1873 Multiparameter Comparison of Cotton Fiber Length Distribution

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Abstract: Length distributions obtained from a broad range of cottons were examined and revealed complex patterns with, in many instances, clear evidence of bimodality. With such complex distributional features, the summary parameters typically used to describe fiber length (means, percentiles, SFC…) are not representative of the distribution, and often show clear insufficiencies in characterizing its alterations during mechanical processing. This paper presents new approaches to modeling and characterizing cotton fiber length distribution, which adequately describe its complex pattern. A measure of bimodality (or departure from unimodality, based on Hartigan's dip test) is used to characterize fiber length alterations. A more comprehensive model based on finite mixture distribution is also used to compare distribution patterns observed at alternative processing stages.

INTRODUCTION

The technological advances leading to single fiber testing instruments such as the AFIS® have added a new dimension to the efforts toward characterizing and understanding fiber properties. However, distribution data pertaining to the main fiber properties (length, fineness, maturity…) is seldom used by the cotton industry (breeders, biotechnologists, and processors). The massive amount of data generated and the lack of understanding of the useful information it carries is one of the major deterrents preventing the industry from taking advantage of this information.

In cotton processing, the alteration of length distribution due to fiber breakage is a crucial factor affecting both quality and productivity. Recent research shows hat the parameters commonly used to characterize the fiber length (mean length, short fiber content…) present multiple shortcomings and are for instance not usable by cotton breeders to improve length distribution, or by ginners and textile manufacturers to reliably optimize the fiber behavior during processing (Robert and Blanchard, 1997; Robert *et al.*, 2000; Robert and Cui, 2001; Krifa, 2004a; Krifa and Hequet, 2005).

The present research seeks to overcome this lack of reliable parameters by acquiring a better understanding of the cotton fiber length alterations. Our approach is to consider the process from the seed to the yarn and to establish parametric models describing the fiber length distribution and its alterations (Krifa, 2006a; Krifa, 2007). With such adequate parameterization of the length distribution, breeders, agronomist and processors will have access to more accurate information allowing interpretation and use of the distribution data. This paper presents a summary of the approaches we used and results we obtained.

METHODS

Forty upland cotton bales were selected to form a wide range of fiber properties and were processed through the carded spinning preparation process. Fiber samples were collected from the raw bales then at alternative stages of the spinning preparation process. The outline of the spinning trials along with sample collection protocols are shown in Figure 1. Two samples were collected at each sampling location in order to account for within-run variability in the analysis. All samples collected from the processed lint, along with the samples from the bales were tested on AFIS (3 replications of 3000 fibers each). Fiber quality parameters typically reported by the AFIS were obtained. More importantly, distributions of these fiber properties were retrieved.

It what follows, we will discuss the length distribution modeling approaches we used, and then examine the alteration of two prominent distribution features in the course of spinning preparation. Details on the derivation of the models and parameters used here can be found in (Krifa, 2006a; Krifa, 2007)

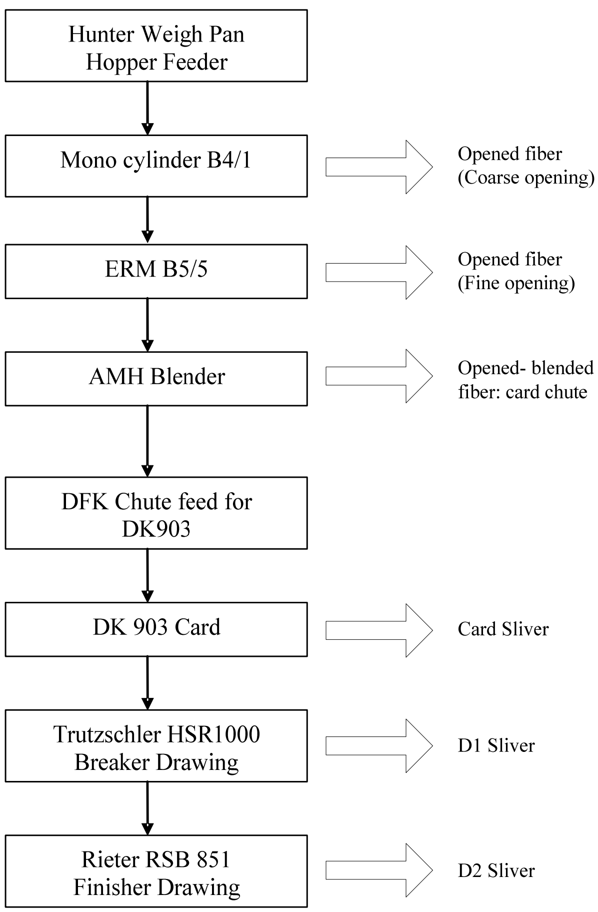

Figure 1: Outline of the experimental procedure

Results

Length distributions obtained at the various processing stages considered (Figure 1) were retrieved from the AFIS and analyzed using two approaches:

- The distribution departure from unimodality was measured using Hartigan's DIP statistic (Hartigan and Hartigan, 1985; Hartigan, 1985; Krifa, 2006a; Krifa, 2006b). Observations made on a multitude of fiber samples taken at various processing stages (i.e., representing a wide range in the degree of fiber damage) suggest that distribution bimodality first appears as a result of limited to moderate fiber damage. Subjecting the fiber to further mechanical stresses appears, through a process of breakage, to gradually dissipate the bimodal structure of the distribution. Eventually, when sufficient mechanical damage has been administered to the fibers, the bimodal character of the distribution evolves into a unimodal one.
- The distribution probability function was modeled using the Weibull mixture model (Krifa, 2004a, b, 2006b, 2007), in which the distribution function (CDF) is expressed as:

$$F(x)=\pi\left(1-e^{-\left(\frac{x}{x_0}\right)^{m_0}}\right)+\left(1-\pi\right)\left(1-e^{-\left(\frac{x}{x_1}\right)^{m_1}}\right)$$

where, π is the mixing weight, x_0 and x_1 are the scale parameters, and m_0 and m_1 are the shape parameters of the distribution components (Krifa, 2007).

The concepts are illustrated in Figure 2, where the first row presents theoretical mixture functions with the parameters set to reflect a hypothetical increasing degree of fiber damage. The second row presents empirical length distribution histograms that show patterns resembling the theoretical functions (observed at different processing stages).

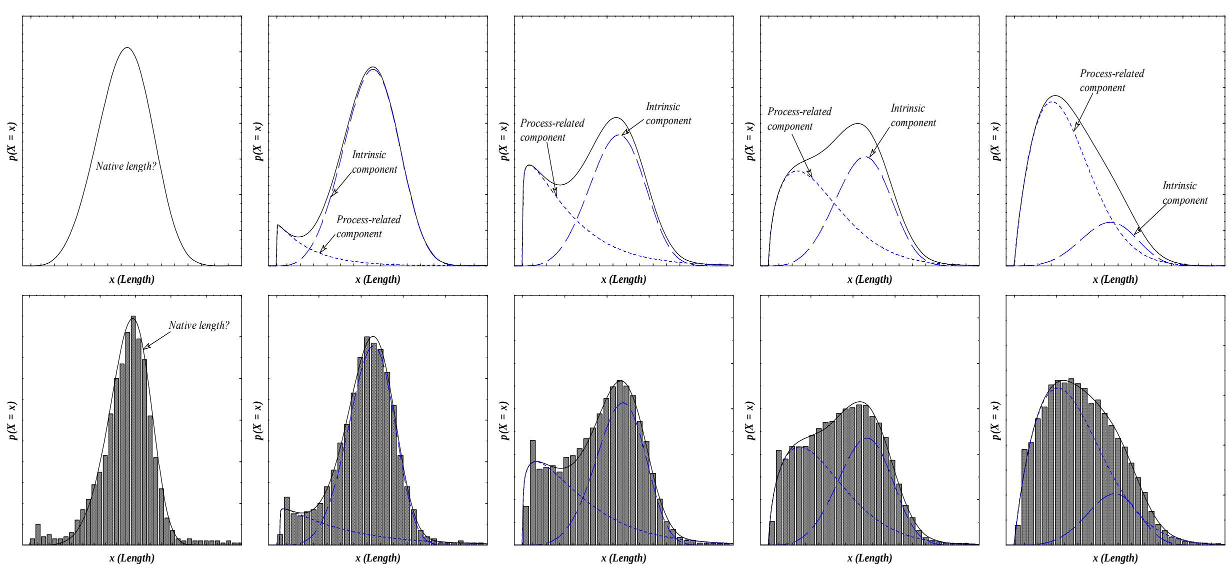

Figure 2: Fiber length distribution in cotton processing – increasing fiber damage.

The composite structure of each distribution reflects breakage at successive stages in processing. Based on the concepts expressed in the mixture distribution model, the component on the left side of the length axis captures the impacts of processing (i.e., the amount of breakage). The component corresponding to longer fibers would be determined primarily by intrinsic factors.

Prior to any damage, the distribution would consist of the intrinsic component only, which would in essence correspond to the native length distribution. As the fibers incur damage due to mechanical handling, the short-fiber component starts forming and the distribution takes its composite structure. The mixing weight π, which measures the contribution of the process-related component in the mixture distribution, is interpreted as an indicator of the amount of fiber damage. Another distribution feature that appears relevant to the degree of damage incurred by the fiber is the modality.

To evaluate and illustrate how the mixing weight π and the distribution modality are related to fiber damage, we examine the alteration of the two parameters with the succession of mechanical processes undergone by the fiber during spinning preparation, i.e., coarse opening, fine opening, blending, and carding.

Figure 3 and 4 depict the effects of these four processes on both the distribution mixing weight and modality, respectively. The effect of each process is represented by the relationship between the parameters measured after processing and those measured in raw fiber samples (i.e., each scatter plot represents the cumulated effects of all mechanical handling from the bale to the corresponding process). Note that on Figure 4, the shaded areas represent a non significant departure from unimodality. This corresponds to a DIP statistic of roughly 0.004 and lower, which was the significance limit determined through bootstrap sampling from a uniform distribution as stipulated by Hartigan (Hartigan and Hartigan, 1985; Hartigan, 1985).

It appears clear from both Figures that among the four processes considered in these trials, carding is the one engendering the most substantial alteration of length distribution. Both the mixing weight π and the distribution departure from unimodality (DIP statistics) appear representative of this alteration. The mixing weight, for instance, appears to increase substantially after carding, thus indicating an increase of the process-related component of the mixture length distribution (component on the left side of the length axis). As for the distribution modality, Figure 4 shows a clear decrease in the DIP statistic observed after carding. Furthermore, it appears obvious that unlike the initial raw samples, the fibers in the carded samples (damaged fiber) show very small variations in the length distribution modality. These results suggest that, when subjected to sufficient mechanical damage, all cottons show a length distribution with no evidence of bimodality (regardless of the initial distribution modality).

Therefore, depending on the point of the cotton process at which the length distribution is observed, the modality feature can be more or less discriminative between cottons.

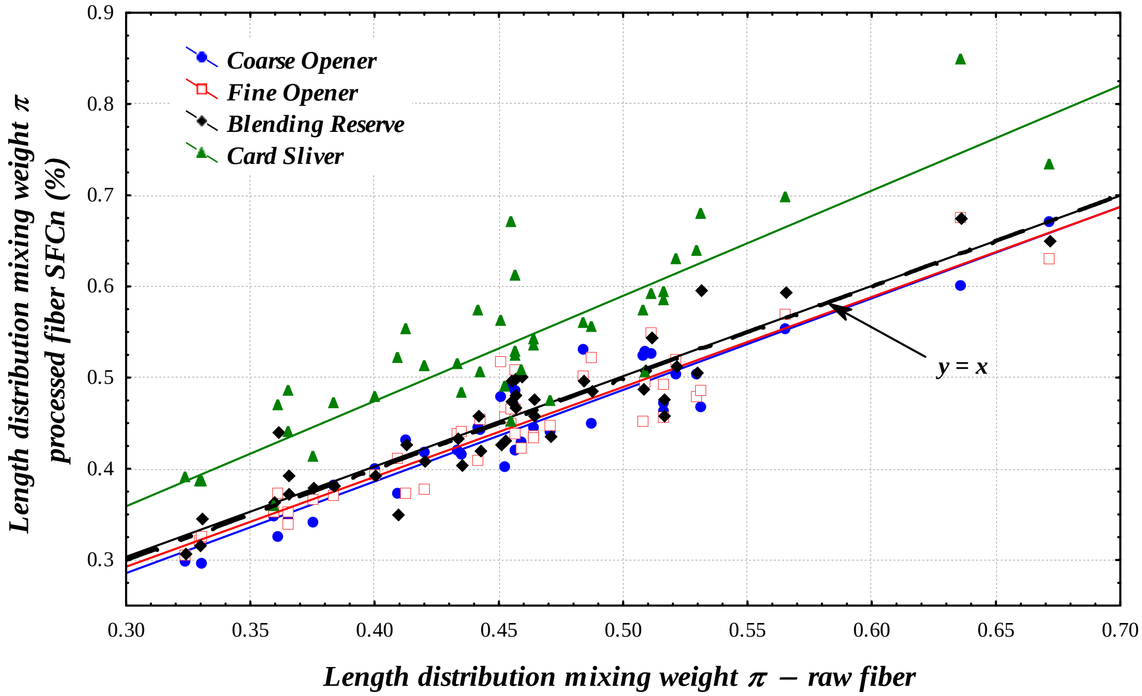

Figure 3: effect of spinning preparation on the length distribution mixing weight π.

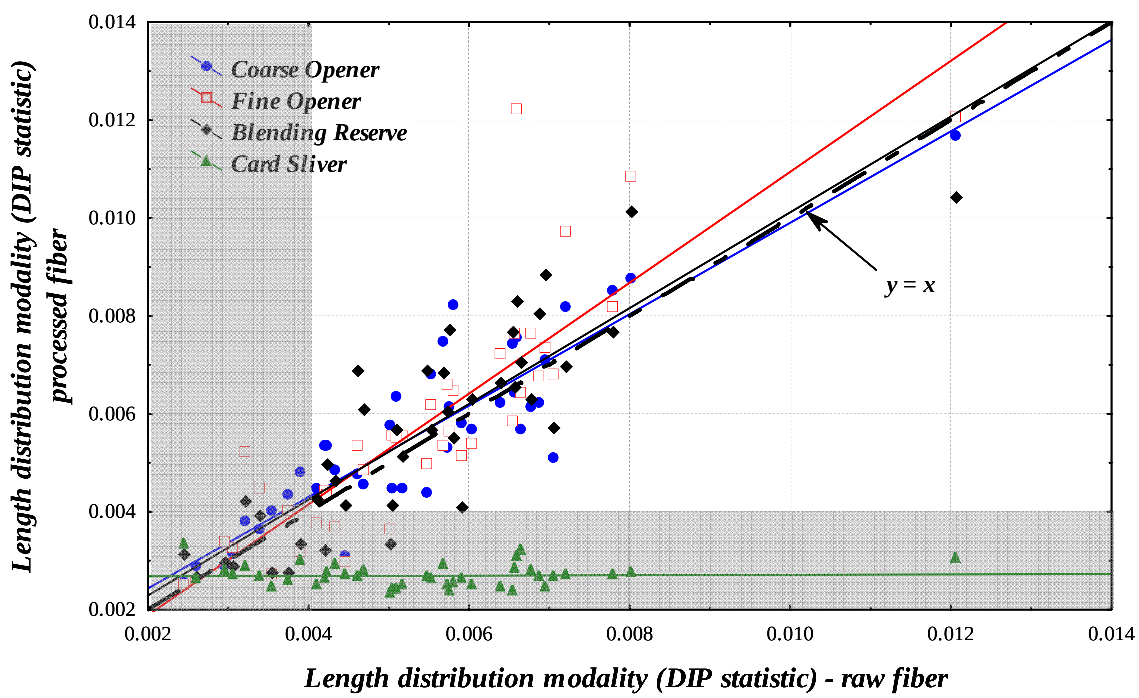

Figure 4: effect of spinning preparation on the length distribution modality (shaded areas indicate non-significant departure from unimodality).

Thus, observations made based on actual processing trials clearly support the concepts developed through this research (see illustration in Figure 2). Cotton fiber length distribution is determined by two essential influences: inherent (genetic, plant-related) and process-related (fiber breakage). The combined effect of these factors confers upon the length distribution its composite/doublet structure observed in the experimental data and formulated through the mixture distribution model. Characterizing this composite structure and consequently the fiber breakage phenomenon is an inevitable step toward the objective of improving the crop's uniformity and reducing the impact of short fibers in cotton processing.

CONCLUSION

Observed fiber length distribution results from a combination of intrinsic (genetic and environmental) and processing factors, which may be separated and quantified at any point in the process using the parametric tools we developed in this research. This would (1) enable breeders and biotechnologists to focus on the intrinsic length properties in their efforts to improve fiber quality, and (2) enable processors to focus on the process-related length properties in their efforts to reduce fiber breakage. This potential is currently being scrutinized in a multidisciplinary collaborative effort involving breeders, agronomists and processors.

ACKNOWLEDGEMENT

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LITERATURE

Hartigan, J. A. and Hartigan P. M., 1985. The Dip Test of Unimodality. *Ann. Statist.,* 13 (1): 70-84.

Hartigan, P. M., 1985. Computation of the Dip Statistic to Test for Unimodality. *Appl. Stat.,* 34 (3): 320-325.

Krifa, M., 2004a. AFIS Length Distribution in Cotton Spinning Preparation. Beltwide Cotton Conferences – Cotton Quality Measurements / Utilization, January 5-9, San Antonio, Tx., National Cotton Council of America. Memphis, TN, USA, pp. 3072-3076.

Krifa, M., 2004b. Fiber Length Distribution as a Mixture of Two Weibull Probability Functions. Cotton Fiber Breakage Workgroup Meeting, May 28, 2004, New Orleans, LA.

Krifa, M. and Hequet E., 2005. Experimental Assessment of Cotton Fiber Behavior During Opening and Cleaning. Proceedings of the Beltwide Cotton Conferences – Cotton Utilization / Textile Technology Symposium, January 4-7, New Orleans, LA, National Cotton Council of America. Memphis, TN, USA, pp. 2713-2716.

Krifa, M., 2006a. Fiber Length Distribution in Cotton Processing: Dominant Features and Interaction Effects. *Textile Res. J.,* 76 (5): 426-435.

Krifa, M., 2006b. Evaluating the Shapes of Cotton Fiber Length Distributions. Beltwide Cotton Conferences – Cotton Quality Measurements, January 3-6, San Antonio, TX, National Cotton Council of America. Memphis, TN, USA, pp. 1971-1975.

Krifa, M., 2007. Fiber Length Distribution in Cotton Processing: A Finite Mixture Distribution Model. *Textile Res. J.,* (in press).

Robert, K. Q. and Blanchard L. J., 1997. Cotton Cleanability. Part I: Modeling Fiber Breakage. *Textile Res. J.,* 67 (6): 417-427.

Robert, K. Q., Price J. B. and Cui X., 2000. Cotton Cleanability – Part II: Effect of Simple Random Breakage on Fiber Length Distribution. *Textile Res. J.,* 70 (2): 108-115.

Robert, K. Q. and Cui X., 2001. Analysis of the Fraction of Broken Fibers in Cotton. Cotton Incorporated Fourteenth Annual Engineered Fiber Selection System Conference Proceedings and Fourteenth Annual Engineered Fiber Selection System Research Forum Proceedings, pp.: 47+, 6 pages (June 11-13, 2001).