IMPACTS OF FIBER MATURITY ON SPINNING PERFORMANCE: CONTROLLING FOR COTTON VARIETY

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Abstract

Known varieties of cotton were grown in locations across the Southern Plains of Texas, resulting in a wide range of micronaire values. Since the varieties were known, the differing micronaire values reflected alternative levels of fiber maturity. Analysis of fiber properties reveals a strong inverse relationship between fiber maturity and short fiber content. Analysis of the spinning performance reveals a strong inverse relationship between short fiber content and quality of ring-spun yarns.

Introduction

The many variety trials conducted on the Southern Plains of Texas in the 2006 crop year resulted in the opportunity to evaluate three varieties that were grown in four diverse locations. The diversity of growing conditions enabled the sampling of a wide range of micronaire values. Within each variety, the differing micronaire values reflect different levels of fiber maturity.

There was significant drought stress during the 2006 growing season, which varied across the locations. Situations at the four locations were as follows:

- Location 1 – Irrigated with low elevation spray irrigation that was adequate to enable normal yields. There was a serious shortage of heat units during the season, making it impossible to mature the large quantity of cotton enabled by abundant irrigation.
- Location 2 – Irrigated with low elevation spray irrigation that was adequate to enable normal yields. Shortage of heat units was not as much as in Location 1, but was still serious. Immaturity was still a serious problem.
- Location 3 – Irrigated with sub-surface drip irrigation that allowed a more exact management of water applications through the season. Heat units were still on the low side, but this production system produced somewhat more mature fibers.
- Location 4 – Irrigated with a limited LEPA (low energy precision application) system. Irrigation water supply was inadequate to compensate for the drought effects, resulting in low yields and abnormally high micronaire values.

All of the fibers sampled had staple lengths suitable for ring spinning. Therefore, this situation presented an opportunity to observe the impacts of maturity variations on ring-spun performance of the fibers.

Procedures

The commercially harvested and ginned lint was purchased from the farmers who were participating in the variety trials. The raw fibers were brought to the International Textile Center (ITC) and the fiber properties were measured under high-accuracy protocols using the Uster HVI® and AFIS®. Then the fibers were processed through the ITC ring spinning laboratory according to the fixed protocols for these types of cottons. The yarn size made was 40 Ne and both carded and combed yarns were spun. Finally, the resulting yarn properties were measured in the ITC materials evaluation laboratory.

Fiber Test Results

HVI test results for the three varieties at the four locations are given in Table 1. AFIS test results are given in Table 2a and 2b. All fiber test results discussed are contained in these tables, with the exception of the length distributions from the AFIS. Some charts will be used to emphasize some of the results and these will be referenced where relevant.

Table 1. HVI Data, by Location and Variety

Location	Variety	Mic	Length	LUI	Strength	Elon	Rd	+b	CG	Leaf
Location 1	Variety A	2.5	1.15	77.9	25.0	6.0	81.9	8.6	11-2	1
	Variety B	2.5	1.16	78.8	26.9	6.9	80.9	9.2	11-2	1
	Variety C	2.3	1.11	76.1	20.9	7.1	80.6	9.6	11-3	1
Location 2	Variety A	2.8	1.17	79.6	25.5	5.6	82.1	7.1	31-1	3
	Variety B	2.9	1.17	80.5	27.5	5.9	81.7	7.3	21-2	3
	Variety C	2.8	1.15	78.9	23.1	6.5	79.9	7.9	31-1	3
Location 3	Variety A	3.3	1.17	81.0	28.0	5.9	80.2	8.9	21-1	1
	Variety B	3.2	1.19	81.8	28.8	7.0	79.0	8.9	21-1	1
	Variety C	3.2	1.14	80.1	25.1	8.1	78.7	9.5	21-3	1
Location 4	Variety A	4.8	1.14	82.2	31.2	4.6	76.9	8.0	31-2	2
	Variety B	4.9	1.16	82.9	32.7	5.2	77.3	8.2	31-1	2
	Variety C	4.8	1.14	82.8	27.7	7.1	77.6	8.9	21-4	1

Definitions: Mic ≡ micronaire; length ≡ upper half mean length (in); LUI ≡ length uniformity index (%);Strength ≡ fiber bundle tenacity (g/tex); Elon ≡ fiber bundle elongation (%); Rd ≡ Reflectance (%); +b ≡ Yellowness; CG ≡ color grade; Leaf ≡ leaf grade.

Table 2a. AFIS Data, by Location and Variety

Location	Variety	Nep Size	Neps	Lw	LwCV	UQL	SFCw	Ln	LnCV	SFCn	Total Count
Location 1	Variety A	779	1416	0.91	44.2	1.18	17.2	0.66	61.2	41.1	523
	Variety B	792	1566	0.86	45.5	1.14	19.6	0.63	61.8	44	681
	Variety C	770	1113	0.86	42.3	1.11	17.8	0.64	58.8	41.2	918
Location 2	Variety A	745	734	0.96	39.5	1.22	11.7	0.75	53.2	30.2	1334
	Variety B	735	663	0.95	35.6	1.16	10.4	0.76	48.8	27.4	1703
	Variety C	727	643	0.97	39.2	1.22	11.5	0.75	53.5	30.4	828
Location 3	Variety A	718	425	0.95	35.1	1.17	10.1	0.78	47.9	26.4	998
	Variety B	737	530	0.98	36.1	1.22	10.2	0.78	49.4	26.9	594
	Variety C	726	420	1.01	34.8	1.26	8.7	0.83	47.7	24.1	532
Location 4	Variety A	711	282	1.01	34.6	1.24	8.0	0.83	47.3	23.0	706
	Variety B	704	181	1.00	29.9	1.16	5.6	0.86	40	16.7	1426
	Variety C	664	209	1.06	29.8	1.25	5.3	0.90	40.9	16.5	764

Table 2b. AFIS Data, by Location and Variety (concluded)

Location	Variety	Trash Size	Dust	Trash	VFM	SCN Size	SCN	H	IFC	MR	Hs
Location 1	Variety A	315	446	76	1.68	1029	17	126	12.3	0.74	170
	Variety B	335	567	114	2.39	995	26	135	12.3	0.74	182
	Variety C	330	764	154	2.85	921	20	135	12.4	0.74	182
Location 2	Variety A	275	1218	115	2.45	1069	14	139	9.6	0.8	174
	Variety B	340	1396	307	5.64	972	28	152	9.1	0.81	188
	Variety C	309	710	118	2.51	911	11	140	9.3	0.8	175
Location 3	Variety A	324	835	163	2.97	1122	11	153	9.4	0.79	194
	Variety B	332	493	101	2.01	856	8	151	9.8	0.79	191
	Variety C	352	434	98	2.11	1134	9	153	9.9	0.79	194
Location 4	Variety A	360	556	149	2.6	1107	10	171	6	0.91	188
	Variety B	350	1154	271	4.34	1137	13	182	5.2	0.91	200
	Variety C	374	603	160	3.14	815	6	181	5.4	0.9	201

Definitions: Nep Size ≡ fiber nep size (microns); Neps ≡ fiber nep count per gram; Lw ≡ mean length by weight (in); LwCV ≡ mean length coefficient of variation by weight (%); UQL ≡ upper quartile length by weight (in); SFCw ≡ short fiber content by weight (%); Ln ≡ mean length by number (in); LnCV ≡ mean length coefficient of variation by number (%); SFCn ≡ short fiber content by number (%); Total Count ≡ dust and trash particle count per gram; Trash Size ≡ trash particle size (microns); Dust ≡ dust particle count per gram; Trash ≡ trash particle count per gram; VFM ≡ visible foreign matter (%); SCN Size ≡ seed coat nep size (microns); SCN ≡ seed coat nep count per gram; H ≡ fiber fineness (mtex); IFC ≡ immature fiber content (%); MR ≡ maturity ratio; Hs ≡ standard fineness (mtex).

The differences in the micronaire values are shown graphically in Figure 1 (using a bar chart) and Figure 2 (using a line chart). For each variety, the highest micronaire value is almost twice as large as the lowest value. It should be noted that none of these trials resulted in an optimal micronaire level. Locations 1 and 2 had values that indicate serious immaturity, Location 3 had values that indicate moderate immaturity, and Location 4 had too-high values that can result from serious drought stress. For these varieties, the "desirable" micronaire range would range from about 4.2 to 4.7, with Variety A and Variety B being closer to the 4.2 value and Variety C being closer to the 4.7 value. This conclusion is based on a knowledge of the "genetic fineness" of each variety; i.e., of the average size of the circumference of the outer cell wall. With a working knowledge of this circumference, an adequate estimate of the "mature micronaire value" can be made.

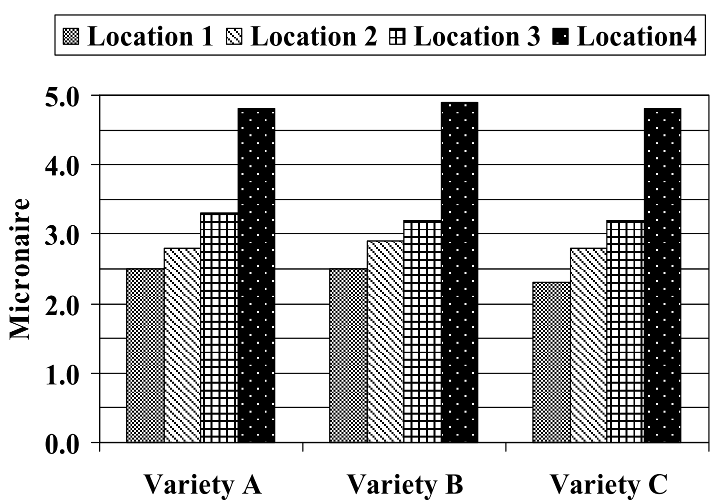

Figure 1. HVI Micronaire Values, by Variety and Location

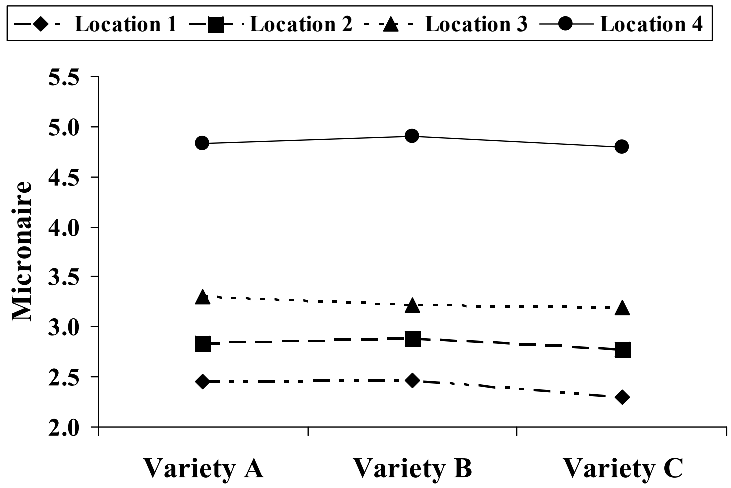

Figure 2. HVI Micronaire Values, by Variety and Location

The correlation between micronaire values for cottons of the same variety and the maturity ratios produced by the AFIS instrument can be seen by comparing Figure 2 with Figure 3. This corroborates the fact that the micronaire values of these three varieties reflect the relative maturity of each one.

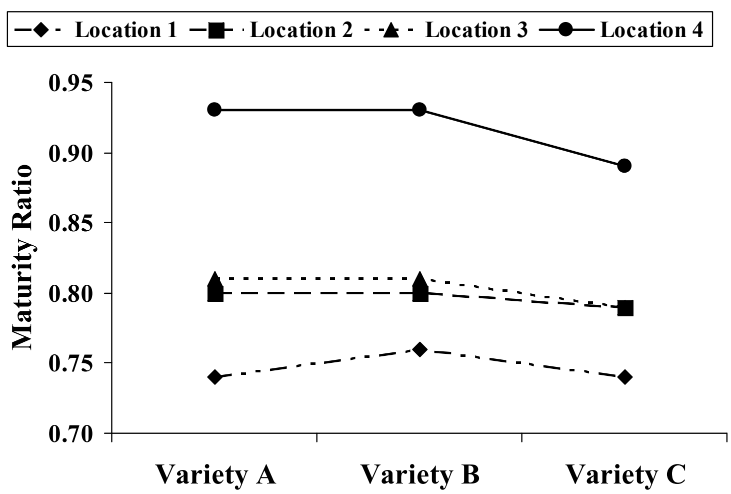

Figure 3. AFIS Maturity Ratios, by Variety and Location

The correlations between the maturity levels of the cottons and other fiber properties may be determined by a careful inspection of the data in Tables 1 and 2. In particular, it may be observed that the indicators of the *distributional characteristics* of fiber length are all negatively affected by a lack of maturity. Thus:

- The length uniformity index (LUI) increases as micronaire values increase.
- The mean length by weight (Lw) and mean length by number (Ln) increase as micronaire values increase.
- The coefficients of variation for Lw and Ln (LwCV and LnCV) decrease as micronaire values increase.
- The short fiber content by weight (SFCw) and by number (SFCn) decrease as micronaire values increase.

These results are all captured by the frequency distributions of the fiber lengths that may be obtained from the AFIS. The fiber length distributions by number of fibers are shown for the three varieties at each location in Figures 4, 5 and 6. (Number of fibers, rather than weight of fibers, is used because it is a much more graphic indicator of the differences among locations.) A superior fiber length distribution has a "left tail" that is as low as possible and a "peak" occurring above 1 inch that is as high as possible. Clearly, for each variety the shape of the length distribution curve improves as the micronaire value increases.

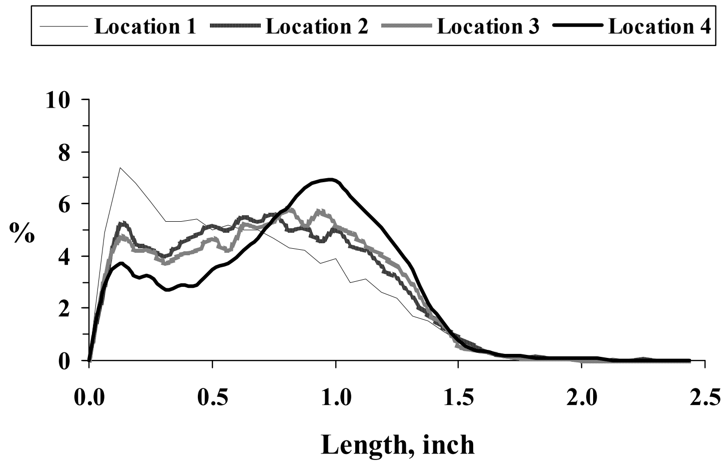

Figure 4. Frequency Distribution of Fiber Length for Variety A, by Locations

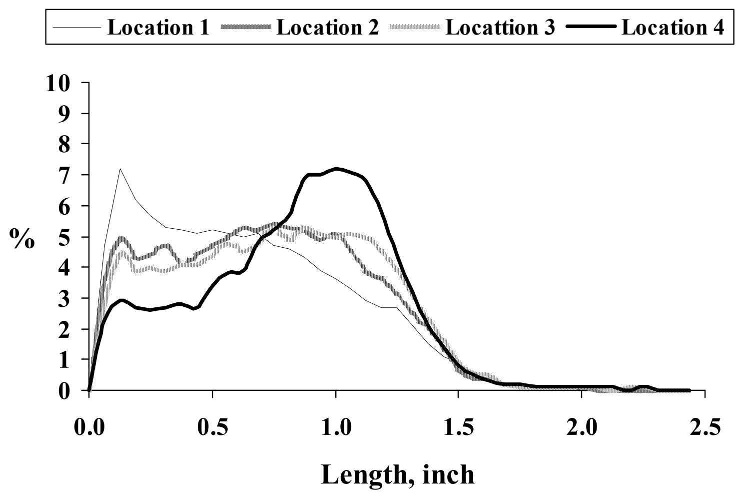

Figure 5. Frequency Distribution of Fiber Length for Variety B, by Locations

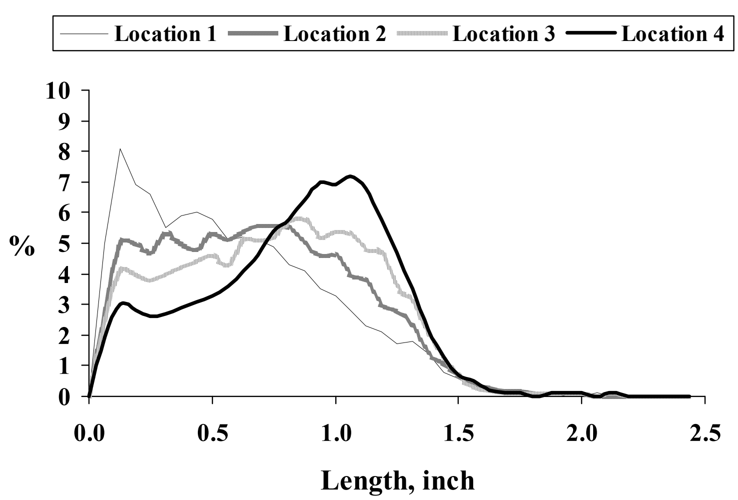

Figure 6. Frequency Distribution of Fiber Length for Variety C, by Locations

The cause of the obvious deterioration in length distribution is the breakage of fibers when exposed to mechanical and other stresses in harvesting and ginning. Mechanical stresses will also occur in textile processing, which can be expected to cause more breakage and further deterioration of the length distribution of the fibers.

Spinning Test Results

Ring spinning is used to evaluate the spinning performance because (1) these fibers have "staple lengths" that are appropriate for ring spinning and (2) this technology is quite sensitive to the length distributions of the cotton fibers being spun. The yarn size is 40 Ne, with both carded and combed yarns being produced. The combed yarns reveal impacts of removing most of the short fibers in the distributions.

Ring-Spun 40 Ne Carded Yarns

All yarn data obtained on the 40 Ne carded yarns from the Uster Tensorapid® strength tester, the Scott skein strength tester, and the Uster UT3® evenness tester are given in Tables 3a and 3b. Textual material will emphasize single-end yarn strength (Ten), yarn coefficient of variation (CV), thin places (Thin), and neps that are 200% of average yarn mass (N200).

Table 3a. Yarn Data for 40 Ne Carded, by Location and Variety

Location	Variety	Count	SkBrk	CSP	Force	Elong	Ten	Work
Location 1	Variety A	39.94	56.10	2240.4	213.72	6.43	14.17	362.94
	Variety B	40.09	45.90	1840.2	189.04	7.38	12.58	385.13
	Variety C	39.76	52.45	2085.6	205.67	7.02	13.58	387.17
Location 2	Variety A	40.11	54.65	2191.9	214.24	6.50	14.26	357.57
	Variety B	40.66	51.85	2108.4	207.77	7.78	14.03	428.17
	Variety C	40.08	58.90	2360.8	228.98	6.81	15.24	402.37
Location 3	Variety A	39.58	53.40	2113.7	205.35	7.71	13.49	435.01
	Variety B	40.40	48.45	1957.5	193.62	7.09	12.99	377.82
	Variety C	39.32	54.35	2137.3	201.09	7.45	13.13	407.17
Location 4	Variety A	40.12	56.95	2284.8	217.85	5.83	14.51	332.97
	Variety B	39.47	60.80	2399.5	229.21	6.88	15.02	418.64
	Variety C	41.09	55.65	2286.5	217.40	6.23	14.80	357.47

Table 3b. Yarn Data for 40 Ne Carded, by Location and Variety (concluded)

Location	Variety	CV	Thin	Thick	N140	N200	N280	Hair	sh
Location 1	Variety A	20.79	255	1105	5107	1391	258	5.47	1.40
	Variety B	22.42	614	1480	6094	1832	390	6.06	1.52
	Variety C	20.46	258	1019	4627	1214	223	5.33	1.35
Location 2	Variety A	20.59	289	1116	4092	1027	164	5.17	1.38
	Variety B	20.61	276	1142	4249	1198	274	5.04	1.35
	Variety C	20.04	224	996	3773	903	146	5.01	1.33
Location 3	Variety A	19.09	128	717	3156	741	163	4.57	1.16
	Variety B	20.47	269	1035	4298	1040	184	4.96	1.29
	Variety C	18.66	120	664	2947	661	123	4.49	1.17
Location 4	Variety A	19.04	106	792	3316	808	145	4.59	1.25
	Variety B	18.26	66	569	2169	528	143	4.15	1.10
	Variety C	18.63	91	660		562	107	4.21	1.15

Definitions: Count ≡ actual yarn count (Ne); SkBrk ≡ force to break yarn skein (lb); CSP ≡ count-strength product (lb·Ne); Force ≡ force required to break single yarn (gf); Elong ≡ elongation before break of single yarn (%); Ten ≡ yarn tenacity (cN/Tex); Work ≡ work-to-break (gf·cm); CV ≡ coefficient of variation (%); Thin ≡ number of thin places (count/km); Thick ≡ number of thick places (count/km); N140 ≡ number of neps 140% of average yarn mass (count/km); N200 ≡ number of neps 200% of average yarn mass (count/km); N280 ≡ number of neps 280% of average yarn mass (count/km); Hair ≡ yarn hairiness; sh ≡ within-sample standard deviation of hairiness.

Yarn strengths for the varieties and locations are shown in Figure 7. In each case, the strength increases as micronaire increases. Furthermore, the incremental increase for the high-micronaire cottons at Location 4 is the largest. It bears emphasis that, since the cottons at Location 4 were drought-stressed, the micronaire values there are undesirably high, resulting in fibers that are too "plump" and "stiff" to enable optimum friction forces in the yarns or optimum numbers of fibers in the cross-sections of the yarns. In spite of these problems, the superior length distributions of these fibers resulted in the strongest yarns.

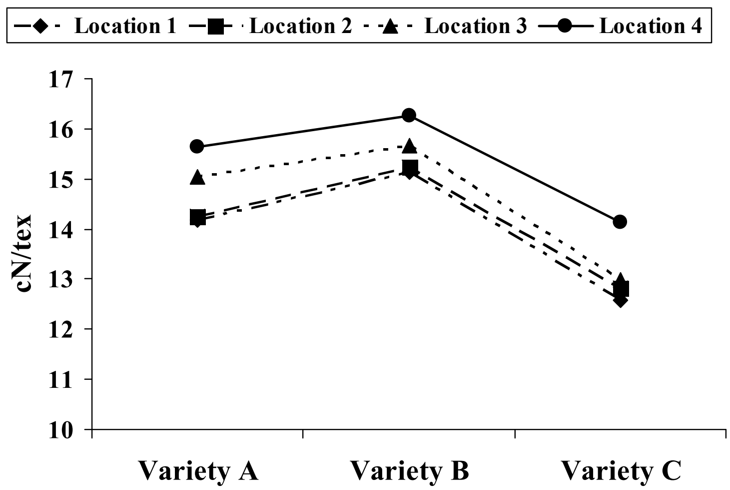

Figure 7. Yarn Strength, 40 Ne Carded, by Variety and Location

Figure 8 shows the strong tendency for the coefficient of variation of the yarn mass to improve (decrease) as the micronaire values increase. For Variety A and Variety B at Location 3 and Location 4, however, the yarn CVs are virtually equal. That the very mature varieties did not do relatively better than the moderately mature varieties may be due to the to-high micronaire values at Location 4. If so, this clearly did not impact Variety C in the same way, since its CV did decrease noticeably between Location 3 and Location 4.

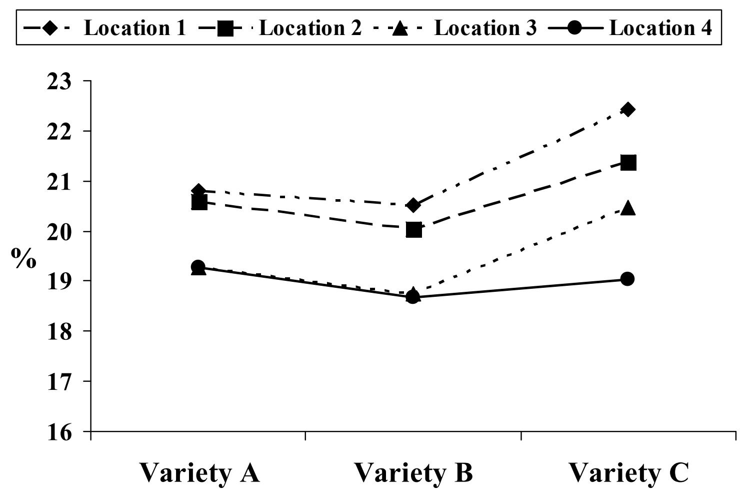

Figure 8. Yarn Coefficient of variation, 40 Ne Carded, by Variety and Location

Figure 9 shows that the thin places in the yarn (places that are 50% smaller than the average mass of the yarn) behaved similarly to the yarn CVs. Thin places are a particularly important defect in yarns, because these places are where the yarn is likely to break when put under mechanical stresses.

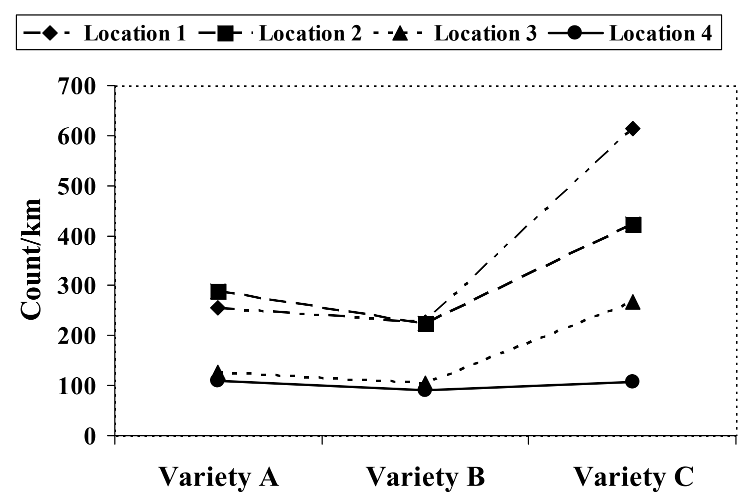

Figure 9. Yarn Thin Places, 40 Ne Carded, by Variety and Location

Figure 10 shows the strong tendency for the neps on the yarn to improve (decrease) as the micronaire values increase. For Variety A, we again see that the nep count is almost as low for the drip irrigation system at Location 3.

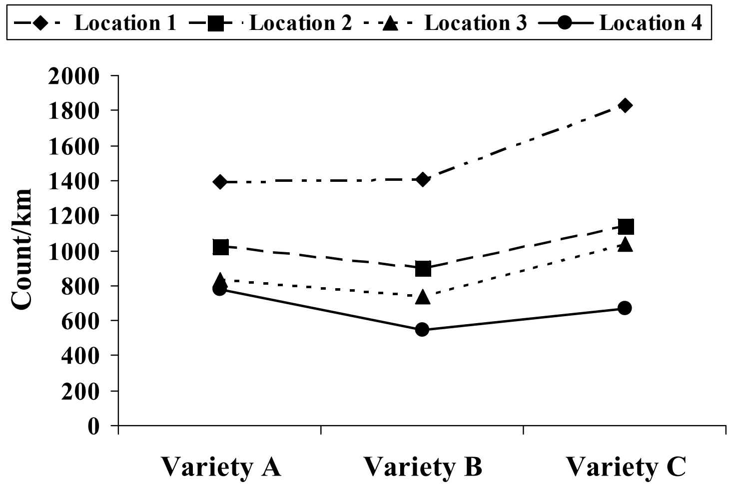

Figure 10. Yarn Neps (200%), 40 Ne Carded, by Variety and Location

For all major yarn quality indicators, the highest micronaire values – even though the values were above optimum values – exhibited the best performance. The fundamental reason appears to be the superior length distributions that result from cottons that are adequately matured. Although not related here, the performance differential becomes even greater when the performance in dyeing and finishing aspects are considered.

Ring-Spun 40 Ne Combed Yarns

Given the results with the carded yarns, a logical expectation is that combing of the cotton fibers will greatly alleviate many of the disadvantages seen for the less mature cottons. After all, the fundamental purpose of combing is to remove the short fibers and thereby improve the length distribution of the remaining fibers. The data shown in Tables 4a and 4b generally corroborate this expectation, as well as reveal the limitations of the drought-stressed cottons from Location 4.

Table 4a. Yarn Data for 40 Ne Combed, by Location and Variety

Location	Variety	Count	SkBrk	CSP	Force	Elong	Ten	Work
Location 1	Variety A	40.31	65.6	2644.2048	248.39	6.71	16.62	428.18
	Variety B	39.88	58.55	2334.9155	231.16	7.93	15.30	491.84
	Variety C	39.50	63.05	2490.6011	238.40	7.39	15.63	460.89
Location 2	Variety A	39.66	68.05	2698.9991	253.80	6.76	16.71	431.84
	Variety B	38.76	64.6	2504.1544	248.74	7.99	16.01	523.46
	Variety C	39.92	68.6	2738.7864	257.58	7.10	17.07	464.48
Location 3	Variety A	39.55	58.95	2331.7083	226.09	8.05	14.84	491.30
	Variety B	40.57	56.15	2277.8932	219.02	7.32	14.75	433.55
	Variety C	39.65	59.55	2361.2171	231.04	7.70	15.21	474.97
Location 4	Variety A	39.90	63.85	2547.4235	244.35	6.03	16.18	380.22
	Variety B	39.99	61.4	2455.3246	236.70	7.11	15.71	441.11
	Variety C	39.74	60.9	2420.2269	237.55	6.48	15.67	400.02

Table 4b. Yarn Data for 40 Ne Combed, by Location and Variety (concluded)

Location	Variety	CV	Thin	Thick	N140	N200	N280	Hair	sh
Location 1	Variety A	15.53	24	127	755	142	27	4.53	1.02
	Variety B	16.54	40	167	1016	191	29	4.93	1.09
	Variety C	16.17	43	160	755	136	20	4.25	1.01
Location 2	Variety A	15.21	21	119	534	111	28	4.21	1.00
	Variety B	15.83	38	171	674	133	32	4.14	0.98
	Variety C	15.21	21	108	505	92	15	4.11	0.97
Location 3	Variety A	15.63	28	119	419	72	12	4.14	0.97
	Variety B	15.75	33	125	573	79	10	4.35	1.00
	Variety C	15.47	32	101	444	75	11	4.15	0.96
Location 4	Variety A	15.28	24	93	360	54	10	4.24	1.03
	Variety B	15.63	46	114	353	66	16	3.99	1.00
	Variety C	15.72	32	148	289	45	7	4.03	1.00

Definitions: Count ≡ actual yarn count (Ne); SkBrk ≡ force to break yarn skein (lb); CSP ≡ count-strength product (lb·Ne); Force ≡ force required to break single yarn (gf); Elong ≡ elongation before break of single yarn (%); Ten ≡ yarn tenacity (cN/Tex); Work ≡ work-to-break (gf·cm); CV ≡ coefficient of variation (%); Thin ≡ number of thin places (count/km); Thick ≡ number of thick places (count/km); N140 ≡ number of neps 140% of average yarn mass (count/km); N200 ≡ number of neps 200% of average yarn mass (count/km); N280 ≡ number of neps 280% of average yarn mass (count/km); Hair ≡ yarn hairiness; sh ≡ within-sample standard deviation of hairiness.

The tabular data do not show, however, the noils (fiber and contaminants) removed at the combing machine, which constitute a loss to the textile manufacturer. The greater the noils obtained in the yarn manufacturing process, the lower the value of the raw cotton fiber to the manufacturer. As shown in Figure 11, the results are not good for the less mature fibers. While the cottons at Location 4 easily meet world standards for noil levels, the cottons at Location 3 are, at best, marginal. The cottons at Locations 1 and 2 are unacceptable.

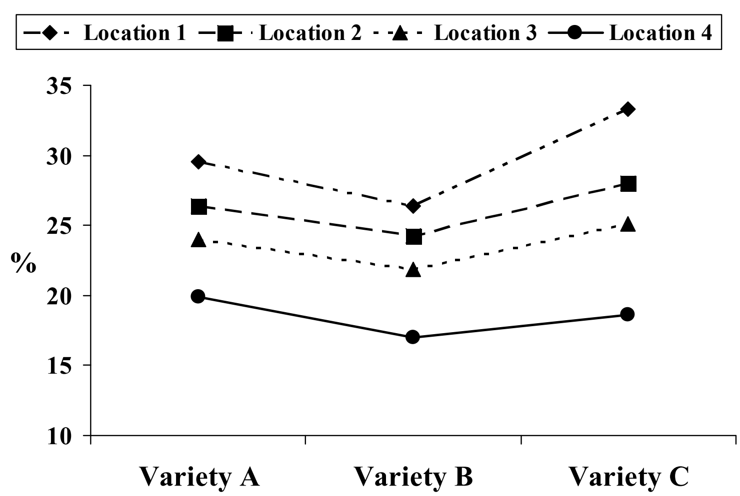

Figure 11. Noils, 40 Ne Combed, by Variety and Location

The following charts picture the results for single-end yarn strength (Figure 12), yarn coefficient of variation (Figure 13), thin places (Figure 14), and neps (Figure 15). They reveal the following:

- Both the yarn strengths and coefficients of variation of all the locations are brought into comparable performance by combing. Getting rid of the short fibers makes the low-micronaire cottons perform as "normal", while the too-high micronaire cottons at Location 4 are not improved much.

- For thin places, the too-high micronaire cottons at Location 4 actually become the worst performers after combing. This may be due to the disadvantages caused by the shorter stapled, plump, and stiff fibers that result from drought stress.
- For neps, the best performers are still the high-micronaire cottons from Location 4. The greater tendency for low-micronaire fibers to form neps under mechanical stresses is still evident.

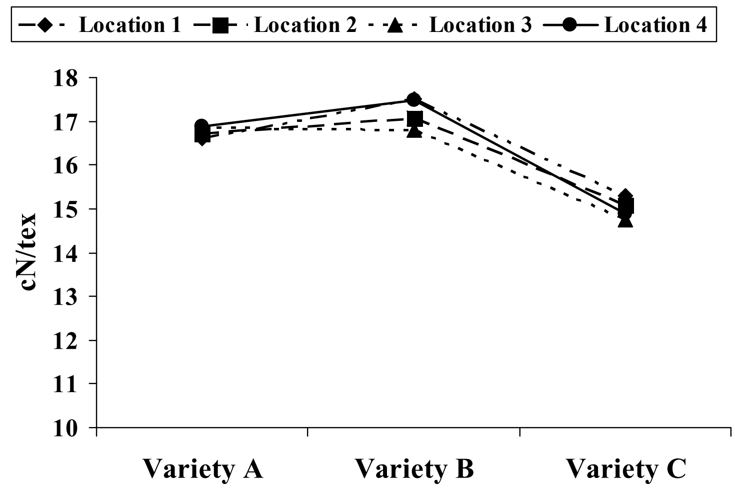

Figure 12. Yarn Strength, 40 Ne Combed, by Variety and Location

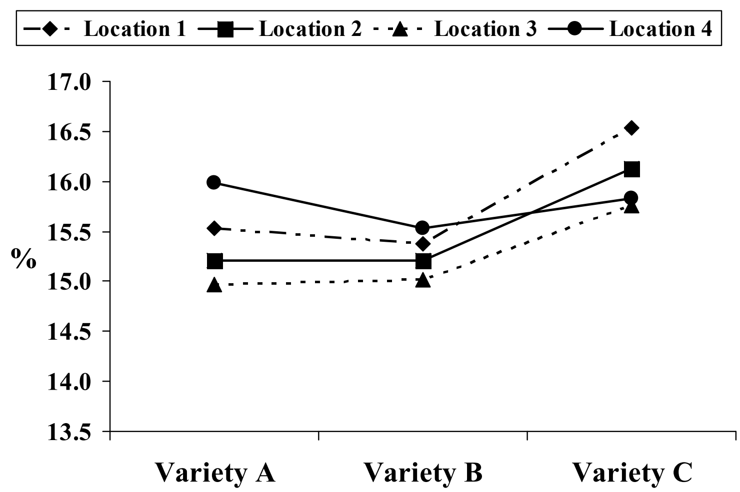

Figure 13. Yarn Neps (200%), 40 Ne Combed, by Variety and Location

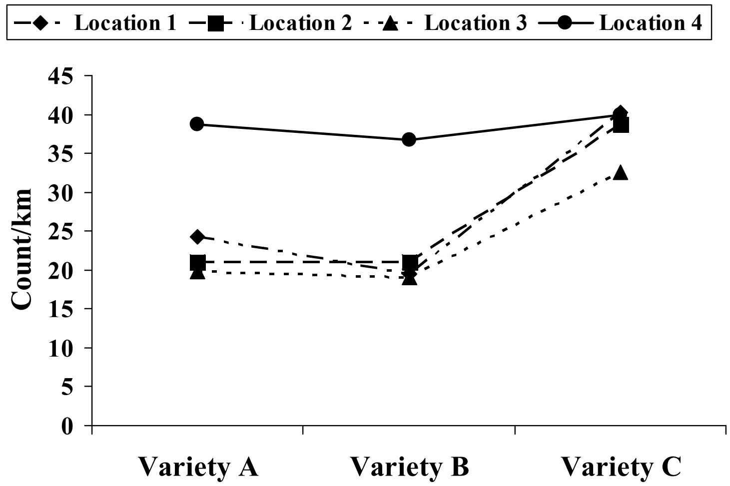

Figure 14. Yarn Thin Places, 40 Ne Combed, by Variety and Location

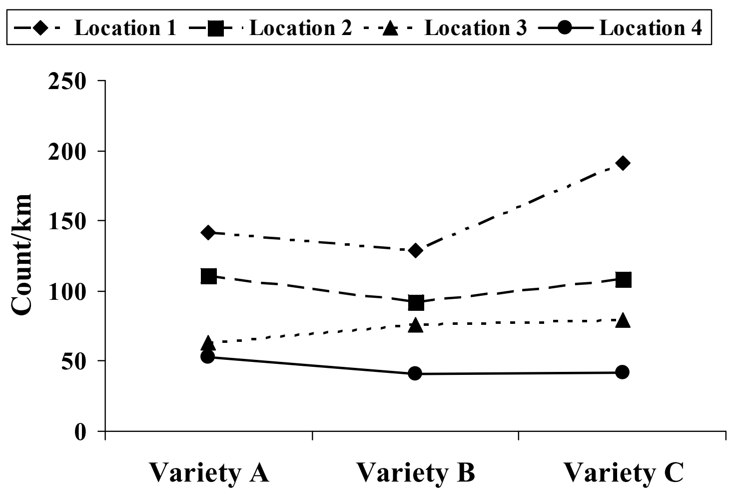

Figure 15. Yarn Neps, 40 Ne Combed, by Variety and Location

Summary and Conclusions

The validity of this study is based on the fact that if we know the variety being measured, then relative micronaire values are a reliable indicator of the relative maturity of the cotton fibers. This, in turn, reminds us that we must think clearly about the "fineness" versus the "maturity" of cotton fibers. Given what is known about the variations in density of the cellulose making up cotton fibers, it is better to conceptualize "fine" fibers as being those with small perimeters (i.e., small circumferences), which are mature at lower micronaire values than are fibers with larger perimeters.

It follows that a specific (and stable) cotton variety has a "mature micronaire value" and that, in order to perform its best in textiles, it needs to reach that value. Conversely, unless we know the variety being measured and know its mature micronaire value, we cannot accurately infer maturity from the micronaire value.

This study corroborates something that has long been realized by people in the cotton and textile sectors; namely, that under certain environmental conditions, such as drought stress, micronaire values may increase to levels that are too high for optimal textile performance. Nevertheless, these results support the conclusion that cottons with a too-high micronaire value generally perform better than do cottons with a too-low value.

While immature fibers are capable of making a fairly strong bundle of fibers, each of the single fibers is weak and fragile; therefore, these fibers break under mechanical stresses, resulting in a bad length distribution (i.e., elevated short fiber content). This bad length distribution is the fundamental cause of the poor performance in ring spinning. Furthermore, for the same variety, the bundle strength for the high-micronaire fibers is greater than that for the low-micronaire fibers, so the increased numbers of fibers in the bundle does not completely compensate for the higher strength of the mature fibers.

Combing of the fibers alleviates the large discrepancy in short fibers, resulting in much better relative performance of the low-micronaire samples in ring spinning. However, the amount of noils at the combing stage is unacceptable for the very-low-micronaire samples.

Acknowledgement

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