INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is one of the most important plants worldwide because of its fiber that is used as raw material for the textile industry. Since the dyes used in dyeing process negatively affect the environment, many people prefer to use natural colored cotton products. The objective of this study was to establish the inter-relationship and direct and indirect effect of various quality traits on seed cotton yield in colored cotton genotypes. The F_3_ and F_4_ generations of the cross between Carmen (white) and Devetüyü-176 (brown fiber) were used for selection process in terms of seed cotton yield per plant and fiber color. The measured quality traits in the selected genotypes from F_3_ and F_4_ generations were micronaire, fiber strength, fiber length, uniformity ratio, short fiber index, fiber elongation. Phenotypic correlation and path coefficients were calculated separately for each generation. As results of the correlation analysis, seed cotton yield was not negatively associated with fiber quality properties. It may be concluded that the selection for seed cotton yield and fiber color should be applied in early generations and fiber quality properties of the selected promising colored cotton genotypes can be determined in further generations of Carmen x Devetüyü-176.

Keywords: colored cotton, yield, fiber traits, correlation, path analysis

Correlation and Path Analysis in Yield and Quality Traits in F_3_ and F_4_ Generation of Carmen x Devetüyü-176

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**ABSTRACT**

Cotton (*Gossypium hirsutum* L.) is one of the most important plants worldwide because of its fiber that is used as raw materials for the textile industry. Since the dyes used in dyeing process negatively affect the environment, many people prefer to use natural colored cotton products. The objective of this study was to establish the inter-relationship and direct and indirect effect of various quality traits on seed cotton yield in colored cotton genotypes. The F_3_ and F_4_ generations of the cross between Carmen (white) and Devetüyü-176 (brown fiber) were used for selection process in terms of seed cotton yield per plant and fiber color. The measured quality traits in the selected genotypes from F_3_ and F_4_ generations were micronaire, fiber strength, fiber length, uniformity ratio, short fiber index, fiber elongation. Phenotypic correlation and path coefficients were calculated separately for each generation. As results of the correlation analysis, seed cotton yield was not negatively associated with fiber quality properties. It may be concluded that the selection for seed cotton yield and fiber color should be applied in early generations and fiber quality properties of the selected promising colored cotton genotypes can be determined in further generations of Carmen x Devetüyü-176.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is one of the most important plants worldwide because of its fiber that is used as raw materials for the textile industry. As almost all the cotton varieties in use have white fiber, dyeing is required to obtain different color in textile fabrics. The enormous consumption of dyes has negatively affected the environment and human health (Hua et al. 2007). Many people prefer to wear clothes made from natural colored cotton which does not contain the dangerous chemicals used by textile units.

Colored cotton is commonly referred as cotton with naturally colored lint. Naturally colored cottons are mutants of plants that normally produce white fiber and have existed for over 5000 years (Hua et al. 2007; Khan et al. 2010). It is stated that colored cotton is being grown and used since 2500 B.C. (Singh et al. 2000).

Commercial cotton has all bright white and creamy yellow lint colors. Colored cotton is a naturally pigmented fiber and has several different lint colors such as brown, black, red, pink, blue and green (Murthy 2001). The brown colour, which is the most common colour, is found in different shades and ranges from light brown to intense mahogany red in all the four cultivated as well as many of the wild species (Singh et al. 2000).

Even though the demand for colored cotton is increasing, its cultivation remains behind white fiber cotton. The most important reason of this is that cotton farmers do not like colored cotton because of low lint yield, short, weak and coarse fiber and nonuniform colour (Murthy 2001; Dutt et al. 2004). Also, the ability of the fiber from colored cotton to be machine spun is lower and color range is limited. In addition to this, the uncertain market demands and the need for newly invented looms for short-fibered colored cotton have contributed to its reduced cultivation (Khan et al. 2010).

Cotton breeders are trying to improve colored cotton with high yield and quality at least similar with white fiber cotton. However, the genes for lint colour are found to be pleotropic that means they control more than one trait (Murthy 2001), and seed cotton yield and fibre quality are controlled by polygenes and highly influenced by the environment (Magadum et al. 2012). Therefore, improving colored cotton varieties with high yield and quality is very grueling. It may be an alternative solution to take advantages of advanced lines of white and colored cotton crosses to combine the superior properties of white cotton with different fiber colors. Although there are limited studies using segregating population of white and colored cotton (Carvalho et al. 2014), it would be helpful to investigate and identify of the associations between yield components and fiber quality traits in colored cotton genotypes for cotton breeders. For this purpose, correlation coefficient and path analysis are mostly used to determine the characters for selection to improve yield or quality in many cotton researches (Ahuja et al. 2006; Magadum et al. 2012; Thiyagu et al. 2010; Ekinci et al. 2010; Wadeyar and Kajjidioli 2014). So, the aims of this research to reveal the relationship between seed cotton yield and quality traits among colored cotton genotypes.
of $F_3$ and $F_4$ generations after crossing white x brown fiber colored cotton varieties.

**MATERIALS AND METHODS**

The varieties, Carmen (G. hirsutum L.) originated from Australia and Devetüyük-176 (G. hirsutum L.) were used as parents in the study. Carmen has high yield potential and its vegetation period is in middle late class. The adaptation ability is very high against all kind of land and climate conditions. It is resistant against the shedding of the flowers and the squares caused by drought conditions. Its ginning out-turn is 43%. It has high resistance against to pests. There are approximately 9700 seeds in 1 kg. With the fiber quality on Fibermax standards, it is the prior choice for textile industry. Devetüyük-176 is a natural colored cotton line. It has brown fiber color and is one of the high-class genotypes in the brown color scale.

The crosses between the parents were made in 2007. The generations ($F_1$, $F_2$, $F_3$, $F_4$) were obtained every following year and cultivated in field conditions. Growing of all generations was designed as single rows in experimental station of Ege University, Field Crops Department, Bornova, İzmir, Turkey. The seeds of all generations were sown by hand then thinned to 20 cm in rows. The rows were three-meter length; consisted of 15 individual plants and the length between the rows were 70 cm. The fertilization was applied to all experiments as 80 kg/ha nitrogen and P$_2$O$_5$ before sowing, then 80 kg/ha nitrogen was given in half ratio with first and second irrigation. All generations were irrigated 5 times after flowering stage by furrow irrigation and the plants were hoed two times for weed control.

Seed cotton yield per plant and some yield components were measured for all individual plants in $F_3$ and $F_4$ generations. The selection process was performed with the 10% selection intensity depending upon seed cotton yield per plant and fiber color based on individual plants in both $F_3$ and $F_4$ generations. In other words, the plants with high yielding and colored fiber were selected for the next generation. For fiber color, the plants were visually selected for two generations at first, later fiber colors of parents and the selected plants in $F_3$ generation were quantified as $L$, $a$, $b$, $\Delta L$, $\Delta a$, $\Delta b$, $\Delta E$ parameters using Minolta C400 Chromameter (Konica Minolta Holdings, Inc., Tokyo, Japan). The 54 and 42 individuals were selected in $F_3$ and $F_4$ generations, respectively, and the fiber quality properties of hand harvested selected individual plants that are micronaire, fiber strength (g/tex), fiber length (mm), uniformity ratio (%), short fiber index (%), fiber elongation (%) were measured by using of USTER HVI 900 A (High Volume Instrument).

The seed cotton yield per plant and quality measurements of selected individual were taken to correlation and path coefficient analyses separately for the $F_3$ and $F_4$ generations. Phenotypic correlation and path coefficients were calculated separately for each set according to the procedures from Singh and Chaudhary (1985) and Dewey and Lu (1959), respectively.

**RESULTS**

The phenotypic variations of seven fiber color parameters of the parents, Carmen (white) and Devetüyük-176 (brown fiber) and the selected individual plants from $F_3$ generation were summarized in Table 1. The skewness and kurtosis values, which should be near zero for normal distributions ranged from -0.38 to 0.40 and -1.62 to -1.49, respectively in the $F_3$ generation. Transgressive segregations could be observed for all fiber color parameters in selected $F_3$ plants (Table 1).

Correlation coefficients at phenotypic level of the selected plants in $F_3$ and $F_4$ generations were presented in the Table 2. The correlations with the plant seed cotton yield were found negative and nonsignificant for micronaire, fiber strength and short fiber index while it was found positive and nonsignificant for other quality traits in $F_3$ generation. However, seed cotton yield had positive nonsignificant correlations for all traits except short fiber index in $F_4$ generation. Micronaire values of the selected plants in $F_3$ generation presented negative and positive significant correlation with fiber length and short fiber index, respectively. Fiber strength revealed positive significant correlation for fiber length, uniformity ratio and fiber elongation and negative significant correlation for short fiber index in $F_3$ generation. This trait only showed positive significant correlation for uniformity ratio in $F_4$ generation. In both generations, fiber length had negative significant correlations with short fiber index and positive significant correlation with fiber elongation. It presented positive significant correlation with uniformity ratio only in $F_3$ generation. Significant and negative correlations were observed between uniformity index and short fiber index in both generations. However, uniformity index showed positive and significant correlation with fiber elongation in $F_3$ generation. Short fiber index had negative and significant correlations with fiber elongation in both generations (Table 2).

The path coefficients showing direct and indirect effects of the quality traits on seed cotton yield per plant in $F_3$ generation are presented in Table 3. The maximum direct effect on seed cotton yield was contributed mostly by fiber elongation (0.3530), followed by uniformity ratio (0.0543) and micronaire (0.0064). On the other hand, the maximum negative direct effect was exhibited by fiber strength (-0.3972), followed by short fiber index (-0.1400) and fiber length (-0.0923).

The direct effect of micronaire to the seed cotton yield was positive but three indirect effects of this trait were negative. Fiber strength recorded a high negative
indirect effects via fiber length, uniformity ratio and fiber elongation on the seed cotton yield. Short fiber index caused high positive indirect effect via fiber length on the seed cotton yield. Fiber elongation revealed positive indirect effects via fiber strength, fiber length and uniformity ratio while high negative indirect effects via short fiber index. The rest of traits showed moderate low positive or negative indirect effects on the seed cotton yield (Table 3).

The path coefficients showing direct and indirect effects of the quality traits on seed cotton yield per plant in F4 generation are presented in Table 4. The maximum direct effect on seed cotton yield was contributed by fiber strength (0.2118), followed by fiber elongation (0.1415), fiber length (0.1263) and micronaire (0.0545). However, the maximum negative direct effect was exhibited by uniformity ratio (-0.1167), followed by short fiber index (-0.0397).

Fiber strength had positive indirect effects via all quality traits except short fiber index on the seed cotton yield. Fiber length caused high negative indirect effects via short fiber index on the seed cotton yield. The indirect effects of uniformity ratio were negative via all other traits except short fiber index. The rest of traits showed moderate to low positive or negative indirect effects on the seed cotton yield.

Table 1. Phenotypic variation of the fiber color parameters in the parent lines Carmen and Devetüyü-176 and 54 selected F3 individuals.

<table>
<thead>
<tr>
<th>Fiber color parameters*</th>
<th>Parent lines</th>
<th>Variation in the selected plants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Carmen</td>
<td>Devetüyü</td>
</tr>
<tr>
<td>L</td>
<td>87.45</td>
<td>64.91</td>
</tr>
<tr>
<td>a</td>
<td>-0.11</td>
<td>7.59</td>
</tr>
<tr>
<td>b</td>
<td>6.68</td>
<td>22.12</td>
</tr>
<tr>
<td>ΔL</td>
<td>-5.76</td>
<td>-40.74</td>
</tr>
<tr>
<td>Δa</td>
<td>-0.38</td>
<td>7.44</td>
</tr>
<tr>
<td>Δb</td>
<td>8.85</td>
<td>22.95</td>
</tr>
<tr>
<td>ΔE</td>
<td>10.64</td>
<td>38.58</td>
</tr>
</tbody>
</table>

* Fiber color parameters: L indicates color brightness (L=0 is black and L=100 is white); a indicates red-green (+ is red and - is green); b indicates yellow-blue (+ is yellow and - is blue); ΔL indicates total black-white color change; Δa indicates total red-green color change; Δb indicates total yellow-blue color change; ΔE indicates total color change independent from each other.

Table 2. Correlation coefficients between quality properties and seed cotton yield among selected plants 54 in F3 and 42 in F4 generation.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Micronaire</th>
<th>Fiber Strength (g/tx)</th>
<th>Fiber Length (mm)</th>
<th>Uniformity Ratio (%)</th>
<th>Short Fiber Index (%)</th>
<th>Fiber Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (g/plant)</td>
<td>F3: -0.05?ns</td>
<td>-0.20?ns</td>
<td>0.028ns</td>
<td>0.041ns</td>
<td>-0.098ns</td>
<td>0.235ns</td>
</tr>
<tr>
<td>F4: 0.028ns</td>
<td>0.199ns</td>
<td>0.202ns</td>
<td>0.089ns</td>
<td>-0.183ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>Micronaire</td>
<td>F3: -0.020ns</td>
<td>-0.546**</td>
<td>0.079ns</td>
<td>0.430**</td>
<td>-0.187ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>F4: 0.176ns</td>
<td>-0.162ns</td>
<td>0.266ns</td>
<td>0.041ns</td>
<td>-0.077ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>Fiber Strength</td>
<td>F3: 0.301*</td>
<td>0.571**</td>
<td>-0.282*</td>
<td>0.420**</td>
<td>0.194ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>F4: 0.104ns</td>
<td>0.445**</td>
<td>-0.188ns</td>
<td>0.064ns</td>
<td>0.041ns</td>
<td>-0.077ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>Fiber Length</td>
<td>F3: 0.324*</td>
<td>0.901**</td>
<td>-0.282*</td>
<td>0.420**</td>
<td>0.194ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>F4: 0.293ns</td>
<td>-0.875**</td>
<td>0.439**</td>
<td>0.064ns</td>
<td>0.041ns</td>
<td>-0.077ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>Uniformity Ratio</td>
<td>F3: -0.541**</td>
<td>0.475**</td>
<td>-0.587**</td>
<td>0.258ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>F4: -0.587**</td>
<td>0.258ns</td>
<td>0.194ns</td>
<td>0.041ns</td>
<td>-0.077ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>Short Fiber Index</td>
<td>F3: -0.358**</td>
<td>-0.452**</td>
<td>0.258ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
</tr>
<tr>
<td>F4: -0.358**</td>
<td>-0.452**</td>
<td>0.258ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
<td>0.194ns</td>
</tr>
</tbody>
</table>

* , **: Significant at the 0.05 and 0.01 probability levels, respectively; ns: nonsignificant.
Table 3. Direct (bold) and indirect effects of the quality properties to seed cotton yield per plant among 54 selected plants in F₃ generation

<table>
<thead>
<tr>
<th></th>
<th>Micronaire</th>
<th>Fiber Strength (g/tex)</th>
<th>Fiber Length (mm)</th>
<th>Uniformity Ratio (%)</th>
<th>Short Fiber Index (%)</th>
<th>Fiber Elongation (%)</th>
<th>Correlation With Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micronaire</td>
<td>0.0064</td>
<td>0.0078</td>
<td>0.0504</td>
<td>0.0043</td>
<td>-0.0602</td>
<td>-0.0662</td>
<td>-0.057ns</td>
</tr>
<tr>
<td>Fiber Strength</td>
<td>-0.0001</td>
<td>-0.3972</td>
<td>-0.0278</td>
<td>0.0310</td>
<td>0.0395</td>
<td>0.1482</td>
<td>-0.206ns</td>
</tr>
<tr>
<td>Fiber Length</td>
<td>-0.0035</td>
<td>-0.1195</td>
<td>-0.0923</td>
<td>0.0176</td>
<td>0.1262</td>
<td>0.1001</td>
<td>0.028ns</td>
</tr>
<tr>
<td>Uniformity Ratio</td>
<td>0.0005</td>
<td>-0.2269</td>
<td>-0.0299</td>
<td>0.0543</td>
<td>0.0758</td>
<td>0.1677</td>
<td>0.041ns</td>
</tr>
<tr>
<td>Short Fiber Index</td>
<td>0.0028</td>
<td>0.1121</td>
<td>0.0832</td>
<td>-0.0294</td>
<td>-0.1400</td>
<td>-0.1264</td>
<td>-0.098ns</td>
</tr>
<tr>
<td>Fiber Elongation</td>
<td>-0.0012</td>
<td>-0.1668</td>
<td>-0.0262</td>
<td>0.0258</td>
<td>0.0501</td>
<td><strong>0.3530</strong></td>
<td>0.235ns</td>
</tr>
</tbody>
</table>

*, **: Significant at the 0.05 and 0.01 probability levels, respectively; ns: nonsignificant.

Table 4. Direct (bold) and indirect effects of the quality properties to seed cotton yield per plant among 42 selected plants in F₄ generation.

<table>
<thead>
<tr>
<th></th>
<th>Micronaire</th>
<th>Fiber Strength (g/tex)</th>
<th>Fiber Length (mm)</th>
<th>Uniformity Ratio (%)</th>
<th>Short Fiber Index (%)</th>
<th>Fiber Elongation (%)</th>
<th>Correlation With Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micronaire</td>
<td>0.0545</td>
<td>0.0372</td>
<td>-0.0205</td>
<td>-0.0310</td>
<td>-0.0016</td>
<td>-0.0109</td>
<td>0.028ns</td>
</tr>
<tr>
<td>Fiber Strength</td>
<td>0.0096</td>
<td><strong>0.2118</strong></td>
<td>0.0131</td>
<td>-0.0519</td>
<td>0.0075</td>
<td>0.0090</td>
<td>0.199ns</td>
</tr>
<tr>
<td>Fiber Length</td>
<td>-0.0088</td>
<td>0.0220</td>
<td><strong>0.1263</strong></td>
<td>-0.0341</td>
<td>0.0347</td>
<td>0.0621</td>
<td>0.202ns</td>
</tr>
<tr>
<td>Uniformity Ratio</td>
<td>0.0145</td>
<td>0.0943</td>
<td>0.0370</td>
<td>-0.1167</td>
<td>0.0233</td>
<td>0.0365</td>
<td>0.089ns</td>
</tr>
<tr>
<td>Short Fiber Index</td>
<td>0.0023</td>
<td>-0.0398</td>
<td>-0.1105</td>
<td>0.0685</td>
<td>-0.0397</td>
<td>-0.0640</td>
<td>-0.183ns</td>
</tr>
<tr>
<td>Fiber Elongation</td>
<td>-0.0042</td>
<td>0.0135</td>
<td>0.0555</td>
<td>-0.0301</td>
<td>0.0180</td>
<td><strong>0.1415</strong></td>
<td>0.194ns</td>
</tr>
</tbody>
</table>

*,**: Significant at the 0.05 and 0.01 probability levels, respectively; ns: nonsignificant.

DISCUSSION

Natural colored cotton is a very old cotton variety and was firstly cultivated by American Indians (Waghmare and Koranne 1998; Dutt et al. 2004). Nowadays, the white cotton cultivars that have high yield potential and quality properties have been developed. So that, cultivation and usage of natural colored cotton is very limited. At the same time, colored cotton varieties are deficient based on both yield potential and fiber quality properties; hence they are not suitable for textile industry. Thus, it is necessity that improving of yield and quality potentials of natural colored cotton cultivars via crossing them with the white colored cotton genotypes. Since, they do not need any chemicals for painting and bleaching, they are eco-friendly industrial fibers.

There is a lot of research on fiber quality and yield associations in cotton; however this research is one of the important studies conducted with similar aims in segregating populations of white x colored cotton cross. The insignificant correlation coefficients between seed cotton yield and micronaire, fiber strength, and uniformity ratio, fiber elongation in both F₃ and F₄ generations agreed with the results of Dinakaran et al. (2012). But, Clement et al. (2012) reported significant negative correlations between yield and fiber length and fiber strength while correlation with micronaire was inconsistent between years. In an another study, the positive and significant phenotypic correlation coefficients between fiber yield and fiber length, fiber uniformity, fiber strength were determined while non-significant correlations occurred with elongation and micronaire (Araujo et al. 2012). Clement et al. (2015) emphasized that the negative association between yield and quality had been effectively broken in one cross cotton population. Notwithstanding, they proposed more research and information on understanding the prime reasons for negative association between yield and quality.

Unlike these studies, the associations between yield and other quality traits were investigated in colored and high yielding individual plants selected from F₃ and F₄ generations in this study. The results of correlation analyses showed that at least the significant negative correlation was absent between yield and the quality characteristics of the selected colored plants. This result indicates that the fiber quality traits did not decrease in the selected colored and high yielding cotton plants. Inability to obtain the significant positive correlation may arise from a single plant selection. Because the single
plant selection or analyses on individual plants could not reveal performance of cross population for the association between yield and quality. Indeed, Clement et al. (2015) proposed to use the bulk made from F2 or F3 population prior to single plant selection to decide utilization of the population in cotton. Besides, Sundarmurthy et al. (1994), Singh et al. (1996) and Dutt et al. (2004) reported that heterosis emerged in F1 plants via crosses between white and colored cottons can be utilized for developing colored cotton genotypes with high yield and quality potential. When fiber color is considered, in the selected single plants from F3 generation, the skewness and kurtosis values were less than 1.0 for all fiber color parameters which indicates continuous variation and quantitative genetic basis. Another reason for this variation is that the selected plants had different shades of fiber color. However, as homozygosity increases in advanced generations, the variation will decrease and the fiber color will become more stable.

As a result of path analysis, fiber elongation and fiber strength had the maximum direct effect on seed cotton yield in F3 and F4 generations, respectively. However, fiber strength had the maximum negative direct effect on seed cotton yield in F3 generation. The contrast on fiber strength and some other quality traits varied between two generations could occur because of the generation differences. Since, the percentage of homozygosity of genes responsible for these traits in the population increase as generation progresses.

In summary, seed cotton yield was not negatively significant associated with fiber quality properties as results of the correlation analysis. It may be concluded that the selection applied in those generations in terms of seed cotton yield and fiber color should be applied and fiber quality properties of the selected individual colored cotton genotypes can be determined in further generations. Also, another suggestion depend on insignificant association between yield and quality properties is that the colored cotton genotypes with high yielding can be selected, made bulk and transferred to the next generations.

REFERENCES


