Impacts of Fiber Length Distribution on Market Value and Yarn Quality: Implications for U.S. Cotton

Eric F. Hequet
M. Dean Ethridge

International Textile Center
Texas Tech University
Lubbock, Texas 79409
USA
INTRODUCTION

The shrinking U.S. textile manufacturing industry dictates an increased reliance on the international market for selling U.S. cotton. This process, in turn, is transforming the requirements on fiber properties. This is well illustrated by the existing “base levels” of fiber properties shown in Table 1. A look at the percentage of the U.S. cotton crop that equals or exceeds the international base quality (Table 2) makes it clear that progress is needed.

Table 1. Base Levels of Cotton Fiber Properties, U.S. Versus International

<table>
<thead>
<tr>
<th>Fiber Property</th>
<th>United States</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staple Length (in)</td>
<td>34</td>
<td>35</td>
</tr>
<tr>
<td>Tenacity (g/tex)</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td>Micronaire</td>
<td>3.5–4.9</td>
<td>3.8–4.6</td>
</tr>
<tr>
<td>Uniformity Index (%)</td>
<td>80–82</td>
<td>82–83</td>
</tr>
<tr>
<td>Color</td>
<td>41</td>
<td>31</td>
</tr>
<tr>
<td>Leaf</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 2. Percentage of U.S. Crop that Reaches or Exceeds Base Qualities

<table>
<thead>
<tr>
<th>Crop Year</th>
<th>United States</th>
<th>International</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003-04</td>
<td>54.8%</td>
<td>7.1%</td>
</tr>
<tr>
<td>2004-05</td>
<td>49.7%</td>
<td>7.9%</td>
</tr>
</tbody>
</table>

The foregoing data does not adequately reveal the emerging emphasis (and the market premium) that is occurring for fiber lengths that are longer and more uniform. The U.S. industry has long been focused on the production of medium and coarse yarns and has long emphasized open-end rotor spinning, rather than ring spinning. But the focus of the dominant international textile industries is on the finer yarns and on ring spinning. Thus global textile mills interested in sourcing cotton from the global market emphasize those cotton growths with longer fiber lengths. A less-appreciated fact is that the focus on fiber length is shifting away from the traditional staple length (which is a measure of the “dominant long fibers”) and toward length distribution (which measures the lengths of all fibers included in the cotton). This shift is obscured by the lack of a high-volume measurement for length distribution. Alternatively, it is revealed by a growing preoccupation of international customers with the “short
fiber content” (SFC) of cotton; i.e., the percentage of fibers with a length of ¼ inch or less. Textile mill operators believe – and the data prove – that higher SFCs result in greater losses at the carding machine, reduced spinning performance and yarn quality, and increased fabric defects.

MEASURING FIBER LENGTH DISTRIBUTION

The only generally available instrument that can provide fiber length distribution data is the Uster® Advanced Fiber Information System (AFIS®). It is not a high-volume instrument and it is not feasible to obtain reliable market-wide measurements with it. Nevertheless, within a carefully controlled laboratory it is feasible to get repeatable and reliable measurements. At the International Textile Center (ITC), standard cottons were developed and are used every day to maintain calibrations on the two AFIS instruments in its laboratory. These “check cottons” are described in Table 3, which shows for each cotton the upper quartile length (UQL), the short fiber content by weight (SFC(w)), and the short fiber content by number (SFC(n)).

Using the ITC protocols, the precision of these instruments over time has proven to be quite good. Furthermore, results have proven that good repeatability of fiber length
Table 3. AFIS Check Cottons Used at the International Textile Center

<table>
<thead>
<tr>
<th></th>
<th># 3116</th>
<th># 3191</th>
<th># 3212</th>
</tr>
</thead>
<tbody>
<tr>
<td>UQL</td>
<td>1.01</td>
<td>1.16</td>
<td>1.30</td>
</tr>
<tr>
<td>SFC(w)</td>
<td>22.1</td>
<td>13.8</td>
<td>8.6</td>
</tr>
<tr>
<td>SFC(n)</td>
<td>43.5</td>
<td>33.1</td>
<td>24.3</td>
</tr>
</tbody>
</table>

distributions is obtained between the two instruments at the ITC. (These two AFIS instruments span two generations; the older one is called “AFIS” and the newer one is called “AFIS Pro”.) As shown in Figure 1(a)-(c), the shapes of the cotton fiber length distributions are repeatable for all check cottons. These results clearly show that fiber length distributions vary for different cottons and that the distributions are repeatable. Therefore, it is a strong hypothesis that length distributions are heritable, which would mean that varieties with superior length distributions could be developed using traditional selection techniques of plant breeders.
Figure 1. Length Distributions by Weight for Three Check Cottons at the ITC

(a) Check Cotton 3116:

(b) Check Cotton 3191:
ALTERATIONS OF FIBER LENGTH DISTRIBUTION

The natural, genetic length distribution of cotton fibers on the seed is inevitably altered by fiber breakage due to mechanical and other stresses placed on the fibers in harvesting, ginning, and manufacturing. Indeed, even the AFIS® instrument breaks substantial numbers of fibers in the process of opening the cotton sample and individualizing the fibers. (Thus, the AFIS® may be used as an indicator of the propensity of fibers to break.) Two factors that are critically important for predicting the fibers’ propensity to break are maturity and fineness. Use of the micronaire measure is frequently misleading because it inherently measures a combination of maturity and fineness. Thus, a coarse, immature fiber may give the
same micronaire value as a fine, mature fiber. Furthermore, as illustrated by the cross-sectional images of a multitude of cottons, there is a clear distributional behavior for both fineness and maturity. This fact is illustrated in Figure 2 using the bivariate distributions between fiber perimeter (a measure of the fineness) and “theta”, which describes the degree of thickening of the fiber cell wall (a measure of the maturity). While the two cotton varieties shown have the same micronaire reading (4.28), they show divergent patterns of fineness and maturity.

Since an immature fiber is weaker than a mature one, it is more susceptible to being broken under stress. Therefore, an average maturity measurement should be a better predictor of fibers’ propensity to break than is the micronaire. And since the stresses in mechanical operations like ginning, cleaning, opening and carding are being placed on individual fibers (rather than on bundles of fibers) the distributional characteristics of maturity should greatly impact the propensity to break.
Figure 2. Bivariate Distributions of Perimeter Versus Theta, for Two Cottons with the Same Micronaire Value of 4.28
Using AFIS® measurements of short fiber content by number (SFC(n)) and by weight (SFC(w)), the distinctive behaviors of mature versus immature of two cottons having the same Upper Quartile Length (UQL) are illustrated in Figure 3. This data was collected from hand-ginned cottons, in order to ensure minimal damage to the native length distributions of the cottons.

The SFC(w) is the more common frame of reference for the cotton/textile industry. But the SFC(n) is often preferred for research purposes, due to its greater sensitivity to movements in SFC. The SFC(w) is less sensitive because the short fibers (whether caused by native length distribution or by the breaking of fibers) must logically comprise a small portion of the total weight of fibers. The increased number of short fibers for the immature cotton (Figure 3(a)) is relatively much larger than is the increased weight of short fibers (Figure 3(b)). Nevertheless, with the cottons used in this example, the differences in short fibers between mature versus immature cotton are quite clear.

It is noteworthy that Figure 3 shows the hand-ginned mature cotton has very low amounts of short fibers. For the immature cotton, however, the short fibers are greatly increased. This is probably due to fiber breakage, both
Figure 3. Length Distributions for two cottons having an UQL of 1.28 - Hand-Ginned Cottons

(a) Short Fiber Content by Number (SFC(n))

(b) Short Fiber Content by Weight (SFC(w))
by the hand ginning and the opening device on the AFIS®. This observation is sufficiently repeatable with immature fibers to lend support to the common hypothesis that short fibers are few within an unharvested boll of cotton and that the vast majority of short fibers come from breakage due to mechanical stresses.

Further evidence is obtained by comparing fiber length distributions with hand-ginning against breeder saw-ginning. Figure 4(a) shows results for an immature cotton (AFIS® maturity ratio = 0.87). Figure 4(b) shows results for a mature cotton (AFIS® maturity ratio = 1.04).

**Figure 4. Cotton Fiber Length Distributions by Number: Hand Ginning Versus Saw Ginning**

(a) For an Immature Cotton (MR = 0.87)
(b) For a Mature Cotton (MR = 1.04)

Results show the following:

- With hand ginning the short fiber content is much greater for the immature cotton.
- The use of a breeder saw gin increases the short fiber content for both cottons, but the increase is much more for the immature cotton.

Comparing breeder saw ginning versus hand ginning over multiple cotton samples reveals a consistent relationship between short fiber contents and maturity (Figure 5). In this example, a short fiber content by weight of about 5% with hand ginning would be expected to increase to 12-13% with the breeder saw gin.
Figure 5. Short Fiber Content by weight: Breeder saw gin vs. Hand gin

Plotting multiple measurements of short fiber content after hand ginning against fiber maturity ratios reveals a consistent inverse relationship (Figure 6(a)), with an asymptote for short fiber content at about 1%. Doing the same thing using a breeder saw gin shows the same inverse relationship, but with a short-fiber asymptote closer to 5% (Figure 6(b)).
Figure 6. Short Fiber Content Versus Maturity Ratio

(a) Hand Ginning

\[ SFC(w) = 325.5 - 634.8 \text{MR} + 310.7 \text{MR}^2 \]
\[ R^2 = 0.878 \]

(B) Breeder Saw Ginning

\[ SFC(w) = 811.7 - 1585 \text{MR} + 778 \text{MR}^2 \]
\[ R^2 = 0.839 \]
IMPACTS ON YARN QUALITY

A look at two varieties studied at the International Textile Center illustrates how distributional properties may determine the success or failure of cotton varieties in yarn spinning. The spinning tests were done using ring spinning and the yarn size was 40 Ne. Thus, the test procedure was set to evaluate performance in higher-valued, finer-count yarns.

Fiber Properties

The critical fiber properties are summarized in Figures 7 and 8. Figure 7 shows fiber fineness and maturity data: micronaire, AFIS maturity ratio, and AFIS fiber perimeter estimates. Note that both varieties have low micronaire readings but that both are equally mature; taken together, these results indicate that these are relatively fine fibers, which are appropriate for making finer yarns. The AFIS estimates of the average perimeters of the fibers verify this. Variety 1 has the smaller perimeter, which explains its lower micronaire value.
Figure 7. Fineness and Maturity Data for Two Varieties

(a) Micronaire

(b) AFIS Maturity Ratio
Figure 8 shows HVU upper half mean length (UHML), AFIS mean length by number (ML), and AFIS short fiber content by weight (SFC(w)). Variety 1 has a significantly longer UHML; however Variety 2 has a significantly longer ML. Furthermore, variety 1 exhibits a much higher SFC(w). Based on measurements like these, the expectation is that variety 2 will perform much better in ring spinning. A look at the length distributions for each of these varieties helps understand what is causing these length measurements. Figure 9 clearly shows that variety 1 has no "peak" near the mean length of the distribution and that it has an excess of fibers in the short length categories.
Figure 8. Length Parameters for Two Varieties

(a) HVI Upper Half Mean Length

(b) AFIS Mean Length by number
(c) AFIS Short Fiber Content by Weight

Figure 9. Fiber length distribution by number for two varieties

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%  

Var 1 Var 2

Figure 9. Fiber length distribution by number for two varieties

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%  

Var 1 - - - Var 2
Yarn Quality

A summary of key yarn quality parameters for these two cotton varieties completes the story. Figure 10 provides results on yarn tensile properties. The first chart (Figure 10(a)) shows yarn breaking strength (tenacity); it reveals that variety 1 is better in this regard. However, variety 2 has a much better elongation (Figure 10(b)). Therefore, the work-to-break, which is a critical indicator of weaving performance, is greater for variety 2 (Figure 10(c)).

Figure 10. Yarn Tensile Properties for Two Varieties (Ring-Spun, 40 Ne Yarns)

(a) Yarn Tenacity
b) Yarn Elongation

(c) Yarn Work-to-Break
Figure 11 shows that variety 2 exhibits better yarn evenness, which means that it has a smaller yarn coefficient of variation (CV%).

**Figure 11. Yarn Evenness for Two Cotton Varieties (Ring-Spun 40 Ne Yarns)**

Figure 12 shows that yarn imperfections are less with variety 2. Thus, both thick places (Figure 12(a)) and thin places (Figure 12(b)) are significantly lower for the yarn spun with variety 2. Also, yarn neps are almost 30% less with variety 2 (Figure 12(c)). Finally, the hairiness of the yarn spun with variety 2 was significantly lower (Figure 12(d)). All of these yarn properties are critical for high-quality, ring-spun yarns.
Figure 12. Yarn Imperfections for Two Cotton Varieties

(Ring-Spun 40 Ne Yarns)

(a) Thick Places

(b) Thin Places
(c) Neps

![Graph showing Neps per km for Var 1 and Var 2 with Neps values ranging from 400 to 650.

(d) Hairiness

![Graph showing hairiness values for Var 1 and Var 2 with hairiness values ranging from 4.4 to 5.6.]
CONCLUSION

It is important that both the research and commercial sectors focused on cotton and textiles realize that:

- Length distribution (as distinct from staple length) is critically important for good spinning performance and high yarn quality,
- Length distribution is highly correlated with strength of individual fibers (therefore, with strength distribution),
- Individual fiber strength is highly correlated with fiber fineness and fiber maturity, and
- Even though the distributional characteristics of either length or maturity are not yet candidates for high-volume measurements, careful measurement and evaluation of these can give indispensable guidance to applied scientists trying to develop superior cotton fibers.

Another implication of these results is that the process of realizing the market potential of cotton varieties with longer fiber lengths will likely require adjustments in crop termination, harvesting, and ginning practices. The
juncture of greatest marginal gains will likely be the beginning.