FIBER PROPERTIES AND TEXTILE PERFORMANCE OF TRANSGENIC COTTON VERSUS PARENT VARIETIES

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Abstract

In 1998, Monsanto / Delta and Pine Land Company contracted with the International Textile Center to evaluate the differences in measurable fiber properties and in textile performance between selected cotton varieties and the existing transgenic variants of these "parent" varieties. (Parents and variants comprise a "family.") Due to recent interest about the impacts of genetic modifications on fiber properties, Monsanto requested that the International Textile Center release a report on the results of its evaluation. The experimental design, growing and delivering of the ginned cotton samples were done independently by the Delta and Pine Land Company. All processing, testing and evaluation of the cotton fibers were done independently by the International Textile Center. No statistically significant differences were detected in fiber properties or in yarn and fabric quality for the genetically modified cottons versus the parent varieties. There were some statistically significant interaction effects between genetic variants and families and between genetic variants and locations; however, none of these appeared to be useful for differentiating the variants. Furthermore, attempts to impute meaning to the interaction effects would tend to favor the genetically modified variants.

Introduction

In mid-1998, research personnel of Monsanto / Delta and Pine Land Company contacted the International Textile Center in order to arrange for a confidential, independent analysis. The issue was differences in measurable fiber properties and in textile performance between two selected cotton varieties (which are important to the cotton production of the Mid-South and Southeast United States) and the existing transgenic variants of them. Each of the parent varieties was genetically modified to have (1) resistance to Roundup® herbicide (called Roundup Ready®) and (2) resistance to predation by the Heliothis complex of insects (called Bollgard®). The company intended that there be no effects on the fiber properties and had seen no evidence of any. The stated purpose of the independent analysis was to see if any unintended effects could be detected either by measurement of fiber properties or evaluation of spinning performances.

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The research personnel of Monsanto / Delta and Pine Land Company clearly wanted third-party corroboration on the fundamental issue of the constancy of fiber properties. Confidentiality was required, but it was made clear that any "surprising" results would either be reconciled or addressed by the company without fail. On this basis, the International Textile Center contracted to provide testing and evaluation of the fibers provided.

When this arrangement was made, the issues involved were seen to be of scientific interest and of fundamental importance, but of little general interest. Events since 1998, however, have resulted in some concerns and speculations about unintended consequences of genetically modified cotton varieties. Therefore, Monsanto / Delta and Pine Land Company released the International Textile Center from its confidentiality agreement, allowing this report on results obtained from its independent analysis.

Field Procedures

During the 1997 growing season, Delta and Pine Land Company executed field trials at three locations: two in the Southeast (locations L_1 and L_2) and one in the Mid-South (location L_3) production regions of the United States. At each location, two parent varieties were grown along with two genetically modified variants of each. Therefore, there are two distinct families (F_A and F_B) and three distinct variants (V_1, V_2 and V_3) within each family. These are summarized as follows:

	Families	
	F_A	F_B
Parent varieties (V_1):	DP 5690	DP 5415
Variants for Roundup® resistance (V_2):	DP 5690RR	DP 5415RR
Variants for heliothis resistance (V_3):	NuCotn 35B	NuCotn 33B

For convenience, the varieties are henceforth identified without using the alphabetic company notation; i.e., the DP and NuCotn are dropped.

Analytical Procedures

Eighteen samples [(2 families) • (3 variants in each family) • (3 locations)] weighing approximately 100 pounds each were delivered to the International Textile Center, identified according to the field procedures described above. The statistical analysis procedure used for determining the existence of significant effects on fiber properties was "analysis of variance" (ANOVA) with a 3rd degree factorial design. The families and the variants were treated as fixed effects, while the locations were treated as a random effect. The Type I error for testing the hypothesis of no significant difference was set at 5% (i.e., probability of rejecting a true hypothesis set at 5%, or a = 5%). All statistical analysis was done using Statistica®.

The following instruments and procedures were used for data on the raw cotton fibers:

- Zellweger Uster HVI 900B – 4 replications for micronaire, color and trash measurements; 10 replications for length and strength measurements
- Zellweger Uster AFIS multidata – 5 replications of 3,000 fibers
- Stelometer 654 – 6 replications (2 technicians)
- Shirley Analyser – 2 replications

All fiber samples were spun into:

- 16/1 and 30/1 Ne yarns on the ring spinning system, and
- 10/1 and 30/1 Ne yarns on the rotor spinning system.

Therefore, a total of 72 yarns were spun in order to test for differences in yarn properties. The process from opening through drawing of the fibers was the same for all yarns. The mechanical processes involved are shown in Exhibit 1.

The following instruments and procedures were used to collect data on the cotton yarns produced:

- Skein tester – 10 replications
- Zellweger Uster Tensorapid – 10 replications of 20 breaks
- Zellweger Uster UT3 – 10 replications of 400 yards

For both the fiber and yarn testing instruments, the long-term and short-term stability of the instruments was verified before, during and after the project.

Each of the yarns was knitted into a sample fabric on the Fiber Analysis Knitting (FAK) machine. The greige fabrics were then evaluated for (1) differences in color using the Macbeth Spectrophotometer and (2) differences in visible trash.

Finally, the knitted fabrics were dyed with Direct Blue 80 dye. The dyed fabrics were then evaluated for (1) differences in shade using the Macbeth Spectrophotometer and (2) differences in visible neps.

Results

Fiber Properties

Tables 2-7 summarize all the fiber data for the variants, for each combination of families and locations. A careful reading of these tables leads to the impression that most of the differences across the variants within each table are not large enough to be "significant."

Results of the statistical analysis of all the raw fiber data are distilled into Table 8, where the entry of the symbol (♦) within a table cell denotes a statistically significant relationship between the fiber property and the "effects." The "main effects" come from the F, V and L variables. Aside from the main effects of each of these variables, there may also be "interaction effects" from the combinations of these variables. The focus of interest in this study was on effects of the variant (V); therefore, of most interest are the columns in Table 8 headed by V, F × V, and V × L.

The main conclusion from Table 8 is that there is no evidence of main effects on fiber properties by the genetic variants. The impact of V is statistically significant only for the HVI reflectance measurement; however, the magnitude is not sufficient to be useful for separating cotton varieties for textile applications. Therefore, we conclude that the genetically modified cottons are indistinguishable from the parent varieties insofar as fiber properties are concerned.

Between the two families, there are statistically significant differences in contamination (as measured by the AFIS) and strength/elongation (as measured by the Stelometer). A look at Tables 2-7 will verify that the family associated with 5690 (F_A) tested somewhat dirtier and somewhat stronger than did the family associated with 5415 (F_B). However, while the breaking strength of the 5690 family is higher, the elongation-before-break is greater for the 5415 family.

As usual in a study such as this, there are several statistically significant location effects; e.g., micronaire, length, length uniformity, and strength. Soil and climate differences are known to affect these properties; indeed, sensitivity to them is important for determining how adaptable a variety is outside of a limited production area.

There were some statistically significant interaction effects involving the variants; namely, with micronaire, length uniformity, seed coat neps, and trash (Table 8). These effects, which are additional to the direct or main effects of each variable, may be important—but the only way to ultimately assess their importance is to examine the actual situation for each interaction effect that tests to be statistically significant. Often a statistically significant interaction effect may be obtained but the actual magnitudes of the differences make them unimportant. Or the patterns of the interactive changes may bring statistical significance but still do not differentiate among the variants.

Looking at the data on micronaire versus families, it is seen that the statistically significant interaction effect comes from the Roundup Ready® variant (V_2) (Table 9). The micronaires associated with the unmodified variety (V_1) and the Bollgard® variant (V_3) are practically the same across families. But the change is larger between families for the Roundup Ready® variant (V_2).

Looking at the data on micronaire versus locations, it is seen that the interaction effects are greater for the V_1 and V_3 variants (Table 10). The Roundup Ready® variant (V_2) exhibits a lower variability across locations than do the others. A low variability across locations is desirable, so perhaps this signals an advantage for the Roundup Ready® variant, but more testing would be necessary to conclude this.

Length uniformity also tested to have statistically significant variant interaction effects with both families and locations (Table 8). A look at the data reveals that the differences were not large. It appears that the greatest change across families occurred for the Roundup Ready® variant, V_2 (Table 11). However, V_2 was the most stable across locations, while significance is due to the unmodified variety (V_1) and the Bollgard® variant (V_3) (Table 12).

The data on seed coat neps versus families reveal that the Roundup Ready® variant (V_2) exhibits little variability across families (Table 13). In this case, the interaction effects come from the unmodified variety (V_1) and the Bollgard® variant (V_3).

The data on trash versus family reveal that the major differences across families is for the Roundup Ready® variant (V_2) and the Bollgard® variant (V_3) (Table 14). However, such differences for trash are not useful for selection among variety trials.

From a practical standpoint, none of the fiber property interaction effects involving variants give reason for concern. On balance, results are neutral or slightly favorable to the genetically modified variants. Ultimately, much larger field tests would be required to decide whether there are any interaction effects of practical importance.

Yarn Properties

Table 15 summarizes results of the statistical analysis of the data on ring-spun yarns, with the 16 Ne yarns given first and the 30 Ne yarns afterward. While there are many statistically significant main family effects and some main location effects, there are no main variant effects on yarn properties.

There is only one statistically significant interaction effect in Table 15; i.e., the family and variant interaction effect on tenacity of the 16 Ne yarns. The data relevant to this property are summarized in Table 16, which reveals that there was a pretty consistent effect across the variants; but it also reveals that the genetically modified variants performed as well as the parent varieties. On balance, these differences are of no practical importance.

Table 17 summarizes results of the statistical analysis of the data on rotor-spun yarns, with the 10 Ne yarns given first and the 30 Ne yarns afterward. Again there are many statistically significant main family effects. Statistically significant main variant effects are indicated for CV of strength (CSP) with the 10 Ne yarns and for elongation with the 30 Ne yarns. The magnitudes of the differences of CV of strength are not useful in differentiating among the variants' spinning performance. Regarding elongation for the 30 Ne yarns, the overall average values (across families and locations) for the variants are as follows: 6.1% for V_1, 6.3% for V_2, and 6.1% for V_3. Therefore, the cause for significance appears to be a somewhat higher yarn elongation with the Roundup Ready® variant. This is of little or no practical importance, but to the extent that it matters, it favors the genetically modified variant.

There are five statistically significant family × variant (F × V) interactions; two for the 10 Ne yarns and three for the 30 Ne yarns (Table 17). For the 10 Ne yarns, the properties involved are count-strength product (CSP) and non-uniformity (expressed as CV%).

- Table 18 summarizes CSP values across families and variants; it reveals the largest change across families for the Roundup Ready® variant (V_2). But the levels of CSP for V_2 are not greatly different from those for the other variants, so there is no practical reason to be concerned with this.
- Table 19 summarizes non-uniformity values across families and variants; it reveals the only change across families occurs for the Roundup Ready® variant (V_2). V_2 also exhibits a slightly higher elongation than the other two variants, but neither the level nor the changes are large enough to be of practical importance.

For the 30 Ne yarns, the properties involved with interaction effects in Table 17 are mean strength, elongation, and thin places.

- Table 20 summarizes mean strength values across families and variants; the changes are larger for the unmodified variant (V_1) and the Roundup Ready® variant (V_2), but the levels of all three variants are quite similar. Therefore, there is no practical importance to these effects.
- Table 21 summarizes elongation values across families and variants; the changes are larger for the unmodified variety (V_1) and the Bollgard® variant (V_3), but the salient fact is that, within the 5690 family (F_A), the Roundup Ready® variant (V_2) has a higher elongation than do V_1 and V_3. If there were any practical importance of this

result, it would be an unexpected gain from introduction of the genes for producing Roundup Ready® cotton in the family associated with 5690.

- Table 22 summarizes average counts of thin places across families and variants; significance is due to the values associated with Roundup Ready® variant (V_2). Again, however, these numbers do not appear to be of practical importance.

Fabric Properties

Table 23 summarizes results of the statistical analysis of the data on both greige fabrics and dyed fabrics that were made from all four of the yarns. There are many statistically significant main effects for L, as well as for F × L interaction effects. But there are no statistically significant main effects for V, and the few interaction effects that involve V are of no practical consequence. Especially in the fabric state, whether greige or dyed, the genetically modified variants cannot be distinguished from the two original varieties.

Conclusion

Of course it is good news that genetic modifications to the cotton varieties tested here did not result in any changes in the measurable fiber properties—given that no changes in fiber properties were targeted. To those who are interested in improving the various fiber properties of cotton, however, it would be better news to learn that such properties were being successfully targeted by genetic engineering techniques. It is especially to be hoped that the focus on genetic engineering does not have the side-effect of causing a hiatus in efforts to develop, by all means available, improved cotton fiber properties.

Table 1. Outline of Mechanical Processes

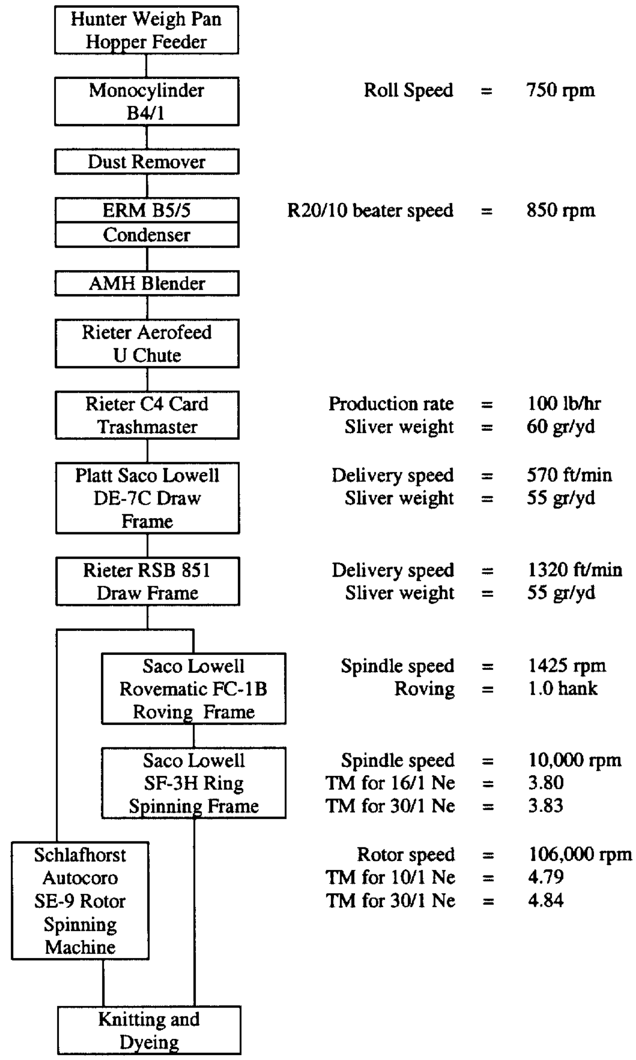

Table 2. Raw Fiber Data for Variants: Family F_A and Location L_1

Instrument & Measurement	Units	Variants 5690	5690RR	35B
Zellweger Uster HVI 900B				
Micronaire		3.80	3.85	3.60
Leaf Grade		5.5	4.5	5.0
Reflectance	%	68.9	69.9	70.2
Yellowness		8.9	9.2	8.6
Upper Half Mean Length	in	1.06	1.06	1.08
Length Uniformity	%	80.7	81.4	80.4
Strength	g/tex	30.2	30.9	29.3
Elongation	%	5.3	5.6	5.1
AFIS Multidata				
Mean length (w)	in	0.92	0.91	0.91
Length CV (w)	%	35.5	34.9	38.2
Short Fiber Content (w)	%	9.6	9.8	12.3
Upper Quartile Length (w)	in	1.11	1.10	1.12
Maturity Ratio		0.85	0.86	0.8 4
Immature Fiber Content	%	10.8	10.2	11.4
Fineness	mtex	156	158	153
Neps	cnt/g	190	208	254
Seed Coat Neps	cnt/g	15	13	15
Dust	cnt/g	735	629	518
Trash	cnt/g	152	145	136
Shirley Analyser				
Non-lint content	%	2.69	3.07	2.88
Stelometer				
Strength	g/tex	22.7	23.8	23.4
Elongation	%	6.4	6.5	6.3

Table 3. Raw Fiber Data for Variants: Family F_B and Location L_1

Instrument & Measurement	Units	Variants 5415	5415RR	33B
Zellweger Uster HVI 900B				
Micronaire		3.80	4.38	3.48
Leaf Grade		4.5	5.0	6.0
Reflectance	%	68.2	70.1	69.2
Yellowness		8.8	9.4	8.6
Upper Half Mean Length	in	1.08	1.07	1.09
Length Uniformity	%	80.6	81.1	80.6
Strength	g/tex	28.6	29.4	27.7
Elongation	%	6.0	6.0	5.8
AFIS Multidata				
Mean length (w)	in	0.90	0.92	0.92
Length CV (w)	%	36.4	33.9	36.3
Short Fiber Content (w)	%	11.8	9.7	11.2
Upper Quartile Length (w)	in	1.12	1.11	1.13
Maturity Ratio		0.84	0.87	0.82
Immature Fiber Content	%	9.9	8.1	10.9
Fineness	mtex	162	170	158
Neps	cnt/g	236	213	256
Seed Coat Neps	cnt/g	20	16	13
Dust	cnt/g	568	384	483
Trash	cnt/g	134	82	110
Shirley Analyser				
Non-lint content	%	2.73	2.81	2.91
Stelometer				
Strength	g/tex	21.7	22.2	21.8
Elongation	%	6.6	6.8	6.7

Table 4. Raw Fiber Data for Variants: Family F_A and Location L_2

Instrument & Measurement	Units	Variants 5690	5690RR	35B
Zellweger Uster HVI 900B				
Micronaire		4.55	4.38	4.35
Leaf Grade		5.5	4.0	4.0
Reflectance	%	74.2	74.8	74.4
Yellowness		7.9	8.0	7.7
Upper Half Mean Length	in	1.09	1.09	1.09
Length Uniformity	%	82.0	82.3	81.0
Strength	g/tex	29.5	30.0	29.1
Elongation	%	5.7	5.7	5.4
AFIS Multidata				
Mean length (w)	in	0.96	0.99	0.94
Length CV (w)	%	34.0	33.8	36.3
Short Fiber Content (w)	%	5.3	7.3	10.2
Upper Quartile Length (w)	in	1.16	1.17	1.14
Maturity Ratio		0.90	0.88	0.87
Immature Fiber Content	%	8.1	9.5	9.1
Fineness	mtex	166	165	161
Neps	cnt/g	152	180	174
Seed Coat Neps	cnt/g	16	18	14
Dust	cnt/g	490	660	532
Trash	cnt/g	128	168	134
Shirley Analyser				
Non-lint content	%	2.81	3.54	3.26
Stelometer				
Strength	g/tex	22.0	22.0	22.1
Elongation	%	6.3	6.4	6.3

Table 5. Raw Fiber Data for Variants: Family F_B and Location L_2

Instrument & Measurement	Units	Variants 5415	5415RR	33B
Zellweger Uster HVI 900B				
Micronaire		4.83	4.70	4.40
Leaf Grade		5.0	2.5	4.0
Reflectance	%	74.5	75.9	75.7
Yellowness		7.9	8.0	7.8
Upper Half Mean Length	in	1.08	1.09	1.09
Length Uniformity	%	82.1	82.1	81.1
Strength	g/tex	27.4	29.0	27.0
Elongation	%	6.0	6.2	6.0
AFIS Multidata				
Mean length (w)	in	0.97	0.95	0.95
Length CV (w)	%	33.2	33.9	34.3
Short Fiber Content (w)	%	8.3	8.7	9.0
Upper Quartile Length (w)	in	1.17	1.15	1.15
Maturity Ratio		0.88	0.88	0.88
Immature Fiber Content	%	7.9	8.0	8.3
Fineness	mtex	175	173	169
Neps	cnt/g	192	175	188
Seed Coat Neps	cnt/g	21	20	15
Dust	cnt/g	489	526	358
Trash	cnt/g	107	104	74
Shirley Analyser				
Non-lint content	%	3.09	3.15	2.79
Stelometer				
Strength	g/tex	21.1	20.7	20.6
Elongation	%	6.6	6.8	6.6

Table 6. Raw Fiber Data for Variants: Family F_A and Location L_3

Instrument & Measurement	Units	Variants 5690	5690RR	35B
Zellweger Uster HVI 900B				
Micronaire		4.80	4.23	4.83
Leaf Grade		4.3	5.0	6.0
Reflectance	%	73.2	74.0	71.4
Yellowness		8.1	8.0	7.8
Upper Half Mean Length	In	1.19	1.18	1.19
Length Uniformity	%	83.5	83.3	83.6
Strength	g/tex	33.0	32.9	33.0
Elongation	%	6.0	6.0	5.9
AFIS Multidata				
Mean length (w)	in	1.05	1.03	1.05
Length CV (w)	%	32.5	34.7	33.5
Short Fiber Content (w)	%	6.7	7.8	7.2
Upper Quartile Length (w)	in	1.26	1.26	1.27
Maturity Ratio		0.97	0.90	0.95
Immature Fiber Content	%	5.5	8.4	5.9
Fineness	mtex	176	163	172
Neps	cnt/g	112	160	132
Seed Coat Neps	cnt/g	13	20	21
Dust	cnt/g	583	582	603
Trash	cnt/g	127	156	154
Shirley Analyser				
Non-lint content	%	3.23	4.21	7.38
Stelometer				
Strength	g/tex	23.5	23.7	23.5
Elongation	%	6.3	6.4	6.3

Table 7. Raw Fiber Data for Variants: Family F_B and Location L_3

Instrument & Measurement	Units	Variants 5415	5415RR	33B
Zellweger Uster HVI 900B				
Micronaire		4.58	4.53	4.60
Leaf Grade		5.0	4.0	4.00
Reflectance	%	73.5	76.1	76.1
Yellowness		7.5	7.7	7.6
Upper Half Mean Length	in	1.18	1.15	1.17
Length Uniformity	%	83.6	82.9	83.6
Strength	g/tex	30.0	29.3	29.4
Elongation	%	6.0	6.0	6.0
AFIS Multidata				
Mean length (w)	in	1.01	1.01	1.03
Length CV (w)	%	34.9	34.8	33.3
Short Fiber Content (w)	%	9.3	8.7	7.7
Upper Quartile Length (w)	in	1.24	1.23	1.25
Maturity Ratio		0.88	0.90	0.90
Immature Fiber Content	%	8.0	6.9	7.1
Fineness	mtex	170	175	170
Neps	cnt/g	273	157	148
Seed Coat Neps	cnt/g	18	16	15
Dust	cnt/g	526	375	416
Trash	cnt/g	120	84	90
Shirley Analyser				
Non-lint content	%	3.48	2.95	2.86
Stelometer				
Strength	g/tex	22.1	22.0	21.8
Elongation	%	6.6	6.8	6.6

Table 8. Statistically Significant Relationships among Fiber Properties of Families (F), Variants (V) and Locations (L)[1/]

Instrument & Measurement	Main Effects F	V	L	Interaction Effects F × V	F × L	V × L
Zellweger Uster HVI 900B						
Micronaire			♦	♦		♦
Leaf Grade						
Reflectance		♦				
Yellowness			♦		♦	
Upper Half Mean Length			♦		♦	
Length Uniformity			♦	♦		♦
Strength					♦	
Elongation					♦	
AFIS Multidata						
Mean length (w)			♦			
Length CV (w)						
Short Fiber Content (w)						
Upper Quartile Length (w)			♦		♦	
Maturity Ratio						
Immature Fiber Content						
Fineness						
Neps						
Seed Coat Neps				♦		
Dust	♦					
Trash	♦			♦		
Shirley Analyser						
Non-lint content						
Stelometer						
Strength	♦		♦			
Elongation	♦					

[1/] Symbol (♦) denotes statistically significant impact with $\alpha = 5\%$.

Table 9. Micronaire Values: Families (F) Versus Variants (V)

Families	Variants V_1	V_2	V_3
F_A	4.38	4.19	4.26
F_B	4.40	4.54	4.16

Table 10. Micronaire Values: Locations (L) Versus Variants (V)

Locations	Variants V_1	V_2	V_3
L_1	3.80	4.12	3.54
L_2	4.69	4.54	4.38
L_3	4.69	4.38	4.72

Table 11. Length Uniformity: Families (F) Versus Variants (V)

Families	Variants V_1	V_2	V_3
F_A	82.1	82.3	81.7
F_B	82.1	81.9	81.8

Table 12. Length Uniformity: Locations (L) Versus Variants (V)

Locations	Variants V_1	V_2	V_3
L_1	83.6	83.1	83.6
L_2	82.1	82.2	81.1
L_3	80.7	81.3	80.5

Table 13. Seed Coat Neps: Families (F) Versus Variants (V)

Families	**Variants**		
	V_1	**V_2**	**V_3**
F_A	15	17	17
F_B	20	17	14

Table 14. Trash: Families (F) Versus Variants (V)

Families	**Variants**		
	V_1	**V_2**	**V_3**
F_A	136	156	141
F_B	120	90	91

Table 15. Statistically Significant Relationships among Ring-spun Yarn Properties for Families (F), Variants (V) and Locations (L)[1/]

Instrument & Measurement	**Main Effects**			**Interaction Effects**		
	F	**V**	**L**	**F × V**	**F × L**	**V × L**
16 Ne Yarns						
Skein Strength Tester						
CSP						
CV of CSP						
Uster Tensorapid®						
Tenacity	♦		♦	♦		
Mean Strength	♦		♦			
CV of Strength						
Elongation	♦					
CV of Elongation						
Uster Tester III®						
Non-uniformity	♦					
Thin Places						
Thick Places	♦					
Neps						
Hairiness	♦		♦			
30 Ne Yarns						
Skein Strength Tester						
CSP	♦					
CV of CSP						
Uster Tensorapid®						
Tenacity	♦					
Mean Strength	♦					
CV of Strength						
Elongation	♦					
CV of Elongation	♦					
Uster Tester III®						
Non-uniformity	♦					
Thin Places	♦					
Thick Places	♦					
Neps	♦					
Hairiness			♦			

[1/] Symbol (♦) denotes statistically significant impact with $\alpha = 5\%$.

Table 16. Tenacity of Ring-spun 16 Ne Yarns: Families (F) Versus Variants (V)

Families	**Variants**		
	V_1	**V_2**	**V_3**
F_A	16.9	17.2	16.8
F_B	15.4	15.2	15.4

Table 17. Statistically Significant Relationships among Rotor-spun Yarn Properties for Families (F), Variants (V) and Locations (L)[1/]

Instrument & Measurement	**Main Effects**			**Interaction Effects**		
	F	**V**	**L**	**F × V**	**F × L**	**V × L**
10 Ne Yarns						
Skein Strength Tester						
CSP	♦			♦		
CV of CSP						
Uster Tensorapid®						
Tenacity	♦					
Mean Strength	♦					
CV of Strength		♦				
Elongation	♦					
CV of Elongation						
Uster Tester III®						
Non-uniformity				♦		
Thin Places						
Thick Places						
Neps						
Hairiness						
30 Ne Yarns						
Skein Strength Tester						
CSP	♦					
CV of CSP						
Uster Tensorapid®						
Tenacity	♦					
Mean Strength	♦		♦	♦		
CV of Strength						
Elongation	♦	♦		♦		
CV of Elongation	♦					
Uster Tester III®						
Non-uniformity						
Thin Places				♦		
Thick Places	♦					
Neps	♦					
Hairiness						

[1/] Symbol (♦) denotes statistically significant impact with $\alpha = 5\%$.

Table 18. CSP of Rotor-spun 10 Ne Yarns: Families (F) Versus Variants (V)

Families	**Variants**		
	V_1	**V_2**	**V_3**
F_A	2745	2788	2726
F_B	2573	2547	2584

Table 19. Non-uniformity (CV%) of Rotor-spun 10 Ne Yarns: Families (F) Versus Variants (V)

Families	**Variants**		
	V_1	**V_2**	**V_3**
F_A	12.4	12.3	12.3
F_B	12.4	12.6	12.3

Table 20. Mean Strength of Rotor-spun 30 Ne Yarns: Families (F) Versus Variants (V)

Families	**Variants**		
	V_1	**V_2**	**V_3**
F_A	272.5	280.7	268.8
F_B	249.1	249.9	252.4

Table 21. Elongation of Rotor-spun 30 Ne Yarns: Families (F) Versus Variants (V)

	Variants		
Families	**V_1**	**V_2**	**V_3**
F_A	5.6	6.0	5.6
F_B	6.1	6.2	6.3

Table 22. Thin Places in Rotor-spun 30 Ne Yarns: Families (F) Versus Variants (V)

	Variants		
Families	**V_1**	**V_2**	**V_3**
F_A	83	69	78
F_B	90	111	82

Table 23. Statistically Significant Relationships among Fabric Properties for Families (F), Variants (V) and Locations (L)[1/]

	Main Effects			**Interaction Effects**		
Instrument & Measurement	**F**	**V**	**L**	**F × V**	**F × L**	**V × L**
16 Ne Ring-spun Yarns						
Greige Fabric						
Total Color Difference (D)			♦		♦	
Yellowness (b)			♦		♦	
Whiteness (L)			♦		♦	
Trash count/sq. inch						
Dyed Fabric						
Total Color Difference (D)						
Nep count/sq. inch					♦	
30 Ne Ring-spun Yarns						
Greige Fabric						
Total Color Difference (D)			♦		♦	
Yellowness (b)			♦		♦	
Whiteness (L)			♦		♦	
Trash count/sq. inch						♦
Dyed Fabric						
Total Color Difference (D)						
Nep count/sq. inch						
10 Ne Rotor-spun Yarns						
Greige Fabric						
Total Color Difference (D)			♦		♦	
Yellowness (b)			♦			
Whiteness (L)			♦		♦	
Trash count/sq. inch	♦					
Dyed Fabric						
Total Color Difference (D)						
Nep count/sq. inch						
30 Ne Rotor-spun Yarns						
Greige Fabric						
Total Color Difference (D)			♦	♦	♦	♦
Yellowness (b)			♦		♦	
Whiteness (L)			♦		♦	
Trash count/sq. inch						
Dyed Fabric						
Total Color Difference (D)				♦	♦	♦
Nep count/sq. inch						

[1/] Symbol (♦) denotes statistically significant impact with $\alpha = 5\%$.