR-B-201	39.6	33.6	37.5	0.30	94.7
Natalia×FR-B-202	39.6	33.4	38.1	0.52	96.2
Natalia×FR-B-203	39.6	33.1	37.9	0.48	95.7
Darmi×FR-B-201	38.8	33.6	37.7	0.58	97.2
Darmi×FR-B-202	38.8	33.4	37.1	0.37	95.6
Darmi×FR-B-203	38.8	33.1	35.4	-0.19	91.2
Boyana×FR-B-201	37.9	33.6	37.7	0.91	99.5
Boyana×FR-B-202	37.9	33.4	37.8	0.96	99.7
Boyana×FR-B-203	37.9	33.1	38.6	1.29	101.8
FR-B-201×Chirpan-539	33.9	39.0	37.8	0.53	96.9
FR-B-201×Helius	33.6	39.3	37.5	0.37	95.4
FR-B-201×Natalia	33.6	39.6	37.5	0.30	94.7
FR-B-201×Boyana	33.6	37.9	36.8	0.49	97.1
FR-B-202×Chirpan-539	33.4	39.0	36.5	0.11	93.6
FR-B-202×Helius	33.4	39.3	36.1	-0.08	91.9
FR-B-202×Natalia	33.4	39.6	35.2	-0.42	88.9
FR-B-202×Boyana	33.4	37.9	35.3	-0.16	93.1
FR-B-203×Chirpan-539	33.1	39.0	38.1	0.69	97.7
FR-B-203×Helius	33.1	39.3	37.2	0.32	94.7
FR-B-203×Natalia	33.1	39.6	36.7	0.11	92.7
FR-B-203×Boyana	33.1	37.9	36.8	0.54	97.1
GD 5.0 %; 1.0 %; 0.1 %	1.3; 1.7; 2.3				

In terms of fiber length the parent with the higher value of the *G. barbadense* species incompletely dominated (Table 5). In individual cases inheritance was additive or with positive overdominance. The F_1 hybrids had a fiber length of 30.1–34.5 mm by 2.5 mm to 8.2 mm longer than that of the parental cultivars of the *G. hirsutum* species. The hybrids from the crosses Chirpan-539 × FR-B-203, FR-B-202 × Chirpan-539, FR-B-202 × Natalia, FR-B-203 × Natalia, FR-B-203× Boyana had the longest fiber of 34.3–34.5 mm and manifested heterosis of 2.1–3.0% followed by Helius × FR-B-203, Natalia × FR-B-203, Darmi × FR-B-203, FR-B-202 × Boyana – 33.3–33.6 mm showed complete dominant inheritance. Çoban et al. (2015; 2017) reported positive mid parent heterosis for all cross combinations from 2.05 to 16.99%. Positive heterosis for fiber length was reported by Bölek et al. (2014), Unay et al. (2018).

Cases of overdominance were observed in both directions of crossing more often in the crosses with *G. barbadense* female parent – in 5 crosses, while in these with the *G. hirsutum* female parent – in only one crosses. In most cases, hybrids with the female parent *G. barbadense* species formed a longer fiber, in 8 out of 12 crosses. In the research of Stoilova (1987) the *G. barbadense* cultivars fiber length was of importance in obtaining hybrids with longer fiber. In our study the cultivars of this species did not differ in fiber length. Of the *G. hirsutum* parental forms Natalia variety had the lon-

Table 5. Inheritance and heterosis for fiber length in the F_1 hybrids *G. hirsutum* × *G. barbadense*

Hybrid combination	P_1	P_2	F_1	d/a	HP %
Fiber length, mm					
Chirpan-539×FR-B-201	26.3	33.6	31.1	0.32	92.6
Chirpan-539× FR-B-202	26.3	33.7	30.1	0.03	89.3
Chirpan-539×FR-B-203	26.3	33.5	34.3	1.22	102.4
Helius×FR-B-201	27.1	33.6	30.5	0.05	90.8
Helius×FR-B-202	27.1	33.7	32.3	0.58	95.8
Helius×FR-B-203	27.1	33.5	33.4	0.97	99.7
Natalia×FR-B-201	29.2	33.6	31.7	0.14	94.3
Natalia×FR-B-202	29.2	33.7	32.3	0.38	95.8
Natalia×FR-B-203	29.2	33.5	33.6	1.05	100.3
Darmi×FR-B-201	27.8	33.6	32.2	0.52	95.8
Darmi×FR-B-202	27.8	33.7	32.8	0.69	97.3
Darmi×FR-B-203	27.8	33.5	33.3	0.93	99.4
Boyana×FR-B-201	26.3	33.6	32.6	0.73	97.0
Boyana×FR-B-202	26.3	33.7	31.7	0.46	94.1
Boyana×FR-B-203	26.3	33.5	32.1	0.61	95.8
FR-B-201×Chirpan-539	33.6	26.3	31.8	0.51	94.6
FR-B-201×Helius	33.6	27.1	30.9	0.17	92.0
FR-B-201×Natalia	33.6	29.2	31.4	0.00	93.5
FR-B-201×Boyana	33.6	26.3	31.0	0.29	92.3
FR-B-202×Chirpan-539	33.7	26.3	34.5	1.22	102.4
FR-B-202×Helius	33.7	27.1	31.8	0.42	94.4
FR-B-202×Natalia	33.7	29.2	34.4	1.31	102.1
FR-B-202×Boyana	33.7	26.3	33.6	0.97	99.7
FR-B-203×Chirpan-539	33.5	26.3	33.0	0.86	98.5
FR-B-203×Helius	33.5	27.1	32.8	0.78	97.9
FR-B-203×Natalia	33.5	29.2	34.5	1.47	103.0
FR-B-203×Boyana	33.5	26.3	34.4	1.25	102.7
GD 5.0 %; 1.0 %; 0.1 %	1.1; 1.5; 1.9				

gest fiber, but hybrids with this variety did not show greater fiber length. The fiber length increased the most, compared to parental form of the *G. hirsutum* species, in the reciprocal crosses of the Chirpan-539 cultivar and Boyana variety, on average by 5.5–5.8 mm in the direct crosses and 6.7-6.8 mm in the reciprocal ones, which was probably due to their better combining ability with the *G. barbadense* varieties.

Combining ability in the G. hirsutum L. x G. barbadense L. hybrids (female parent G. hirsutum)

Analysis of the combining ability variance in the hybrids with the *G. hirsutum* female parent showed significant differences in the GCA of the maternal forms and the SCA for the productivity/plant and lint percentage, the paternal forms had insignificant GCA for both characters (Table 6). Significant differences in the GCA of the paternal forms and SCA were observed for the fiber length, the GCA of the maternal forms was insignificant. The presence of significant GCA and SCA variances (for the productivity, fiber length and lint percentage) shows that additive and non-additive gene effects were important for their inheritance. For the boll weight the GCA variances of female and male parents were significant, the SCA effects were insignificant, and for the number of matured bolls only GCA of female parents was significant.

The contribution of σ^2_{GCA} and σ^2_{SCA} to the genetic variance of productivity/plant reveales that non-additive gene effects were of greater importance for its inheritance, which is consistent with that reported by Basal et al. (2009), Munir et al.

Table 6. Analysis of variance of combining ability for productivity, boll number and boll weight, fiber length and lint percentage in the F_1 hybrids of *G. hirsutum* × *G. barbadense*

Source of variation	Degree of freedom	Sum of squares	Mean square	F-experienced
Productivity /plant				
GCA – female parents	4	110.516	27.629	14.052^{++}
GCA – male parents	2	6.941	3.471	1.765
SCA	8	59.102	7.388	3.757^{+}
Error	15		1.966	
Variance components	σ^2_{GCA}=0.185; σ^2_{SCA}=1.807			
	F=0 σ^2_A=0.740. σ^2_D=7.228; F=1 σ^2_A=0.370. σ^2_D=1.807			
Number of matured bolls				
GCA – female parents	4	5.011	1.253	3.227^{+}
GCA – male parents	2	0.742	0.371	0.955
SCA	8	7.443	0.930	2.396
Error	15		0.388	
Boll weight				
GCA – female parents	4	0.431	0.108	6.074^{++}
GCA – male parents	2	0.300	0.150	8.453^{++}
SCA	8	0.329	0.041	2.317
Error	15		0.018	
Lint percentage				
GCA – female parents	4	10.107	2.527	7.727^{++}
GCA – male parents	2	2.097	1.049	3.207
SCA	8	23.029	2.878	8.803^{++}
Error	15		0.327	
Variance components	σ^2_{GCA}=-0.013; σ^2_{SCA}=0.850			
	F=0 σ^2_A=-0.052. σ^2_D=3.400; F=1 σ^2_A=-0.026. σ^2_D=0.850			
Fiber length				
GCA – female parents	4	1.506	0.376	2.205
GCA – male parents	2	11.006	5.503	32.235^{++}
SCA	8	9.665	1.208	7.077^{++}
Error	15		0.171	
Variance components	σ^2_{GCA}=0.013; σ^2_{SCA}=0.346			
	F=0 σ^2_A=0.052. σ^2_D=1.384; F=1 σ^2_A=0.026. σ^2_D=0.346			

(2017), Çoban & Ünay (2017). In study of Patel et al. (2014) $\sigma^2_{GCA} > \sigma^2_{SCA}$ indicating prepondarance of additive gene effects in inheritance of this trait. Estimates of components σ^2_{GCA} and σ^2_{SCA} for fiber length and lint percentage indicate that non-additive gene effects were also of greater importance for the inheritance of both traits.

Hosseini (2014) in a complete diallel cross with 9 cotton genotypes (*G. hirsutum* × *G. barbadebse*) reported that in the F_1 generation most of the traits were influenced by additive gene action. The lint percentage was controlled by non-additive genes, which is consistent with our results. A non-additive gene action in the inheritance of fiber length and lint percentage was reported by Patel et al. (2014), Bölek et al. (2014), Munir et al. (2017), Roy et al. (2018). Non additive gene effects for fiber length were greater than additive in the study of Çoban & Ünay (2017).

GCA effects for productivity/plant and for number of matured bolls and boll weight in the *G. hirsutum* × *G. barbadense* crosses are presented in Table 7. Of the maternal forms, the cultivar Chirpan-539 had a positive GCA for productivity/plant, the Helius variety had a positive, but insignificant GCA for this trait. The cultivar Chirpan-539 had also a positive GCA for number of matured bolls, Boyana variety had a positive, but insignificant GCA for this trait. As for boll weight positive GCA was found for the Helius variety (significant) and for the cultivar Chirpan-539 (insignificant). From the paternal forms, FR-B-201 had positive GCA effects significant for boll weight and insignificant for productivity per plant, and FR-B-203 had a positive but insignificant GCA for the number of matured bolls. Given that GCA is determined by additively acting genes, it can be considered that the cultivar Chirpan-539 had the highest number of additive genes for the productivity/plant and the number of matured bolls among the maternal forms. From female parents, Helius variety and the cultivar FR-B-201 from male parents, had the most additive genes for the boll weight.

Of the female parent forms, the cultivar Chirpan-539 had positive GCA for lint percentage (Table 8). The varieties Helius, Boyana (from the female parents) and FR-B-201 (from the male parents) had positive but insignificant effects on this trait. From the female parents, the Darmi variety had a weakly significant positive GCA for the fiber length. From the male parents, significant high GCA effects on this trait was found for the cultivar FR-B-203.

In general, parents belonging to *G. hirsutum* species showed good general combining ability for yield and yield components while *G. barbadense* parents found to be good general combiners for fibre quality traits (Patel et al., 2014).

From the evaluations of GCA effects, it is confirmed that the parent forms had a different manifestation of GCA for the fiber length and for the lint percentage. With a positive GCA

Table 7. Evaluation of GCA effects on productivity, number of matured bolls and boll weight in F_1 interspecific hybrids of *G. hirsutum* L. × *G. barbadense* L.

Female parents	GCA	Male parents	GCA
Productivity/plant			
Chirpan-539	4.758	FR-B-201	0.949
Helius	0.458	FR-B-202	-0.611
Natalia	-0.398	FR-B-203	-0.338
Darmi	-3.464		
Boyana	-1.353		
Standard error	1.145		0.887
Number of matured bolls			
Chirpan-539	1.011	FR-B-201	-0.180
Helius	-0.300	FR-B-202	-0.133
Natalia	-0.422	FR-B-203	0.313
Darmi	-0.555		
Boyana	0.267		
Standard error	0.509		0.394
Boll weight			
Chirpan-539	0.122	FR-B-201	0.200
Helius	0.255	FR-B-202	-0.010
Natalia	-0.211	FR-B-203	-0.010
Darmi	-0.133		
Boyana	-0.033		
Standard error	0.109	Standard error	0.084

Table 8. Evaluation of GCA effects on lint percentage and fiber length in F_1 interspecific hybrids of *G. hirsutum* L. × *G. barbadense* L.

Lint percentage				Fiber length			
Female parents	GCA	Male parents	GCA	Female parents	GCA	Male parents	GCA
Chirpan-539	0.980	FR-B-201	0.527	Chirpan-539	-0.333	FR-B-201	-0.847
Helius	0.202	FR-B-202	-0.300	Helius	-0.089	FR-B-202	-0.327
Natalia	-0.309	FR-B-203	-0.227	Natalia	-0.144	FR-B-203	1.173
Darmi	-1.409			Darmi	0.600		
Boyana	0.536			Boyana	-0.033		
St. error	0.467		0.362	St.error	0.337		0.261

for the fiber length, they showed a negative GCA for the lint percentage and vice versa, except the varieties Nataliya (from the female parents) and FR-B-202 (from the male parents) showed an insignificant negative GCA for both traits. Of the female parent forms, cultivar Chirpan-539 had a positive GCA for productivity/plant and its elements – number of matured bolls and boll weight (insignificant) and lint percentage. The variety FR-B-201 from the male parents possessed a positive GCA for productivity/plant (insignificant), boll weight and lint percentage (insignificant). The presence of a significant and high GCA, and an insignificant, but positive GCA, for several traits makes them very valuable for selection.

The effects of SCA on the productivity/plant and its elements are presented in Table 9. There were 6 crosses possessing positive SCA for productivity/plant (for 3 significant and for 3 non-significant). The crosses Chirpan-539×FR-B-201 and Boyana×FR-B-201 had the highest SCA effects and exceeded the more productive *G. hirsutum* parent and showed heterosis of 26.4% and 18.2%. Their high SCA for productivity was associated with positive (non-significant) SCA effects on the number of matured bolls (in Boyana×FR-B-201) and boll weight (in Chirpan-539×FR-B-201). Parental forms with high GCA for productivity/plant (cultivars Chirpan-539 and FR-B-201) had high variances (s^2_i, s^2_j) of SCA and are recommended for obtaining highly productive heterosis hybrids.

Table 9. Evaluation of SCA effects (S_{ij}) and variances ($\sigma^2 s_i$; $\sigma^2 s_j$) on productivity, number and weight of bolls, in F_1 interspecific hybrids of *G. hirsutum* L. × *G. barbadense* L.

Female parents / Male parents	FR-B-201	FR-B-202	FR-B-203	σ^2_{Si}
Productivity per plant				
Chirpan-539	3.029	-0.611	-2.418	6.648
Helius	-2.471	0.622	1.849	3.907
Natalia	-3.382	2.078	1.304	7.680
Darmi	0.018	-1.356	1.338	0.765
Boyana	2.807	-0.733	-2.073	5.308
	MD = 1.355			
σ^2_{Sj}	7.6008	0.8146	3.2149	

There are 7 crosses with a positive SCA effects on lint percentage (significant in 2 and non-significant in 5 crosses) (Table 10). The crosses Helius × FR-B-201 and Boyana × FR-B-203 showed the highest SCA for this trait, the F_1 hybrids exceed the average parental value and were equal to the higher yielding G. hirsutum parent. The parental forms possessing high GCA for lint percentage, the cultivars Chirpan-539 and FR-B-201 (non-significant), had low and high variance of SCA, respectively.

For the fiber length 9 crosses showed positive SCA effects (significant in 2 crosses), the highest values were found for Boyana × FR-B-201 and Chirpan-539 × FR-B-203. The F_1 hybrids from the first cross combination in fiber length were equal to the long-fibered *G. barbadense* parent and from the second one they surpassed it and showed a heterosis effect of 2.4%. The cross combination Boyana × FR-B-201 showed a high SCA for productivity and fiber length. Darmi variety with a high GCA for fiber length from the female parents, had a low variance of SCA and it is suitable for the synthetic selection, while the variety FR-B-203 with a high GCA for thid trait from the male parents, had a high SCA variance and it is suitable for the heterosis selection.

Estimates of the SCA variances of the parental forms possessing high GCA effects on lint percentage and fiber length showed that those of the species *G. hirsutum* had low SCA variances for both traits and their high GCA was mainly determined by additive gene effects which makes them suitable for synthetic selection, while those of the *G. barbadense* species had high SCA variances and their high GCA due to additive and non-additive gene actions and interactions, and they are more suitable for heterosis selection.

Combining ability in hybrids G. barbadense L. x G. hirsutum L. (female parents G. barbadense L.)

Analysis of the combining ability variance in the hybrids from the crosses *G. barbadense* × *G. hirsutum* showed sig-

Table 10. Evaluation of SCA effects (S_{ij}) and variances ($\sigma^2 s_i$; $\sigma^2 s_j$) on lint percentage and fiber length, in F_1 interspecific hybrids of *G. hirsutum* L. × *G. barbadense* L.

Female parents/ Male parents	FR-B-201	FR-B-202	FR-B-203	σ^2_{Si}
Lint percentage				
Chirpan-539	-0.827	0.967	-0.140	0.644
Helius	2.718	-1.555	-1.162	5.404
Natalia	-0.838	0.555	0.282	0.371
Darmi	0.462	0.655	-1.118	0.772
Boyana	-1.515	-0.622	2.138	3.453
	MD = 0.552			
σ^2_{Sj}	2.646	0.945	1.643	
Fiber lenth				
Chirpan-539	0.113	-1.373	1.260	1.652
Helius	-0.731	0.582	0.149	0.357
Natalia	-0.975	0.571	0.404	0.630
Darmi	0.247	0.360	-0.607	0.188
Boyana	1.347	-0.140	-1.204	1.553
	MD = 0.399			
σ^2_{Sj}	0.752	0.584	0.808	

nificant differences in GCA for female parents and male parents, and SCA, for lint percentage and fiber length (Table 11). In terms of productivity/plant, the GCA effects of female and male parents were significant, the SCA effects were non-significant. Regarding the boll weight, only the GCA effects of the female parents were significant, the GCA of the male parents and the SCA effects were non-significant. Therefore, the female parents – varieties of the *G. barbadense* species differed in GCA by 4 traits, and the male parents – the varieties of the *G. hirsutum* species – by 3 traits.

The ratio of the genetic components $\sigma^2_{GCA}/\sigma^2_{SCA}$ show that the additive variance was more important for lint percentage, and the non-additive one – for fiber length.

In the cross direction *G. barbadense* L. × *G. hirsutum* L., the *G. barbadense* parents showed significant GCA effects for a greater number of traits (4 pieces), compared to the direct crosses used as male parents (2 pieces). The GCA of *G. barbadense* cultivars, used as female parents, in addition to boll weight and fiber length being significant in straight crosses (where they were used as male parents), was also significant for productiviy per plant and lint percentage, but insignificant in direct crosses.

The GCA for the number of bolls of the *G. barbadense* cultivars used as female and male parents was non-significant.

The GCA of *G. hirsutum* cultivars, used as male parents, except for the productivity per plant and lint percentage (significant in the direct crosses, where they were used as female parents), it was also significant for fiber length.

In direct crosses, GCA of the maternal forms (*G. hirsutum*) was significant for 4 traits, of the male parents (*G. barbadense*) it was significant for two traits.

Table 11. Analysis of combining ability variance for productivity, number of bolls, boll weight, lint percentage and fiber length in F_1 hybrids *G. barbadense* L. × *G. hirsutum* L.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-experienced
Productivity				
GCA – female parents	2	37.361	18.681	11.058^{++}
GCA – male parents	3	100.563	33.521	19.843^{++}
SCA	6	22.018	3.670	2.172
Error	12		1.689	
Number of bolls				
GCA – female parents	2	5.406	2.703	3.010
GCA – male parents	3	1.344	0.448	0.499
SCA	6	16.670	2.778	3.094
Error	12		0.898	
Boll weght				
GCA – female parents	2	0.345	0.172	9.922^{++}
GCA – male parents	3	0.114	0.0381	2.195
SCA	6	0.264	0.044	2.536
Error	12		0.017	
Lint percentage				
GCA – female parents	2	11.352	5.676	54.364^{+++}
GCA – male parents	3	2.682	0.894	8.562^{+++}
SCA	6	3.156	0.526	5.039^{++}
Error	12		0.104	
Variance components	σ^2_{GCA}=0.044; σ^2_{SCA}=0.009			
	F=0 σ^2_A=0.176. σ^2_D=0.036; F=1 σ^2_A=0.088. σ^2_D=0.009			
Fiber length				
GCA – female parents	2	14.956	7.478	59.514^{+++}
GCA – male parents	3	4.319	1.440	11.459^{+++}
SCA	6	3.332	0.555	4.420^{+}
Error	12		0.126	
Variance components	σ^2_{OKC}=0.065; σ^2_{CKC}=0.143			
	F=0 σ^2_A=0.260. σ^2_D=0.572; F=1 σ^2_A=0.130. σ^2_D=0.143			

In direct crosses, the GCA of the maternal forms (*G. hirsutum*) for the number of matured bolls and boll weight was significant, while they were used as male parents GCA was non-significant for both traits.

Crossing direction influenced the genetic structure of lint percentage. In direct crosses, the genetic component of variance for lint percentage was mainly of a non-additive type, while in the crosses *G. barbadense* × *G. hirsutum* additive gene effects were of greater importance.

SCA effects in the crosses with the *G. barbadense* female parents were significant for fiber length and lint percentage, as in direct crosses, but were not significant for productivity per plant. It can be considered that the higher productivity per plant in some of the direct crosses with the *G. hirsutum* female parent was largely due to the presence of significant SCA effects.

The GCA effects of the parental forms in the *G. barbadense* × *G. hirsutum* crosses on productivity, number of bolls and boll weight are presented in the Table 12. Of the maternal *G. barbadense* forms, the variety FR-B-202 had high and significant GCA for productivity/plant, while FR-B-201 variety showed a positive but non-significant GCA for this trait. The positive GCA effects of both cultivars on productivity per plant were associated with positive but non-significant GCA effects on number of bols/plant and boll weight in FR-B-201.

Of the male parents, the cultivar Chirpan-539 had the highest and significant GCA for productivity per plant. The Boyana variety had a positive, but non significant GCA for this trait, associated with a positive GCA for boll weight.

The varieties FR-B-201 and FR-B-203 from the female parents and the cultivar Chirpan-539 from the male parents showed positive and significant GCA effects on lint percentage. The cultivars FR-B-202 and FR-B-203 (from the female parents) and Natalia variety (from the male parents) showed positive and significant GCA effects for fiber length. The varieties Chirpan-539 and Boyana had positive, but non-significant effects on this trait (Table 13).

Summary of results of the GCA estimates show that parental forms of both species, with few exceptions, exhibited positive, and in some cases high, GCA effects for the same traits as maternal and as paternal components. Some parents showed high GCA effects on two or more traits, regardless of the crossing direction. The cultivar Chirpan-539 showed a high GCA for productivity/plant and lint percentage used as a maternal and paternal component. This variety could prove very valuable for breeding programs using the interspecific hybridization *G. hirsutum* L. × *G. barbadense* L. The Helius variety had a positive GCA for the boll weight in both directions of crossing. From the species *G. barbadense*, the cultivar FR-B-201 showed simultaneously a good GCA for productivity per plant, boll weight and lint percentage as female parents and male parent, FR-B-203 – for fiber length.

In female parents *G. barbadense* species the SCA variances were non-significant for productivity and its elements, but there were crosses with positive weakly significant SCA effects on these traits. The crosses FR-B-202 × Helius and FR-B-203 × Natalia showed the highest values of SCA for productivity per plant. High SCA of the first cross was associated with positive SCA effects on the number of bolls. The crosses FR-B-201 × Chirpan-539 and FR-B-202 × Natalia had the highest and significant values of the SCA for the total number of bolls, the crosses FR-B-201 × Natalia and FR-B-202 × Boyana – for the boll weight.

Table 12. Evaluation of GCA effects on productivity, number of bolls and boll weight in F_1 *G. barbadense* L. × *G. hirsutum* L. hybrids

Female parents	GCA	Male parents	GCA
Productivity per plant			
FR-B-201	0.589	Chirpan-539	4.350
FR-B-202	1.805	Helius	-1.661
FR-B-203	-2.394	Natalia	-3.372
		Boyana	0.683
Standard error	0.919	0.6701	1.061
Boll weight			
FR-B-201	0.239	Chirpan-539	-0.092
FR-B-202	-0.103	Helius	0.086
FR-B-203	-0.136	Natalia	-0.103
		Boyana	0.108
Standard error	0.093	Standard error	0.107

Table 13. Evaluation of GCA effects on lint percentage and fiber length in F_1 *G. barbadense* L. × *G. hirsutum* L. hybrids

Lint percentage				Fiber length			
Female parents	GCA	Male parents	GCA	Female parents	GCA	Male parents	GCA
FR-B-201	0.550	Chirpan-539	0.792	FR-B-201	-1.578	Chirpan-539	0.253
FR-B-202	-1.367	Helius	-0.208	FR-B-202	0.739	Helius	-1.003
FR-B-203	0.817	Natalia	-0.130	FR-B-203	0.839	Natalia	0.586
		Boyana	-0.453			Boyana	0.164
Standard error	0.228		0.264	Standard error	0.251		0.289

Table 14. Evaluation of SCA effects(S_{ij}) and variances ($\sigma^2 s_i$; $\sigma^2 s_j$) for lint percentage and fiber length in F_1 hybrids *of G. barbadense* L. × *G. hirsutum* L.

Male parents / Female parents	Chirpan-539	Helius	Natalia	Boyana	σ^2_{Si}
Lint percemtage					
FR-B-201	-0.683	4.910	0.094	0.728	0.284
FR-B-202	-0.067	0.500	-0.444	0.011	0.099
FR-B-203	0.750	-0.550	0.559	-0.739	0.515
	MD = 0.295				
σ^2_{Sj}	0.465	0.225	0.196	0.486	
Fiber length					
FR-B-201	0.289	0.611	-0.444	-0.455	0.225
FR-B-202	0.672	-0.772	0.239	-0.139	0.312
FR-B-203	-0.961	0.161	0.205	0.594	0.386
	MD = 0.323				
σ^2_{Sj}	0.667	0.435	0.086	0.227	

Positive SCA for lint percentage was found in 7 crosses, significant in 5 crosses, and for fiber length was also found in 7 crosses, significant in 5 (Table 14). The cross combination FR-B-201 × Helius showed high SCA effects for both traits. The cross combinations FR-B-202 × Chirpan-539 and FR-B-203 × Boyana possessed high SCA effects for fiber length.

Some parent pairs showed high and significant SCA in both directions of crossing – Boyana × FR-B-201 and FR-B-201 × Boyana for productivity per plant; Helius × FR-B-201 and FR-B-201 × Helius for lint percentage. There were reciprocal crosses, with positive, but non-significant or significant only one-way SCA effects: for the productivity per plant, reciprocal high SCA effects were observed for 4 crosses (Helius × FR-B-202, Natalia × FR-B-203 and their reciprocals); for lint percentage in two 2 crosses (Natalia × FR-B-203 and the reciprocal); for fiber length in 6 crosses (Helius × FR-B-203, Natalia × FR-B-202, Natalia × FR-B-203 and their reciprocals).

Conclusions

In interspecific crosses *G. hirsutum* L. × *G. barbadense* L., additive and non-additive gene effects were important for inheritance. The genetic variance of boll weight was additive, suggesting faster selection. For lint percentage non-additive or additive gene action predominated, depending on the direction of crossing, for other traits the genetic variance was mainly non-additive.

F1 hybrids *G. hirsutum* L. × *G. barbadense* L. inherited incompletely, completely and overdominantly the higher productivity of the species *G. hirsutum* L. Overdominance prevailed causing heterosis of 5.2 to 36.1% in crosses with female parent *G. hirsutum* L. and from 7.2 to 32.7% in crosses with female parent *G. barbadense* L. The direction of crossing did not show a regular character on the inheritance.

The longer fiber of the *G. barbadense* L. species was inherited incompletely dominantly, in individual cases it was additive or with positive overdominance with weak heterosis (2.1-3.0%). In some cases, in hybrids with female parent *G. barbadense* L. species, a longer fiber length was formed.

Of the *G. hirsutum* species, the cultivar Chirpan-539 had a high GCA for productivity in both directions of crossing and from the *G. barbadense* L. species positive GCA was shown in FR-B-201 in both directions of crossing and FR-B-202 as parent component. The varieties Helius (*G. hirsutum* L.) and FR-B-201 (*G. barbadense* L.) have stood out as very good general combiners for the boll weight.

From the *G. hirsutum* L. species, with high GCA for the fiber length were found to be the varieties Darmi (as maternal component) and Natalia (as paternal component), and from the *G. barbadense* L. species, high GCA for this trait was found for the cultivars FR-B-202 (as paternal component) and FR-B-203 (in both crossing directions). Regarding the lint percentage the cultivar Chirpan-539 – *G. hirsutum* L. and FR-B-201 – *G. barbadense* L. had a high GCA. The *G. hirsutum* parental forms have shown high GCA for both characteristics had low SCA variances and are very suitable for synthetic selection.

The direction of crossing may be important for the manifestation of the general combinative ability and specific combinative ability of the parental forms of the two species for the studied traits. GCA of *G. hirsutum* cultivars was significant in both crossing directions for productivity/plant and lint percentage, of *G. barbadense* cultivars – for boll weight and fiber length, SCA – for lint percentage and fiber length.

References

Adetunji, S. T. (1997). Inheritance, heterosis and combinative ability in interspecific cotton hybrids *Gossypium hirsutum* L. × *G. barbadense* L. Dissertation for awarding the scientific and educational degree "Doctor" (PhD), Specialized Scientific Council for Plant Breeding and Plant Biotechnologies at VAK, Sofia.

Adsare, A. D., Salve, A. N. & Patil, N. P. (2017). Heterosis studies for quantitative traits in interspecific hybrids of cotton (*G hirsutum* L. x *G barbadense* L.). *Journal of Phytology, 9*(1), 11-14.

Anwar, M., Iqbal, M. Z., Abro, A. A., Memon, S., Bhutto, L. A., Memon, S. A. & Peng, Y. (2022). Inter-Specific hybridization in cotton (*Gossypium hirsutum*) for crop improvement. *Agronomy, 12*(12), 3158. https://doi.org/10.3390/agronomy12123158.

Basal, H., Unay, A., Canavar, O. & Yavas, I. (2009). Combining ability for fiber quality parameters and within-boll yield components in intraspecific and interspecific cotton populations. *Span J. Agric. Res.,7*(2), 364-374. Available online at: www.inia.es/sjar.

Bölek, Y., Çokkizgin, H. & Bardak, A. (2014). Genetic analysis of fiber traits in cotton. *KSU J. Nat. Sci., 17*(1), 15-20.

Borzan, G. & Guvercin, R. S. (2021). Combining ability and hybrid vigor in interspecific (*Gossypium hirsutum* L. x *Gossypium barbadense* L.) line x tester hybrids of cotton. *Turk. J. Field Crops*, *26*(1), 96-102. DOI: 10.17557/tjfc.871366.

Bozhinov, M. & Dimitrova, L. (1974). The Bulgarian cotton – a specific ecological group of the species *G. hirsutum* L. *Agricultural Science*, *1* (Bg).

Chaudhry, M. R. & Guitchounts, A. (2003). Cotton Facts. Technical Paper No. 25 of the Common Fund for Commodities. International Cotton Advisory Committee, First Edition 2003. ISBN 0-9704918-3-2. Library of Congress Control No. 2003 107 604.

Chen, Y., Liu, G., Ma, H., Song, Z., Zhang, C., Zhang, J., Zhang, J., Wang, F. & Zhang, J. (2018). Identification of introgressed alleles conferring high fiber quality derived from *Gossypium barbadense* L. in secondary mapping populations of *G. hirsutum* L. *Front. Plant Sci., 9,*1023. doi: 10.3389/fpls.2018.01023.

Çoban, M., Ünay, A., Çifci, H. & İlhan, B. (2015). Effects of interspecific hybridization on cotton (*Gossypium hirsutum* L. × *Gossypium barbadense* L.). October 2015, Conference: ICAC 12th Inter-Regional Cooperative Research Network on Cotton for the Mediterranean and Middle East Regions At: Egypt. doi: https://doi.org/10.20546/ijcmas.2018.710.399.

Çoban, M. & Ünay, A. (2017). Gene action and useful heterosis in interspecific cotton crosses (*G hirsutum* L. x *G barbadense* L.). *Journal of Agricultural Sciences, 4*(23), 438-443.

Furong, W., Gong, Y., Zhang, C., Liu, G., Wang, L. Xu, Z. & Zhang, J. (2011). Genetic effects of introgression genomic components from Sea Island cotton (*Gossypium barbadense* L.) on fiber related traits in upland cotton (*G. hirsutum* L.). *Euphytica*, *181*(1), 41-53.

Genchev, G., Marinkov, V., Yovcheva, V. & Ognyanova, A. (1975). *Biometrical methods in plant science, genetics and breeding*. Zemizdat, Sofia, (Bg).

Grover, C. E., Zhu, X., Grupp, K. K., Jareczek, J. J., Gallagher, J. P., Szadkowski, E., Seijo, J. G. & Wendel, J. F. (2015). Molecular confirmation of species status for the allopolyploid cotton species, Gossypium ekmanianum Wittmack. *Genetic Resourses and Crop Evolution, 62*, 103–114. doi: 10.1007/s10722-014-0138-x.

Gungor, H. & Efe, L. (2017). A heterosis study for fiber quality traits in cotton. *Journal of Natural Science, 20*(1), 54-66. DOI: 10.18016/ksujns.65079, ISSN & 1309-1743.

Hosseini, G. (2014). Estimation of genetic parameters for quantitative and qualitative traits in cotton cultivars (*Gossypium hirsutum* L. *& Gossypium barbadense* L.) and new scaling test of additive – dominance model. *Journal of Plant Molecular Breeding (JPMB), 2*(1), 45-63.

Hu, Y., Chen, J., Fang, L., Zhang, Z., Ma, W., Niu, Y., Ju, L., Deng, J., Zhao, T., Lian, J., Baruch, K., Fang, D., Liu, X., Yong-ling, R., Rahman, M.-ur, Han, J., Wang, K., Wang, Q., Wu, H., Mei, G., Zang, Y., Han, Z., Xu, Ch., Shen, W., Yang, D., Si, Z., Dai, F., Zou, L., Huang, F., Bai, Y., Zhang, Y., Brodt, A., Ben-Hamo, H., Zhu, X., Zhou, B., Guan, X., Zhu, Sh., Chen, X. & Zhang, T. (2019). *Gossypium barbadense* and *Gossypium hirsutum* genomes provide insights into the origin and evolution of allotetraploid cotton. *Nature Genetics*, *51*(4), 739–748. https://doi.org/10.1038/s41588-019-0371-5.

Koynov, G. & Stoilova, A. (1996). A new variety long fiber cotton. *Plant Science*, *l*(4) XXXIII, Agricultural Academy, Sofia, 13-15 (Bg).

Li, T., Wang, F., Yasir, M., Li, K., Qin, Y., Zheng, J., Luo, K., Zhu, S., Zhang, H., Jiang, Y., Zhang, Y. & Rong, J. (2022) Expression patterns divergence of reciprocal F1 hybrids between Gossypium hirsutum and Gossypium barbadense reveals overdominance mediating interspecific biomass heterosis. *Front. Plant Sci*., *13*, 892805. doi: 10.3389/fpls.2022.892805.

Malathi, S., Patil, R. S. & Saritha, H. S. (2019). Heterosis studies in interspecific cotton hybrids (*G hirsutum* L. x *G barbadense* L.) under irrigated condition. *Electronic Journal of Plant Breeding, 10*(2), 852-861.

Mehboob-ur-Rahman, Shaheen, T., Tabbasam, N., Iqbal, M. A., Ashraf, M., Zafar, Y. & Paterson, A. H. (2012). Cotton genetic resources. A review. *Agron. Sustain. Dev., 32*, 419–432. doi: 10.1007/s13593-011-0051-z.

Mingbao, L., Guo, X., Zhang, Y. & Yao, J. (2010). Genetic effects of special chromosome from *Gossypium barbadense* L. on fiber quality in *G. hirsutum* L. *Journal of Natural Fibers, 7*(3), 178-193.

Munir, S., Qureshi, M. K., Shahzad, A. N., Manzoor, H., Shahzad, M. A., Aslam, K. & Athar, H. (2017). Assessment of gene action and combining ability for fibre and yield contributing trais in interspecific and intraspecific hybrids of cotton. *Czech J. Genet. Plant Breed*., *54*(2), 71-77. doi: 10.17221/54/2017-CJGPB.

Ognyanova, A. (1975). Elements of Biometric Genetics. Biometric methods in plant breeding, genetics and selection. *Zemizdat,* Sofia, 216-304 (Bg).

Patel, D. H., Patel, D. U. & Kumar, V. (2014). Heterosis and combining ability analysis in tetraploid cotton (*G.hirsutum* L. and *G.barbadense* L.). *Electronic J. Plant Breed*., *5*(3), 408-414.

Rajeev, S., Patil, S. S., Manjula, S. M., Pranesh, K. J., Srivalli,

P. & Kencharaddi, H. G. (2018). Studies on heterosis in cotton interspecific heterotic group hybrids (*G.hirsutum* x *G.barbadense*) for seed cotton yield and its components. *Int. J. Curr. Microbiol. App. Sci., 7*(10), 3437-3451.

Roy, U., Paloti, M. C., Patil, R. S. & Katageri, I. S. (2018). Combining ability analysis for yield and yield attributing traits in interspecific (*G hirsutum* L. x *G barbadense* L.) hybrids of cotton. *Electronic Journal of Plant Breeding, 9*(2), 458-464.

Sanamyan, M. F., Bobohujayev, S. U., Abdukarimov, S. S., Makamov, A. K. & Silkova, O. G. (2022). Features of chromosome introgression from *Gossypium barbadense* L. into *G. hirsutum* L. during the development of alien substitution lines. *Plants*, *11*(4), 542. https://doi.org/10.3390/ plants11040542.

Savchenko, V. K. (1984). *Genetic analysis in netlike test crosses*. Science and Technic, Minsk, (Ru).

Shiming, L., Llewellyn, D. J., Stiller, W. N., Jacobs, J., Lacape, J.-M. &. Constable, G. A. (2011). Heritability and predicted selection response of yield components and fibre properties in an inter-specific derived RIL population of cotton. *Euphytica*, *178*(3), 309-320.

Stoilova, A. (1987). Genetic studies in the hybridization of the species *Gossypium hirsutum* L. × *G. barbadense* L. – Dissertation for the award of the scientific degree Candidate of Biological Sciences (PhD), Specialized Scientific Council for Genetics, BAN, Sofia (Bg).

Tyagi, P., Bowman, D. T., Edmisten, K., Bourland, F. M., Campbell, B. T., Fraser, D. E., Wallace, T. P. & Kuraparthy, V. (2014). Components of hybrid vigor in upland cotton (*Gossypium hirsutum* L.) and their relationship with environment. *Euphytica*, *195*(1), 117–127.

Unay, A., Altintas, D. & Çoban, M. (2018). The determination of leaf anatomy, yield and quality characteristics in F_1 and F_2 generations of interspecific cotton hybrids (*G hirsutum* L. x *G barbadense* L.). *Turkish Journal of Field Crops, 23*(2), 146-150.

Yu, J., Zhang, K., Li, S., Yu, S., Zhai, H., Wu, M., Li, X., Fan, S., Song, M., Yang, D., Li, Y. & Zhang, J. (2013). Mapping quantitative trait loci for lint yield and fiber quality across environments in a *Gossypium hirsutum* × *Gossypium barbadense* backcross inbred line population. *Theor. Appl. Genet.*, *126*, 275–287. doi: 10.1007/s00122-012-1980-x PMID: 23064252.

Zhang, J. (2011). Twenty-five years of introgression breeding through interspecific hybridization between *Gossypium hirsutum* and *Gossypium barbadense*. Belt Wide Cotton Conferences, Atlanta, Georgia, January 4-7, 2011.

Zhang, J. F., Percy, R. G. & McCarty, J. C. (2014). Introgression genetics and breeding between Upland and Pima cotton – a review. *Euphytica*, *198*, 1–12.

Zhang, T., Hu, Y., Jiang, W., Fang, L., Guan, X., Chen, J., Zhang, J., Saski, C.A., Scheffler, B. E., Stelly, D. M., Hulse-Kemp, A. M., Wan, Q., Liu, B., Chunxiao, L., Wang, S., Pan, M., Wang, Y., Wang, D., Ye, W., Chang, L., Zhang, W., Song, Q., Kirkbride, R. C., Chen, X. & Chen, Z. J. (2015). Sequencing of allotetraploid cotton (*Gossypium hirsutum* L. acc. TM-1) provides a resource for fiber improvement. *Nat. Biotechnol*., *33*, 531–537. doi: 10.1038/nbt. 3207.

Zhang, J., Wu, M., Yu, J., Li, X. & Pei, W. (2016). Breeding potential of introgression lines developed from interspecific crossing between upland cotton(Gossypium hirsutum) and Gossypium barbadense: heterosis, combining ability and genetic effects. *PLoS ONE*, *11*(1), e0143646. doi:10.1371/journal.pone.0143646.

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