The *Journal of Cotton Science 12:298–305 (2008)*
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TEXTILE TECHNOLOGY

A Comparison of Methods for Measuring the Short Fiber Content of Cotton

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ABSTRACT

Twenty-nine bales of cotton with short fiber content ranging from approximately 5% to 25% were selected for the purpose of comparing the effectiveness and relationships among the current testing methods for fiber length. The instruments and/or methods used to measure short fiber include HVI, AFIS, and Suter-Webb array. Comparisons between the three methods indicate that they correlate well with each other. The Suter-Webb array technique gives higher estimates of short fiber content than those of HVI and AFIS, and shows greater discrimination among the samples. Highly significant regression models were developed to predict short fiber content from long fiber data (length and strength) and micronaire.

The presence of excess amounts of short fibers in cotton can cause significant problems for the spinner. These problems include excess waste, loss of yarn strength, increased ends-down, and more yarn defects (Backe, 1986). Several methods can be used to measure the short fiber content (defined as percent by weight of fibers of 12.7 mm or less) of cotton, and all of them essentially require some type of measurement of the distribution of total length. The most fundamental, direct (and tedious) measure of fiber length is the Suter-Webb array method in which a comb-sorting technique is used to segregate the fibers into length groups, each of which are weighed on an analytical balance (ASTM D1440, 2002). The AFIS (Advance Fiber Information System) instrument is also a direct measurement of fiber lengths, as it utilizes a mechanical opener to inject individual fibers into a rapid air stream where the length of each fiber can be measured by a high speed electro/optic system (Bragg and Shofner, 1993). There is some legitimate concern that the AFIS mechanical opener can cause some fiber breakage, which would bias its length measurement (Cui et al., 1997).

In the late 1980s, researchers began considering the possibilities of utilizing data from HVI (High Volume Instrument) to predict short fiber content as determined by the other more tedious methods. Ramey and Beaton (1989) described a study that used samples from the crop quality survey of the 1984 and 1985 U.S. cotton crop. Data were obtained with the Suter-Webb array method, the Peyer Almeter, the digital fibrograph, and the MCI (Motion Control Incorporated) HVI. The results showed negative correlations in the order of $-0.7 < r < -0.6$ between short fiber content and the uniformity index. Additionally, when they employed a series of staple length standards, correlations of approximately $r = -0.95$ were obtained.

Zeidman et al. (1991) developed regression models using quality survey data from 1985, 1986, and 1987. They used modified Suter-Webb array distributions to determine short fiber content in terms of the HVI parameters for length, UHM (upper-half mean length), and uniformity. They developed models for both SFN (short fiber by number) and SFW (short fiber by weight) based on array data. Their regression equations could be expressed in terms of uniformity and both mean and UHM. Multiple R^2 values were approximately 0.391 and 0.483, respectively.

In the late 1990s, Zellweger-Uster (now Uster Technologies) modified its HVI program to allow for calculation of the short fiber content of a sample of cotton based upon an algorithm that calculates a short fiber index (SFI) from the other conventional HVI measures of length, strength, and micronaire (Gipson, 1999). Subsequently, the USDA Agricultural Marketing Service AMS Cotton Program developed an improved short fiber prediction equation based upon HVI length and uniformity index (Knowlton, 2001). Because the

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HVI length/strength sample consists of a combed fiber beard held at one end by a clamp with finite depth, most of the short fiber is hidden within the jaws of the clamp. For that reason, HVI SFI was developed from regression-type studies using either Suter-Webb or AFIS as reference methods.

Rowland (1999) undertook a study using bales processed by National Textiles to study the relationship between short fiber content measured by HVI and short fiber measured by AFIS. Approximately 12,000 bales were sampled from five spinning plants. HVI SFW was measured on an HVI line equipped to give direct short fiber measurements using the Uster SFW algorithm (described by Knowlton, 2004). Official AMS classing data was also used in the study as the source of HVI data. Some of the findings were (1) HVI uniformity ratio showed the general trend of short fiber content, (2) there was a poor correlation between HVI and AFIS short fiber determinations, and (3) the best model for SFW utilized quadratic relations involving both uniformity and length with multiple R values = 0.8432.

Cui et al. (2003) reported a study to evaluate the differences between the various measures of short fiber content including Suter-Webb, AFIS, and HVI. Included in this study were 36 upland cottons grown on experimental plots in Mississippi. These cottons ranged in short fiber content from 6.5 to13.9%. Studies of the interrelationships between Suter-Webb, AFIS, and HVI yielded correlation coefficients between 0.6 and 0.7. Some of the conclusions reached in that study were that real differences existed between the three methods and that a significant contributor to these differences was the general non-uniformity of the samples.

At the 2004 Beltwide Cotton Conference, James Knowlton 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 included several different laboratories conducting a wide range of tests on several different instruments. Twenty-nine commercial bales having a wide range of fiber properties were chosen for the study. The results Knowlton presented were preliminary, but they indicated good correlations among the various test methods, although different methods were on different amounts of short fiber contents.

The present study deals with specific data from the same set of cottons. We concentrated on HVI measurements from the USDA-AMS Memphis Classing Office, Memphis, TN; the AFIS instrument at the Southern Regional Research Center in New Orleans, LA; and from Suter-Webb array analysis performed at the Cotton Quality Research Station in Clemson, SC. In this study we seek to validate and possibly improve upon the previously reported studies by using a wider range of cotton properties measured on state-of-the-art instrumentation (AFIS and HVI). Our emphasis is to study the relationships between the various short fiber measurements and also their relationships to other fiber properties. It should be emphasized that the number of replicated measurements of the various properties (discussed below) is larger than the number normally used in practice. The increased precision of the average measurements permits sharper distinctions among the various methods of short fiber content.

More specifically: (1) we considered a large and diverse sample set to take a close (statistical) look at the short fiber measurement parameters to ascertain their similarities, differences, advantages, and short-comings. (2) Because the measurement of short fiber content is part of the overall task of fiber length measurements, we compared the measured length parameters for each of the three length methods. These studies were driven by the underlying premise that the Suter-Webb array method should be considered as the reference determination of cotton fiber length distribution. (3) Given that, in general, the Suter-Webb array method is not available to those concerned with short fiber content, it is of interest to derive predictive models that would use either data from AFIS or from HVI for predicting Suter-Webb array short fiber content. (4) Finally, because the HVISFI is not included as a standard output from the AMS bale class results, we investigated how standard classing data can be used to predict short fiber content (HVISFI).

MATERIALS AND METHODS

The cottons chosen for this study represent a wide range of fiber properties as shown in Table 1. UHM measurements are between 2.34 cm and 3.07 cm with a wide range uniformity index between 77.8 and 84.4 %. Fiber strength varies between 23.39 and 33.17 cN/tex, and micronaire varies between approximately 2.9 and 5.5. The HVI short fiber index varies between 6.86 and 17.13%. Among the five properties, SFI is by far the most variable, with a CV more than twice that of the other properties.

Table 1. Descriptive statistics of the HVI properties for the 29 cottons selected for this study

	HVIUHM (cm)	HVIUNIF (%)	HVISTR (cN/tex)	HVIMIC	HVISFI (%)
N	29	29	29	29	29
MEAN	2.77	81.60	28.39	4.34	10.13
MED	2.79	82.20	28.46	4.27	8.76
MAX	3.07	84.40	33.17	5.52	17.13
MIN	2.34	77.80	23.39	2.92	6.86
STDEV	0.23	1.86	2.94	0.58	2.83
CV	7.90	2.28	10.36	13.39	27.94

Table 2. Glossary of variable names

AFISDUST	AFIS dust particle count (/g)
AFISFINE	AFIS fineness (millitex)
AFISIFC	AFIS immature fiber content (%)
AFISLN	AFIS mean length by number (cm)
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 (%)
AFISSIZE	AFIS mean nep size
AFISTOT	AFIS total nep count (/g)
AFISTR	AFIS trash particle count (/g)
AFISUQL	AFIS upper-quartile length (cm)
AFISVFM	AFIS visible foreign matter (%)
HVILE	HVI mean length (cm)
HVIMIC	HVI micronaire (dimensionless)
HVISFI	HVI short fiber index (%)
HVISTR	HVI strength (cN/tex)
HVIUHM	HVI upper-half mean length (cm)
HVIUNIF	HVI uniformity (%)
RECPSFI	the reciprocal of HVISFI (1/%)
SWLE	Suter-Webb mean length (cm)
SWSFC	Suter-Webb short fiber content (%)
SWUQL	Suter-Webb upper-quartile length (cm)

As mentioned above, HVI measurements reported on these bales were conducted at the Memphis Classing Office of the USDA AMS Cotton Program. The values used in this analysis are averages of approximately 150 individual repetitions on each of the bales.

The AFIS measurements were obtained at the Southern Regional Research CenterLA. Ten replicate samples from each of the 29 cottons were run at each of the locations. Each of the AFIS measurements represented characterizing at least 15,000 fibers per rep.

Table 3. Descriptive statistics for the three measures of short fiber compared in this study

	HVISFI (%)	AFISSFC (%)	SWSFC (%)
N	29	29	29
MEAN	10.13	12.09	13.17
MEDIAN	8.76	12.03	11.60
MAX	17.13	19.76	26.60
MIN	6.86	5.61	6.40
STDEV	2.83	4.09	5.19
C.V.	27.94	33.90	39.39

Suter-Webb array analyses were conducted at the Cotton Quality Research Station according to ASTM D-1444 (ASTM, 2005). Determinations were based upon averaging three separate samples run by three different operators.

RESULTS AND DISCUSSION

A list of the descriptive statistics of the HVI properties for the 29 cottons selected for this study is given in Table 1. A glossary of terms is provided in Table 2. The bales show a wide range of fiber properties. Note that for length, strength, and micronaire each property's median and mean values are approximately the same indicating symmetric distributions of these values. This is not so in the case of the uniformity indices and short fiber indices where the difference between the mean and median would indicate a skewed distribution where uniformity is negatively skewed and short fiber exhibits positive skewness.

Comparing short fiber measurement parameters. Descriptive statistics are shown in Table 3 for the three measures of short fiber included in this study. These include short fiber as measured by HVI (HVISFI), AFIS (AFISSFC), and Suter-Webb (SWSFC). Comparing the differences between mean and median values shows AFIS short fibers are symmetrically distributed, whereas SWSFC, like HVISFC, is positively skewed.

Side-by-side box-and-whiskers plots of the three short fiber measures are shown in Figure 1. The length of the box represents the middle 50 % of the distribution, i.e. the top is the 75th percentile and the bottom the 25th percentile. The single line within the box is the median level. The extent of the lines (whiskers) above and below the boxes represents the remaining parts of the distribution. Asterisks indicate outliers from the regular distributions. Examination of Figure 1 reveals that HVISFI values are more narrowly distributed and strongly skewed in the positive direction. The widest distribution of values occurs with the SWSFC, which also tends to be slightly positively skewed. AFISSFC is more normally distributed with an extent of values intermediate between HVI and SW. As discussed above, Suter-Webb Arrays are generally accepted as the standard for short fiber content.

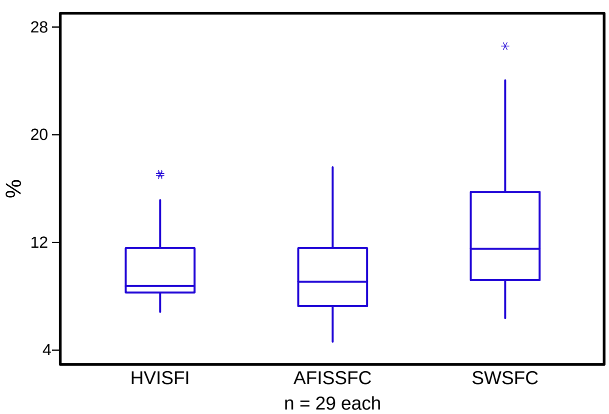

Figure 1. Box-and-whisker plots indicating the distribution of short fiber contents measured by HVI, AFIS, and Suter-Webb array.

Despite the three measurement protocols yielding quite different distributions, we found that the association between the three was quite good. The Pearson's correlations (*r*-values) among the three are shown in Table 4. The strongest correlation is that of HVISFI to SWSFC (*r* = 0.945). The correlations between AFISSFC and HVISFI and SWSFC are somewhat less (*r* = 0.886 and 0.898, respectively). These correlations are illustrated in the matrix plot shown in Figure 2. That figure (generated with Minitab™ 15 software (Minitab, Inc., State College, PA) is three scatterplots of combinations of pairs of the three short fiber measures. These confirm the close relationship between the determinations of short fiber accomplished with HVI and AFIS compared with Suter-Webb array analysis.

Table 4. Pearson's correlations (*r*-values) among the three measures of short fiber (HVISFI, AFISSFC, and SWSFC)

	HVISFI (%)	AFISSFC (%)	SWSFC (%)
HVISFI (%)	1		
AFISSFC (%)	0.886	1	
SWSFC (%)	0.945	0.898	1

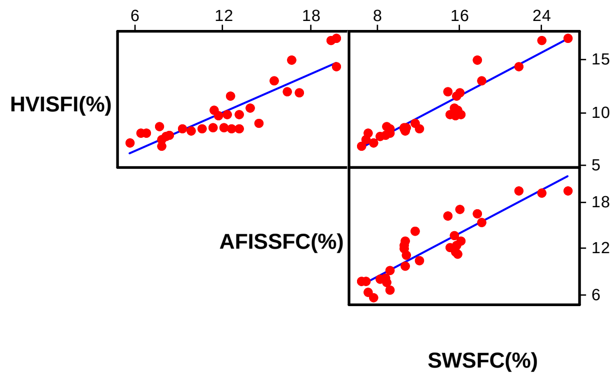

Figure 2. Matrix plots illustrating the correlations between HVISFI and AFISSFC and SWSFC.

Comparing fiber length measurements. *Mean length*. Accurate measurements of the short fiber content of a collection of fibers is dependent on the basic measurements of fiber length by any instrument under consideration. By comparing the basic measurements of length of Suter-Webb, AFIS, and HVI we can gauge the impact any of these differences might contribute to the differences we observed in their respective measures of short fiber content. Descriptive statistics are shown in Table 5 for the three measures of mean fiber length included in this study. These include mean length measurements by HVI (HVILE), AFIS (AFISLW), and Suter-Webb (SWLE). Again comparing the differences between mean and median values, AFISLW and HVILE mean lengths are symmetrically distributed, whereas SWLE is negatively skewed. This is confirmed by the box-and-whisker plots shown in Figure 3. The correlation matrix of the Pearson correlations between HVILE, AFISLW, and SWLE shown in Table 6 indicates mutual correlations (*r*'s ~ 0.95) between these three length parameters. These correlations are illustrated in the matrix plots shown in Figure 4. They confirm the relationship between the determinations of mean fiber length measured by HVI and AFIS as compared with Suter-Webb array analysis.

Table 5. Descriptive statistics for the three measures of mean fiber length examined in this study

	HVILE (cm)	AFISLW (cm)	SWLE (cm)
N	29	29	29
MEAN	2.268	2.322	2.311
MEDIAN	2.291	2.342	2.395
MAX	2.563	2.687	2.725
MIN	1.816	1.913	1.806
STDEV	0.218	0.224	0.274
C.V.	9.634	9.609	11.859

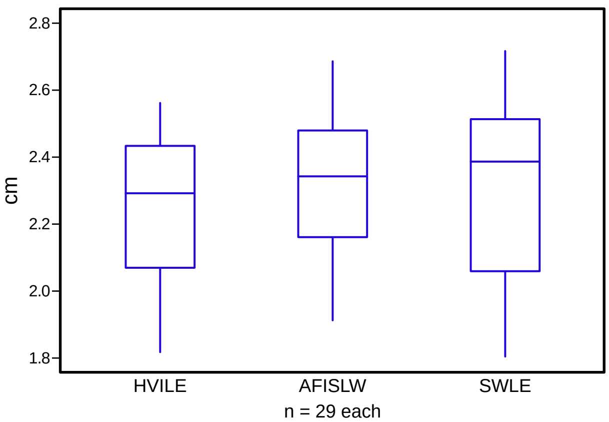

Figure 3. Box-and-whisker plots indicating the distribution of mean fiber lengths measured by HVI, AFIS, and Suter-Webb array.

Table 6. Pearson's correlations (*r*-values) among the three measures of mean fiber length (HVILE, AFISLW, and SWLE).

	HVILE	AFISLW	SWLE
HVILE	1		
AFISLW	0.955	1	
SWLE	0.970	0.942	1

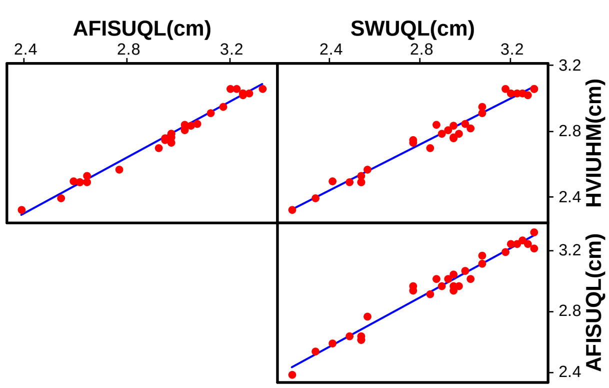

Figure 4. Matrix plots illustrating the correlations between HVILE and AFISLW and SWLE.

Upper-half mean/Upper-quartile lengths. Because overall textile performance is largely dictated by the longer fibers in a distribution, it is appropriate also to consider the longer fiber data. Suter-Webb and AFIS both estimate the upper-quartile length (SWUQL and AFISUQL, respectively), whereas HVI , depending on fibrogram theory, measures the UHM length (HVI-UHM). Descriptive statistics are shown in Table 7 for the three measures of the longer fiber lengths included in this study. These include the longer length measurements by HVI (HVIUHM), AFIS (AFISUQL), and Suter-Webb (SWUQL). Comparisons of the differences between their mean and median values, HVIUHM and AFISUQL lengths are symmetrically distributed, whereas SWUQL is negatively skewed. This is confirmed by the box-and-whisker plots shown in Figure 5. The correlation matrix of the Pearson correlations among HVIUHM, AFISUQL, and SWUQL shown in Table 8 indicates mutual correlations ($0.98 < r < 0.993$) between these three length parameters. These correlations are illustrated in the matrix plot shown in Figure 6.

Table 7. Descriptive statistics for the three measures of longer fiber length used in this study

	HVIUHM (cm)	AFISUQL (cm)	SWUQL (cm)
N	29	29	29
MEAN	2.77	2.95	2.87
MEDIAN	2.79	2.97	2.95
MAX	3.07	3.33	3.30
MIN	2.34	2.39	2.34
STDEV	0.229	0.254	0.305
C.V.	7.83	8.59	10.59

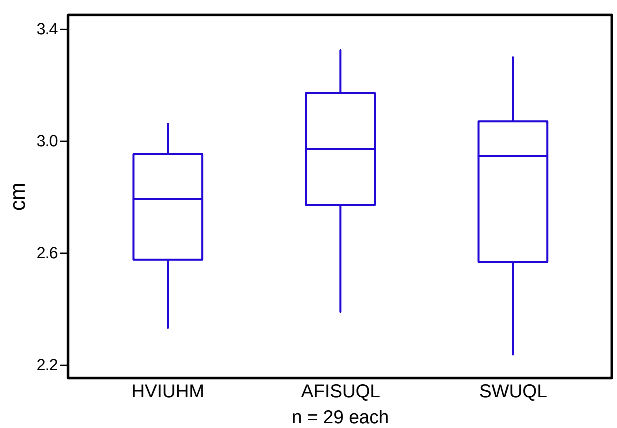

Figure 5. Box-and-whisker plots indicating the distribution of long fiber lengths measured by HVI, AFIS, and Suter-Webb array.

Table 8. Pearson's correlations (*r*-values) among the three measures of longer fiber length (AFISUQL, SWUQLE, and HVIUHM).

	AFISUQL	SWUQL	HVIUHM
AFISUQL	1		
SWUQL	0.983	1	
HVIUHM	0.992	0.986	1

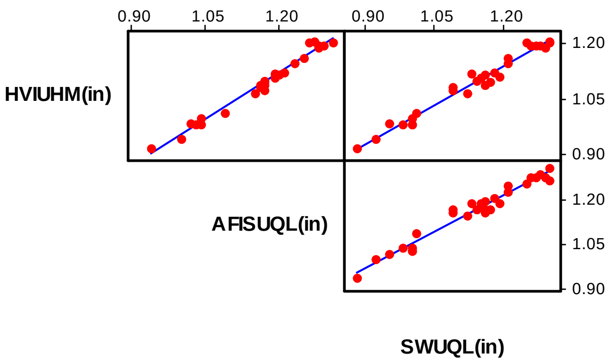

Figure 6. Matrix plots illustrating the correlations between HVIUHM and AFISUQL and SWUQL.

Predictive models for SWSFC. _Using HVI data_. The Suter-Webb array is traditionally considered the most accurate measure of short fiber content. However this method is extremely tedious, requiring highly skilled technicians, and is not widely used. On the other hand, the basic HVI properties are usually known for any bale of cotton. An estimate of SWSFC can be calculated from HVI uniformity (HVIUNIF) as indicated below.

In a stepwise forward regression with candidate predictors HVISTR, HVIUHM, HVIUNIF, and HVIMIC, the only significant predictor was HVIUNIF. Details of the resulting regression model are given in Table 9 The final regression equation is:

$$SWSFC = 229 - 2.65 * HVIUNIF. \qquad [1]$$

As an indication of the precision with which SWSFC can be estimated, 95% confidence limits for the mean SWSFC of all bales of cotton with HVIUNIF = 81.6 (the sample mean value of HVIUNIF) are 12.530 < mean SWSFC < 13.808.

Residuals analysis indicates the regression model is appropriate (although there is some evidence that the scatter is greater for lower uniformity values). This can be seen in Figure 7, which illustrates 95% confidence and prediction limits for the mean value of SWSFC and a single value of SWSFC, respectively, given HVIUNIF.

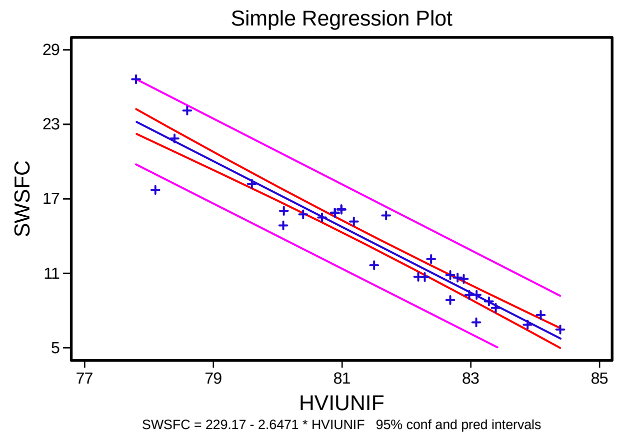

Figure 7. Simple regression plot Showing the 95% confidence and prediction limits for SWSFC for a given HVIUNIF.

Using AFIS data. Models for predicting SWSFC from AFIS properties were examined. The 13 AFIS properties considered were AFISLW, AFISLWCV, AFISLN, AFISUQL, AFISFINE, AFISIFC, AFISMAT, AFISNEPS, AFISTOT, AFISSIZE, AFISDUST, AFISTR, and AFISVFM (see Table 2 for definition of terms). A good model for SWSFC is one with two predictors: length by number (AFISLN) and maturity ratio (AFISMAT) (see Table 10). Thus, the final regression equation is:

$$SWSFC = 28.47 - 71.61 * AFISLN + 44.43 * AFISMAT. \qquad [2]$$

Table 9. Details for the Regression Model for SWSFC in Terms of HVI Variables (Equation 1).

Predictor Variables	Coefficient	Std Error	T	P
Constant	229.2	13.923	16.46	0.0000
HVIUNIF	-2.647	0.171	-15.52	0.0000
R-Squared	.08992	Resid. Mean Square (MSE)		2.81402
Adjusted R-Squared	08995	Standard Deviation		1.67750

Table 10. Details for the Regression Model for SWSFC in Terms of AFIS Variables (Equation 2).

Predictor Variables	Coefficient	Std Error	T	P	VIF
Constant	28.4774	8.22566	3.46	0.0019	
AFISLN	-71.6119	4.95676	-14.45	0.0000	1.7
AFISMAT	44.4344	11.3009	3.93	0.0006	1.7
R-Squared	0.8992	Resid. Mean Square (MSE)		2.81402	
Adjust. R- Squared	0.8995	Standard Deviation		1.67750	

Residuals plots indicate that the model is appropriate and there that there is little colinearity. A plot of the observed values of SWSFC versus the model-predicted values is shown in Figure 8.

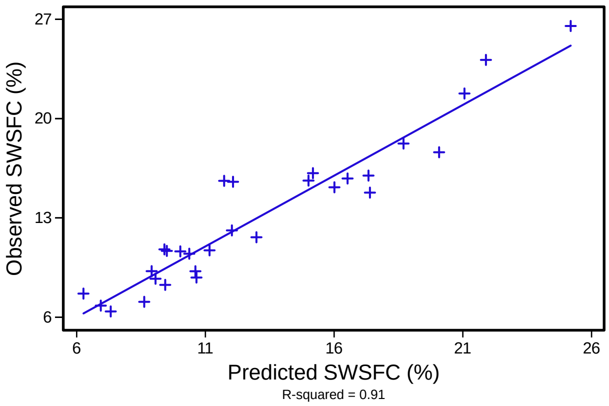

Figure 8. Plot of the observed values of SWSFC versus the model-predicted values.

As an indication of the precision with which SWSFC can be estimated, 95% confidence limits for the mean SWSFC of all bales of cotton with AFISLN = 0.768 and AFISMAT = 0.893 (the sample mean values of AFISLN and AFISMAT, respectively) are 12.530 < mean SWSFC < 13.79. These limits are almost identical to those for predicting SWSFC from the HVI property HVIUNIF (see above).

Predictive models for HVISFI. As can be inferred from the box plots in Figure 1, the relationship of HVISFI to the other two short fiber indexes is curvilinear. HVISFI does not discriminate as sharply among bales with low short fiber content as do the other two measures. The relationship of HVISFI to other HVI fiber properties, except micronaire, is curvilinear as well.

A satisfactory model to predict HVISFI directly from the other HVI fiber properties could not be found, even when squared terms and reciprocals of the predictors were added. Also, a satisfactory model to predict a logarithmic transformation of HVISFI could not be found. However, a good model for predicting the reciprocal of HVISFI is possible. Results of a stepwise forward regression for RECPSFI with candidate predictors HVISTR, HVIUHM, HVIUNIF, and HVIMIC are shown below. Two variables are significant: HVIUNIF and HVIUHM. The principal significant variable in the model is HVIUNIF with a significantly high R^2 of 0.9716. Adding HVIUHM to the model in step 2 increases R^2 by a little more than a single unit, but it is significant and shows little evidence of colinearity (Table 11). The final regression equation is

$$RECPSFI = -0.827 = 0.0107 * HVIUNIF + 0.0509 * HVIUHM. \quad [3]$$

The 95% confidence limits for the mean RECPSFI of all bales of cotton with HVIUNIF = 81.6 and HVIUHM = 1.09 (the means of the variables) are 0.1036 < mean RECPSFI < 0.1061. Therefore, 95% confidence limits for mean HVISFI are 9.425 < mean HVISFI < 9.65. A plot of the observed values of HVISFI versus the model-predicted (untransformed) values of HVISFI is shown in Figure 9. (The R^2 value for this relationship, 0.96, differs slightly from the R^2 for the model for RECPSFI.)

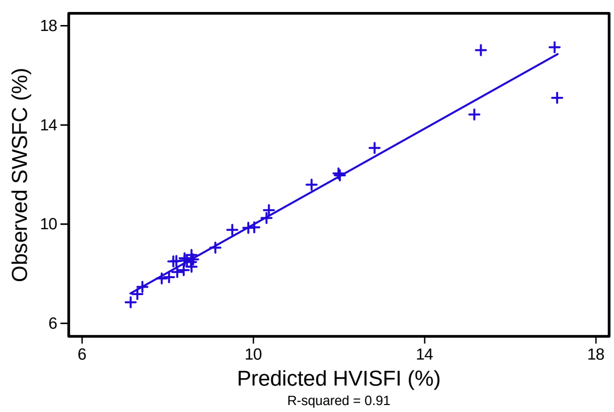

Figure 9. Plot of the observed values of HVISFI versus the model-predicted (untransformed) values of HVISFI.

Table 11. Details for the Regression Model for RECPSFI in Terms of HVI Variables (Equation 3).

Predictor Variables	Coefficient	Std Error	T	P	VIF
Constant	-0.82684	0.03535	-23.39	0.0000	
HVIUNIF	0.01074	5.513E-04	19.48	0.0000	2.9
HVIUHM	0.05090	0.01188	4.29	0.0002	2.9
R-Squared	0.9074	Resid. Mean Square (MSE)		2.6846	
Adjust. R- Squared	0.9003	Standard Deviation		1.6385	

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the effectiveness of several instrumental measurements of the short fiber content of cotton. The three methods studied included using the Suter-Webb array method as compared with AFIS and HVI. This study included many repetitions per measurement, which would not be possible under usual operations. This was done to account for the normal variability of cotton and thus have a more precise evaluation of each of the techniques on their own merit.

Our results lead to the following conclusions: (1) For the 29 bales of cotton examined in this study, the Suter-Webb array produced a wider distribution of short fiber measurement than either HVI or AFIS. That is, Suter-Webb differentiated the lots more than did the machine methods, especially compared to HVI short fiber measurements for lots with low short fiber content. However, there is a strong degree of linear association between the pairs of short fiber measurements ($0.88 < r < 0.95$). (2) The distributions of mean fiber lengths are similar for the three measurement methods, with Suter-Webb differentiating somewhat more than HVI and AFIS among the lots. There is a strong linear association among the pairs of measurements ($r \sim 0.95$). (3) Likewise, the distributions of UQL and UHM are similar, again with Suter-Webb producing (narrowly) the widest distribution of values. The linear associations among HVIUIHM, AFISUQL, and SWUQL are even stronger ($r \sim 0.98$). (4) Although the tedious Suter-Webb array method may yield sharper distinctions in length measurements among different cottons (or possibly spurious differences) the two machine methods give strongly related measures on slightly shifted scales. (5) An estimate of SWSFC can be obtained from the basic HVI properties using HVIUNIF alone, with $R^2 = 0.90$. The margin of error (95% confidence) for estimating the mean SWSFC given HVIUNIF is generally less than ±1%. (4) SWSFC can be estimated also from the AFIS properties using AFISLN and AFISMAT with virtually the same R^2 and margin of error values. (5) In cases where only the four basic HVI properties are known, an estimate of the HVISFI can be obtained by regression using HVIUNIF and HVIUHM as predictors with $R^2 = 0.96$. The margin of error in estimating mean HVISFI is generally less than $\underline{+}0.5\%$. (6) Given the associations among similar fiber length properties produced by the three methods, there is little reason to perform the expensive and tedious Suter-Webb array in order to obtain length estimates if either HVI or AFIS data are available. Likewise, if length measurements have been made by one machine method, little additional information about fiber length is gained by obtaining measurements from the other machine.

ACKNOWLEDGMENTS

We gratefully accept the support of Cotton Incorporated under Cooperative Agreement No. 07-158.

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