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COTTON IMPROVEMENT

Analysis of Commonality for Traits of Cotton Fiber

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INTERPRETIVE SUMMARY

Genetic improvements in the physical properties of cotton fiber have lagged behind improvements in the machines that make thread from cotton fiber. Genetic improvement has been hampered by the association of poor fiber properties with high yields and a lack of knowledge about genes that affect fiber properties. For example, the degree to which traits of the fiber are interrelated is not known. Such information is immediately useful; selection for one trait can automatically affect another and thereby make breeding more efficient. When similar experiments were done with corn, a minimum of 40% of the variability for yield between hybrids could be accounted for by four traits. This experiment uses a statistical method called commonality to determine if the traits of the cotton fibers are interrelated. Perimeter, a trait much-neglected by breeders and geneticists, was identified as having an effect on micronaire, length, and strength. Selection for smaller perimeter may help achieve lower micronaire, longer, and stronger fiber, though this must be established by further experimentation. Understanding fiber properties will benefit the producers of the crop or the public in two discernable ways: (i) American cotton, better suited to modern spinning equipment, can become a preferred source on the world market; and (ii) fabric made more efficiently will have a lower price.

ABSTRACT

Indirect selection can be a useful means of improving quantitatively inherited traits. The purpose of this experiment was to determine how the quantitatively inherited traits of cotton fiber quality are related, and if this information could be applied to the improvement of cotton fiber. Correlations between traits indicate relationships, but are frequently difficult to interpret. Analysis of commonality, which is analogous to path coefficients and based on analysis of variance, is one method used to make sense of relationships found through correlations. During the summers of 1993 and 1994, plants were grown in the vicinity of Stoneville, MS. The experimental design was a randomized complete block with two replicates. One hundred and seven randomly selected F_2-derived lines of upland cotton (*Gossypium hirsutum* L.) from the cross, Acala 1517-75BR1 X DPL SR-383, were sampled for fiber in the F_3 and F_4 generations. Eight fiber traits were measured -- elongation, maturity, micronaire, perimeter, 2.5% span length, strength, wall thickness, and weight fineness. The analysis of commonality identified perimeter as the only fiber trait that influenced all traits. Perimeter had the greatest effect on micronaire (76.5% of total sums of squares), but also affected slightly more than 35% (uniquely and in conjunction with other traits) of the variation in models explaining length and strength. Elongation had the least in common with other fiber traits. These results indicate the potential to decrease micronaire and increase fiber length and strength by selection for smaller perimeter. However, indirect selection for fiber quality may not be practical as measuring perimeter adds additional costs and perimeter's effects on length and strength may be too small for meaningful improvement in length and strength.

Correlation between traits can be useful in developing selection criteria, but correlation can also present a morass of interrelationships. To make sense of correlations, Wright (1921) developed the method of path coefficients which have been used to develop selection criteria for complex traits in several crop species (Dewey and Lu, 1959; Diz et al., 1994; Fonseca and Patterson, 1968; Gravois et al., 1991; Ivanovic and Rosic, 1985; Kang et al., 1983; Pandey and Torrie, 1973). However, path coefficients are troubling in their interpretation

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Abbreviations: MCP, mean cross products.

when the independent variables are correlated (Emigh, 1984; Kempthorne, 1957). Kempthorne (1957) responded to the problem by developing an alternative approach which is referred to as analysis of commonality (Emigh, 1984) and is based on the analysis of variance.

Contributions to the variation of a dependent variable made by independent variables, either alone or in combination, can be calculated by analysis of commonality. The unique effect [$U(X_i)$] of an independent variable, X_i, is that part of the variation in the dependent variable that is contributed by X_i, after fitting every other term in the model. Given a model with three independent variables, unique terms are calculated from partial regression sums of squares. For example, the unique contribution of X_1 is

$$U(X_1) = R(X_1, X_2, X_3) - R(X_2, X_3).$$

The strength of commonality is in determining how two or more independent variables jointly affect the dependent variable. The general expression for the common term among some number, n, of X_i independent variables is $\mathrm{Com}(X_i ,..., X_n)$. The joint, or common, term is the variation in the dependent variable that is uniquely contributed by $X_i ,..., X_n$ after fitting every other term in the model. For a model with three independent variables, the joint effect of two independent variables is calculated by

$$\mathrm{Com}(X_1, X_2) = R(X_1, X_2, X_3) - R(X_3) - U(X_1) - U(X_2).$$

Because common terms are differences, they may have a negative value. A negative common term is interpreted as a lack of a joint effect between the independent variables and dependent variable. To determine the total effect an independent variable, X_i, has on the dependent variable, the unique and all joint terms involving X_i are summed. Emigh (1977) has also shown how unique and common terms relate to variances.

Analysis of commonality was used by Meredith (1991, 1992) to examine components of micronaire, an economically important trait of cotton fiber and bundle strength. Meredith (1991), using a large number of year-location combinations, found that maturity and perimeter contributed equally to micronaire at the genotypic level. Bundle strength was found to be related to 50% span length, a factor not given much consideration in breeding for fiber strength (Meredith, 1992). In this paper, analysis of commonality is used to examine the relationships among eight fiber traits (elongation, maturity, micronaire, perimeter, 2.5% span length, strength, weight fineness, and wall thickness) in a segregating population.

MATERIALS AND METHODS

During the summer of 1990, two inbred lines, Acala 1517-75BR1 and Delta and Pine Land (DPL) SR-383, were crossed to produce F_1 seed. F_1 seed was bulked, planted in the summer of 1991, and self-pollinated to produce F_2 seed. In the summer of 1992, $F_{2:3}$ lines were producedby self-pollinating F_2 plants. One hundred and seven $F_{2:3}$ lines were planted in two randomized complete blocks in 1993. Two plots of each parent were planted in a block as controls. Plots consisted of a single, 6.1 m-long row with 1 m spacing between rows. Seedlings were thinned to 0.1 m apart. Seed cotton was produced with standard cultural practices for the Mississippi Delta. The experiment was repeated in 1994 with $F_{2:4}$ lines.

A bulk sample (40-50 fruits plot^{-1}) was harvested from each plot in 1993 ($F_{2:3}$) and 1994 ($F_{2:4}$), and a 15 g sample of lint was sent to Star Lab, Knoxville, TN. Using single instrument tests on each sample, Star Lab made two measurements of micronaire, 2.5% span length, and strength. Star Lab also measured the fibers' specific area and apparent specific area twice on each sample with the arealometer (American Society for Testing and Materials, 1963). These values were used to calculate maturity, perimeter, weight fineness, and wall thickness of the cotton fiber (National Cotton Variety Testing Program, 1996, p. 5-6).

Combined analysis of variance over years was conducted with Proc GLM (SAS Institute, 1996) on a balanced data set. However, Proc MIXED (SAS Institute, 1996) was used to calculate variances. Proc MIXED had years set as a fixed effect, but blocks, genotypes, and the year x genotype interaction as random effects. Proc MIXED calculates estimates for the variances of the random effects by maximum likelihood solution of a variance model matrix that is built from the general linear mixed model (SAS Institute, 1996).

Analysis of commonality was performed as described by Emigh (1984) with Proc RSQUARE (SAS Institute, 1996) using progeny means that were combined over years. Results for the commonality analysis are expressed as percent of the total sums of squares (regression SS + residual SS). Genotypic correlations were calculated by the method of Mode and Robinson (1959) using a Pascal program written by the author. Genetic covariance was estimated from mean cross products (MCP) by two calculations. If Y x G was not significant, then genetic covariance was calculated by 0.25[MCP(Genotype) - MCP(Error)]; otherwise, 0.25[MCP(Genotype)-MCP(Y x G)] was employed. Phenotypic correlations were calculated on an F_2 progeny mean basis (combined over years) with Proc CORR (SAS Institute, 1996) by the product moment (Pearson) method.

RESULTS AND DISCUSSION

A randomly segregating population was created by crossing Acala 1517-75BR1 and DPL SR-383. These lines were chosen because of their widely different fiber traits (Kloth, 1992) and unrelated genetic background (Calhoun et al., 1997). Progeny from this cross produced a broad range of values for each fiber trait measured (Table 1). This broad range is reflected in highly significant ($P \leq 0.01$) variation between F_2-derived families for each fiber trait (data not shown). Of the eight fiber traits measured, only maturity and elongation did not have a significant ($P > 0.05$) year effect (data not shown). With the exception of elongation, genotypic variation for fiber traits was at least 10-fold greater than the interactions between genotype and year (Table 2).

Correlations between traits are used to build models for analysis, though no formal rules are presently available. Correlations between traits at the phenotypic level were generally unchanged when genetic correlations were calculated (Table 3). Correlations between micronaire, strength, and wall thickness were found at the phenotypic level, but were non-existent at the genotypic level (Table 3). Both elongation and strength, and maturity and strength were correlated genotypically, but not phenotypically (Table 3). The correlations between fiber traits (independent variables) make analysis of commonality the method of choice in determining the relationships between fiber traits.

Table 1. Mean, standard deviation, and range for eight fiber traits of F_2 -derived lines from the cross, Acala 1517-75BR1 x DPL SR-383, grown at Stoneville, MS in 1993 and 1994.

Trait	Mean	Standard deviation	Range
Elongation, %	6.30	0.64	3.5
Maturity, %	90.2	6.1	48
Micronaire	4.52	0.45	2.5
Perimeter, µm	45.6	3.64	21.2
2.5% span length, cm	2.88	0.12	0.71
Strength, k*N* m kg^{-1}	231	24	120
Wall thickness, µm	2.94	0.30	1.75
Weight Fineness (µg cm^{-1})	1.61	0.30	0.97

To develop the models for commonality analysis, genotypic correlations would be preferred, because these relationships would indicate the potential for improvement by selection. However, a case can be made for the inclusion of wall thickness and micronaire in initial stages of developing a model for strength, as measured by stelometer. Because stelometer strength is measured with a known weight of fiber (Perkins et al., 1984), other variables (including the number of fibers in the bundle, single fiber strength, and degree of secondary cell wall development) may affect bundle fiber strength. Thus, all fiber traits were initially included in a model, and only those traits that had more than 1% commonality with the dependent trait were included in the final model.

Wall thickness and perimeter closely modeled the traits maturity, micronaire, and weight fineness (Table 4). These relationships are logical as the fiber's perimeter and wall thickness would influence these three related traits that attempt to measure the size of the fiber’s lumen relative to the secondary wall. Based on the correlation data, models which included other fiber traits were tried. The inclusion

Table 2. Variance estimates for genotype, year x genotype, and error for eight fiber traits of F_2 -derived lines from the cross, Acala 1517-75BR1 x DPL SR-383, grown at Stoneville, MS in 1993 and 1994.

Trait	Genotype	Year x genotype	Error
Elongation	0.154	0.034	0.200
Maturity	21.654	0	16.280
Micronaire	0.107	0.004	0.042
Perimeter	5.304	0	5.4
2.5% span length	0.011	0.001	0.003
Strength	1.680	0.093	1.336
Weight fineness	0.093	0.001	0.054
Wall thickness	0.054	0	0.025

Table 3. Genetic (r_G) and phenotypic (r_P) correlation coefficients between fiber traits of F_2-derived lines from an Acala 1517-75BR1 x DPL SR-383 population.

Trait	Correlation coefficient	Perimeter	Weight fineness	Wall thickness	Micronaire	Elongation	Strength	2.5% span length
Maturity	r_G	-0.68	0.12	0.89	0.76	-0.16	0.26	0.08
	r_P	-0.69	-0.07	0.83	0.53	-0.07	0.08	0.05
Perimeter	r_G		0.65	-0.30	0.05	-0.25	-0.46	-0.41
	r_P		0.77	-0.19	0.18	0.17	0.13	-0.19
Weight fineness	r_G			0.53	0.73	0.15	-0.34	-0.47
	r_P			0.47	0.73	0.16	0.24	-0.22
Wall thickness	r_G				0.97	-0.11	0.08	-0.12
	r_P				0.86	0	0.22	-0.06
Micronaire	r_G					0	-0.07	-0.26
	r_P					0.05	0.27	-0.13
Elongation	r_G						-0.47	-0.43
	r_P						-0.08	-0.19
Strength	r_G							0.46
	r_P							0.34

of other fiber traits, either uniquely or jointly, did little to account for the remaining sums of squares. Meredith (1991) has devised a model to explain variation in micronaire that included perimeter and maturity. This is a well-founded choice. It is based on the relationship between micronaire and fineness, and the observation that maturity, a trait which reflects the ability of cotton to absorb dye, influenced micronaire. When environmental effects were held constant, Meredith (1991) found 83% of the variation in micronaire was explained by the unique and joint effects of perimeter and wall thickness. Although applying a maturity and perimeter model to micronaire data in this study gave identical results (87% of the variation in micronaire was explained by maturity and perimeter and these traits had equal effects on micronaire), this model was not chosen for micronaire because the residual is lower and the model is simpler when perimeter and wall thickness are used (Table 4).

Because micronaire had the most in common with wall thickness and perimeter, these traits were substituted for micronaire in the remaining analyses. Choice of fiber properties to include in models explaining variation in elongation, length, and strength were based on genotypic and phenotypic correlations. No fiber trait had a large effect on elongation; perimeter and 2.5% span length had an effect on this trait, but the commonality analysis showed 4.3% of the variation in elongation was explained by an effect of perimeter and span length (data not shown). Fiber length, as determined by 2.5% span length, was modeled with elongation, perimeter, and strength (Table 5). No element of the model, when considered uniquely, had a large effect on length. This is reflected in joint terms twice as large as the greatest unique source. The analysis of commonality for stelometer strength (Table 6) used perimeter, 2.5% span length, and wall thickness as independent sources. This strength measurement was influenced most by the joint effect of length and perimeter, but perimeter and wall thickness had small, but noticeable effects (Table 6).

Perimeter emerged as the single quantitative trait of fiber that affected all other traits. Perimeter has its greatest unique effects on traits of the cell wall (Table 4), and greatest joint effects on length (Table 5) and strength (Table 6). The results of the

Table 4. Analysis of commonality for maturity, micronaire, and weight fineness expressed as a ratio of the total sums of squares.

Source	Maturity	Micronaire	Weight fineness
Wall thickness	0.499	0.396	0.836
Perimeter	0.299	0.765	0.126
Wall thickness, perimeter	0.182	-0.175	-0.093
Remainder	0.02	0.014	0.131

Table 5. Analysis of commonality for fiber length expressed as a ratio of the total sums of squares.

Source	Analysis of commonality
Elongation	0.026
Perimeter	0.083
Elongation, perimeter	-0.001
Strength	0.11
Elongation, strength	0.009
Perimeter, strength	0.226
Elongation, perimeter, strength	0.226
Remainder	0.321

Table 6. Analysis of commonality for fiber strength expressed as a ratio of total sums of squares.

Source	Analysis of commonality
Perimeter	0.099
Wall thickness	0.058
Perimeter, wall thickness	0.004
2.5% span length	0.128
Perimeter, 2.5% span length	0.279
Wall thickness, 2.5% span length	-0.009
Perimeter, wall thickness, 2.5% span length	0.279
Remainder	0.162

commonality analysis indicate that indirect selection for lower perimeter has the potential to change the length, micronaire, and strength of cotton fibers. However, for indirect selection to be useful there needs to be an advantage in cost, simplicity, or rate of gain in comparison to direct selection. Such a case cannot be clearly made for indirect selection with perimeter. Costs for fiber testing would be higher because additional tests with an arealometer are needed. Values derived from commonality analysis are untested in selection experiments, so the minimum value before a unique, joint, or total effect is useful in selection is unknown. Lastly, the influence of perimeter on strength is questionable; perimeter is weakly related to stelometer strength (Tables 3 and 6). Meredith (1992) found fineness, a trait for which perimeter is a component, had no unique effect on bundle strength.

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