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Calibration of HVI cotton elongation measurements

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Abstract

Background: The strength of cotton fiber has been extensively studied and significant improvements in fiber strength have been made, but fiber elongation has largely been ignored, despite it contributing to the energy needed to break fibers, which affects fiber handling and processing. High Volume Instruments (HVI) measure fiber elongation but have not been calibrated for this property, making the measurement unavailable for comparative work among instruments. In prior work, a set of elongation calibration materials had been developed based on Stelometer results. A round trial of ten Australian and U.S. instruments was conducted on six cotton samples representing a range of 4.9% to 8.1% elongation.

Results: By scaling the HVI elongation values of each instrument to the values of the two calibration samples, the coefficient of variation in instrument measurements was reduced from an average of 34% for the uncalibrated measurements to 5% for the calibrated measurements. The reduction in variance allows for the direct comparison of results among instruments. A single-point elongation calibration was also assessed but found to be less effective than the proposed two-point calibration.

Conclusion: The use of an effective calibration routine on HVI measurement of cotton significantly reduces the coefficient of variation of the elongation measurement within and between instruments. The implementation of the elongation calibration will allow testing and breeding programs to implement high-speed elongation testing which makes the use of elongation values possible in breeding programs.

Keywords: Cotton, Elongation, High volume instrument, Tenacity, Work-to-rupture

Background

Virtually every bale of U.S. produced upland cotton (*Gossypium hirsutum* L.) is classified by the Agricultural Marketing Service (AMS) of the United States Department of Agriculture (USDA). The Smith-Doxey Act, signed into law in 1937, authorizes AMS to classify cotton that is to be commercially traded. Human classers were used initially, but with the introduction of the High Volume Instrument (HVI) in 1980, the process started to be automated. Since 1991, the entire U.S. cotton crop has been classed using the HVI.

Cotton classification by HVI assigns values for fiber length, strength, micronaire, color, and non-lint content, but not elongation. The goal of cotton classification is to allow cotton buyers to purchase cotton bales with fiber properties that will result in textile products with consistent and desired properties. As HVI technology gained acceptance, researchers also began to use HVI measurements in efforts to improve cotton fiber quality traits; however, the needs of researchers are different than the needs of cotton marketing.

Fiber length is generally considered one of the most important cotton fiber quality traits. Fiber length is at its maximum prior to harvest; mechanical handling can only reduce the fiber length. Cotton fibers which can maintain their length after aggressive mechanical processing are superior to fibers which suffer from degradation of length and length distribution during processing (Dever et al. 1988), spin more efficiently (Fiori et al. 1956), and can produce

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yarns with improved quality and weaving performance (Backe 1996; Mathangadeera et al. 2020; May and Taylor 1998). Tougher fibers can better maintain their length during processing. Toughness is a function of both fiber strength and elongation, and yet only fiber strength is routinely calibrated.

Calibrated fiber length and strength measurements are commonplace, while calibrated fiber elongation measurements are not typically performed. Most instruments report fiber strength as tenacity, which is the breaking force divided by the linear density of the fiber or bundle. Fiber tensile measurements are commonly carried out on a bundle of fibers but can also be performed on single fibers. However, bundle tenacity is typically lower than single fiber tenacity, primarily due to variation in the elongation of individual fibers within the bundle (Sasser et al. 1991; Frydrych 1995).

Laboratory testing of the tensile properties of cotton fiber, both strength and elongation, became commonplace with the development of the Pressley flat bundle tester in 1939 and the publication of an ASTM standard in 1952 (Orr et al. 1955). In the 1950s, the Stelometer tester was introduced and became the dominant fiber bundle strength test method until the development of the HVI. Although similar fiber preparation steps were used, the Pressley and Stelometer methods differed in the rate of loading and, therefore, did not provide the same numerical values (Kerr 1954; Lawson 1964; Rouse 1964), and neither instrument provides the same tensile strength values as the HVI (Sasser et al. 1991; Taylor 1986). The Pressley and Stelometer methods provided for the calibration of strength and elongation, while the HVI method traditionally only provides for calibration of strength.

During strength testing, fibers are subjected to increasing force. As the force increases, the fiber eventually reaches the maximum load it can support, and then it breaks. With applied force, the fiber also stretches or elongates. The amount of elongation at the breaking point is referred to as break elongation or simply 'elongation'. Elongation is important because when combined with the breaking force, the work or energy needed to break the fiber or bundle can be measured, and then the toughness of the fiber can be reported.

Fiber improvement programs have largely neglected elongation simply because it has not been included in marketing systems (Hertel and Craven 1956; May and Jividen 1999). Although fiber improvement programs have mostly neglected elongation there have been some research efforts which have demonstrated that elongation is heritable, but the results from HVI and Stelometer instruments are not consistent which complicates the interpretation of results (May and Taylor 1998; May and Jividen 1999; Meredith et al. 1991; Ng et al. 2014a). The inconsistency is likely because Stelometer is calibrated for both tenacity and elongation measurements while HVI is only calibrated for tenacity. Considerable gains in fiber quality may be possible by addressing this new area of genetic diversity because breeders have largely not focused on elongation (Benzina et al. 2007; Ng et al. 2014b).

To be useful for breeding, fiber elongation measurements need to be made quickly and accurately. Stelometer testing is not useful because it is laborious and operator dependent. HVI testing provides the necessary speed but has challenges. As an uncalibrated parameter, its results have not been reproducible between instruments (Taylor 1992), although the results are consistent within a single instrument (Benzina et al. 2007). The preparation of calibration materials for elongation has recently been undertaken by Kelly and Hequet (2017) and McCormick et al. (2019), and this work has resulted in a pair of high and low elongation standards.

The next step in the development of HVI elongation calibration is to determine if these materials can be used with different HVI instruments to produce consistent elongation results. To test for this, six fiber samples were characterized with the Stelometer and were then tested with a series of HVI instruments from different laboratories. The calibrated standards were then used to adjust HVI values to determine if instrument consistency could be improved.

The implementation of elongation reference material for HVI lines would enable researchers to utilize fiber elongation data and to replicate and compare results from multiple instruments. The performance of the proposed elongation materials needs independent verification. The research reported here evaluated the performance of ten Uster Technologies HVI 1000 (Knoxville, TN) instruments in five laboratories in the United States and Australia for elongation measurement when testing cotton samples with a diverse range of elongation values, as measured on the Stelometer.

Materials and methods

HVI calibration materials

Instructions were provided to participating laboratories to calibrate their HVI instruments for length, strength, and micronaire using Universal HVI calibration cotton standards purchased from USDA-AMS (Memphis, TN). The Universal calibration standards were created by USDA-AMS per ASTM D7642–12 (2012) and have been recommended by the International Cotton Advisory Committee Task Force on Commercial Standardization of Instrument Testing of Cotton (CSITC) and the International Textile Manufacturers Federation International Committee on Cotton Testing Methods (ICCTM) (2012) for use with all high volume cotton testing instruments.

Elongation calibration materials
Elongation reference materials were provided by the Fiber and Biopolymer Research Institute (FBRI) of Texas Tech University (Lubbock, TX). The two samples represented cotton with low elongation (5.17%) and cotton with high elongation (9.00%) which were developed in previously reported research efforts (Kelly and Hequet 2017; McCormick et al. 2019). The reference materials were sub-sampled (~ 2 kg) from the well-blended bales produced via the previous efforts and sent to each cooperating laboratory.

Elongation test cottons
The USDA Agricultural Research Service (ARS) maintains a warehouse to store cotton bales for use in fiber quality and textile processing research. Thirty-two candidate bales were selected for initial testing. The candidate bales were tested on an in-house HVI 1000 (five replicates per bale) and produced uncalibrated HVI elongation values between 5.4% and 9.3%. Stelometer testing on these bales produced a range of 4.9% to 8.1% elongation. The 32 candidate samples were then sent to FBRI for testing on their HVI 1000. FBRI testing produced a range of elongation values between 4.0% and 9.3%. From these results, six samples, with Stelometer testing values between 4.9% and 8.1%, were selected for use in the round test (Table 1).

HVI testing
Ten instruments, which included both mill and classing instruments, were used in the round trial (Table 2). The five laboratories housing the instruments were all participants in the CSITC round trials and followed USDA guidelines and ASTM International standards for conditioning of samples (ASTM D1776-16 2016) and procedures for testing with cotton classification instruments (ASTM D5867-12e1 2012). The ten units were randomly assigned instrument identification numbers (1–10).

The six experimental samples and the two calibration samples were evaluated on each instrument, following CSITC round test protocols (Dreiling et al. 2012). Each sample was tested on five separate days, with six replications per day for a total of 30 tests per sample.

Methods
Two-point calibration
A simple linear interpolation, like the HVI length/strength and micronaire calibration, was performed in post-processing of the data to calibrate the elongation results (Eq. 1).

$$E_c = \frac{x_{c,l}\left(x_{m,h} - E_m\right) + x_{c,h}\left(E_m - x_{m,l}\right)}{\left(x_{m,h} - x_{m,l}\right)} \quad (1)$$

E_c = corrected elongation value

$x_{c,\ l}$ = reference value of low elongation calibration material

$x_{m,\ h}$ = measured value high elongation calibration material

E_m = measured elongation value

$x_{c,\ h}$ = reference value of high elongation calibration material

$x_{m,\ l}$ = measured value low elongation calibration material

The typical operation of the HVI testing includes a calibration check by testing calibration materials daily. The internal software determines if recalibration is needed. The daily mean values of the high and low elongation calibration materials were used to calibrate elongation results each day in a post-processing manner. The daily mean value for the high and low calibration materials were used in Eq. 1 as $x_{m,h}$ and $x_{m,l}$, respectively, for each HVI instrument. The measured elongation value (E_m) for each HVI test was then inputed into Eq. 1 to produce the calibrated elongation value, E_c. The daily calibration of each HVI instrument is performed to avoid results drifting over time.

Single-point calibration
One HVI instrument was upgraded to Version 71 of the Uster Technologies HVI software after the round trial

Table 1 Elongation values of round trial cotton samples

Sample	Stelometer Elongation/%	Uncalibrated HVI elongation[a]/%		Calibrated HVI elongation[b] /%	
		Mean	SE[c]	Mean	SE[c]
A	5.0	4.82	0.0057	5.67	0.0012
B	4.9	4.04	0.0049	4.72	0.0012
C	6.4	5.60	0.0063	6.63	0.0012
D	8.1	7.81	0.0075	9.56	0.0025
E	7.5	6.81	0.0068	8.16	0.0021
F	6.5	6.13	0.0065	7.31	0.0016

[a] Uncalibrated data from all participating instruments
[b] Calibrated data from all participating instruments
[c] SE is standard error

Table 2 Round trial participants

Laboratory	Location	# of HVI lines	Type(s)
Auscott	Artarmon, NSW, AUS	3	Classing
Cotton Inc	Cary, NC, USA	2	Mill / Classing
FBRI	Lubbock, TX, USA	3	Mill
USDA-AMS	Memphis, TN, USA	1	Classing
USDA-ARS	New Orleans, LA, USA	1	Mill

sample measurements were completed. This software provides for a single-point elongation calibration, but neither Uster Technologies nor the USDA-AMS Cotton and Tobacco Program currently provides elongation calibration materials or recommendations on how to implement this software feature best. Uster Technologies does not provide any insight into the algorithm used in the internal software to apply the single-point elongation calibration. This feature was applied to the values of our experimental samples using each of the high elongation and low elongation calibration samples to develop an understanding of how the option might be implemented.

Data analysis

Data from each instrument were assessed for the stability of measured elongation across the 5 days of testing. Elongation values were compared between instruments, both with and without the two-point elongation calibration applied to the data. An analysis of variance (ANOVA) was performed to determine if significant differences existed among the HVI measurements. The six daily replicates were averaged to provide the best daily value for each cotton sample on each instrument. The overall analysis was then conducted on the five daily averages for each of the six cotton samples. Tukey's multiple comparison test was used for means comparison at the 95% confidence level, $P \leq 0.05$. Linear regressions were performed to assess the relationship between the various HVI measures of elongation both with and without calibration and the original Stelometer results. Results from the linear regression were analyzed by t-tests. Minitab 18.1 (Minitab Inc., State College, PA) was used for all data analyses.

Results and discussion

Averaged results

Uncalibrated HVI elongation results showed a great deal of instrument variability. The average uncalibrated elongation of the six-sample set from instrument to instrument ranged from 3.37% to 8.57%. The ten instruments were differentiated into eight classes by Tukey's multiple comparison test (Table 3). The post-processing two-point calibration procedure reduced the range of mean results from 6.47% to 7.53% across the ten instruments. Ideally, the average of all tests of all cotton samples would result in a statistically identical result from each instrument. Although calibration did not eliminate statistical differences between instruments, it did reduce the differences. Uncalibrated results were statistically different between all instruments except HVI lines 1 and 5 and line 2 which was statistically the same as lines 4 and 8, although 4 and 8 were significantly different. Calibration allowed at least five of the ten instruments to be compared, and no instruments were significantly different from all others.

Table 3 Mean values for six cotton samples and 30 tests per HVI line

HVI Line	Uncalibrated Elongation /%	Calibrated Elongation /%
1	7.31 c	6.54 de
2	3.45 gh	7.53 a
3	5.09 f	7.27 abc
4	3.37 h	7.44 ab
5	7.37 c	6.82 cde
6	6.53 d	6.96 bcde
7	5.92 e	7.03 abcd
8	3.50 g	7.29 abc
9	7.69 b	6.47 e
10	8.57 a	6.72 de

Means in the same column with different letters are statistically different ($P \leq 0.05$)

Stelometer and HVI elongation values are not expected to be numerically equal for several reasons. Because all fibers span both clamps in the flat bundle used in Stelometer testing but likely do not span both clamps in the tapered bundle used by the HVI, numerical differences are to be expected (Naylor et al. 2014). Additionally, Stelometer testing removes short fibers, neps, and non-lint content prior to analysis. It was expected that the uncalibrated HVI elongation trends would follow the Stelometer results (Table 1). The ranking of the samples, based on both calibrated and uncalibrated HVI testing, is the same as that found on the Stelometer. The mean uncalibrated HVI values for the six samples, averaged over the ten instruments, were consistently lower than the Stelometer values, with a mean difference of − 0.53%. After two-point calibration, the HVI elongation had a mean difference of + 0.61% with Stelometer and + 1.14% with the uncalibrated HVI elongation. Each cotton sample exhibited the same general trend for all test methods.

Variance within a single instrument

Routine calibration is performed on HVI instruments for length, strength, micronaire, color, and non-lint content, and the measurement variance within an instrument for these properties is well understood. Consideration of the variance within an HVI instrument is needed to determine repeatability. Tables 4 and 5 show the uncalibrated

Table 4 Uncalibrated means and coefficient of variation for each cotton and HVI line

HVI Line	1		2		3		4		5		6		7		8		9		10	
Sample	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**
A	6.46	3.72	2.64	3.03	4.28	2.80	2.55	3.92	5.85	5.47	5.21	5.57	4.52	18.14	2.75	2.55	6.70	2.39	7.26	3.03
B	5.51	4.54	2.07	2.90	3.77	1.86	2.04	4.41	5.08	6.30	4.40	5.68	3.58	14.53	2.36	9.75	5.92	2.36	5.70	4.56
C	7.21	4.58	3.15	2.54	4.79	2.30	3.10	3.23	7.08	4.94	6.25	6.24	5.43	8.84	3.24	3.09	7.48	2.01	8.26	3.51
D	9.20	2.72	5.07	1.97	6.63	2.11	4.20	3.10	9.93	3.93	8.76	3.08	8.24	7.28	4.96	2.82	9.67	2.59	11.46	4.45
E	7.95	2.64	4.15	2.89	5.79	1.73	4.10	1.95	8.67	4.04	7.88	5.84	7.35	6.80	4.04	3.22	8.39	2.74	9.78	4.50
F	7.55	3.71	3.61	2.22	5.29	2.08	3.53	2.55	7.61	4.60	6.69	2.99	6.39	13.30	3.64	2.75	8.00	1.88	8.98	3.90
Avg	7.31	3.65	3.45	2.59	5.09	2.15	3.25	3.19	7.37	4.88	6.53	4.90	5.92	11.48	3.50	4.03	7.69	2.33	8.57	3.99
Min	5.51	2.64	2.07	1.97	3.77	1.73	2.04	1.95	5.08	3.93	4.40	2.99	3.58	6.80	2.36	2.55	5.92	1.88	5.70	3.03
Max	9.20	4.58	5.07	3.03	6.63	2.80	4.20	4.41	9.93	6.30	8.76	6.24	8.24	18.14	4.96	9.75	9.67	2.74	11.46	4.56

Table 5 Calibrated means and coefficient of variation for each cotton and HVI line

HVI Line	1		2		3		4		5		6		7		8		9		10	
Sample	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**	**Mean**	**CV /%**
A	5.52	3.80	5.98	2.84	5.81	3.79	5.85	3.76	5.43	5.34	5.61	3.92	5.67	13.05	5.77	2.43	5.33	3.00	5.68	2.64
B	4.38	7.08	4.88	2.87	4.87	2.46	4.85	3.92	4.73	5.71	4.79	5.01	4.78	18.20	5.00	8.20	4.43	3.16	4.45	4.04
C	6.41	6.08	6.94	2.16	6.73	2.97	6.90	3.19	6.55	4.12	6.68	4.94	6.60	9.55	6.78	2.95	6.23	2.09	6.46	2.79
D	8.80	2.95	10.66	1.97	10.06	2.49	10.44	2.78	9.15	4.92	9.23	3.14	9.30	10.75	10.24	2.93	8.75	2.74	8.99	3.56
E	7.30	3.97	8.88	2.59	8.53	2.23	8.85	2.03	8.00	5.00	8.33	5.88	8.37	9.44	8.39	3.22	7.28	3.43	7.67	3.91
F	6.82	4.25	7.84	1.91	7.62	2.62	7.74	2.20	7.04	5.26	7.12	3.09	7.44	9.27	7.58	3.03	6.83	2.34	7.04	3.27
Avg	6.54	4.69	7.53	2.39	7.27	2.76	7.44	2.98	6.82	5.06	6.96	4.33	7.03	11.71	7.29	3.79	6.48	2.79	6.72	3.37
Min	4.38	2.95	4.88	1.91	4.87	2.23	4.85	2.03	4.73	4.12	4.79	3.09	4.78	9.27	5.00	2.43	4.43	2.09	4.45	2.64
Max	8.80	7.08	10.66	2.87	10.06	3.79	10.44	3.92	9.15	5.71	9.23	5.88	9.30	18.20	10.24	8.20	8.75	3.43	8.99	4.04

and calibrated means and coefficient of variation (CV) for each cotton sample and each instrument across the 5 days of testing, respectively. Instrument 7 had a consistently high CV (uncalibrated mean of 11.48%) compared with the other nine instruments (uncalibrated mean of 3.52%). Although the variance of making a measurement was higher than for the other instruments, the average individual calibrated results from instrument 7 trended as with the other instruments (Table 5).

Calibration will not significantly impact the CV of sample measurement, as this variation is an inherent part of the sample and random instrumentation effects. Instrument calibration simply adjusts the measurements to be more in line with other instruments by accounting for systematic instrument differences. High variance within instrument 7 is likely due to mechanical conditions. Riley (1997) has discussed the mechanical factors relating to the high standard deviation of elongation within the HVI. Although the HVI has undergone revision since this time, the basic mechanics of the strength and elongation test module have not changed. The data in Tables 4 and 5 do not suggest any significant change in instrument variance after calibration.

Variance among different instruments

Calibration materials are chosen for consistent values of the property that they will be used to calibrate. It is reasonable to expect that routine samples may have higher variation than calibration materials. It is also likely that cotton samples near the limits of typical property values will likely be more variable than those in the middle of the distribution. The instrument variance was reduced by from > 30% for each sample before calibration to between 3.37% and 7.48% after calibration (Table 6). The calibration allows for a more reliable comparison of results between HVI lines. A lower CV indicates less variable cotton. Tukey analysis identified each of the six cotton samples as significantly different, which was expected since the samples were selected to represent a broad range of values; the analysis was able to differentiate samples for both calibrated and uncalibrated results.

Table 7 shows the instrument mean and CV for other typical HVI properties of the six test samples. Elongation CV after calibration was much closer to the CV of other HVI measured properties. The CV of calibrated elongation (5.22%) is in a similar range as fiber strength (3.41%). Cotton D had the highest CV. Cotton D also had the highest elongation in the test, and the increased variance may be associated with high elongation. Although not the strongest cotton in the trial, cotton D also has the highest variation in strength, which may indicate that this sample was inherently more variable. The increased elongation variance was not apparent in the uncalibrated data because it was hidden by the substantial variance of this data. ANOVA showed significant differences between the six cotton samples in the uncalibrated dataset as well as the calibrated dataset (Table 6).

Although variance was significantly reduced between HVI lines after calibrating elongation testing, no assessment has been made on what amount of variance is acceptable. The cotton industry has set tolerances for length, strength, and color measurement repeatability during calibration, and that work must be done to establish elongation calibration procedures fully.

HVI internal single-point elongation calibration

Version 71 of the HVI software incorporates single-point calibration, in which a single cotton sample with known elongation is used with the standard HVI's internal calibration procedure. After processing, the instrument reports an offset. However, it is unknown how Uster implements this single-point calibration in the software.

Generally, single-point calibration is performed by deriving a correction factor (Eq. 2), such as is used in

Table 6 Elongation variance across HVI instruments

Sample	Uncalibrated mean elong. /%	Uncalibrated elong. CV /%	Calibrated mean elong. /%	Calibrated elong. CV /%
A	4.82 e	36.55	5.67 e	3.52
B	4.04 f	37.47	4.72 f	4.60
C	5.60 d	34.88	6.63 d	3.37
D	7.81 a	31.46	9.56 a	7.48
E	6.81 b	31.21	8.16 b	7.12
F	6.13 c	32.73	7.31 c	5.21
Avg	5.87	34.05	7.01	5.22
Min	4.04	31.21	4.72	3.37
Max	7.81	37.47	9.56	7.48

Means in the same column with different letters are statistically different ($P \leq 0.05$)

Table 7 Instrument variance for typical HVI properties

	Micronaire		Strength /($g \cdot tex^{-1}$)		UHML /mm		Uniformity index	
Sample	Mean	CV /%	Mean	CV /%	Mean	CV /%	Mean	CV /%
A	4.80	1.25	30.49	3.61	29.41	1.21	82.30	0.85
B	4.30	1.86	32.02	3.25	29.44	1.21	82.50	0.85
C	3.66	1.64	29.46	2.95	29.08	1.14	81.40	0.86
D	3.52	1.99	26.59	3.65	27.28	1.58	81.40	0.86
E	3.64	1.92	28.50	3.54	27.08	1.31	81.10	0.86
F	3.49	1.72	29.99	3.47	29.11	1.48	82.20	0.85
Avg	3.90	1.73	29.51	3.41	28.57	1.32	81.82	0.86
Min	3.52	1.25	26.59	2.95	27.08	1.14	81.10	0.85
Max	4.80	1.99	32.02	3.65	29.44	1.48	82.50	0.86

ASTM D1445-12 (2012) for the Stelometer, which is then applied to the observed values (Eq. 3).

$$F_c = C_s/C_o \tag{2}$$

F_c = correction factor
C_s = standard value for calibration material
C_o = observed value for calibration material

$$E_c = E_o\ F_c \tag{3}$$

E_c = corrected elongation
E_o = observed elongation

During operation, the Version 71 program requests input of an elongation calibration value during the calibration procedure. Applying the procedure to our samples, very different elongation values were obtained depending on which of our calibration samples was used. The single-point calibration slightly altered the results when the high elongation calibration cotton was used but a larger difference was obtained when the low calibration cotton was used. The correction factor, F_c, of 0.96 was calculated from Eq. 2 with the high elongation cotton standard and 0.83 using the low elongation cotton standard. These correction factors were obtained by recording the instrument measured values for the high and low elongation calibration standards, as the HVI was performing the calibration. The application of a single-point correct factor should result in a predictable shift of the results from the uncalibrated values;

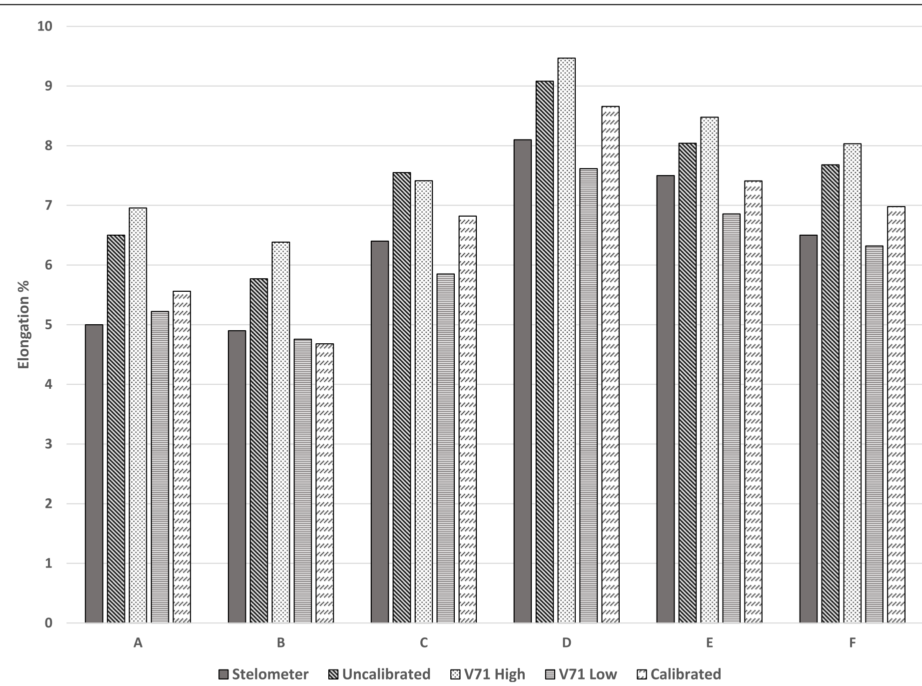

Fig. 1 Comparison of calibration techniques on a single HVI

however, that is not what was observed. Figure 1 shows that for all but cotton C, the single-point calibration with the high elongation cotton results in higher elongation values than the uncalibrated HVI reported. Hence, a simple offset correction cannot result in the values derived. Consequently, it is unclear how the Version 71 internal single-point calibration algorithm functions. This suggests that the software is taking other fiber quality parameters into account when applying elongation calibration.

Correlation among calibration procedures

The correlation and linear regression among the various HVI elongation measures (uncalibrated, calibrated with a single high or low elongation standard, or calibrated with both standards) and the Stelometer elongation values are shown in Table 8. The Stelometer was highly correlated with all of the HVI measurements (R^2 between 0.93 and 0.96). It should be noted that these relationships are for six samples only, and there are no statistically significant differences amongst the coefficients of determination (R^2) or linear regressions in this dataset per the t-test. Although R^2 is highest for the Version 71 calibration technique utilizing the low elongation standard (V71 Low), the slope and intercept for that method are considerably larger than for the two-point calibration procedure. If a single-point calibration procedure is used, the difference in measured and standard value of the single reference point has an impact on the effectiveness of the calibration. Multi-point calibration allows for a calibration curve to be determined. It will be a straight line in the case of a two-point linear calibration. Obviously, with a single-point calibration, slope and intercept cannot be determined. Only a correction factor can be calculated; however, it is not known if the correction factor is a ratio, difference, or of some other construct.

Conclusion

Elongation calibration for the HVI will allow for elongation values of cotton to be utilized in breeding and fiber selection programs. The presented work demonstrated the differences in elongation values for the same sample measured on different HVI lines. The use of a two-point calibration technique and the FBRI elongation standards significantly reduced the level and variance differences between instruments. The calibrated elongation variance is in line with the instrument to instrument variance of other physical properties measured by the HVI. Calibrated HVI values do not match Stelometer values, although that was not unexpected due to the differences in the testing methods.

A single-point calibration technique from Uster Technologies was evaluated and found lacking. Testing demonstrated that the Uster single-point calibration is applying a more complex correction than used in the single-point correction of Stelometer data. The round trials were initiated to assess the performance of the proposed two-point calibration routine. The coincidental release of the Uster Technologies software with an internal single-point calibration provided an opportunity to assess the performance of an alternative calibration scheme. An automated internal calibration would likely be preferable to performing calibration via post-processing of data for most users. Elongation calibration materials are needed regardless of the elongation calibration technique.

Overall, the use of FBRI developed high and low elongation calibration cotton and a two-point linear interpolation calibration does allow for HVI elongation values to be evaluated between instruments. A well-calibrated HVI is a viable replacement for the Stelometer to incorporate elongation into breeding and other research programs.

Table 8 Correlation and linear regression between Stelometer and HVI elongations on a single instrument

HVI Condition	R-squared	Slope	Intercept
Uncalibrated	0.94	1.07	−0.94
Single-point calibration, high elongation standard (V71)	0.93	1.12	−2.34
Single-point calibration, low elongation standard (V71)	0.96	1.20	−0.94
Two-point calibration	0.94	0.89	0.43

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Authors' contributions
Delhom CD conceived the methodology, constructed the cotton populations, conducted the formal analysis of the data, and wrote the manuscript. Hequet EF and Martin VB aided in the conceptualization of the experiment. Kelly B and Abidi N assisted with the curation of resources for the study. Martin VB assisted in the acquisition of funding for the study. All authors read, revised, and approved the manuscript.

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Competing interests
The authors declare that they have no competing interests.

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