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Effects of Spinning Processes on HVI Fiber Characteristics and Spun Yarn Properties

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Abstract: The effects of opening, carding, and repeated drawings on single fiber and bundle cotton characteristics were studied by employing Mantis®, AFIS® and HVI Testers. Some of the significant changes in single fiber properties were found to be due to process parameters as well as the changes in the fiber crimps, parallelness of fibers within HVI beards, and the actual changes in the tensile properties of the fibers. The study showed that the HVI test data taken just prior to spinning had the highest correlation with the yarn tensile properties. Based on the study results, we point out the potential of HVI for future quality and process control in spinning by recommending a set of expanded HVI output that is more scientific and comprehensive for the future control needs.

Keywords: Cotton spinning, Process parameters, Mantis® single fiber properties, HVI bundle properties, AFIS® fiber length

Introduction

In manufacturing a spun yarn, it is necessary to have procedures on optimal selection of the component fibers and processing conditions in order to optimize the yarn properties. Many studies [1-4] on yarn structure and properties are based on single fiber properties in the past due to lack of proper instrument and/or speed. As the use of HVI bundle data continues to expand in the U. S. and throughout the world, the interest is also on the rise to study the potential of HVI output for quality and process control in spinning. The various studies associated with HVI systems have been carried out on the development of prediction equations of yarn quality and processing performance [5-7]. As the tensile and length properties change progressively as each process is added, it is imperative to know how they are changing in order to optimize the machine setting and understand fully the implications of adding or deleting a given process step. An automated HVI line, therefore, can be an alternative to tedious single fiber tests if the output can indeed provide the necessary scientific details.

As a first step, this study examines the changes in single fiber properties and the corresponding HVI bundle test results in raw cotton bales and cotton samples taken at the end of each process stage of spinning. By establishing the relations between and among the data sets, the idea is to frame a concept of quality/process control in spinning by use of HVI data. Furthermore, the study is to recommend an expanded HVI output for accomplishing the objectives in the future.

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Experimental

In order to examine the effects of spinning processes on the outcomes of the tests on the fiber properties, samples from four different cottons, "I," "B," New T ("NT") and "Y" cottons, were taken progressively after each of four processing stages, namely, opening, carding, 2nd and 3rd drawings. The items tested were the single fiber tensile properties, length, diameter and short fiber contents using Mantis® and AFIS®, respectively and for the bundle tensile properties using the HVI. The single fiber data before and after processing were compared against yarn properties to look for the possible relationship between the single fiber and yarn properties. The four cottons were processed into 16/1 Ne carded ring-spun yarns (RSK yarns) with TM 4.5 on the laboratory spinning machines at the USDA-ARS-SRRC Labs.

AFIS® Fiber Length, Diameter and Short Fiber Contents

A total of 25,000 tests, 5 replications of 5,000 tests each, were performed on AFIS® for length, diameter and short fiber contents before and after each stage of processing according to ASTM D 5332 [8].

Mantis® Single Fiber Tensile Properties

A total of 32,000 tests were performed on the Mantis® for single fiber tensile properties which involved about 8,000 fibers for each cotton and approximately 2,000 fibers at the end of each processing stage.

HVI Bundle Tensile Properties

Another lot of 128 tests were performed on HVI for the bundle tensile properties using standard test method [9], 32 beard for each cotton, and 8 beards each from raw cotton bale, after opening, after carding and after 2nd drawing.

Yarn Tensile Properties

For the four different cottons, the tensile properties of 16/1 Ne spun yarns were tested 20 times per bobbin, 5 bobbins for each cotton using the standard test method [10].

Results and Discussion

The length and tensile property changes are observed as each process is added. In order to examine the effects of spinning processes, the yarn tensile properties were analyzed with respect to the fiber properties obtained at the end of each process.

Effects of Spinning Processes on Fiber Length, Short Fiber Contents and Fineness

The effects of processing are shown in Figures 1-3. It is seen that the fiber length becomes longer after passing the carding and 2nd drawing. This might be due to some removal of fiber crimps after 2nd drawing accompanied by actual loss of short fibers after carding. The fact that the drawing operation causes to reduce the fiber diameters may have two possible implications. One is the reflection of presence of a correlation between length and diameter (negative), the other may be explained by a systematic measurement uncertainty of AFIS®. According to Simonton [7], the fibers are oriented and paralleled in the drawn sliver with less crimp than the previous processes. The length of the electronic signal and its height are then modified giving higher length readings and lower diameter readings.

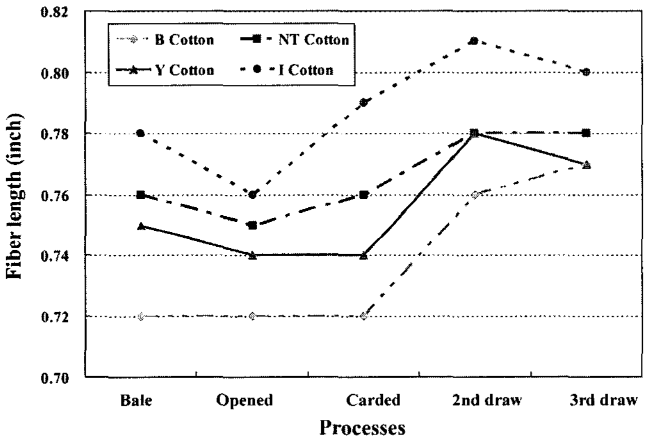

Figure 1. Effects of processing on AFIS® fiber length.

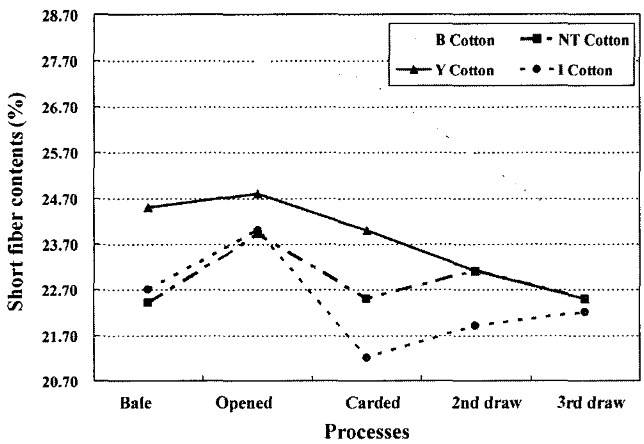

Figure 2. Effects of processing on AFIS® short fiber contents.

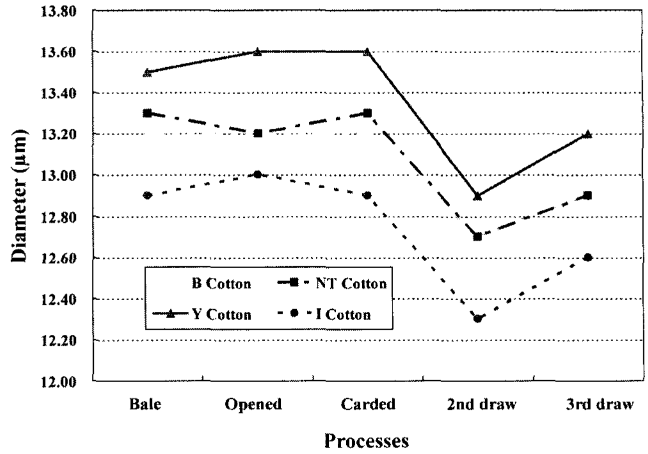

Figure 3. Effects of processing on AFIS® fiber diameter.

Effects of Spinning Processes on Single Fiber and Bundle Tensile Properties

The effects of processing on the single fiber tensile properties are shown in Figures 4-9. It is seen that the single fiber strengths for NT, I and Y cottons are reduced by carding, significantly ($p < 0.001$). This implies that carding action may inflict most damages on the fiber and the fact is hardly surprising. This confirms the general belief that each processing weakens the fibers as they are continuously stretched by adding processes. At the same time, the fiber crimps and breaking elongations tend to be decreasing as the fibers do not completely

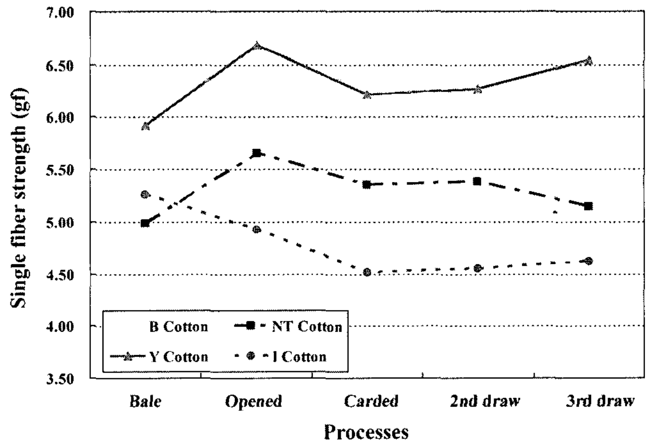

Figure 4. Effects of processing on Mantis® single fiber strength.

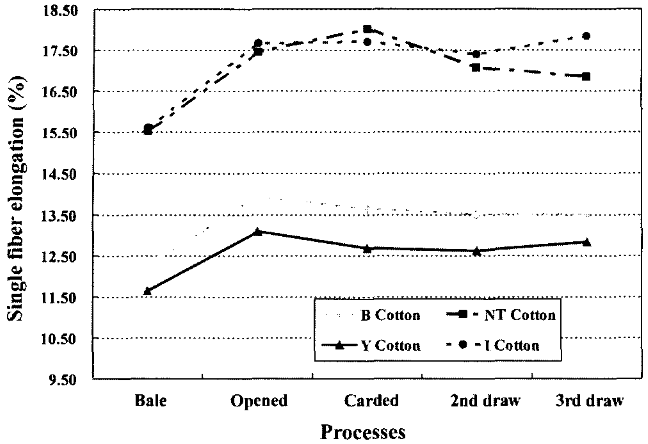

Figure 5. Effects of processing on Mantis® single fiber elongation.

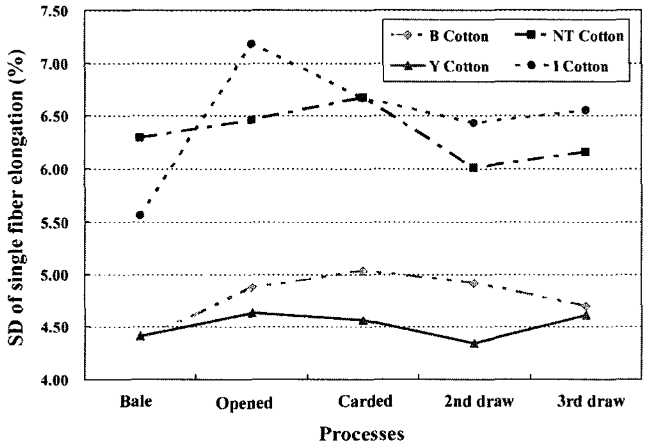

Figure 6. Effects of processing on variation of Mantis® single fiber elongation.

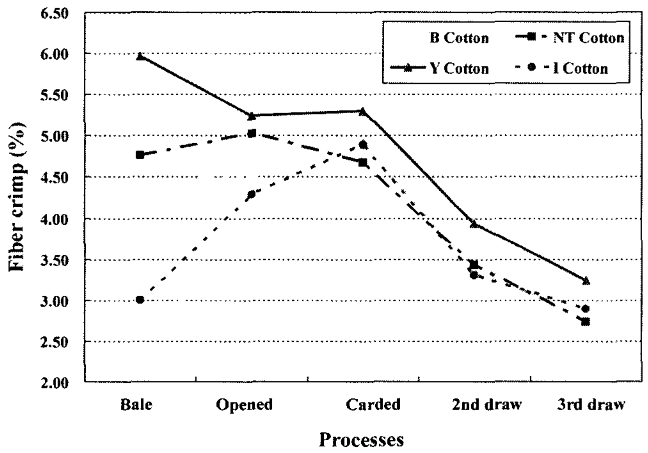

Figure 7. Effects of processing on Mantis® single fiber crimp.

recover from the stress/strain of the previous process or processes.

The effects of processing on HVI bundle strength are shown

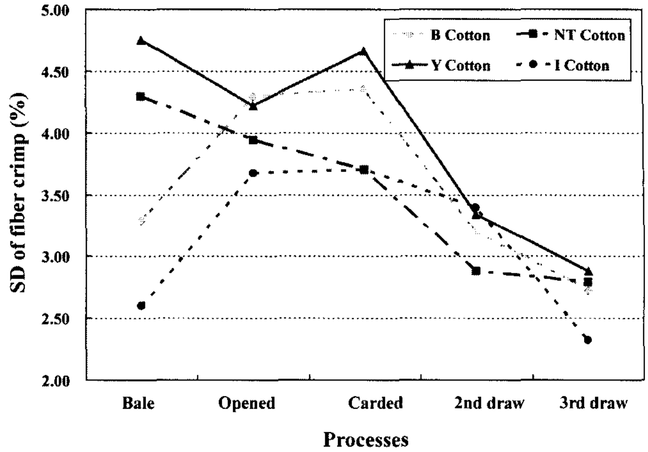

Figure 8. Effects of processing on variation of Mantis® single fiber crimp.

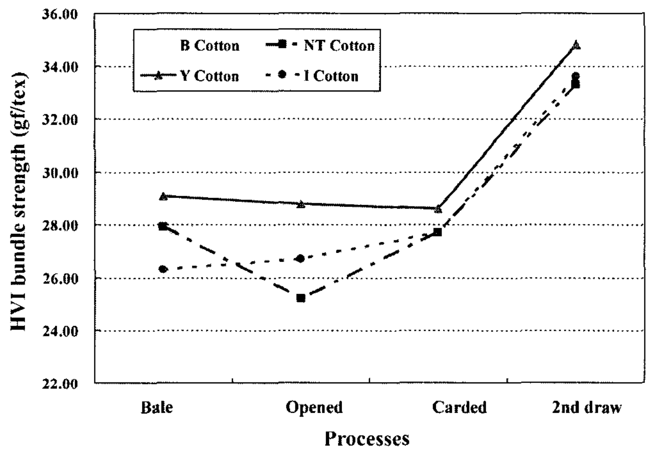

Figure 9. Effects of processing on HVI bundle strength.

in Figure 9. It was found that the HVI bundle strength for all cottons became significantly stronger after 2nd drawing. This is not due to an increase in single fiber strength. This might be due to the reduction of means and variances of single fiber elongation and crimp after 2nd drawing. The effects of fiber crimp and elongation on bundle tensile strength agree with the results shown by Cui [11]. The bundle strength decreases as the standard deviation of fiber crimp increases. The bundle strength reduction of as much as 15% was observed compared with the strength of a bundle without fiber crimps. The bundle strengths obtained from different amounts of average fiber crimps, however, did not differ much from each other. This indicates that it is the variation instead of the average crimp, that reduces the bundle strength. In addition, Simonton [7] explained that the higher HVI strength is due to the higher brushing force accumulated by the repeated drawing processing. The harder brushed HVI beards have lower optic density [12] and results in a lower calculated mass of the sample to be broken and higher HVI strength.

Effects of Spinning Processes on Correlations between and Among Fiber Properties

Prior to investigate the effects of spinning processes on the relationships between yarn and fabric properties, pairwise correlation analyses were run between and among fiber properties using SAS® system and the correlation coefficients are given in Tables 1-5. In the case where some of fiber properties are highly correlated each other, we should select them for the further statistical analyses with caution [13,14].

Based on the results of correlation analyses, the pairwise correlation coefficients and the number of significant correlation coefficients were greatly changed due to the changes of fiber properties at the end of opening and carding processes. The fiber properties that are most frequently correlated with other ones are length (FL), micronaire (MIC), diameter (D), single fiber strength (SFS) and elongation (ELO). Looking at the subsequent stages of processes, the fiber properties are most frequently correlated to each other where carding was done and the number of significant correlation coefficients drops from 10 to 6 after drawing; however, the magnitudes of them do not change before and after processing.

HVI bundle strength (BS) does not show any significant correlation with other fiber properties except the only significant correlation coefficient with fiber length after carding. This implies that the HVI bundle strength may show quite different effect on yarn properties from single fiber strength.

The micronaire shows strong positive correlation with single fiber strength, independently of the diameter and

Table 1. Correlation coefficients between raw cotton fiber properties

	FL	D	MIC	SFS	BS	ELO	CV (ELO)	C
D	−0.44							
MIC	−0.75	0.79						
SFS	−0.84	0.28	0.80					
BS	−0.43	0.99**	0.83	0.33				
ELO	0.75	−0.64	−0.98**	−0.90	−0.70			
CV (ELO)	0.16	0.58	−0.03	−0.56	0.50	0.25		
C	−0.86	0.83	0.93*	0.71	0.83	−0.86	0.17	
CV(C)	0.69	−0.84	−0.86	−0.95**	−0.45	0.95**	0.54	−0.68

Note: **statistical significance at the 95% confidence level, *statistical significance at the 90% confidence level.

Table 2. Correlation coefficients between cotton fiber properties after opening

	FL	D	MIC	SFS	BS	ELO	CV (ELO)	C
D	−0.53							
MIC	−0.80	0.86						
SFS	−0.83	0.91*	0.98**					
BS	−0.66	0.50	0.84	0.72				
ELO	0.78	−0.79	−0.99**	−0.94*	−0.91*			
CV (ELO)	0.93*	−0.79	−0.88	−0.95*	−0.57	0.82		
C	−0.23	0.88	0.52	0.64	0.09	−0.40	−0.58	
CV(C)	−0.54	−0.31	0.22	0.11	0.57	−0.31	−0.19	−0.68

Table 3. Correlation coefficients between cotton fiber properties after carding

	FL	D	MIC	SFS	BS	ELO	CV (ELO)	C
D	−0.60							
MIC	−0.86	0.81						
SFS	−0.98**	0.74	0.95*					
BS	0.98**	0.32	0.79	0.87				
ELO	0.80	−0.65	−0.96**	−0.88	−0.85			
CV (ELO)	0.68	−0.97**	−0.92*	−0.82	−0.50	0.82		
C	−0.33	0.58	0.74	0.50	0.43	−0.82	−0.74	
CV(C)	−0.95*	0.70	0.97**	0.98*	0.91	−0.95*	−0.82	0.61

Table 4. Correlation coefficients between cotton fiber properties after 2nd drawing

	FL	D	MIC	SFS	BS	ELO	CV (ELO)	C
D	–0.74							
M	–0.74	0.88						
SFS	–0.84	0.93*	0.98**					
BS	0.71	0.53	0.86	0.80				
ELO	0.66	–0.76	–0.98**	–0.92*	–0.93*			
CV(ELO)	0.34	–0.88	–0.62	–0.66	–0.14	0.49		
C	–0.13	0.73	0.69	0.62	0.34	–0.64	–0.87	
CV(C)	0.44	–0.83	–0.47	–0.58	0.04	0.28	0.93*	–0.62

Table 5. Correlation coefficients between cotton fiber properties after 3rd drawing

	FL	D	MIC	SFS	BS	ELO	CV (ELO)
D	–0.87						
MIC	–0.92*	0.87					
SFS	–0.92*	0.88	1.00**				
ELO	0.90*	–0.83	–0.99**	–0.99**			
CV (ELO)	0.73	–0.36	–0.75	–0.74	0.78		
C	–0.30	0.64	0.60	0.61	–0.60	–0.05	
CV(C)	–0.62	0.38	0.26	0.26	–0.21	–0.32	–0.46

negative correlation with single fiber elongation at the end of each spinning process. There are two possible implications. One is the micronaire correlated closely to the maturity rather than fineness and the other is the reflection of presence of a negative correlation between single fiber strength and elongation.

Before running the stepwise regression analyses, the collinearity should be considered where there is a high degree of interrelationships between regressors in a model that assumes independent [13,14]. We choose the variance inflation factors (VIF) [15] as a method of dealing with collinearity data.

Effects of Spinning Processes on the Relationship between Fiber Properties and Yarn Tensile Properties

Regression analyses were run using SAS® system in order to evaluate the relationship between the fiber properties before and after processing and relate them to the yarn tensile properties. The fiber properties and the yarn tensile properties were averaged by cotton and by process to make up the data for regression analyses. In making the multiple regression analyses, the average single fiber length, strength, diameter, elongation, CV% of elongation and HVI bundle strength were used as the predictor (X) variables, and the yarn strength as the dependent (Y) variables.

In addition, two sets of multiple regression analyses were also run by removing all non-contributory variables ($p > 0.05$) with high VIF values (> 10) [15] through the variable selecting process in stepwise regression and checking the multicollinearity between regressors. The first set includes single fiber tensile properties and other fiber properties as the predictor (X) variables, and the yarn strength (YTS) as the dependent (Y) variables. The second set includes HVI bundle strength and other fiber properties as the predictor (X) variables, and the yarn strength as the dependent (Y) variables.

The stepwise regression analyses results related to the first set of analyses show that only fiber length (FL), strength (SFS) and diameter (D) were the most significant predictor variable at the end of all manufacturing processes whereas the fiber length and CV of crimp (CV(C)) were significant at the end of the 3rd drawing process, respectively. However, the diameter and single fiber strength were deleted at the end of opening and carding after checking the multicollinearity between regressors. The results are in accordance with ones of correlation analyses. The details are given in Table 6.

The results related to the second set in Table 7 show that only fiber length and HVI bundle strength (BS) were the most significant predictor variables. The fiber length was significant at all manufacturing process. On the other hand, HVI bundle strength was significant only at the end of carding and 2nd drawing. The R^2 shows higher after 2nd drawing than after carding. This means that HVI bundle strength and perhaps other data as well become more meaningful when the HVI test samples are taken at the end of a process which is closest to spinning.

Effects of Changes in Fiber Properties on Quality/Process Control in Spinning

The single fiber test data, as obtained from Mantis® and

Table 6. Multiple regression analysis results (first set)

Process	Equations	Prob. > | *t* |	VIF	R^2
Bale	YTS = −1249 + 1866 FL + 46 SFS	FL: 0.0001 SFS: 0.0001	3.5 3.5	0.69
Opening	YTS = −368 + 1079 FL	FL: 0.0001	–	0.48
Carding	YTS = −144 + 746 FL	FL: 0.0001	–	0.45
2nd Drawing	YTS = −246 + 1870 FL + 43 SFS − 82 D	FL: 0.0001 SFS: 0.04 D: 0.009	3.7 8.1 9.7	0.70
3rd Drawing	YTS = 69 + 685 FL − 2.02 CV(C)	FL: 0.0394 CV(C): 0.0002	1.6 1.6	0.66

Table 7. Multiple regression analysis results (second set)

Process	Equations	Prob. > | *t* |	VIF	R^2
Carding	YTS = −1691.28 + 33.1 BS + 1554 FL	BS: 0.0001 FL: 0.0071	5.4 5.4	0.57
2nd Drawing	YTS = −1360 + 14.1 BS + 1655 FL	X_1: 0.0001 X_5: 0.0076	1.8 1.8	0.70

AFIS® at various stages of spinning processes, have confirmed some of the fears. Namely, the processing methods can change the fiber characteristics significantly, affecting the yarn qualities likewise. For an effective process control, however, the single fiber properties are correlated to each other and consequently, not highly useful to predict yarn properties. In addition, the single fiber testing is considered too expensive and time consuming and hence impractical. As an alternative to these, HVI can be used without the fears of multicollinearity if the output is modified to include some of more scientific quality features of fibers at the end of each process. The load-elongation diagram of HVI bundle, the length array diagram, and several indices derivable from these could provide useful tool for quality and process control in spinning. Addition or deletion of certain processes, severity of each processing through various machine setting, and confirmation of blending uniformity can be checked for their effects.

Economics relating to process selection and setting can be weighted against the quality consequences arising from them only when the measurements can be made scientifically at the end of each textile processing. For this, HVIs potential is considered excellent since the current HVI data are already based on several key statistical distributions that are sufficient for providing more scientific details on single fiber and bundle quality characteristics.

Conclusion

This study has shown that each processing stage in spun yarn production changes both the single fiber properties and the bundle tensile and other quality characteristics. More specially, the increase in HVI bundle strength in the absence of an increase in single fiber strength, was due to a gradual improvement in the parallelness of fibers within HVI test beards through removal of crimps.

Regression analyses revealed that the fiber length is shown to be significant contributing factor at all manufacturing processes whereas yarn tensile strength has shown no significant correlation with single fiber tensile properties and fineness due to multicollinearity among other fiber properties. However, the multiple regression using fiber length and HVI bundle strength as the significant predictor variables has shown high predictability for yarn tensile strength. In addition, HVI data and perhaps other fiber test data become more useful when they are taken at the end of a process which is closest to spinning.

In light of this study, HVI test data taken from raw cotton bales are not highly useful for predicting the quality characteristics of the resulting yarn. Although the value of HVI test data has been well established for fiber selection and bale laydown, it is strongly suggested that a different set of HVI output would be most useful for predicting the yarn qualities in the future. This would include the bundle "load-elongation" diagrams and diagrams for fiber length arrays.

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