Field Crop Studies (2019) XII(1): 115-128
http://fcs.dai-gt.org/bg/
ISSN: 2535-1133 (Online)
ISSN: 1312-3882 (Print)

ORIGINAL PAPER

Inheritance and combining ability analysis of productivity in F_1 cotton diallel crosses

Valentina Dimitrova[1] • Minka Koleva[1] • Ana Stoilova[1]

[1]Institute of field crops - Chirpan, 6200, Chirpan, Bulgaria

Corresponding Autor: Minka Koleva; E-mail: m_koleva2006@abv.bg

Received: October 2018 / Accepted: February 2019 /
Published: March 2019

Abstract

Dimitova, V., Koleva, M. & Stoilova, A. (2019). Inheritance and combining ability analysis of productivity in F_1 cotton diallel crosses. Field Crops Studies, XII(1), 115-128.

The inheritance and combining ability of parental forms in two cotton diallel crosses were studied. The first diallel cross included the varieties: „Beli Iskar", „Barut 2005"(Turkish); „Darmi", „Mytra" (Greek), „Helius" and „Dorina" and the second one - the varieties: „Chirpan-539"; „Helius", „Rumi", „Boyana", „Natalia" and „Nelina". In the first diallel cross, crosses with positive over-dominant inheritance of productivity have predominated. Over-dominance in these crosses caused heterosis, which reached 22.0%, on average for two years. In the second diallel cross, the inheritance of productivity in 40% of the crosses was positively over-dominat, while another 40% demonstrated incomplete dominace of the more productive parent. Heterosis manifestations were less pronounced (up to 17.7%). The significant positive values of the GCA were found for the varieties „Beli Iskar" (1st diallel cross) and „Natalia" (2nd diallel cross), have showed high yield/plant. The presence of positive GCA in some of the parental forms depended on the year conditions. Positive and significant SCA effects were found in both diallel crosses. The analysis of the variance components of the GCA and SCA showed that non-additive gene effects were important for inheritance of productivity.

Key words: Combining ability, Cotton, Diallel crosses, *G. hirsutum* L., Inheritance, Productivity

Introduction

Estimate of combining ability is of importance in determining the breeding values of parental forms and hybrids as well as in choice of appropriate selection strategy to use in a breeding program. Combining ability analysis helps in identification of parents with high general combining ability (GCA) and parental combinations with high specific combining ability (SCA) effects (Singh et al., 2010).

It is generally accepted in contemporary literature that the differences in parental GCA are due to additive gene actions and interactions, while differences in SCA result from non-additive gene actions and interactions. The aditive variance appears to be the main one in the inheritance of quantitative characters; the non-additive variance also has its significance in the manifestation of the individual traits.

The general combining ability (GCA) effects are important indicators of the value of inbreeds in hybrid combinations. Differences in GCA effects have been attributed to additive, additive × additive and higher-order additive interactions, whereas differences in specific combining ability (SCA) have been attributed to non-additive genetic variance (Falconer, 1960).

Information on combining ability will help the breeder in developing the future breeding programme to be adopted for exploiting additive and/or non-additive components present in the material (Kumar et al., 2017).

Parents with high GCA are believed to be carriers of a greater number of additive genes, and such parents are more desirable for breeding programs to genetically improve economically valuable traits. Hybrids with high SCA are suitable for heterotic breeding for the use of heterosis. Their high SCA effects are conditioned by non-additive type of gene action. The high variance of GCA due to GCA effects is conditioned by an additive type of gene action, whereas the high SCA variance due to SCA effects is conditioned by non-additive action of genes. Estimit of SCA is important for heterotic breeding for the selection of superior parents to develop superior hybrids manifested useful heterosis and hetero beltiosis based on non-allelic gene interactions (overdominance and epistasis).

Combining ability describes the breeding value of parental genotypes to produce hybrids. Significant GCA is indicating the role of additive gene action, while significant SCA is indicating the role of non-additive gene action (Ekinci et al., 2015).

Combining ability also helps in assessing the gene action involved in controlling components of yield. General combining ability (GCA) variances reflect the additive gene action while specific combining ability (SCA) variances reflect the non-additive gene action (Muniri et al., 2018).

Combining ability of parental forms has been always studied by applying definite system of crosses. In cotton, some authors prefer diallel crosses others find some forms of “line × tester” crosses to be more effective.

Diallel analysis provides information regarding the combining ability variances and effects of the genotypes and is widely used in genetic and breeding studies to evaluate breeding value of parental forms and hybrids even in the earliest generations. This analysis provides information to identify and select the appropriate parents and superior crosses. A number of authors, using various schemes of complete and incomplete diallel crosses, have established the breeding value of a large number of cotton varieties and the effects of gene action in terms of yield, its components and fiber quality characteristics. Many studies showed that variation in seed cotton yield and its components as well as fiber properties were influenced by additive and non-additive gene effects. Jatoi et al. (2010), Wandhare et al. (2010) reported significant variation due to GCA and SCA effects, for various characters of upland cotton. Singh et al. (2011) concluded that additive and non-additive gene effects played a parallel role in inheritance of the various characters, including yield and and its structural elements. Non-additive type gene action has determined the inheritance of yield and its components in the studies conducted by Pole et al. (2008), Khan et al. (2009a), Gamel et al. (2009), Karademir and Gencer (2010) and Makhdoom (2011). Additive gene effects were observed for many of the yield-related traits with sufficient genetic variation for an effective selection (Igbal et al., 2011; Igbal et al., 2013; Raza et al., 2013; Kumar et al., 2014; Usharani et al., 2014; Chapepa et al., 2015; Vasconcelos et al., 2018). Additive-type gene action with partial dominance for most of the yield-related traits was noted by Khan et al. (2011), Sarwar et al. (2011).

The aim of this study was to estimate the importance of GCA and SCA in the inheritance of productivity in F_1 cotton hybrids obtained from diallel crosses in the frame of *G. hirsutum* L. species in view of the selection strategy, and to select the superior ones to be used in cotton breeding programmes.

Materials and methods

In 2010-2011 diallel-crosses were made between 6 cotton varieties: Beli Iskar (P_1); Barut 2005 (P_2) (Turkish); Darmi (P_3); Mytra (P_4) (Greek); Helius (P_5) and Dorina (P_6). In 2012, others diallel-crosses were made between the varieties: Chirpan-539 (P_1); Helius (P_2); Rumi (P_3); Boyana (P_4); Natalia (P_5) and Nelina.

An incomplete diallel scheme was used, including the parents and one set of F_1 crosses. The trials were set in three replicates, the parents and F_1 hybrids were sown in 2 rows of 2.4 m long in a 60×20×1 sowing scheme. Ten plants of each replication were accounted. Normal cultivar practices were followed throughout the vegetation period.

In terms of temperature security the years were characterized as follows: 2010 and 2011 were moderately warm (P%=21.84; 25.29); 2012 was very hot (P%=2.30). About rainfall supply 2010 was moderately humid (P%=28.73), 2011 and 2012 were dry (P%=83.91; 81.60). (P% - coefficient of security for temperature security and for rainfall supply, respectively).

Combination ability was determined by Griffing Method 2, Model II (Griffing, 1956) (Mark Burow and James G. Coors program was used).

Results and Discussion

The inheritance of productivity by crosses is presented in Table 1. At the first diallel combination F_1-2010 and F_1-2011, crosses with positive over-dominant inheritance of productivity predominated (86.6% in 2010 and 66.7% in 2011). The overdominance resulted in a pronounced heterosis, most strongly expressed at the crosses Beli Iskar × Dorina and Barut × Dorina, 25.1% and 22.0%, respectively, on average for the two years. Both crosses had high productivity - 37.9 g and 39.0 g/plant. High values of heterosis - 119.1-119.4% and high productivity - 37.3-37.4 g/plant were also found for the crosses Beli Iskar × Darmi and Barut × Helius. The cross Helius × Dorina - 38.5 g/plant was high-productive in 2010, but in the second year the inheritance of its productivity was with negative overdominance and negative heterotic effect. In 2011, 20% of crosses showed incomplete dominance towards a more productive parent.

In F_1-2012, in 40% of the crosses the inheritance of the productivity/plant was with positive over-dominance, which caused heterosis, while another 40% of the crosses showed incomplete dominance of the higher productive parent (Table 2). Heterosis manifestations were less pronounced, from 2.2 to 17.7%. The highest values of heterosis - 9.9-17.7% and the highest productivity -21.0-21.5 g/plant were found for the crosses Rumi × Nelina, Chirpan-539 × Boyana and Chirpan-539 × Helius.

From Table 3, it is evident that for the study trait, there were significant additive (GCA) and non-additive (SCA) effects in the first diallel combination, while in the second diallel combination only SCA effects were significant. In the 1st diallel combination, the GCA variances showed a high significance when they were tested against the average error, but they were non significant in the SCA test.

The GCA effects of the parental forms are presented in Table 4. Significant positive values of the GCA were found for the varieties Beli Iskar (1st diallel combination) and Natalia (2nd diallel combination), showed a high yield/plant. The presence of positive GCA in some of the parental forms depended on the year conditions. Helius variety showed high positive GCA in 2010 and negative GCA in 2011, while Barut variety showed negative GCA in 2010 and positive GCA in 2011. Significant negative effects were found for the varieties Mytra (1st diallel combination) and Boyana (2nd diallel combination). Mytra variety was high-productive in 2010 and low-productive in 2011, while Boyana variety was low-productive (2012). Productivity of many foreign varieties in our country depends on the year conditions, to what extent these ones are suitable for maturing of cotton in earlier period.

Table 1. Inheritance (d/a) and heterosis for the productivity/plant in F_1 diallel crosses, 2010-2011 (I[-st] diallel combination)

Хибридна комбинация Hybrid combinations	Продуктивност /растение, g Productivity/ plant, g		d/a		HP %		
	F_1 2010	F_1 2011	F_1 2010	F_1 2011	F_1 2010	F_1 2011	Средно Average
Бели Искър × Барут Beli Iskar × Barut	51,6	21,0	1,74	24,00	117,5	112,3	114,9
Бели Искър × Дарми Beli Iskar × Darmi	52,1	22,7	22,43	6,33	116,8	121,4	119,1
Бели Искър ×Митра Beli Iskar × Mytra	46,9	24,8	1,31	3,39	100,9	132,6	116,7
Бели Искър ×Хелиус Beli Iskar × Helius	52,3	21,6	6,64	28,00	113,4	114,3	113,9
Бели Искър ×Дорина Beli Iskar × Dorina	50,1	25,6	42,33	137,00	114,1	136,2	125,1
Барут × Дарми Barut × Darmi	46,3	21,5	1,16	5,62	103,8	116,2	110,0
Барут × Митра Barut × Mytra	42,8	20,5	0,69	1,82	92,0	110,8	101,4
Барут ×Хелиус Barut × Helius	49,8	24,7	1,32	30,00	108,0	130,7	119,4
Барут ×Дорина Barut × Dorina	56,3	21,6	2,23	19,67	129,1	114,9	122,0
Дарми ×Митра Darmi × Mytra	48,3	19,0	2,89	2,00	103,9	110,5	107,2
Дарми ×Хелиус Darmi × Helius	51,3	16,0	7,93	-2,41	111,3	84,7	98,0
Дарми × Дорина Darmi × Dorina	50,5	18,1	12,80	0,13	113,2	96,3	104,7
Митра ×Хелиус Mytra × Helius	50,9	17,4	23,00	0,43	109,5	92,1	100,8
Митра ×Дорина Mytra × Dorina	47,9	18,6	1,97	0,92	103,0	98,9	100,9
Хелиус × Дорина Helius × Dorina	58,9	18,1	11,24	-15,00	127,8	95,8	111,8
GD 5 %;	*2,1*	*2,0*					
GD 1 %;	*2,8*	*2,7*					
GD 0.1 %;	*3,7*	*3,6*					

Table 2. Inheritance and hetrosis for the productivity/plant in F_1 diallel crosses, 2012

Хибридна комбинация Hybrid combinations	F_1-2012				
	P_1	P_2	F_1	d/a	HP %
Чирпан-539 × Хелиус Chirpan-539 × Helius	18,1	19,1	21,0	4,80	109,9
Чирпан-539 × Руми Chirpan-539 × Rumi	18,1	19,4	19,0	0,38	97,9
Чирпан-539 × Бояна Chirpan-539 × Boyana	18,1	16,4	21,3	4,76	117,7
Чирпан-539 × Наталия Chirpan-539 × Natalia	18,1	20,8	20,7	0,93	99,5
Чирпан-539 × Нелина Chirpan-539 × Nelina	18,1	17,9	18,5	5,00	102,2
Хелиус × Руми Helius × Rumi	19,1	19,4	19,4	1,00	100,0
Хелиус × Бояна Helius × Boyana	19,1	16,4	18,8	0,78	98,4
Хелиус × Наталия Helius × Natalia	19,1	20,8	20,3	0,41	97,6
Хелиус × Нелина Helius × Nelina	19,1	17,9	17,9	-1,00	93,7
Руми × Бояна Rumi × Boyana	19,4	16,4	20,2	1,53	104,1
Руми × Наталия Rumi × Natalia	19,4	20,8	20,5	0,57	98,6
Руми × Нелина Rumi × Nelina	19,4	17,9	21,5	3,80	110,8
Бояна × Наталия Boyana × Natalia	16,4	20,8	20,2	0,73	97,1
Бояна × Нелина Boyana × Nelina	16,4	17,9	19,0	2,47	106,1
Наталия × Нелина Natalia × Nelina	20,8	17,9	20,9	1,07	100,5
GD 5,0%; 1,0%; 0,1%	1,8; 2,4; 3,1				

ISSN: 2535-1133 (Online)
ISSN: 1312-3882 (Print)

Table 3. Analysis of the GCA and SCA variances for the productivity/plant in F_1-2010, F_1-2011 (I-st diallel combination), and F_1-2012 (II-nd diallel combination)

Източник на вариране Source of variation	Степени на свобода Degree of freedom	Средни квадрати Mean squares	F-опитно F-experimental
F_1-2010			
Кръстоски/Crosses	20	160.370^{++}	22,26^{++}
ОКС/GCA	5	244.248^{++}	99.74^{++}/1.84 ns
СКС/SCA	15	132,411^{++}	151.93^{++}
Грешки/Errors	40	1.608	-
F_1- 2011			
Кръстоски/Crosses	20	27.235^{++}	17.88^{++}
ОКС/GCA	5	34.041^{++}	22.35^{++}/1.36 ns
СКС/SCA	15	24.967^{++}	16.40^{++}
Грешки/Errors	40	1.523	-
F_1-2012			
Кръстоски/Crosses	20	5.381	4.70^{+}
ОКС/GCA	5	7.149	6.24 /1.49 ns
СКС/SCA	15	4.791	4.18^{+}
Грешки/Errors	40	1.146	-

Table 4. Ranking of the parents on the GCA for productivity/plant in F_1-2010 and F_1-2011 (I^{st} diallel combination), and F_1-2012 (II^{nd} diallel combination)

Ранжиране по обща комбинативна способност Ranking on General Combined Ability (GCA)								
F_1-2010			**F_1-2011**			**F_1-2012**		
Родител Parent	x	ОКС GCA	Родител Parent	x	ОКС GCA	Родител Parent	x	ОКС GCA
P_5-Хелиус P_5-Helius	46,1	3,354	P_1-Б. Искър P_1- B. Iskar	18,7	1,763	P_5-Наталия P_5-Natalia	20,8	0,910
P_6-Дорина P_6-Dorina	43,6	1.929	P_2-Барут P_2-Barut	18,5	0,937	P_3-Руми P_3-Rumi	19,4	0,318
P_1-Б. Искър P_1-B. Iskar	43,9	0,996	P_6-Дорина P_6-Dorina	18,8	0,087	P_1-Ч-н-539 P_1-Ch.-539	18,1	-0,032
P_3-Дарми P_3-Darmi	44,6	0,296	P_5-Хелиус P_5-Helius	18,9	-0,433	P_2-Helius P_2-Helius	19,1	-0,182
P_4-Митра P_4-Mytra	46,5	-0,717	P_3-Дарми P_3-Darmi	17,2	-0,912	P_6-Нелина P_6-Nelina	17,9	-0,428
P_2-Барут P_2-Barut	23,0	-5,858	P_4-Митра P_4-Mitra	13,6	-1,442	P_4-Бояна P_4-Boyana	16,4	-0,586
L.S.D. 5 %	2,09		L.S.D. 5 %	2,04		L.S.D. 5 %	1,8	
Станд. грешка Stand. error		0.366	Станд. грешка Stand. error		0.356	Станд. грешка Stand. error		0,309

Table 5. Mean values (x), specific combining ability (SCA) and heterosis in terms of productivity in F_1-2010 and F_1-2011 (I[st] diallel combination), and F_1-2012 (II[nd] diallel combination) (Ranking on GCA)

2010				2011				2012			
Кръстоски Crosses	x	СКС SCA	HP	Кръстоски Crosses	x	СКС SCA	HP	Кръстоски Crosses	x	СКС SCA	HP
С положителни СКС ефекти Having positive SCA effects				**С положителни СКС ефекти Having positive SCA effects**				**С положителни СКС ефекти Having positive SCA effects**			
Барут × Дорина Barut × Dorina	56,3	12,281	129,1	Бели Искър × Митра Beli Iskar × Mytra	24,8	4,631	132,6	Чирпан-539 × Бояна Chirpan-539 × Boyana	21,3	2.320	117,7
Бели Искър × Хелиус Beli Iskar × Helius	52,3	6,802	113,4	Барут × Хелиус Barut × Helius	24,7	4,348	130,7	Руми × Нелина Rumi × Nelina	21,5	2.011	110,8
Хелиус × Дорина Helius × Dorina	58,9	5.,669	127,8	Бели Искър × Дорина B. Iskar × Dorina	25,6	3,936	136,2	Чирпан-539 × Хелиус Chirpan × Helius	21,0	1,615	109,9
Барут × Хелиус Barut × Helius	49,8	4,390	108,0	Бели Искър × Дарми Beli Iskar × Darmi	22,7	2,002	121,4	Хелиус×Бояна Helius × Boyana	18,8	-0,030!	98,4
Бели Искър × Барут Beli Iskar × Barut	51,6	4,348	117,5	Барут × Дарми Barut × Darmi	21,5	1,661	116,2	Наталия × Нелина Natalia × Nelina	20,9	0,886	100,5
Барут × Дарми Barut × Darmi	46,3	3,948	103,8	Дарми × Митра Darmi × Mytra	19,0	1,473	110,5	Бояна × Нелина Boyana × Nelina	19,0	0.449	106,1
Бели Искър × Дарми Beli Iskar × Darmi	52,1	2,861	116,8	Барут × Митра Barut × Mytra	20,5	1,189	110,8	Бояна × Наталия Boyana × Natalia	20,2	0.311	97,1
Барут × Митра Barut × Mytra	42,8	1,427	92,0	Барут × Дорина Barut × Dorina	21,6	0,727	114,9	Чирпан-539 × Наталия Chirpan-539 × Natalia	20,7	0.257	99,5
Дарми × Митра Darmi × Mytra	48,3	0,806	103,9	Бели Искър × Хелиус Beli Iskar × Helius	21,6	0,390	114,3	**С негативни СКС ефекти Having negative SCA effects**			
Дарми × Дорина Darmi × Dorina	50,5	0,361	113,2	Митра × Дорина Mytra × Dorina	18,6	0,106	98,9	Хелиус × Наталия Helius × Natalia	20,3	-0,026	97,6

ISSN: 2535-1133 (Online)
ISSN: 1312-3882 (Print)

Митра × Хелиус Mytra × Helius	50,9	0,348	109,5	**С негативни СКС ефекти Having negative SCA effects**				Хелиус × Бояна Helius × Boyana	18,8	-0,030	98,4
С негативни СКС ефекти Having negative SCA effects				Митра × Хелиус Mytra × Helius	17,4	-0,606	92,1	Руми × Наталия Rumi × Natalia	20,5	-0,259	98,6
Дарми × Хелиус Darmi × Helius	51,3	-0,231	111,3	Дарми × Дорина Darmi × Dorina	18,1	-0,923	96,3	Хелиус × Руми Helius × Rumi	19,4	-0,268	100,0
Бели Искър × Дорина Beli Iskar × Dorina	50,1	-0,706	114,1	Хелиус × Дорина Helius × Dorina	18,1	-1,402	95,8	Чирпан-539 × Нелина Chirpan-539 × Nelina	18,5	-0.639	102,2
Митра × Дорина Mytra × Dorina	47,9	-1,260	103,0	Бели Искър × Барут Beli Iskar × Barut	21,0	-1,548	112,3	Чирпан-539 × Руми Chirpan-539 × Rumi	19,0	-0.818	97,9
Бели Искър × Митра Beli Iskar × Mytra	46,9	-1,293	100,9	Дарми × Хелиус Darmi × Helius	17,4	-0,606	92,1	Хелиус × Нелина Helius × Nelina	17,9	-1,089	93,7
GD 5 %	2,09			GD 5 %	2,04			GD 5 %	1,8		
Ст. грешка Stand. error		0,896		Ст. Грешка Stand. error		0,872		Ст. грешка Stand. error		0,757	

Crosses showed significant positive and negative SCA effects are shown in **Table 5**. In the first diallel combination positive GCA effects in both years of the study were found for the crosses of Barut × Dorina, Beli Iskar × Helius, Barut × Helius, Barut × Darmy, Barut × Mytra and Darmi × × Mytra. High GCA effects and high mean values for the productivity/plant in F_1-2012 (2nd diallel combination) were found for the crosses of Chirpan-539 × Boyana, Rumi × Nelina and Chirpan-539 × Helius. All crosses having positive GCA effects, showed heterosis towards the better parent (hetero beltiosis).

In the first diallel combination the highest GCA and the highest productivity/plant, on average for two years, were found for the crosses of Barut × Dorina and Barut × Helius showing heterosis of 22% and 19.3%. These crosses appeared to be very valuable for both heterotic breeding to use heterosis, as well as for pedigree breeding as a source of transgressive variability emerging in F_2 segregating generations. The cross Beli Iskar × Dorina, having high productivity and the highest heterotic effect - 25.1% (Table 6) showed a non-permanent SCA from year to year, insignificant negative in 2010 and significant high positive in 2011.

Analysis of the components of GCA and SCA variances (Table 6) showed that non-additive gene effects were of importance for the inheritance of productivity, confirming the results obtained from the diallel analysis (Dimitrova et al., 2017).

Table 6. Components of the variance of productivity/plant in F_1-2010 and F_1-2011 (I-st diallel combination), and F_1-2012 (II-nd diallel combination)

Sources of variation	F_1 – 2010		F_1 – 2011		F_1 – 2012	
	Варианс Variance	Станд. грешка Stand. error	Варианс Variance	Станд. грешка Stand. error	Варианс Variance	Станд. грешка Stand. error
Кръстоски Crosses	$52,921^{++}$	16,905	$8,571^{+}$	2,873	1,4117+	0,5736
ОКС GCA	4,660ns	6.744	0,378ns	0,974	0,0982ns	0,2020
СКС SCA	$43,601^{++}$	16,117	$7,815^{++}$	3,041	1,2152+	0,5894
Грешки Errors	$1,607^{+++}$	0,359	$1,523^{+++}$	0,341	$1,1457^{+++}$	0,2562

Over-dominant type of inheritance of productivity was reported by Latif et al. (2014), Akhtar (2017). Usharani et al. (2015), at diallel crosses with 9 parents, they had a maximum positive relative heterosis of 34.82% and a maximum heterobeltiosis of 27.41%.

The results obtained from our study confirmed the research of other authors that the seed cotton yield was more strongly influenced by the non-additive gene effects (Pole et al., 2008, Gamel et al., 2009; Ali et al., 2009; Khan et al., 2011; Makhdoom, 2011).

Controversial findings in the literature on inheritance of seed cotton yield, according to Khan et al. (2009b) may be due to various factors such as the use of different breeding material and different climatic conditions in which the experiments were conducted.

Conclusion

The genetic control of productivity in the studied sets of varieties included in diallel crosses was basically non-additive. Larger participation of non-additive genetic variation suggests that the selection could be carried out in later hybrid generations - F_3-F_4.

In the first diallel combination, the crosses showed positive over-dominant inheritance of productivity were predominated. Over-dominance in these crosses caused heterosis reaching 22.0%, on average for the two years.

In the second diallel combination, the inheritance of productivity was basically positively over-dominat and incompletely dominat to the more productive parent. Heterosis manifestations were less pronounced (up to 17.7%).

Very good common combinatories of productivity appeared to be the varieties Beli Iskar (1st diallel combination) and Natalia (2nd diallel combination), showed high productivity/plant and significant positive GCA effects in different ecological environments.

References

Akhtar M.A. (2017). Genetics of yield and some yield causative traits in Upland cotton (*Gossypium hirsutum* L.). Global Journal of Plant Breeding and Genetics. ISSN: 2437-1874 Vol. 4 (2), pp. 347-353.

Ali, M.A. & Awan, S.I. (2009). Inheritance pattern of seed and lint traits in *Gossypium hirsutum* L. Int. J. Agric. Biol., 11 (1): 44-48.

Chapepa B., Manjeru, P., Ncube, B., Mudada, N. & Mubvekeri, W. (2015). Diallel analysis on variation of Verticillium wilt resistance in upland cotton grown in Zimbabwe. African Journal of Agricultural Research, Vol. 10(2), pp.39-48, 8 January, 2015

Dimitrova, V., Stoilova, A. & Koleva, M. (2017). Inheritance of productivity in f1 cotton diallel crosses (*Gossypium hirsutum* L.). VIII International Scientific Agriculture Symposium, „Agrosym 2017", Jahorina, Bosnia and Herzegovina, October 2017. Book of Proceedings 2017 pp.118-123 ref.19 (Bg)

Ekinci, R. & Basbag, S. (2015). Combining Ability for Yield and its Components in Diallel Crosses of Cotton. Not Sci Biol, 7 (1):72-80.

Falconer, D.S. (1960). Introduction to quantitative genetics. Ronald Press Co., New York.

Gamel, I.A.M., S.H.M. Abd-El-Halem and E.M.A. Ibrahim (2009). A genetic analysis of yield and its components of Egyptian cotton (*Gossypium hirsutum* L.). American-Eurasian J. Agric. and Environ. Sci., 5 (1): 5-13.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Austral J. Biol. Sci., 9: 463-493.

Iqbal, M.,. Khan, M.A, Jameel, M., Yar, M.M., Javed, Q., Aslam, M.T., Iqbal, B., Shakir, S. & Ali, A. (2011). Study of heritable variation and genetics of yield and yield components in upland cotton (*Gossypium hirsutum* L.). African Journal of Agricultural Research, 6 (17), 4099-4103.

Iqbal A., Ali, S., Zia, M.A., Shahzad, A., Ud Din J, Asad, M.A.U., Ali, G.M. & Zafar, Y. (2013). Comparative account of Bt gene expression in cotton under normal and salt affected soil. Int. J. Agric. Biol., Vol. 15, No. 6

Jatoi, W.A., Baloch, M.J., Khan, N.U., Veesar, N.F. & Batool, S. (2010). Identification of potential parents and hybrids in intraspecific crosses of upland cotton. Sarhad Journal of Agriculture, 26 (1): 25-30.

Karademir, E. & Gencer, O. (2010). Combining ability and aeterosis for yield and fiber quality properties in cotton (*G. hirsutum L.*) obtained by half diallel mating design. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 38 (1): 222 - 227.

Khan, N.U., Hassan, G., Marwat, K.B., Kumbhar, M.B., Khan, I., Soomro, Z.A., Baloch, M.J. & Khan, M.Z. (2009a). Legacy study of cotton seed traits in upland cotton using Griffing's combining ability model. Pak. J. Bot. 41 (1): 131-142.

Khan, N.U., Hassan, G., Marwat, K.B., Farhatullah, M.B., Kumbhar, A., Parveen, Umm-E-Aiman, Khan, M.Z. & Soomro, Z.A. (2009 b). Diallel analysis of some quantitative traits in *G. hirsutum L.* Pakistan Journal of Botany, 41 (6): 3009-3022.

Khan, S. A., Khan, N.U., Mohammad, F., Ahmad, M., Khan, I.A., Bibi, Z., Khan, I.U. (2011). Combining ability analysis in intraspecific F_1 diallel cross of upland cotton. *Pak. J. Bot.*, 43 (3): 1719-1723.

Kumar, A., Nirania, K.S., Chhavikant & Bankar, AH. (2017). Combining ability for seed cotton yield and attributing traits in American cotton (*Gossypium hirsutum* L.). The Journal of Pharmacognosy and Phytochemistry 2017; 6(6): 376-378

Kumar, S., Kumar, K.A., Kesavan, R. (2014). Genetic effects of combining ability studies for yield and fibre quality traits in diallel crosses of upland cotton (*Gossypium hirsutum* L.). Afr. J Biotechnol. 2014; 13(1):119-126.

Latif, A., Ahmad, T., Hayat, S., Sarwar, G., Zahid Ehsan, M., Raza, M., Sarwer, M. and Ahmad Khan, I. (2014). Genetics of yield and some yield contributing traits in Upland cotton (*Gossypium hirsutum* L.). Journal of Plant Breeding and Crop Science, Vol. 6(5), pp. 57-63, May 2014

Makhdoom, K. (2011). Combining ability estimates through line x tester analysis and heritability in upland cotton. *M.Sc (Hons.) Thesis*, Khyber Pakhtunkhwa Agril. Univ. Peshawar, Pakistan.

Munir S., Qureshi, M.K., Shahzad, A.N., Manzoor, H., Shahzad, M.A., Aslam, K. & Athar, H.R. (2018). Assessment of Gene Action and Combining Ability for Fibre and Yield Contributing Traits in Interspecific and Intraspecific Hybrids of Cotton. Czech J. Genet. Plant Breed., 54, 2018 (1).

Pole, S.P., Kamble, S.K. & Madrap, I.A., Sarang D.H.. (2008). Diallel analysis for combining ability for seed cotton yield and its components in upland cotton (*Gossypium hirsutum L.*). Journal of Cotton Research and Development, 22 (1): 2008, 19-22.

Raza, M., Habib, S. & Latif, A. (2013). Genetic Analysis of Some Metric Plant Traits in Upland Cotton (*Gossypium hirsutum* L.) through Hybridization. Universal Journal Plant Science, 1: 1-7.

Sarwar, G., Baber, M., Hussain, N., Khan, I.A., Naeem, M., Ullah, M.A. & Khan, A.A. (2011). Genetic dissection of yield and its components in upland cotton (*Gossypium hirsutum L.*). African Journal of Agricultural Research, 6 (11): 2527-2531.

Singh, P., Mittal, V.P. & Brar, K.S. (2011). Analysis of first degree statistics to estimate gene effects in cotton (*Gossypium hirsutum L.*). Journal of Cotton Research and Development, 25 (2): 2011, 165-167.

Singh, S., Singh, V.V. & Choudhary, A.D. (2010). Combining ability estimates for oil content, yield components and fibre quality traits in cotton (*G. hirsutum*) using an 8 × 8 diallel mating design Tropical and Subtropical Agroecosystems, 12: 161 - 166

Usharani K.S., Vindhiyavarman, P. & Amala B. (2014). Combining ability analysis in intraspecific F_1 diallel cross of upland cotton (*Gossypium hirsutum* L.). *Online published on 9 October, 2014.*

Usharani, K.S., Vindhiyavarman, P., Balu, P.A. & Boopathi, N.M. (2015). Heterosis studies for fibre quality traits in diallel crosses of upland cotton (*Gossypium hirsutum* L.). Nature to Survive 10(2): 793-799 (Supplement on Genetics and Plant Breeding).

Vasconcelos, Araújo, U.A., Cavalcanti, J.J., Farias, F.J., Vasconcelos, W.S. & Santos, R.C. (2018). Diallel analysis in cotton (*Gossypium hirsutum* L.) for water stress tolerance. Crop Breeding and Applied Biotechnology, 18 (1): 24-30.

Wandhare, M.R., Patil, B.R., Ambhore, K.T. & Bhongle, S.A.. (2010). Combining ability studies for seed cotton yield and fibre quality parameters in *Gossypium* *hirsutum L.* Annals of Plant Physiology, Akola: Forum for Plant Physiologists, 24 (1): 65-67.