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TEXTILE TECHNOLOGY

The Impact of Short Fiber Content on the Quality of Cotton Ring Spun Yarn

D. Thibodeaux,* H. Senter, J. L. Knowlton, D. McAlister, and X. Cui

ABSTRACT

This study was designed to quantitatively assess the effects of short fiber (< 12.7 mm long) in raw cotton on the quality of 20s ring spun yarn. Twenty-eight bales of cotton with a wide range of fiber properties and an especially diverse population of short fiber content were utilized. Properties of the raw cotton were measured by High Volume Instrumentation (HVI), Advanced Fiber Information System (AFIS) instruments, and the manual Suter-Webb (SW) Array method. Ring spun yarns produced from these cottons were tested for process and product quality. Results indicate that most of the yarn properties—especially yarn strength, irregularity, and frequency of thick and thin defects—are strongly correlated with each of the three measures of short fiber content. A pool of 23 potential predictors from the AFIS, HVI, and SW fiber properties was utilized to develop "best" regression models for seven yarn properties. In five of the seven models, the short fiber content variable was the most important predictor, exceptions being the models for yarn strength and elongation. For five of the yarn properties, models developed using the four basic HVI properties alone were nearly as good in predicting yarn quality as those using all 23 fiber properties. Exceptions were models for elongation and for ends down.

One of the biggest concerns relative to the global marketing of U.S. cotton is the perception by international spinners that it contains excessive amounts of short fiber (i.e., fiber < ½ in (12.7mm) in length). Because machine-picked U.S. cotton is essentially "dirtier," it requires excessive lint cleaning that can lead to fiber damage and the creation of broken, short fiber fragments. For the spinner, the presence of excessive amounts of short fiber in the input mix can result in production inefficiencies and losses in textile quality. Behery (1993) described how short fibers behave during textile processing: during cotton spinning, the fiber strands are thinned or drafted by passing between pairs of drafting rolls that are spaced at distances that allow most fibers to pass through without bridging the gap between the rollers, which would result in breaking of the fibers. Short fibers are allowed to float between the drafting rollers where they can bunch up or thin out causing thick and/or thin imperfections in the yarn with accompanying diminished strength.

Over the years, several researchers have studied problems arising in cotton spinning resulting from the presence of short fibers. Tallant et al. (1959) prepared cottons having four different levels of short fiber by cutting sliver into ¼- and ½-in segments that were then added to the parent cotton in varying amounts. Defining short fiber as fiber < 3/8 in (9.5 mm) in length, they found that yarn strength and elongation both diminished with increased short fiber whereas Uster yarn uniformity (% CV) increased. Similarly, Bargeron (1986) studied the effects of short fiber on spinning performance by adding varying percentages of comber noils to raw cottons from well-blended bales. His study included additions of 5%, 10%, 15%, and 20% comber noils. Over the range of increase (represented by increasing amounts of short fiber), ends down per 1000 spindle hours increased exponentially from approximately 50 to more than 200. Yarn strength diminished by more than 10%, appearance grade decreased by more than 30%, and irregularity %CV increased by more than 20%.

The impact of short fiber in commercial cotton spinning was reported by Backe (1986). He conducted a large-scale plant trial (400 bales) to examine the effects of low (8.6%) and high (11.6%) short fiber content as measured by the Peyer AL-101 instrument (manufactured by Peyer Texlab, Zurich Switzerland (out of business)). Short fiber showed a statistically

D. Thibodeaux* , USDA-ARS, Cotton Quality Research Station, P.O. Box 792, Clemson, SC 29633; H. Senter, Clemson University, Department of Mathematical Sciences, Clemson, SC 29634; J.L. Knowlton, USDA-AMS-Cotton Program, 3275 Appling Road, Memphis, TN 38133; D. McAlister, Uster Technologies, Inc., 456 Troy Circle, PO Box 51270, Knoxville, TN 37919; X. Cui, USDA, ARS, SRRC, 1100 Robert E. Lee Blvd., New Orleans, LA 70124
*Corresponding author: devron.thibodeaux@ars.usda.gov

significant influence on ends-down in spinning. There was also a significant increase in Uster %CV and Classimat (manufactured by Zellweger Uster, Charlotte, NC) long thin places with short fiber content. Likewise, yarn strength, appearance index, and Uster IPI thick and thin places were all affected by an increase in short fiber at the 95% confidence level.

Chanselme et al. (1997) reported on the use of Advanced Fiber Information System (AFIS) fiber data to study the effects of fiber properties (including short fiber) on the quality of ring spun yarns. They utilized a micro-spinning test on 23 Upland cottons producing both ring and rotor yarns (20 tex) and studied yarn strength, elongation, evenness, thick and thin places, neps, and hairiness. Fiber length and diameter parameters showed the highest correlations with %CV, neps, hairiness, and the square roots of thick and thin places. Short fiber content (by weight) correlated significantly with hairiness and the square root of thin places. Hequet (1999) also utilized AFIS fiber data to study the effects of fiber properties on ring spun yarns (both 36s and 50s English count NE) for both Upland and San Joaquin Valley (SJV) cottons. Significant correlations were found between AFIS short fiber by weight and yarn evenness, thin places, thick places, neps, and hairiness. Hequet and Ethridge (2000) reported further progress on the previous study where they considered the effects of other fiber length distribution parameters as measured by AFIS. These results essentially supported their previous findings on the same set of cottons.

At the 2004 Beltwide Cotton Conference, Knowlton (2004) reported on a collaborative effort "to evaluate available short fiber measurements relative to each other and relative to textile processing performance" (Knowlton, 2004). The study encompassed several laboratories conducting a wide range of tests on several different instruments. Twenty-nine commercial bales that had a wide range of fiber properties were chosen for the study.

MATERIALS AND METHODS

For the same set of cottons, relationships among High Volume Instrumentation (HVI), AFIS, and Suter-Webb (SW) fiber properties were discussed in Thibodeaux et al. (2007), with emphasis on measures of fiber length, especially short fiber content. The fiber data reported in that paper, which are also used in this study, were based on HVI measurements from the USDA-Agricultural Marketing Service (AMS) Memphis Classing Office, the AFIS instrument at the Southern Regional Research Center in New Orleans, and from SW array analysis performed at the Cotton Quality Research Station in Clemson, NC. This paper focuses on the relationship of fiber properties—especially short fiber content—to selected characteristics of 20s ring spun yarn made from those 29 cottons. Ring spinning was carried out at approximately 10,000 rpm spindle speed with a twist multiplier (T.M.) of 3.85. Testing involved about 240 spindle hours. Yarn strength was measured on a Statimat M (manufactured by Textechno, Mönchengladbach, Germany) tester at 254 mm gauge length. The rate of elongation used was 5000 mm/min and a total of 400 breaks per determination were utilized. An Industrial Laboratory Equipment (ILE 65, Charlotte, NC) was used for evenness testing on 20 bobbins using 1000 yd per bobbin at a speed of 400 yd/min. Two independent replications of yarn measurements were made for each of the cottons. Yarn data for one cotton was inadvertently lost reducing the number of measurements per yarn property to 56. The yarn spinning and measurements of the yarn properties were done at the Cotton Quality Research Station.

RESULTS

Abbreviated names of the important fiber properties and yarn characteristics considered, and the notations for them are listed in Table 1. Lower case abbreviations are given to the yarn characteristics, reserving upper case abbreviations for fiber properties. The fiber variable names are the same ones used in the earlier companion report (Thibodeaux et al., 2007) for these cottons.

Differences in fiber characteristics among the 28 bales are indicated by the summary statistics for the HVI variables given in Table 2. As was observed in Thibodeaux et al. (2007, Table 1), the bales show a wide range of fiber properties: (2.33 < HVIUHM < 3.07), (77.8 < HVIUNIF < 84.4), (23.4 < HVISTR < 33.2), (2.92 < HVIMIC < 5.52), and (6.86 < HVISFI < 17.13). As seen in Table 3, the ranges of short fiber contents from the three methods are: HVI, 6.86–17.13%; AFIS, 5.61–19.76%; and SW, 6.40–26.60%. The three measures of short fiber content—HVISFI, AFISSFC, and SWSFC—are strongly pairwise correlated with Pearson's correlations between 0.88 and 0.95 (Table 4). Regression models for predicting SWSFC (the more difficult measurement to make and generally considered the "gold standard") from HVI and AFIS fiber properties are also discussed in Thibodeaux et al. (2007).

Table 1. Fiber variable names and yarn characteristic variable names

Fiber Variable Names	
AFISFINE	AFIS fineness (millitex)
AFISIFC	AFIS immature fiber content (%)
AFISLW	AFIS mean length by weight (cm)
AFISLWCV	Coefficient of variation of AFIS mean length by weight (%)
AFISMAT	AFIS maturity ratio (dimensionless)
AFISNEPS	AFIS nep count (/g)
AFISSFC	AFIS short fiber content (%)
AFISUQL	AFIS upper-quartile length (cm)
HVILE	HVI mean length (cm)
HVIMIC	HVI micronaire (dimensionless)
HVISFI	HVI short fiber index (%)
HVISTR	HVI strength (g/tex)
HVIUHM	HVI upper-half mean length (cm)
HVIUNIF	HVI uniformity (%)
SWLE	SW mean length (cm)
SWSFC	SW short fiber content (%)
SWUQL	SW upper-quartile length (cm)
Yarn Characteristic Variables	
elong	Elongation to break (%)
endsdown	Number of spinning breaks per 1000 spindle hours
irrcv	Coefficient of variation of yarn mass (%)
neps	Number of yarn neps/1000 m
thicks	Number of yarn thick spots/1000 m
thins	Number of yarn thin spots/1000 m
yarnstr	Yarn breaking strength (cN/tex)

Table 2. Descriptive statistics for the HVI properties

Variable	N	Mean	StDev	Minimum	Median	Maximum
HVISFI	28	10.183	2.863	6.860	8.915	17.130
HVILE	28	2.262	0.222	1.817	2.291	2.564
HVIUHM	28	2.769	0.220	2.327	2.790	3.066
HVIUNIF	28	81.571	1.886	77.800	81.950	84.400
HVISTR	28	28.338	2.982	23.393	28.278	33.173
HVIMIC	28	4.332	0.591	2.920	4.270	5.520

Table 3. Descriptive statistics for short fiber properties by the three methods.

Variable	N	Mean	StDev	Minimum	Median	Maximum
HVISFI	28	10.18	2.86	6.86	8.92	17.13
AFISSFC	28	12.15	4.16	5.61	12.17	19.76
SWSFC	28	13.21	5.28	6.40	11.20	26.60

Table 4. Correlations between the three measures of short fiber (Pearson's correlation coefficient with *p* value below) .

	HVISFI	AFISSFC
AFISSFC	0.885	
	0.000	0.000
SWSFC	0.947	0.898
	0.000	0.000

Here we are concerned with the relationship of SFC, in conjunction with other fiber properties, to corresponding yarn properties (for 20s ring spun yarn). Descriptive statistics for the distributions of the yarn properties are given in Table 5. The wide range of values of the fiber properties are reflected in the spans of the yarn characteristics. Some of the variables—ends down, thicks, and thins—have strongly (right) skewed distributions. In subsequent analyses, square root transformations of these variables are used to get better predictive models (Chanselme et al., 1997).

The relationships of individual fiber properties to yarn characteristics are examined in the correlation matrix in Table 6. HVISFI is significantly correlated (all r-values with $p < 0.05$ are shown in bold) to each of the yarn variables. The HVIUNIF correlations are close in magnitude to those of HVISFI but opposite in sign. Correlations between AFISSFC and the yarn variables are similar to those for HVISFI, but are slightly weaker. Correlations between SWSFC and the yarn variables are close to those for HVISFI. Correlations between the yarn variables and the staple length measures—HVILE, AFISLW, and SWLE—are close in value, with SWLE showing slightly stronger correlations. Correlations between the yarn variables and upper-half lengths—HVIUHM, AFISUQL, and SWUQL—track the corresponding correlations for staple lengths, but are generally weaker. These six length measures are strongly correlated with all the yarn variables except elong and neps.

Table 5. Descriptive statistics for yarn properties

Variable	N	Mean	StDev	CoefVar	Minimum	Median	Maximum
yarnstr	56	14.21	2.69	18.95	9.84	13.90	18.76
elong	56	6.06	0.56	9.27	4.73	6.09	7.04
endsdown	56	21.89	42.10	192.30	0.00	8.00	246.00
neps	56	97.80	40.94	41.86	32.81	88.58	188.10
thicks	56	803.50	490.70	61.07	193.60	738.20	2260.50
thins	56	234.70	279.20	118.97	6.60	120.30	1217.20
irrcv	56	18.41	2.24	12.17	14.70	18.25	24.20

Table 6. Correlations between fiber and yarn properties for short fiber and length variation (Pearson's correlation coefficient with *p* value < 0.05 shown in italics).

	yarnstr	elong	endsdown	neps	thicks	thins	irrcv
AFISFINE	*-0.396*	0.057	-0.137	-0.167	0.094	0.135	0.162
AFISIFC	0.019	*0.647*	-0.345	-0.049	-0.181	-0.271	-0.122
AFISLW	*0.885*	0.195	-0.404	-0.290	*-0.794*	*-0.801*	*-0.861*
AFISLWCV	-0.355	-0.065	0.273	*0.526*	*0.615*	*0.534*	*0.583*
AFISMAT	*0.517*	*-0.542*	0.070	-0.073	-0.306	-0.256	-0.403
AFISNEPS	-0.175	0.164	0.206	0.317	0.381	0.316	0.369
AFISSFC	*-0.725*	-0.164	*0.472*	*0.485*	*0.810*	*0.777*	*0.830*
AFISUQL	*0.856*	0.196	-0.372	-0.163	*-0.708*	*-0.768*	*-0.777*
HVILE	*0.889*	0.231	-0.391	-0.223	*-0.761*	*-0.795*	*-0.825*
HVIMIC	-0.077	-0.063	-0.268	-0.171	-0.158	-0.118	-0.132
HVISFI	-0.807	-0.406	0.609	0.407	0.881	0.906	0.888
HVISTR	*0.959*	0.014	-0.326	-0.276	*-0.761*	*-0.747*	*-0.842*
HVIUHM	*0.864*	0.216	-0.371	-0.147	*-0.693*	*-0.749*	*-0.765*
HVIUNIF	*0.824*	0.274	*-0.428*	*-0.456*	*-0.879*	*-0.844*	*-0.901*
SWLE	*0.890*	0.291	*-0.413*	-0.307	*-0.828*	*-0.829*	*-0.874*
SWSFC	*-0.794*	-0.366	*0.529*	*0.484*	0.906	0.879	0.897
SWUQL	*0.858*	0.294	-0.389	-0.181	*-0.733*	*-0.781*	*-0.791*

Fiber properties that correlate strongly with yarn strength, thicks, thins, and irrcv are HVISTR and all of the measures of fiber length and short fiber content. By contrast, only AFISIFC and AFISMAT have a correlation stronger than 50% with elongation, whereas just one of the fiber properties in Table 6 has a correlation stronger than 50% with neps. One fiber property that shows little association with the yarn variables is HVIMIC. The related measure AFISFINE is marginally significantly correlated with only yarnstr. The strong pairwise correlations between the three measures of short fiber content and all of the yarn variables suggest that short fiber content is an important determinant (or predictor) of spinning performance. Despite a lack of simple association with the yarn variables, HVIMIC and AFISFINE, in combination with other fiber properties, are useful predictors of some yarn properties as will be seen below.

Regression models for yarn properties. In this section, regression models for estimating the seven yarn characteristics from fiber properties are presented. As observed in the previous section, most of the fiber properties are correlated with each of the yarn properties. The fiber properties are highly correlated among themselves (Thibodeaux et al., 2007). The models discussed here were selected from many candidate models as parsimonious ones with relatively good explanatory power (high R^2), low colinearity, small variance inflation factors (VIFs), and good residuals plots. For some yarn properties, two or even several models were about equally good because one or more fiber properties such as HVIUNIF or SWSFC could be substituted for another such as HVISFI. The models reported are the simplest ones with relatively high R^2 among the good candidate models. Ideal values for the VIFs are 1, indicating no colinearity among the predictors. VIF values in excess of 10 suggest severe colinearity and an unstable model (Kutner et al., 2004). In the models presented, most of the VIFs are less than 5.0, and all are less than 6.0. Because we are interested in short fiber content, models with a measure of short fiber content were preferred.

Because the four basic HVI properties—HVIUHM, HVISTR, HVIUNIF, and HVIMIC—are almost always available, whereas some of the other fiber properties (such as the SW ones) may not be, models built from the basic HVI properties are described and compared to the best models built from all the fiber properties.

For model building purposes, the list of candidate predictors included all 17 fiber properties listed in Table 1 plus six AFIS variables not listed: dust particle count, length by number, mean neps size, total nep count, trash particle count, and visible foreign matter. These AFIS variables did not exhibit significant correlation with more than one yarn property and they were not significant predictors in models for yarn properties.

Models for yarn strength (yarnstr). As seen in Table 7, a good model for estimating yarn strength using HVI, AFIS, and SW fiber properties as potential predictors is one with three predictors and R^2 = 0.9488. The regression equation is:

$$\begin{aligned} yarnstr = & -0.543 + 0.696 * HVISTR \\ & -0.746 HVIMIC - 0.132 * SWSFC \end{aligned} \quad [1]$$

Several alternative models that include HVISTR, HVIMIC, plus some measure of fiber length (AFISLW, AFISLN, HVILE, SWLE, AFISUQL, HVIUHM, SWUQL, AFISSFC, or HVISFI) are similar in terms of R^2 (values from 0.9285 to 0.9511), but exhibit greater colinearity among the predictors. The model above has the least colinearity; standard errors of the common predictors HVISTR and HVIMIC are smallest for this model. Thus the regression coefficients for this model are estimated with the greatest precision. Evidently fiber length is an important predictor of yarn strength (in conjunction with HVISTR and HVIMIC) and any of several measures of fiber length can serve nearly as well. SWSFC may have an edge in this analysis because the cottons used were deliberately selected to have a wide range of short fiber content.

Table 7. Best unweighted least squares linear regression of yarnstr

Predictor Variables	Coefficient	Std Error	T	*P*	VIF	STB
Constant	**-0.5433**	**2.095**	**-0.260**	**0.796**		**0.000**
HVISTR	**0.6960**	**0.049**	**14.250**	**0.000**	**2.900**	**0.764**
HVIMIC	**-0.7462**	**0.163**	**-4.580**	**0.000**	**1.300**	**-0.162**
SWSFC	**-0.1318**	**0.029**	**-4.540**	**0.000**	**3.200**	**-0.256**

R^2	**0.9488**	**Resid. Mean Square (MSE)**	**0.39259**
Adj. R^2	**0.9458**	**Standard Deviation**	**0.62657**

The regression coefficients in Eq. 1 indicate the effect on yarnstr of a unit increase in a fiber property holding the other properties fixed. However, the magnitudes of the coefficients do not necessarily indicate the relative importance of the predictors in their impact on yarnstr because they are measured in different units. A unit increase in a length variable (1 cm) is astronomical, whereas a unit increase in short fiber content (1%) is modest.

Standardized regression coefficients, denoted STB in Table 7, are unitless and permit a direct comparison of the impact of the predictors on the response (Kutner et al., 2004). A standardized coefficient is the effect on the response in standard deviations of a one standard deviation increase in a predictor, holding the other predictors fixed. We see in Table 7 that a one standard deviation increase in HVISTR will increase yarnstr by 0.764 standard deviations (holding HVIMIC and SWSFC fixed). Because the standardized coefficient of HVISTR is the largest in absolute value, we can say that HVISTR has the most effect on yarnstr of the three predictors. Moreover, it has about three times the effect of SWSFC.

A model that is nearly as good is one with three of the four basic HVI properties (see Table 8), with HVIUNIF replacing SWSFC in the first model. The Pearson's correlation between HVIUNIF and SWSFC is –0.95, and HVIUNIF acts as a surrogate for SWSFC. A model relating SWSFC and HVIUNIF is discussed in Thibodeaux et al. (2007). The regression equation is

$$yarnstr = -33.72 + 0.669 * HVISTR - 0.802 * HVIMIC + 0.398 * HVIUNIF \quad [2]$$

It is not surprising that HVISTR and HVIUNIF are significant in the model because both are strongly correlated with yarn strength (r = 0.96 and 0.82 respectively, Table 6). But HVIMIC alone shows no correlation with yarnstr (r = –0.077) yet it is a highly significant predictor of yarnstr (p = 0.0001) in linear combination with the other two properties. We observe this role of HVIMIC in other models.

Hequet (1999) found that the ratio AFISFINE/AFISMAT, which he called "standard fineness," is a good predictor of yarn strength for ring spun yarn. For the cottons and yarns in this study, the correlation between standard fineness and yarnstr is r = –0.70. We, too, found that standard fineness, denoted STDFINE, together with HVISTR is a good predictor of yarn strength with an R^2 = 0.9259. The regression equation is

$$yarnstr = -4.42 - 0.024 * STDFINE + 0.814 * HVISTR \quad [3]$$

Replacing HVISTR with HVISFI in the above model gives an equally good model (R^2 = 0.9241), illustrating that different combinations of fiber properties can yield comparable models for yarn properties.

Models for elongation (elong). Most of the fiber properties show little correlation with elong (Table 6). The strongest association is between elong and AFISIFC (r = 0.64). As seen in Table 9, a good model for elong is one with three fiber properties, having an R^2 = 0.81. The regression equation is

$$elong = 17.90 + 0.014 * AFISFINE - 14.17 * AFISMAT - 0.150 * HVISFI \quad [4]$$

In this model, if AFISFINE and AFISMAT are replaced by standard fineness = AFISFINE/AFISMAT (Hequet, 1999), the R^2 value drops substantially to 0.44. The best model for elong with just basic HVI properties results in the regression equation

$$elong = -18.27 - 0.192 * HVISTR - 14.17 * HVIMIC + 0.391 * HVIUNIF \quad [5]$$

These results are inferior with R^2 = 0.37.

Table 8. Best unweighted least squares linear regression of yarnstr based solely upon basic HVI variables

Predictor Variables	Coefficient	Std Error	T	P	VIF	STB
Constant	-33.7190	6.412	-5.260	0.000		0.000
HVISTR	0.6694	0.060	11.090	0.000	4.100	0.735
HVIMIC	-0.8017	0.181	-4.430	0.000	1.500	-0.174
HVIUNIF	0.3976	0.101	3.930	0.000	4.700	0.276
R^2	0.9448	Resid. Mean Square (MSE)			0.42287	
Adj. R^2	0.9416	Standard Deviation			0.65029	

Table 9. Best unweighted least squares linear regression of elong

Predictor Variables	Coefficient	Std Error	T	*P*	VIF	STB
Constant	17.8979	1.0884	16.44	0.000		0.000
AFISFINE	0.01399	0.0040	3.50	0.001	1.1	0.217
AFISMAT	-14.1691	1.0768	-13.16	0.000	1.2	-0.894
HVISFI	-0.1498	0.0131	-11.42	0.000	1.2	-0.757

R^2	0.8079	Resid. Mean Square (MSE)	0.064
Adj. R^2	0.7969	Standard Deviation	0.2529

Models for neps (neps). Yarn neps range somewhat uniformly from 30 to 172. A strong predictive model for neps could not be found, and using a logarithmic or square root transformation of the response did not help. The best model (Table 10) has an R^2 = 0.48. The regression equation is

$$neps = -871.8 + 186.8 * HVIUHM + 59.73 * HVIMIC + 15.94 * AFISSFC \quad [6]$$

Although one would expect neps to increase with short fiber content, it is surprising that increased HVIUHM is associated with more neps. Relatively, short fiber content is the most important of the three predictors. The best model for neps using basic HVI properties substitutes HVIUNIF for AFISSFC in the previous model yielding an R^2 = 0.41. The regression equation is

$$neps = 1945 + 192.7 * HVIUHM + 28.84 * HVIMIC - 30.73 * HVIUNIF \quad [7]$$

Models for ends down (√ends). Ends down is the most variable of the seven yarn properties considered (CV = 192%, Table 5) and its distribution of values is positively skewed. To mitigate skewness, a square-root transformation of ends down, denoted √ends, is used as the response (Chanselme et al., 1997). The best model (Table 11) has an R^2 = 0.55. The regression equation is

$$\sqrt{ends} = -34.95 + 1.471 * HVISFI + 10.37 * HVILE \quad [8]$$

The positive coefficient for HVILE is surprising. The simple correlation between √ends and HVILE is –0.46. The best model using just basic HVI fiber properties is a simple linear model involving HVIUNIF alone, which has an R^2 = 0.30. The regression equation is

$$\sqrt{ends} = 78.42 - 0.919 * HVIUNIF \quad [9]$$

Models for thicks (√thicks). A square-root transformation of thicks, denoted √thicks, is used as the response because the distribution of thicks is highly (positively) skewed (Chanselme et al., 1997). A good model with no colinearity involves fineness and short fiber content (Table 12) yielding an R^2 = 0.86. The regression equation is

$$\sqrt{thicks} = -14.53 + 0.134 * AFISFINE + 1.47 * SWSFC \quad [10]$$

The importance of fineness and short fiber content on thick places concurs with results reported by Hequet (1999). He used standard fineness, the ratio AFISFINE/AFISMAT. Replacing AFISFINE by standard fineness in the above model has little effect (R^2 = 0.85). The best model for √thicks using basic HVI properties involves HVIMIC and HVIUNIF and yields R^2 = 0.82, where HVIMIC substitutes in the first model for AFISFINE and HVIUNIF for SWSFC:

$$\sqrt{thicks} = 360.4 + 1.77 * HVIMIC - 4.18 * HVIUNIF \quad [11]$$

Table 10. Best unweighted least squares linear regression of neps

Predictor Variables	Coefficient	Std Error	T	*P*	VIF	STB
Constant	-871.834	177.290	-4.92	0.000		0.000
HVIUHM	186.7880	37.642	4.96	0.000	4.0	0.997
HVIMIC	59.7332	12.780	4.67	0.000	3.3	0.854
AFISSFC	15.9426	2.412	6.61	0.000	5.9	1.607

R^2	0.4802	Resid. Mean Square (MSE)	921.359
Adj. R^2	0.4502	Standard Deviation	30.3539

Table 11. Best unweighted least squares linear regression of √ends

Predictor Variables	Coefficient	Std Error	T	*P*	VIF	STB
Constant	-34.9505	9. 045	-3.86	0.0003		0.000
HVISFI	1.4705	0.234	6.27	0.0000	5.2	1.320
HVILE	10.3689	3.02	3.43	0.0012	5.2	0.722
R^2	0.5503	Resid. Mean Square (MSE)			4.6583	
Adj. R^2	0.5334	Standard Deviation			2.1583	

Table 12. Best unweighted least squares linear regression of √thicks

Predictor Variables	Coefficient	Std Error	T	*P*	VIF	STB
Constant	-14.5327	8.400	-1.73	0.0894		
AFISFINE	0.13395	0.049	2.71	0.0091	1.0	0.141
SWSFC	1.46808	0.082	17.69	0.0000	1.0	0.925
R^2	0.8559	Resid. Mean Square (MSE)			10.2980	
Adj. R^2	0.8504	Standard Deviation			3.20906	

Models for thins (√thins). As for thick places, a square-root transformation of thins, denoted √thins, is used as the response because the distribution of thins is highly (positively) skewed. The best model for √thins (Table 13) has the same predictors as those for √thicks and has a similar R^2 value (R^2 = 0.9023). The regression equation is

$$\sqrt{thins} = -46.07 + 0.240 * AFISFINE + 1.455 * SWSFC \quad [12]$$

As was the case for √thicks, replacing AFISFINE by standard fineness yields an equivalent model (R^2 = 0.8974). The best model for √thins using basic HVI properties is one in which HVIMIC substitutes in the first model for AFISFINE and HVIUNIF for SWSFC with a resulting R^2 = 0.8711. The regression equation is

$$\sqrt{thins} = 349 + 3.22 * HVIMIC - 4.29 * HVIUNIF \quad [13]$$

Models for irr CV (irrcv). As for √thicks and √thins, the best model for irrcv is one with AFISFINE and SWSFC (see Table 14) with R^2 = 0.8785. The regression equation is

$$irrcv = 4.20 - 0.054 * AFISFINE + 0.398 * SWSFC \quad [14]$$

Table 13. Best unweighted least squares linear regression of √thins

Predictor Variables	Coefficient	Std Error	T	*P*	VIF	STB
Constant	-46.0740	6.787	-6.79	0.0000		
AFISFINE	0.2398	0.040	6.00	0.0000	1.0	0.258
SWSFC	1.4550	0.067	21.70	0.0000	1.0	0.935
R^2	0.9023	Resid. Mean Square (MSE)			6.7247	
Adj. R^2	0.8986	Standard Deviation			2.5930	

Table 14. Best unweighted least squares linear regression of irrcc

Predictor Variables	Coefficient	Std Error	T	*P*	VIF	STB
Constant	4.1972	2.082	2.02	0.049		
AFISFINE	0.0538	0.012	4.39	0.001	1.0	0.211
SWSFC	0.3983	0.021	19.37	0.000	1.0	0.930
R^2	0.8785	Resid. Mean Square (MSE)			0.6327	
Adj. R^2	0.8739	Standard Deviation			0.7954	

Table 15. Effects of short fiber content on predicted yarn properties

HVISFI	yarnstr	elong	neps	endsdown	thicks	thins	irrcv
8.00	14.75	6.39	46.74	0.06	447.71	50.49	16.78
10.00	14.19	6.09	105.91	10.15	751.80	176.94	18.48
12.00	13.69	5.79	152.33	37.53	1081.42	350.14	19.96
14.00	13.27	5.49	185.99	82.20	1410.56	544.61	21.23

Replacing AFISFINE by standard fineness gives essentially the same model ($R^2 = 0.8813$). The best model using basic HVI properties substitutes AFISFINE with HVIMIC and SWSFC with HVISFC giving an $R^2 = 0.8438$. The resulting equation is

$$irrcv = 109.6 + 0.673 * HVIMIC - 1.15 * HVIUNIF \quad [15]$$

The pairs of models for √thicks, √thins, and irrcv use the same sets of predictors (AFISFINE and SWSFC or HVIMIC and HVIUNIF) and have similar standardized regression coefficients (STBs) and R^2 values. In the models with AFISFINE and SWSFC as predictors, SWSFC is relatively more important. Analogously HVIUNIF is relatively more important in the models with HVIMIC and HVIUNIF.

Each of the best models for the seven yarn properties includes a short fiber content predictor, either HVISFI, AFISSFC, or SWSFC. To quantify the effects of short fiber content on yarn, the models were used to predict properties of yarn spun from cottons with short fiber content ranging from 8% to 14%. Other fiber properties were assumed to be at their mean levels: specifically, HVISTR = 28.34 g/tex, HVIMIC = 4.33, HVIUHM = 2.77 cm, HVILE = 2.26 cm, AFISFINE = 166.26 millitex, and AFISMAT = 0.892. Table 15 shows the effects on predicted yarn properties of increasing HVISFI from 8% to 14%. For models that use AFISSFC or SWSFC instead of HVISFI, corresponding values were obtained by regression. This clearly illustrates the degree to which all yarn properties will degenerate as short fiber content increases.

SUMMARY AND CONCLUSIONS

Measures of short fiber content are correlated with all of the yarn properties, most strongly with yarnstr, thicks, thins, and irrcv. The six long fiber measures are also strongly correlated with yarnstr, thicks, thins, and irrcv. Correlations between the various fiber properties and elong, ends down and neps are much weaker. None of the long fiber variables is significantly correlated with elong, whereas AFISIFC and AFISMAT are.

A summary of regression models for predicting yarn properties that utilized all fiber properties is given in Table 16. From a pool of 23 potential predictors including 14 AFIS, 6 HVI, and 3 SW fiber properties, best models for seven yarn properties were obtained. Each of the models included a measure of short fiber content. In five of the seven models, the short fiber content variable was the most important predictor, exceptions being the models for yarnstr and elong.

Table 16. Summary of regression models for predicting yarn properties that utilized all fiber properties

Variable	Predictor Variables	R^2
yarnstr	HVISTR, HVIMIC, SWSFC	0.9488
elong	AFISFINE, AFISMAT, HVISFI	0.8079
neps	HVIUHM, HVIMIC, AFISSFC	0.4802
√ends	HVISFI, SWLE	0.6062
√thicks	AFISFINE, SWSFC	0.8559
√thins	AFISFINE, SWSFC	0.9023
irrcv	AFISFINE, SWSFC	0.8785

Although HVIMIC and AFISFINE show little association individually with the seven yarn properties, they are important predictors in combination with other fiber properties. The only model that does not contain one of these as a predictor is the model for ends down. When just the four basic HVI variables are considered as candidate predictors, HVIMIC is in every model except the one for ends down.

A summary of regression models for predicting yarn properties that utilized only HVI properties is given in Table 17. For five of the yarn properties, models built from the basic HVI properties were nearly as good (in terms of R^2 and colinearity) as those built from all of the 23 fiber properties. Exceptions were the models for elongation and for ends down. Even the best model for ends down was poor ($R^2 = 0.48$). From a practical point of view, the basic HVI properties provide as much information about yarn characteristics as do all of the fiber properties.

Table 17. Summary of regression models for predicting yarn properties that utilized only HVI fiber properties

Variable	Predictor Variables	R^2
yarnstr	HVISTR, HVIMIC, HVIUNIF	0.9448
elong	HVISTR, HVIMIC, HVIUNIF	0.3700
neps	HVIUHM, HVIMIC, HVIUNIF	0.4076
√ends	HVISFI, HVILE	0.5503
√thicks	HVIMIC, HVIUNIF	0.8235
√thins	HVIMIC, HVIUNIF	0.8711
irrcv	HVIMIC, HVIUNIF	0.8438

Among the 14 AFIS properties considered, three of them—AFISIFC, AFISFINE and AFISMAT—appear to capture qualities of the fibers that other variables do not measure. Although AFISFINE is correlated with HVIMIC, the two variables evidently do not measure the same characteristics of the fibers. The ratio of AFISFINE/AFISMAT, which estimates standard fineness, did not offer advantages over AFISFINE is predicting yarn properties.

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