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Heterosis Performance and Correlation Analysis on Economic Traits of Upland Cotton Hybrids in Different Ecological Environments

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Abstract: 24 combinations by NC Ⅱ mating design and their ten parents were used to evaluate their surpassing parental heterosis of yield and fiber quality traits in three different ecological environments. The results showed that surpassing parental heterosis of yield traits were widely existed in three ecological environments. Especially the lint and seed cotton yield performed the most prominent heterosis, followed by boll number. In the Yangtze River Valley experimental stations, the hybrids and their parents had higher yield, but heterosis was not significant, and in Sanya, Hainan and Anyang, Henan experimental station with relatively lower production levels, though the hybrids had relatively low yield, their parents were significantly lower than the hybrids in yield, so heterosis was significant. This indicated that hybrids exhibited relatively stable yield performances in different environments, but the parents were greatly affected by environments. Fiber quality traits varied with ecological environments, but the surpassing parental heterosis was not significant. Correlation analysis showed that the boll numbers had the closest relation with lint yield. Moreover, there were significantly positive correlations among boll number, boll weight and lint percentage, which indicated the three yield traits can be simultaneously improved through parents selection. Correlations were inconsistent among fiber quality traits in different environments, while the micronaire had significantly positive correlation with other fiber quality traits, hence it was very important to select materials with low micronaire value as parents in high yield and fine fiber quality hybrid breeding.

Key words: upland cotton(*G. hirsutum* L.); ecological environment; heterosis; correlation analysis

The area of transgenic Bt hybrid cotton accounted for 80% of total hybrid cotton planting area in China, and this has made great contribution to increasing cotton yield and reducing cotton planting cost. At present, the transgenic Bt hybrid cotton has been widely planted in the Yangtze River Valley and the Yellow River Valley, so it was very necessary to study their yield, fiber quality traits and their heterosis as well as adaptability in different ecological environments. In this paper, the surpassing parental heterosis of yield and fiber quality traits were evaluated in three different ecological environments, this was expected to guide breeding and extension of the transgenic Bt hybrid cotton.

1 Materials and Methods

1.1 Materials

Using six non-Bt commercial varieties (CCRI 12, Shiyuan 345, Simian 3, Emian 9, Yumian 668, and Huikang 1) from the Yangtze River Valley and the Yellow River Valley as female parents and four transgenic Bt cotton varieties (CCRI 41, Shuangjia 321, DP33B and GKP 4) as male parents, 24 combinations were made according to an incomplete diallel design

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(NC Ⅱ) in the experimental station of Cotton Research Institute of CAAS, 2～4 kg hybrid seeds were harvested from each combination for three ecological experiments.

1.2 Methods

The 24 combinations and their 10 parents were planted in three ecological regions, Wangjiang Cotton Experimental Station in Anhui Province (the Yangtze River Valley ecological areas), Anyang Cotton Experimental Station in Henan Province (the Yellow River Valley ecological areas), and Sanya cotton plantation in Hainan Province (specific cotton ecological areas), in 2003 and 2004, respectively. Each combination and parent was grown in three row plots with planting density of 52500 plants per hm^2; In Sanya, 37500 plants per hm^2 in Anyang, and 30000 plants per hm^2 in Wangjiang by randomly designing blocks. Field management was same as that in commercial production. At opening boll stage (on Sep. 28th 2004 in Anyang; on Sep. 24th, 2004 in Wangjiang; on Mar. 15th, 2004 in Sanya), 50 normally opened bolls were picked randomly for assaying the boll weight, lint percentage. The combinations and parents' fiber samples were tested with HVI 900 system in Cotton Research Institute of CAAS. Seed cotton was harvested eventually from each individual plot, and lint yield was gained by lint percentage.

2 Results and Analysis

2.1 The trait performance of the transgenic Bt combinations in three ecological regions

2.1.1 *Yield traits and heterosis.* Based on the analysis of yield for the 24 combinations and their parents in three environments, it was found that the average yield of F_1s and their parents was the highest in Wangjiang, and the lowest in Sanya. This demonstrated that cotton in the Yangtze River Valley had better performance in yield, which mainly benefited from longer growth period, higher accumulating temperature and enough fertilizer and water. Whereas the combinations and their parents had lower yield in Sanya, the main reasons were the lower temperature at flowering stage, shorter flowering period and few boll number. For yield and its components, the average boll number in Wangjiang ranked first, the second in Anyang, and the third in Sanya. No significant differences were found in lint percentage among three experimental environments, and the average boll weight in Wangjiang was slightly lower than those in Anyang and Sanya. For their parents had lower yield in Anyang and Sanya, surpassing parental heterosis of the F_1s was very significant at the 0.01 level of probability. Though F_1s yield performed well in Wangjiang, because their parents also had high yield, the surpassing parental heterosis was not significant. The surpassing maternal parent heterosis in boll number was significant at the 0.05 or 0.01 levels of probability in Anyang and Sanya, but no significance in Wangjiang, whilst no significant differences in boll weight and lint percentage were detected in the three environments. These results showed that the F_1s performed higher yield level in optimum and inferior ecological environments, but their parents could have higher yield only in superior environment, which indicated that yield performances of hybrid were relatively stable in different environments, and parental yield performances were greatly affected by environments (Table 1).

2.1.2 *Fiber quality traits and heterosis.* There was no significant difference among the three environments for the trait of 2.5% span length. The averaged 2.5% span length of the F_1s in Wangjiang was just slightly shorter than those in the other two environments, and it exhibited positive surpassing parental heterosis in three environments, but not significant. The averaged strength of the F_1s in Wangjiang were stronger by 0.7 $cN \cdot tex^{-1}$ than that in Sanya and by 2.2 $cN \cdot tex^{-1}$ than that in Anyang, but their parents performed better in strength, so it exhibited the negative surpassing parental heterosis, but not significant. The averaged micronaire of the F_1s in Wangjiang were higher by 1.1～1.2

Table 1 Yield traits and heterosis of insect-resistant transgenic cotton combinations and their parents in different environments

Env.	Generation	Seed cotton yield		lint yield		boll number		boll weight		lint percentages	
		Ave. /(kg·hm^{-2})	S. P. H /%	Ave. /(kg·hm^{-2})	S. P. H /%	Ave.	S. P. H /%	Ave. /g	S. P. H /%	Ave. /%	S. P. H /%
Anyang	female	2266.5	39.4**	996.0	39.2**	47.6	19.7*	6.0	0.0	43.7	0.0
	male	2536.5	25.5**	1020.0	35.9**	54.3	4.8	5.5	9.1*	40.4	8.4
	F_1	3159.0		1386.0		57.0		6.0		43.8	
Wangjiang	female	3751.5	4.4	1668.1	4.9	64.8	0.0	5.1	5.9	44.4	0.7
	male	3844.5	1.9	1696.5	3.2	63.9	1.4	5.4	0.0	44.0	1.6
	F_1	3916.6		1750.5		64.8		5.4		44.7	
Sanya	female	1299.0	53.8**	577.5	57.1**	31.5	30.0**	6.0	8.3	44.4	2.0
	male	1516.4	31.8**	652.5	39.1*	36.7	11.4*	5.9	10.2*	44.0	3.0
	F_1	1998.0		907.5		40.9		6.5		45.3	

Note: *, ** -Significantly different at the 0.05 or 0.01 level of probability; S. P. H- Surpassing parental heterosis.

than those in the other two environments, but no significant surpassing parental heterosis was detected, which indicated fiber had the tendency of becoming thick. There was also no significant surpassing parental heterosis for fiber uniformity in three environments. The average elongation of the F_1s in Anyang was close to Sanya, and elongation in these two environments was longer than that in Wangjiang, but there were no significant surpassing parental heterosis for elongation among three environments. The fiber quality of parents and F_1s in Anyang was near to Sanya. Compared to Anyang and Sanya, the fiber was shorter, stronger, thicker and lower elongation in Wangjiang. These results indicated that the variation in fiber quality was caused by ecological environment rather than heterosis itself (Table 2).

Table 2 Fiber quality traits and heterosis of insect-resistant transgenic cotton combination and their parents under different environments

Env.	Generation	2.5% Span length		Strength		Micronaire		Uniformity		Elongation	
		Ave. /mm	S. P. H /%	Ave. /(cN·tex^{-1})	S. P. H /%	Ave.	S. P. H /%	Ave. /%	S. P. H /%	Ave. /%	S. P. H /%
Anyang	Female	28.4	2.8	25.4	4.3*	4.9	-2.0	84.7	0.2	7.3	1.4
	Male	29.1	0.3	26.4	0.4	4.7	2.1	84.5	0.5	7.8	-5.1
	F_1	29.2		26.5		4.8		84.9		7.4	
Wangjiang	Female	27.6	2.5	29.0	-1.0	6.1	-1.6	84.6	-0.9	5.4	0.0
	Male	28.3	0.0	29.2	-1.7	6.0	0.0	84.2	-0.5	5.4	0.0
	F_1	28.3		28.7		6.0		83.8		5.4	
Sanya	Female	28.4	2.1	27.2	2.9	4.8	2.1	85.1	0.7	7.1	4.2*
	Male	29.2	-0.7	28.5	-1.8	5.1	-3.9	85.3	0.5	7.3	1.4
	F_1	29.0		28.0		4.9		85.7		7.4	

Note: * - significant at 5% level; S. P. H- Surpassing parental heterosis.

2.2 Correlation analysis between yield traits and quality traits in different environments

Correlations of genetic and phenotypic value were consistent with yield and fiber quality traits. Significant positive correlations were detected between yield (seed cotton yield, lint yield) and its components (boll weight, boll number and lint percentage), and the correlative coefficient between yield and boll number was bigger than that between yield and boll weight, as well as between yield and lint percentage, which indicated boll number made great contri-

bution to yield. Significant positive correlations were also observed among boll number, boll weight and lint percentage, indicating that these three yield traits could be improved synchronously through parent selection. The positive correlation was also detected between yield and 2.5% span length, strength, micronaire, indicating yield increase might go with the increase of 2.5% span length, strength, micronaire, but micronaire increased always faster than other traits, and with the increase of micronaire, the fiber became thicker, which affects the fiber quality. Seed cotton yield had negative correlation with elongation, whilst micronaire had negative correlation with 2.5% span length and elongation, and significant positive correlation with uniformity (Table 3). The inconsistent correlations among fiber quality traits implied it would be difficult to gather high yield with fine fiber quality.

Table 3 Correlations of yield traits with quality traits under different environments

	Lint yield	Boll number	Boll weight	Lint percentage	2.5% Span length	Uniformity	Strength	Elongation	Micronaire
Seed cotton	0.974**	0.716**	0.451**	0.314**	0.201**	0.183	0.190**	-0.038	0.213**
	0.971**	0.757**	0.540**	0.406**	0.209**	0.199	0.212**	-0.085	0.294**
Lint yield		0.707**	0.459**	0.513**	0.153*	0.166	0.140**	-0.012	0.212**
		0.756**	0.532**	0.605**	0.164*	0.180	0.139**	-0.042	0.272**
Boll number			0.102*	0.261**	0.064	0.157	0.041	0.061	0.171**
			0.154*	0.384**	0.078	0.159	0.023	0.058	0.262**
Boll weight				0.223**	0.001	0.194*	0.364**	-0.440**	0.377**
				0.237**	0.021	0.324*	0.433**	-0.494**	0.414**
Lint percentage					-0.204**	0.020	-0.253**	0.100**	0.098**
					-0.226**	0.051	-0.274**	0.139**	0.078*
2.5% Span length						0.148	0.283**	0.226**	-0.263**
						-0.025	0.276**	0.254**	-0.274**
Uniformity							0.341**	-0.042	0.283**
							0.465**	-0.042	0.383**
Strength								-0.408**	0.263**
								-0.551**	0.334**
Elongation									-0.496**
									-0.524**

Note: the phenotypic correlation and genetic correlation were in the upper and lower line, respectively; * and **: significant at 5% and 1% level, respectively.

3 Discussions

3.1 Adaptability to environment of yield and fiber quality

Heterosis of the transgenic Bt hybrid cotton has been reported in many papers. Some papers[1-3] pointed out that contributions of boll number and boll weight to heterosis were bigger than lint percentage, and the others[4-5] concluded that boll weight and lint percentage played important roles in yield heterosis. The reason might lie on the different materials used in each research. So far, the F_1 heterosis of the transgenic Bt hybrid cotton yield and quality in different ecological environments is known less. Tang[6-7] reported F_2 hybrids yield performed more stable than their parent in different ecological environments. Our studies showed hybrids and their parents exhibited higher yield level in the superior environment but had no significant heterosis, whereas, heterosis was more apparent in the inferior environment, though hybrids and their parents exhibited lower yield level, the yield of the parents was significant lower than that of the hybrids. These results implied that hybrids possessed better adaptability to environment than their parents. According to the performance of transgenic Bt hybrid, the Yellow River Valley was superior to the Yangtze River Valley in planting the transgenic Bt hybrid cotton. If the technology of nutritive bowl for saving hybrid seeds is widely used in the Yellow River Valley, prospect of application of the transgenic Bt hybrid cotton will be very bright.

More studies showed fiber quality traits varied with the environments[8-10], and no significant surpassing parental heterosis could be detected[11].

3.2 Correlation of yield traits with quality traits

Studying on correlation between yield and quality could provide an important guide in hybrid breeding. Previous study showed that there was a negative correlation between yield and quality, implying it was difficult to improve yield and quality synchronously[12]. Our study showed that yield had positive correlations with 2.5% span length, strength, micronaire, indicating yield and the three major quality traits could be improved simultaneously through parent selection, but micronaire's increasing may make fiber thicker, which degraded the cotton quality. In spinning industry, only the kind of cotton fiber with well-matched length, strength and fineness is needed[13]. So in high yield and fine quality hybrid breeding, the key point is to select those parents with low micronaire.

Moreover, previous study also showed that significant positive correlation between boll number and cotton yield, therefore, boll number per plant contributed to cotton yield greatly. Hence in cotton high yield breeding, plants with more bolls should be selected, because more bolls are one of the main reasons of high yield.

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