CURRENT AND FUTURE FIBER QUALITY DEMAND: IMPLICATIONS FOR THE COTTON PRODUCTION SECTOR

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Texas Tech University
Main Research Interests

- Develop new measuring methods for fibers, yarns, and fabrics.
- Improve the measurement and understanding of cotton fiber properties and contaminants;
- Study the impacts of these on textile processing performance;
- Work collaboratively with the cotton breeding and cotton biotechnology community to develop improved properties in cotton fibers;
The textile industry relocates: Impact on research objectives
Cotton yield evolution (average world)

Yield = 9.11 Year - 17,560
$R^2 = 0.95$

Source: ICAC
Cotton production evolution (world)

Production = 308.8 Year – 595,792
$R^2 = 0.92$

Source: ICAC
Cotton: Consumption per capita and market share

Source: ICAC
Cotton in % of total fiber available for home use by region

Source: FAO-ICAC
Cotton in % of total fiber available for home use by region

Source: FAO-ICAC
1997 Cotton Sales (millions)

Domestic: 11.3
Foreign: 7.5
2014/15 Cotton Sales (millions)

Domestic: 3.6
Foreign: 11.0

Domestic share: 24.7%
Foreign share: 75.3%
### Rotor spun yarn

<table>
<thead>
<tr>
<th>Rank</th>
<th>Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Strength</td>
</tr>
<tr>
<td>2</td>
<td>Fineness</td>
</tr>
<tr>
<td>3</td>
<td>Length</td>
</tr>
<tr>
<td>4</td>
<td>Cleanliness</td>
</tr>
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</table>

### Ring spun yarn

<table>
<thead>
<tr>
<th>Rank</th>
<th>Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Length</td>
</tr>
<tr>
<td>2</td>
<td>Strength</td>
</tr>
<tr>
<td>3</td>
<td>Fineness</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
### Installed Spinning Capacities (short staple)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rotor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>300,000</td>
<td>1,008,000</td>
<td>569,000</td>
<td>364,000</td>
<td>303,000</td>
</tr>
<tr>
<td>China</td>
<td>100,000</td>
<td>550,000</td>
<td>1,160,000</td>
<td>2,037,000</td>
<td>2,260,000</td>
</tr>
<tr>
<td><strong>Ring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>14,330,000</td>
<td>6,261,000</td>
<td>1,602,000</td>
<td>1,043,000</td>
<td>670,000</td>
</tr>
<tr>
<td>China</td>
<td>22,000,000</td>
<td>41,585,000</td>
<td>67,000,000</td>
<td>99,000,000</td>
<td>120,000,000</td>
</tr>
</tbody>
</table>

Source: ITMF
# 2010 Installed Spinning Capacities

<table>
<thead>
<tr>
<th>Region</th>
<th>Spindles Short staple</th>
<th>Spindles Long staple</th>
<th>OE Rotors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>2.3%</td>
<td>1.7%</td>
<td>2.2%</td>
</tr>
<tr>
<td>America, North</td>
<td>2.3%</td>
<td>6.2%</td>
<td>6.2%</td>
</tr>
<tr>
<td>America, South</td>
<td>3.9%</td>
<td>4.8%</td>
<td>6.7%</td>
</tr>
<tr>
<td>Asia &amp; Oceania</td>
<td>86.0%</td>
<td>44.9%</td>
<td>54.9%</td>
</tr>
<tr>
<td>Europe, East</td>
<td>1.5%</td>
<td>8.8%</td>
<td>18.6%</td>
</tr>
<tr>
<td>Europe, West</td>
<td>1.3%</td>
<td>28.5%</td>
<td>3.4%</td>
</tr>
<tr>
<td>Europe, Turkey</td>
<td>2.7%</td>
<td>5.1%</td>
<td>7.9%</td>
</tr>
<tr>
<td>World</td>
<td>243,573,557</td>
<td>14,663,468</td>
<td>7,566,164</td>
</tr>
</tbody>
</table>

Source: ITMF
<table>
<thead>
<tr>
<th>Region</th>
<th>Spindles Short staple</th>
<th>Spindles Long staple</th>
<th>OE Rotors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>0.9%</td>
<td>2.1%</td>
<td>1.0%</td>
</tr>
<tr>
<td>America, North</td>
<td>0.4%</td>
<td>1.8%</td>
<td>4.4%</td>
</tr>
<tr>
<td>America, South</td>
<td>0.7%</td>
<td>4.7%</td>
<td>5.0%</td>
</tr>
<tr>
<td>Asia &amp; Oceania</td>
<td>94.0%</td>
<td>59.5%</td>
<td>76.2%</td>
</tr>
<tr>
<td>Europe, East</td>
<td>0.1%</td>
<td>5.0%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Europe, West</td>
<td>0.4%</td>
<td>8.0%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Europe, Turkey</td>
<td>3.4%</td>
<td>18.9%</td>
<td>9.6%</td>
</tr>
<tr>
<td>World</td>
<td>99,299,614</td>
<td>1,670,226</td>
<td>3,791,350</td>
</tr>
</tbody>
</table>

Source: ITMF
### 2010 Installed Weaving Capacities*

<table>
<thead>
<tr>
<th></th>
<th>Shuttle-less</th>
<th>Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>1.2%</td>
<td>4.1%</td>
</tr>
<tr>
<td>America, North</td>
<td>4.3%</td>
<td>3.2%</td>
</tr>
<tr>
<td>America, South</td>
<td>5.6%</td>
<td>4.9%</td>
</tr>
<tr>
<td>Asia &amp; Oceania</td>
<td><strong>73.2%</strong></td>
<td><strong>85.3%</strong></td>
</tr>
<tr>
<td>Europe, East</td>
<td>9.4%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Europe, West</td>
<td>3.0%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Europe, Others</td>
<td>3.4%</td>
<td>1.3%</td>
</tr>
<tr>
<td>World</td>
<td><strong>1,168,666</strong></td>
<td><strong>1,484,116</strong></td>
</tr>
</tbody>
</table>

* Looms primarily for weaving yarns spun on the cotton system

Source ITMF
# Weaving Machinery Cumulative Shipments 2002-2011

<table>
<thead>
<tr>
<th>Region</th>
<th>Shuttle-less</th>
<th>Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>0.8%</td>
<td>0.1%</td>
</tr>
<tr>
<td>America, North</td>
<td>0.6%</td>
<td>0.0%</td>
</tr>
<tr>
<td>America, South</td>
<td>1.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Asia &amp; Oceania</td>
<td><strong>91.4%</strong></td>
<td><strong>99.2%</strong></td>
</tr>
<tr>
<td>Europe, East</td>
<td>0.5%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Europe, West</td>
<td>2.9%</td>
<td>0.1%</td>
</tr>
<tr>
<td>Europe, Others</td>
<td>2.8%</td>
<td>0.2%</td>
</tr>
<tr>
<td>World</td>
<td><strong>734,885</strong></td>
<td><strong>67,057</strong></td>
</tr>
</tbody>
</table>

Source: ITMF
Cotton Fiber Maturity
Thin primary walls are adhering to each other

Picture: R. Goynes
Developing fiber bundle cross section showing better developed primary walls
As the secondary cell wall development begins, fibers separate to show individual walls.

Picture: R. Goynes
Young individual fibers

Fiber bundle cross section at stage of development where fibers are individual entities

Picture: R. Goynes
25 DPA fiber cross sections

Picture: R. Goynes
36 DPA fiber cross sections

Picture: R. Goynes
49 DPA fiber cross sections

Picture: R. Goynes
Mature, field dried fiber cross sections
Typical cotton fiber cross-sections
Immature cotton fiber cross-sections
Bivariate distributions: Perimeter and $\theta$

Two cottons having the same micronaire (4.3)
Fiber maturity is essential to evaluate the fiber propensity to break during mechanical handling.

It should be therefore directly related to fiber length distribution.
Within-sample force-to-break distribution vs. length (bale 3175)
Cotton Fiber Length
HVI Fiber Length Parameters

- Upper Half Mean Length (UHML)
- Mean Length
AFIS: fiber individualizer
Schematic of a cotton fiber with crimp

Length of the signal
AFIS Fiber Length Parameters

![Graph showing fiber length parameters with relative frequency on the y-axis and length in inches on the x-axis. The graph includes lines for UQL(w) [in], L(n) [in], L5%(n) [in], and SFC(n) [%].]
Length Distribution Comparison
Bales with UHML of 1.10 in

Length (in)

Relative Frequency

Bale 1
Bale 2
Bale 3
HVI UHML vs. AFIS Length-by-Number
(3,129 commercial bales)
AFIS Maturity Ratio vs. AFIS SFC(w)

\[ R^2 = 0.8586 \]
Combing
AFIS SFC(w) vs. Noils

R² = 0.8565
Cotton 3457

- $H = 165$ mtex
- $MR = 0.86$
- $Ln = 0.73$
Cotton 3457 (20% noils)

H = 145 mtex
MR = 0.71
Ln = 0.38
41% by number

H = 183 mtex
MR = 0.94
Ln = 0.84
59% by number
Within-sample force-to-break vs. length
Cotton Fiber Tensile Properties: Focus on Elongation
Typical Load – Elongation curve

Area under curve = Work-to-break

Load, N

Elongation, mm
Single fiber tensile properties of developing cotton fibers

Elongation @ break, % vs DPA for TX55 and TX19 cotton fibers.
Single fiber tensile properties of developing cotton fibers
Background

The contribution of fiber bundle elongation in the work of rupture of fiber bundles is critically important to processing performance.
Hypothesis

New cultivars with improved work of rupture should result in lower fiber breakage when the cotton fibers are submitted to different mechanical stresses (ginning, carding, spinning, and weaving).
High Heritability

May et al. reported that “heritability of fiber tenacity is generally high”. Among eighteen studies undertaken between 1954 and 1994, the narrow sense heritability for fiber tenacity was ranging from 0.10 to 0.86 while for fiber elongation the narrow sense heritability was ranging from 0.36 to 0.90.
But, May also reported negative correlations between fiber elongation and fiber tenacity.
Elongation vs. HVI tenacity
547 wild-type cotton samples

$R^2 = 0.131$ ***
FAVIMAT:
Elongation-at-break vs. Force-to-break

\[ y = 3.632 + 0.143 \times x \]
\[ R^2 = 0.162 \]
FAVIMAT Elongation-at-break vs. FAVIMAT
Stdev Elongation-at-break (among fibers)

\[ y = 0.5804 + 0.2561 \times \]

\[ R^2 = 0.689 \]
Background

Because of the lack of HVI calibration for elongation and the negative correlation with strength most of the breeders simply ignore fiber elongation.

However, this level of correlation does not preclude simultaneous improvement of fiber tenacity and fiber elongation.
Is it possible to improve the work-to-break (quantity of energy necessary to break a fiber or a bundle of fibers) of cotton using HVI?
Tensile Strength Tester
Load vs. Elongation

Load, N

Elongation, mm

$1_0$
We cannot record the curves load-elongation for the HVI. Nevertheless, the HVI work of rupture should be related to the product tenacity * elongation.
Work of rupture (Instron) W vs. HVI Tenacity * Elongation

R² = 0.894
Estimated HVI work of rupture W vs. HVI Tenacity for selected elongations

Base: 24 cN/tex – 6% El.
Conclusion

There is a strong relationship between work of rupture measured with an Instron and the product tenacity elongation measured with HVI.

With the current marketing system the variety with a higher strength and a lower elongation would receive a premium while its performance in spinning and weaving (all other parameters being equal) would be probably lower.
Breeding for elongation to improve fiber and yarn quality
An example (J. Dever program)

- 25 crosses
- Divergent selection based on HVI elongation
- For each cross, divergent elongations (high – low) keeping everything else as constant as possible.
- 3 couples (High – Low elongation) in 2 locations with 4 replications.
HVI Elongation

Year: 2011

Year: 2012

Light color = Halfway - Dark color = Lubbock
Year: 2011

Year: 2012

Light color = Halfway - Dark color = Lubbock
Yarn elongation (RS 18Ne carded)

Year: 2011

Year: 2012

Light color = Halfway - Dark color = Lubbock
Yarn tenacity (RS 18Ne carded)

Year: 2011

Year: 2012

Light color = Halfway - Dark color = Lubbock
Year: 2011

Light color = Halfway  -  Dark color = Lubbock

Year: 2012

Best entry (C High): + 62.1% in 2011 and +50.2% in 2012 versus control
Conclusion

- Better elongation translates into better work-to-break.
- Therefore, less fiber breakage when fibers are submitted to mechanical stress is likely.
- Less fiber breakage should translate into better fiber length distribution and less yarn defects.
AFIS Short Fiber Content by number

Entry |
---|
A Low |
A High |
B Low |
B High |
C Low |
C High |
Control |
Yarn elongation vs. Thick places +50% (RS 18Ne carded)

![Graph showing the relationship between yarn thick places and yarn elongation with a regression line and data points. The R² value is 0.5465.]
It is possible to improve bundle elongation with HVI.

Better HVI elongation translates into less fiber breakage when fibers are submitted to mechanical stress. Less fiber breakage means better fiber length distribution.

Better HVI elongation translates into better yarn elongation, better work-to-break, less yarn defects.
It is critically important to estimate the propensity to break of cotton fibers.

Propensity to break is related to:
- fiber length (longer fibers tend to break more and need to be processed more gently)
- Maturity (poor fiber micro-structure leads to weak fibers)
- elongation-to-break (brittle fibers do not process well),
- force-to-break (weak fibers tend to break when submitted to mechanical processing).

Conclusion
General Conclusion

- Cotton production in Brazil is on the rise.

- A significant part of the production is exported.

\[
\text{Production} = 28.2 \text{ year} - 55439 \\
R^2 = 0.527
\]
A large part of the exports from Brazil is directed to Asia where ring spinning is dominant.
General Conclusion

- The ring spinning market needs fiber that are:
  - Long (at least 35 staple)
  - Uniform in length (low short fiber content*)
  - Strong
  - Fine and mature

* Short fibers are mostly immature fibers that have been broken when submitted to mechanical processing. Therefore, fiber maturity is of the utmost importance.
General Conclusion

- Due to the demand of the ring spinning market cotton breeders, agronomists, and plant protection specialists need to concentrate their efforts on improving both yield and fiber quality.

- The biggest threat to our industry is producing a mediocre cotton fiber that cannot compete with man-made fibers in terms of cost, productivity in the field and in the textile mills, and quality of the end-product.