Full Length Article

Performance of Yield Components and Morphological Traits and Their Relationships of the Lint Yield in *Bt* Cotton (*Gossypium hirsutum*) Hybrids

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ABSTRACT

A field experiment was conducted with the objective to compare the mean performance of yield components and morphological traits among *Bt* cotton hybrids with diverse yield level, and to evaluate their relationships of the lint yield. Thirty insect-resistant transgenic upland cotton crosses were divided into three types (high, medium, low) based on lint yield per hectare by squared Euclidean distance and Ward linkage. Three yield components and 10 morphological traits of the three types were separated using ANOVA procedure and the Duncan's multiple range test. The relationships between them and lint yield were investigated using correlation analysis and stepwise regression analysis. The results showed there was statistically significant difference in bolls per plant and lint percentage for the three types, which increased with increasing lint yield. The Pearson's correlation coefficients between them and lint yield were the highest. The direct path coefficient was the maximum for bolls per plant to lint yield. No statistically significant difference was found for the ten morphological traits in the three types. The direct path coefficient of fruiting sites per sympodia to lint yield was positive and significant at 0.05 level. The minimum direct path coefficient to lint yield was due to height of the first fruiting branch. © 2012 Friends Science Publishers

Key Words: Upland cotton; *Bt* hybrid; Morphological traits; Yield components; Lint yield

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) fibre is becoming an increasingly important issue in modern textile industry. Currently production of high fiber quality (staple length not shorter than 31 mm, fiber strength not lower than 34cN/tex, micronaire ranges 3.8 to 4.4, HVICC level) cotton fails to meet the market requirement in China(Tang & Yang, 2006).

A low production is attributable to the scarcity of proper cotton varieties with high quality. Insect-resistance is an essential attribute for cotton varieties cultivated commercially in china, which helps to reduce application of pesticide and environmental pollution and increase lint yield. Development of productive *Bacillus thuringiensis* (*Bt*) transgenic hybrid cotton with high quality has long been an objective of Chinese. Breeders think it is feasible to improve cotton yield and fiber properties by heterosis utilization. Meredith and Brown (1998) reported that yield heterosis over the better parent or best commercial cultivar (useful heterosis) averaged 21.4% for F_1 hybrids, and 10.7% for F_2s in cotton. Verma *et al.* (2006) observed a maximum heterosis of 72.55% for seed cotton yield, and 82.35% for number of bolls per plant in 50 cross-combinations. Tuteja

et al. (2006) reported a maximum heterosis of 14.72% for 2.5% span length, 7.11% for bundle strength and a maximum negative heterosis of -9.30% for fibre fineness in 41 hybrids. However, heterosis is not uniformly manifested in all crosses and for all traits. Positive and negative heterosis was observed for most characters in cotton crosses (Khan, 2002; Preetha & Raveendran, 2008). It would be worthwhile to identify the properties governing heterosis and productivity. Among three yield components, no. of bolls per plant was considered the first important contributor to seed yield of the cotton, followed by boll weight (Rauf *et al.*, 2004). Cultivars of cotton with diverse genetic background could express different growth and development habits and morphological characteristics. Zhu *et al.* (2002) and Zhang and Ni (2006) reported that high quality cotton varieties were characterized by strong vegetative development with long fruiting branches and numerous vegetative branches. Introduction of *Bt* gene led to reduced vegetative growth, early flowering onset and shorten effective flowering period in transgenic insect-resistant cotton (Tian *et al.,* 1999; Yi *et al.*, 2009).

It is not well known how combinations of *Bt* gene and superior fibre genes affect vegetative and reproductive

growth and the yield of cotton. Cotton is an indeterminate plant. Development of morphological traits is easily influenced by environment and cultivation conditions. Plant architecture modifications that allow more light penetration into the lower depths of the canopy may be an approach to enhance the yield of cotton. Reta-sanchez and Fowler (2002) proposed that cultivars with reduced plant height, short branches, modified leaves, and combinations of these characteristics grown at high plant densities and in a narrow-row system could be a good alternative to increase the yield of cotton. Kerby and Buxton (1981) suggested that cultivars with short fruiting branches and reduced leaf area in the upper canopy could increase efficiency of assimilate utilization in narrow-row cotton. The relationships between some plant architecture traits and seed cotton yield for conventional cotton cultivars grown at medium-high plant densities have been investigated by Preetha and Raveendran (2007) and Sekloka *et al.* (2008).

Compared to conventional cotton cultivars, hybrid cotton exhibits vigorous vegetative growth and a larger plant body. So plant density of them should be lower, which usually ranged from 22500 to 27000 plants ha^{-1} in Yangtse Valley region, China (Niu, 2007). Little information is available regarding selection of ideotype for productive *Bt* cotton hybrids containing superior fibre genes grown in low stand densities. The purpose of this research was to determine the differences in yield components and ten morphological traits among combinations between *Bt* transgenic and high quality lines, and evaluate the relationships between those traits and lint yield.

MATERIALS AND METHODS

Six cotton genotypes with high fiber quality, Yumian No.1(1), Jinxing No.2(2), AX(3), 2870(4), A801-5(5), A9-1(6) were used as females and five transgenic *Bt* genotypes, 33B(7), Y22(8), 99B(9), 9007(10),GK22(11) were used as males. Thirty F$_1$ hybrids were obtained in a 6×5 diallel crossing way in 2006.

The thirty hybrids were raised in a randomized block design with three replications during 2007 at the agriculture experimental station, Jiangxi Agricultural University, Nanchang, China. Obtained seedlings were raised in warm room covered by plastic film of the field with sowing date 18 April and transplanted on 7 May in 9.3 m rows spaced 1.05 m apart and with an interplant distance of 0.45 m. All the cultural practices were adopted as recommended. Ten randomly selected plants in the middle of each plot were investigated for bolls per plant and plant architecture data in late September 2007. Plant type characters were measured as follows:

Plant Height (PH), measures the height of the main stem (in cm) from the cotyledonary node to the tip. Height of the First Sympodia (HFS), measures the height of the main stem (in cm) from the cotyledonary node to the first fruiting branch. Main-stem Internodal Length (MIL), is the

ratio of the plant height (in cm) to the total number of nodes counted above the cotyledonary node on the main stem. Length of Sympodia (LS) was measured (in cm) on the fifth fruiting branch of the plant. Sympodial Branch Angle (SBA), measured as the angle between the main stem and sympodia recorded for the sixth to eighth sympodias. No. of Sympodia per plant (NOS) is the number of fruiting branches on the main stem. Sympodia Internodal Length (SIL) was measured for the first internode of the sixth to eighth fruiting branches. No. of Fruiting Positions (NFP), is the total number of fruiting forms on the plant.

Ratio of Plant height to Length of Sympodia (RPLS), is the ratio of the plant height (in cm) to the length of sympodia. Fruiting sites per sympodia (FSPS), is the ratio of No. of fruiting positions to No. of sympodia per plant.

A 50-boll, sample was harvested by hand from each plot, which was composed of first or second position bolls from approximately the middle five fruiting nodes as described by Cheatham *et al.* (2003). These samples were ginned using a laboratory gin and used to determine lint percentage and boll weight. Cotton in each plot was hand–harvested four times at 3-weeks intervals, lint yield was determined after ginning and expressed as kilogram per hectare (kg/ha).

The yield data of cotton was subjected to hierarchical cluster analysis to classify the thirty hybrids into three types (high yielding, medium yielding & low yielding) based on lint yield per hectare according to squared Euclidean distance and Ward linkage suggested by Yang and Zhou (1995). All data were statistically analyzed for variance sources and Duncan's multiple range test at a significant level of 0.05/0.01 applied to determine differences among the three types. Relationships between yield components and morphological traits and lint yield were investigated by the pearson correlation coefficient analysis and stepwise regression analysis. The data processing was carried out using SPSS 13.0 and EXCEL statistical software.

RESULTS

Cluster analysis: The thirty crosses were divided into three types or classes (high, medium & low yielding) based on lint yield per hectare using squared Euclidean distance and Ward linkage (Fig. 1). The high yielding type included a total of 5 crosses (1×8、2×11、5×11、6×8 & 6×7). The medium yielding type contained a total of 11 crosses (1×7、1×11、2×8、3×7、3×8、3×9、3×11、4×10、4×11、5×7 & 6×11). The low yielding type consisted of a total of 14 crosses (1×9、1×10、2×7、2×9、2×10、3×10、4×7、4×8、4×9、5×8、5×9、5×10、6×9 & 6×10).

Variance analysis results: Statistically significant differences were detected for lint yield per hectare, bolls per plant and lint percentage, whereas the ten traits investigated didn't exhibit prominent difference among the three types

(Table I). Means of the three characters were compared among those types using the Duncan's multiple range test. It was showed that bolls per plant and lint percentage increased with the enhancement of lint yield per hectare in those transgenic cotton hybrids investigated in this research.

The correlation coefficients and stepwise regression analyses: Correlation analysis indicated that bolls per plant and lint percentage were positively correlated to lint yield per hectare. The Pearson's coefficients were 0.489 and 0.463, respectively (Table II). NFP and FSPS had positive and significant associations with lint yield per hectare. The Pearson's coefficients were 0.410 and 0.408, respectively (Table II). Partial correlation analysis showed all the traits investigated in this study exhibited low and non-significant associations with lint yield per hectare. Stepwise regression analysis revealed that bolls per plant, FSPS and HFS had prominent impacts on lint yield per hectare. The linear regression model is $Y = 22.663X_1 + 205.876X_2 - 69.109X_3 + 391.903$, $r^2 = 0.487^{**}$, where Y is stand for lint yield, X_1 is stand for bolls per plant, X_2 is stand for FSPS, X_3 is stand for HFS, r^2 is stand for coefficient of determination. Standardized partial regression coefficients (viz., direct path coefficients) of them to lint yield per hectare were 0.425, 0.392 and -0.334 respectively (Table II). Bolls per plant had maximum positive direct effect on lint yield per hectare followed by FSPS, whereas, HFS had maximum negative direct effect on lint yield per hectare.

DISCUSSION

In China, cotton is grown in three agro climatic regions, Xijiang region (northwestern), Huang-Huai (northern) and Yangtse Valley region (south). Yangtse Valley possesses the longer non-frost period, more accumulated temperature and rainfall than the other two regions. Such climatic conditions could have cotton thriven more easily. Nevertheless, the characteristics of yield components and plant type traits for productive cotton crosses with high quality grown in Yangtse Valley have not been documented before. In this study, there were significant differences for bolls per plant and lint percentage among the three types. However, the three types didn't exhibit prominent differences in boll weight and ten morphological traits. Correlation and stepwise regression analysis revealed that bolls per plant had the maximum positive effect on lint yield followed by lint percentage (Table II). Thus, bolls per plant and lint percentage should be key characters for selecting the high yielding cotton genotypes. Most of researchers reported that bolls per plant was the most important contributor to seed cotton yield (Naveed *et al.*, 2004; Rauf *et al.*, 2004; Gite *et al.*, 2006).

Boll weight had low and negative association with lint yield in terms of Pearson's correlation coefficient (PeCC, -0.003), but showing non-significant and positive association with lint yield in terms of partial correlation

Table I: Means of the three yielding types for lint yield per hectare, bolls per plant and lint percentage

Yielding type	Lint/kg.ha⁻¹	Bolls per plant	Lint percentage/%
High yielding	2229.538Aa	49.060Aa	41.126Aa
Medium yielding	1729.636Bb	48.071Aa	40.304Aa
Low yielding	1272.370Cc	40.150Bb	38.076Ab

Note: Values within a column followed by the same letter are not significantly different.

Table II: Correlation coefficients and direct path coefficients between the three yield components and ten morphological traits and lint yield per hectare in upland cotton crosses

Traits	PeCC	PaCC	DPC
BPP	0.489**	0.306	0.425**
BW	-0.003	0.301	0.134
LP	0.463**	0.182	0.240
HFS	-0.359	-0.258	-0.334*
PH	-0.134	0.113	0.002
MIL	-0.115	-0.029	-0.030
NOS	0.044	-0.078	0.038
SBA	0.132	0.417	0.212
LS	0.082	-0.182	0.021
RPLS	-0.192	-0.178	-0.039
SIL	0.230	0.177	0.056
NFP	0.410*	0.124	0.059
FSPS	0.408*	-0.072	0.392**

Notes:*,** significant at the 0.05 and 0.01 probability levels, respectively. PeCC is stand for Pearson's correlation coefficient; PaCC is stand for partial correlation coefficient; DPC is stand for direct path coefficient. BPP is stand for bolls per plant; BW is stand for boll weight; LP is stand for lint percentage; HFS is stand for height of the first sympodia; PH is stand for plant height; MIL is stand for main-stem internodal length; NOS stands for no. of sympodias per plant; SBA is stand for sympodial branch angle; LS is stand for length of sympodia; RPLS is stand for ratio of plant height to length of sympodia; SIL is stand for sympodia internodal length; NFP is stand for No. of fruiting positions; FSPS is stand for fruiting sites per sympodia

coefficient (PaCC, 0.301) and direct path coefficient (DPC, 0.134). Simple linear correlation is a measure of the degree to which two variables vary together, or a measure of the intensity of the association between two variables. It does not always mean that one causes the other. It is very possible that there is a third factor involved. Partial correlation is a method used to describe the association between two variables, whilst taking away the effects of another variable, or several other variables, on this association. Path coefficient analysis (Wright, 1921) provides an effective means of partitioning correlation coefficients into direct effects and indirect effects, thus revealing the true nature of cause-and –effect relationships among of a set of variables. The positive association between boll weight and seed cotton yield was reported by (Rauf *et al.*, 2004; Gite *et al.*, 2006; Preetha & Raveendran, 2007). The opposite result was given by Naveed *et al.* (2004).

Negative correlation between HFS and lint yield was detected according to PeCC, PaCC and DPC, and its direct negative effect on lint yield reached significance at 0.05 level. HFS could be served as a reliable early maturing trait as node of the first fruiting branch (Iqbal *et*

Fig. 1: Dendrogram of the 30 upland cotton crosses

Dendrogram using Ward Method
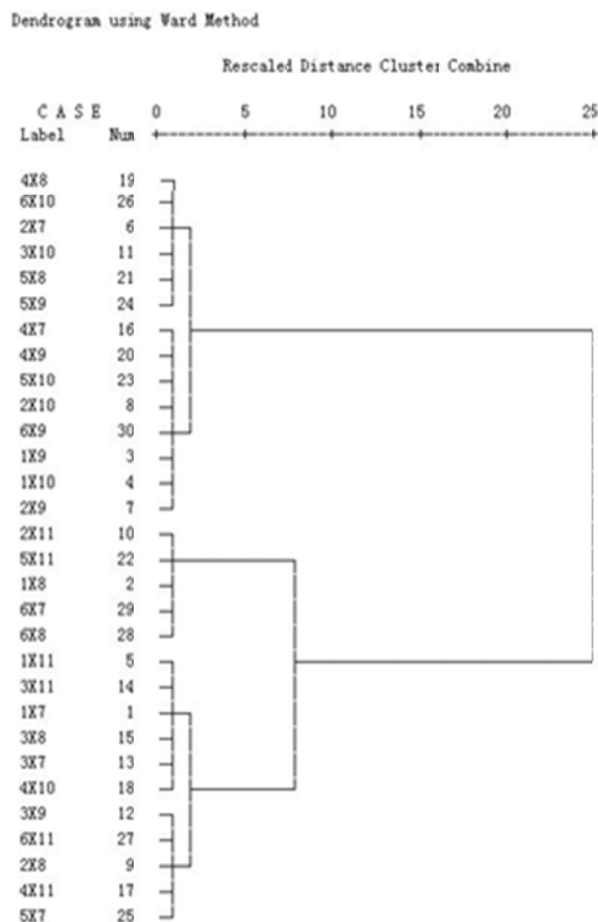
al., 2003). High HFS might be associated with delayed crop maturity resulting in yield loss. This information suggests that a proper decrease in HFS increases lint yield for the present plant materials.

Little association between plant height with lint yield was observed. Similar result was reported by Rauf *et al.* (2004). Therefore, plant height cannot be used as a criterion of lint yield improvement in cotton.

Negative and non-significant association between MIL and lint yield was detected in terms of PeCC, PaCC and DPC, as was in conformity with the Rauf *et al.* (2004), who found that intermodal length had maximum negative direct effect on seed yield of cotton. However, our result was not in accordance with Preetha & Raveendran (2007). They reported that internode length exhibited significant and positive association with seed cotton yield in semi-compact plant type. The difference might be accredited to the various experimental materials used with diverse genetic background.

NOS showed low and positive correlation with lint yield in terms of PeCC and DPC, but neglectable and negative in terms of PaCC. Rauf *et al.* (2004) reported that the direct effect of sympodial branches on seed cotton yield was low and negative. Gite *et al.* (2006) observed that

number of sympodias per plant had positive and significant genotypic and phenotypic correlations with seed cotton yield.

LS showed positive correlation with lint yield for PeCC and DPC, but non-significant and negative for PaCC. RPLS showed non-significant and negative correlation with lint yield for PaCC, PeCC and DPC. These results suggest that a certain degree of horizontal extension for sympodia is necessary for *Bt* cotton hybrids to increase the lint yield of cotton.

Both SBA and SIL showed positive correlations with lint yield for PaCC, PeCC and DPC. The results suggest robust plant type produces higher lint yield as compared to compact plant type for *Bt* cotton hybrids grown at low plant densities.

NFP was positively associated with lint yield. The PeCC between NFP and lint yield reached significance at 0.05 level (0.410). FSPS was found to have significant and positive correlation with lint yield for PeCC and DPC, but low and non-significant for PaCC (-0.072). These results imply that more fruiting positions on plant and sympodia contribute to increase lint yield. Thus they also form critical traits for cotton improvement.

CONCLUSION

Productive cotton genotypes are characterized by higher bolls per plant and lint percentage than low-medium yielding genotypes. In contrast with conventional cotton varieties, greater efforts should be made to enhance individual plant productivity for *Bt* cotton hybrids due to strong heterosis vigor expressed in growth and development. Robust plant types with increased SBA, LS, SIL, NFP and FSPS have yield advantage over compact ones. Low HFS means shorten days to first flowering and prolonged effective flowering period resulting in the increase of the yield of cotton. But an extremely low HFS is usually accompanied with increased boll rot on the bottom fruiting branches due to high humidity and bad sunlight in the bottom. A proper decrease of HFS should be desirable for selection of productive *Bt* cotton hybrids.

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