35th INTERNATIONAL COTTON CONFERENCE BREMEN 2021

PAPER

Session:

Cotton Quality & Testing 2 (T5)

Presentation Title:

Developments and implementation of HVI elongation standards

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Presentations are available on the conference archive:

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DEVELOPMENT AND IMPLEMENTATION OF HVI ELONGATION STANDARDS

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Abstract
The textile industry is ever evolving and with that evolution comes the need for improved cotton fibre quality. In order to provide the supply of raw material needed by the textile industry, cotton breeders are continuously working to improve cotton traits. One are that has largely been ignored is elongation-to-break. The cotton community has ignored elongation due to the inability to rapidly test large numbers of samples and compare the results between laboratories. To address this shortcoming researchers have developed calibration materials for the measurement of elongation. The efficacy of these standards has been tested in an international round trial. The round trial results demonstrate that cotton fibre elongation may be successfully measured on HVI lines when results are adjusted through the use of elongation standards.

Introduction
The textile industry requires long and strong cotton fibres. As a natural material, the properties of cotton are inherently variable, and while this variation gives cotton many of its unique properties, it is desirable to have as fibres with as long length and high length uniformity as possible. Long fibres allow fine and strong yarns to be spun. The fibre length and length distribution of cotton are best prior to harvest. The harvesting, ginning, and processing of cotton from plant to fabric reduces the overall length of the fibres and the length uniformity due to fibre breakage. Fibre strength, or tenacity, is the most common focus for improving the ability of cotton to resist fibre breakage; however, it is a function of both fibre strength and elongation that determines the amount of energy required to break fibres. High volume instrument (HVI) measurements do not typically report the elongation values, although the instrument does measure the elongation-to-break while performing the bundle-strength test. The limitation has been that it is an uncalibrated value, and therefore, comparison between instruments is not practical.

The development and implementation of HVI elongation standards was undertaken to 1) allow elongation measurements to be compared between HVI lines, 2) enable cotton breeding programs to select for elongation in order to provide fibres that meet the needs of the textile industry, and 3) allow the textile industry and cotton researchers to better predict and understand fibre performance during processing. Implementation of HVI elongation standards required the development of the calibration materials and then the assessment of elongation measurements across a large number of HVI instruments. Once elongation standards were developed, the performance of the elongation standards was compared across 10 HVI lines in the United States and Australia located in four laboratories. The elongation standards allow for the variance within and between HVI lines to be accounted for in reporting test results.

Evolution of tensile testing

It has long been known that the tensile properties of cotton fibre are critical, and measurement of fibre strength became mainstream with the development of the Pressley Flat bundle tester in 1939. The Stelometer (Strength and Elongation Meter) was introduced in the 1950s as a successor to the Pressley (Orr et al., 1955). As the name implies, elongation was recognized as an important factor since the beginning of the mechanical testing of cotton. These early flat-bundle testers were purely mechanical in nature, and although tedious, served as the industry-standard measures for tensile properties until automated high-speed strength testing was developed in the 1960s by Motion Control Industries. However, Stelometer was a primary strength measurement until the 1990s.

The high-speed automated testing of cotton strength by Motion Control Industries established the principals of testing a tapered beard using automatic controls for placement of the jaws and eliminating the tedious nature of the testing. The main concepts of the Motion Control tester have been carried through to today's Standard Instrument for Testing Cotton (SITC), such as the Uster HVI and other instruments focused on high volume testing (Delhom et al., 2018).

The Pressley and Stelometer instruments produced different results due to differences in the rate of loading and gauge length (Kerr, 1954). It is also well understood that neither Pressley nor Stelometer provides identical test results as SITC methods (Sasser et al., 1991).

Testing a bundle of fibres, whether flat or tapered, has numerous challenges. Amongst them are addressing the natural crimp that exists in cotton fibres and ensuring that the results accurately represent all fibres in the sample and not just the strongest or weakest. Single-fibre testing can address the removal of crimp by pre-loading each fibre; however, it requires many tests to represent all fibres in the sample accurately. Additionally, bundle tenacity is typically lower than single fibre tenacity, largely due to variation in fibre elongation within the bundle (Sasser et al., 1991).

The Pressley and Stelometer instruments were calibrated using USDA International Calibration Cotton Standards (ICC), which provided known values for both strength and elongation for each instrument. As of 2011, the USDA Agricultural Marketing Service (AMS) no longer produces ICC calibration materials with Pressley or Stelometer values. SITC instruments can be calibrated with USDA AMS' Universal HVI Calibration Cotton Standards, but these standards only provide for calibration of length, length uniformity index, and strength, not elongation.

Tensile testing has evolved to provide the cotton industry with rapid and accurate measurements of fibre strength, but not so for elongation. While the SITC instruments are capable of measuring elongation-to-break and reporting the value, the instruments have been shown to give a wide variety of results due to lack of calibration materials and potential influences of specific instruments (Bargeron, 1998; Foulk et al., 2009; Long et al., 2013).

Development of elongation standards

Researchers at the Fiber and Biopolymer Research Institute of Texas Tech University in Lubbock, Texas, USA, previously demonstrated that HVI testing of cotton fibre elongation to effect change in cotton fibre quality was possible by using only a single HVI instrument for all testing (Hequet et al., 2014). As a result of this demonstration, work was begun to develop elongation standards which would allow the comparison of elongation data across HVI instruments.

A large number of commercial bales were examined as potential candidate bales, from which 44 bales were purchased for further testing. The 44 bales were further tested, and 10 bales of high elongation and 10 bales of low elongation cotton were identified. The 10 selected bales of high and low candidate bales were further screened with Stelometer testing to identify the highest (HEB) and lowest elongation bales (LEB). The final HEB and LEB bales were processed through an opening line to blend the fibres and increase the uniformity (McCormick et al., 2019).

As reported by McCormick et al. (2019), the HEB and LEB cottons were subjected to stability testing that demonstrated both the short- and long-term stability of the elongation measurements within HVI lines. The work was performed on three HVI lines for 30 days of testing.

Implementation of elongation correction

At the time this research began, Uster HVI 1000 instruments did not have any elongation calibration ability within their software. Length, strength, and micronaire are calibrated by providing known values to the software for a high-value and low-value cotton for each property and then testing these cottons. The HVI software internally calibrates the results using those two-points. The elongation calibration is performed in a similar manner but must be done in a post-testing process external to the HVI. The HEB and LEB cottons are tested in the same manner as other calibration cottons before testing of experimental samples begins each day. The reported elongation value for the experimental samples can be calibrated by using a simple linear interpolation formula, as shown in Equation 1.

$$y = \frac{y_0(x_1 - x) + y_1(x - x_0)}{x_1 - x_0} \qquad \text{(Equation 1)}$$

y = corrected elongation value
x = measured elongation value
x_0 = measured value low elongation calibration material
y_0 = reference value of low elongation calibration material
x_1 = measured value high elongation calibration material
y_1 = reference value of high elongation calibration material

During the conduct of this research, Uster Technologies released Version 71 of the HVI 1000 software. This software version provided an elongation calibration option using a single point. No commercial elongation calibration cotton was provided nor was available for routine purchasing. Additionally, the operator would have to decide whether to use a high, low, or average calibration material for this single data point. It is interesting to note that no other HVI parameter is calibrated using a single point.

Independent verification of elongation standards

Researchers at Texas Tech University had demonstrated the potential for HVI elongation calibration to be feasible using the calibration cottons which they had identified. However, the work had not been assessed outside their laboratory. In order to independently verify the performance, USDA Agricultural Research Service (ARS) researchers undertook the planning and execution of an international round trial. Five laboratories across the US and Australia with a total of 10 HVI 1000 lines participated in the round trial. Testing followed the protocols established by the International Cotton Advisory Committee Task Force on Commercial Standardization of Instrument Testing of Cotton (CSITC) round trials in which each experimental and elongation calibration cotton was tested with six replications per day for five days. All test results were sent to ARS for analysis.

To conduct the round trials, ARS selected six cottons based on Stelometer testing at both ARS and FBRI laboratories. The six cottons represented a range of 4.9 to 8.1% elongation on the Stelometer. Unlike the FBRI testing of the HEB and LEB cottons, the six cottons were commercial bales, sampled for testing as-is with no additional blending to improve the uniformity of the properties. Participating laboratories were supplied with several pounds of each of the six cottons and two calibration materials. The HVI 1000 instruments represented both classing and mill instruments. The participating laboratories are active participants in monthly AMS check tests and quarterly CSITC round trials which ensure the instruments are in proper working order. All testing was conducted under standard atmospheric conditions per ASTM D1776 (2016).

Results and Discussion

One goal of instrument testing of cotton is to allow for the comparison of results between instruments. This allows a sample tested in one laboratory to be retested in another laboratory and the results compared. In order to accomplish this, the variance of cotton must be addressed. It is well understood that cotton fibre properties are inherently variable within a sample; however it is not known how elongation compares to other properties. Table I illustrates the variance of fibre quality for the six cottons across the ten HVI lines. Similarly, the means of elongation values for all testing were examined across the ten HVI lines (Figure 1).

Table I. Variance of six cottons across ten HVI lines

Property	Average CV%
Micronaire	1.73
Strength	3.41
UHML	1.32
Uniformity Index	0.86
Uncalibrated Elongation	34.05
Calibrated Elongation	5.22

The HVI lines were randomly identified by number, 1-10 and the six experimental cottons were randomly assigned a letter, A-F. Figure 2 illustrates the 95% confidence interval for the mean value of uncalibrated, raw, elongation value for each cotton and HVI line, while Figure 3 shows the same information after calibration is performed. Table II provides an alternative look at this data. It is readily apparent that calibration significantly reduces the variance between HVI lines for a given cotton. Although calibration reduced the variance between HVI lines and altered the means, the ranking of the cottons, from lowest to highest elongation values, did not change nor did the statistical rankings. However, it is also apparent that some cottons are inherently more variable than others. At least for this dataset, the variance was higher for the higher elongation value cottons. It is important to recall that the test cottons were selected for their average elongation value and not for their low variance, such as in calibration materials.

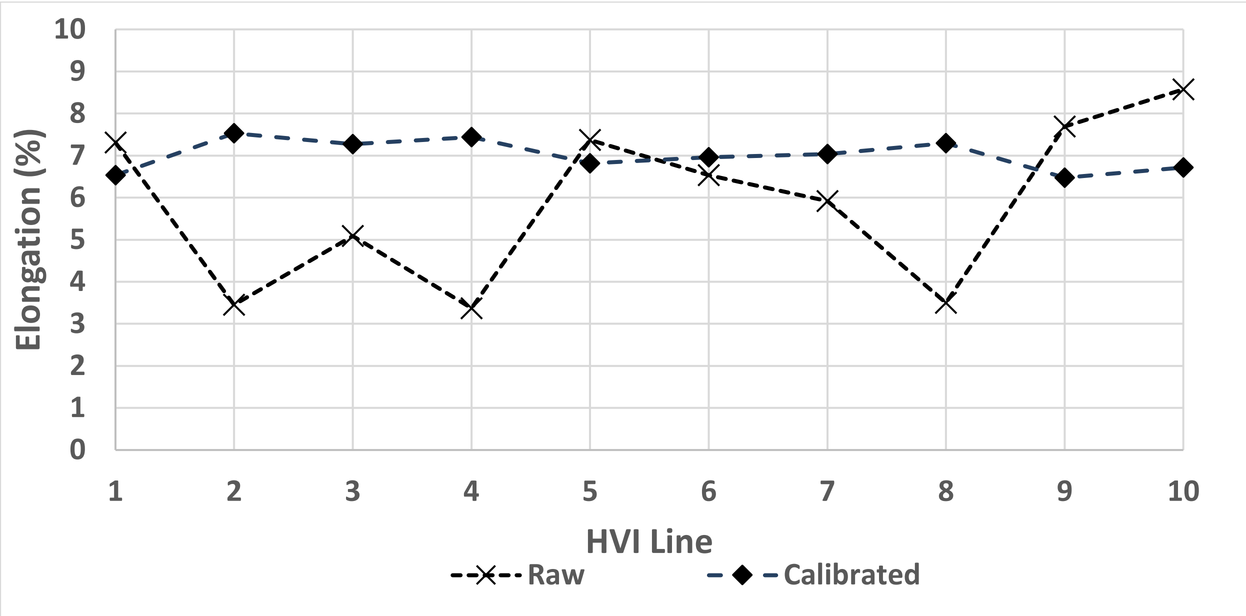

Figure 1. Elongation means of all cottons and all days by HVI line

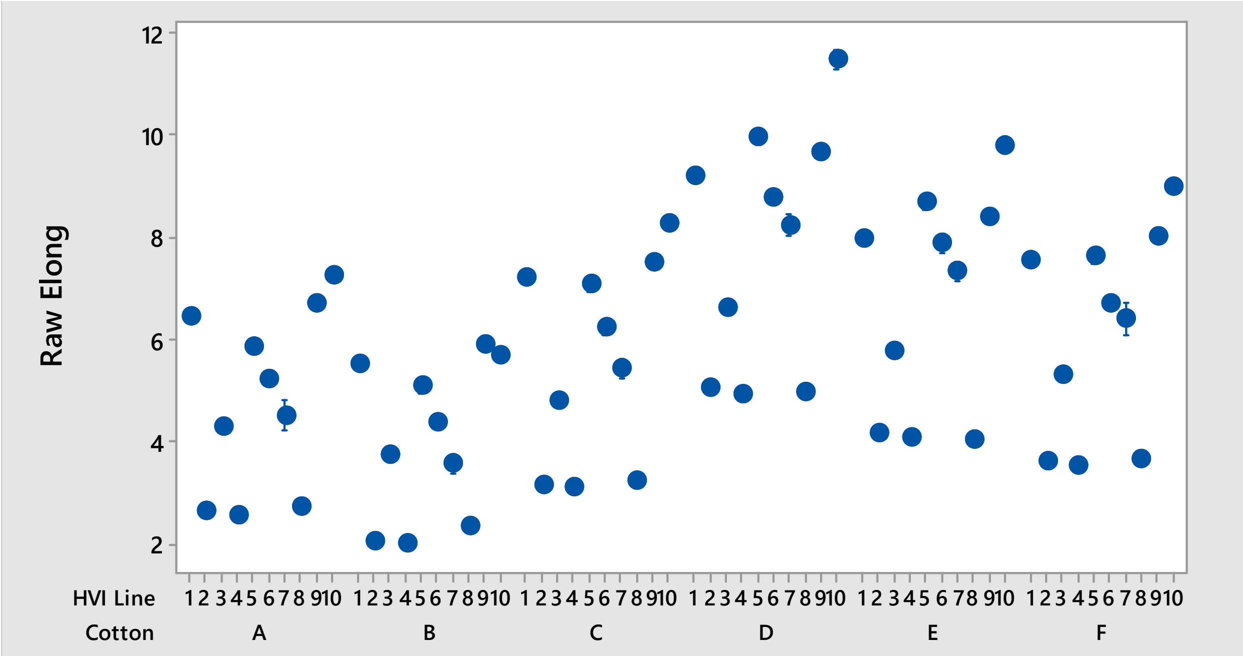

Figure 2. 95% confidence interval of uncalibrated HVI elongation by cotton and HVI line

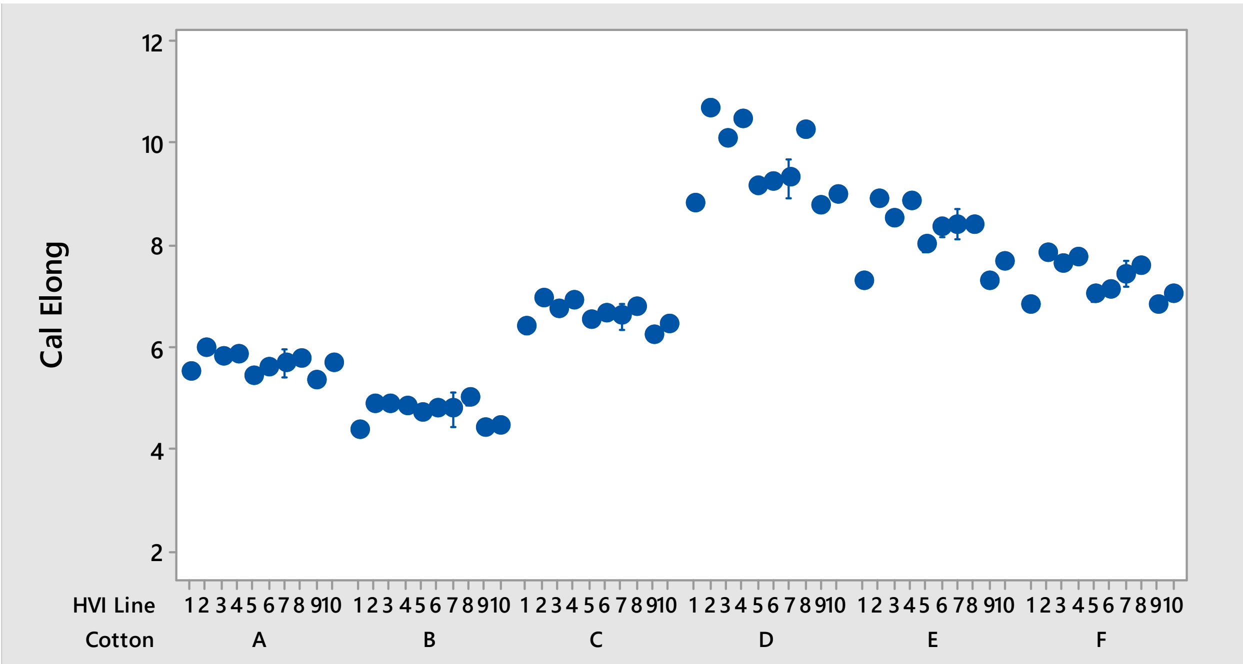

Figure 3. 95% confidence interval of calibrated HVI elongation by cotton and HVI line

Table II. Elongation variance across HVI lines

Cotton	Uncalibrated Elongation (%)	Uncalibrated CV(%)	Calibrated Elongation (%)	Calibrated CV(%)
A	4.82e	36.55	5.67e	3.52
B	4.04f	37.47	4.72f	4.60
C	5.60d	34.88	6.63d	3.37
D	7.81a	31.46	9.56a	7.48
E	6.81b	31.21	8.16b	7.12
F	6.13c	32.73	7.31c	5.21

Means that do not share a letter are significantly different (Tukey-Kramer test $p>0.05$)

Table III shows the average results of the six cottons for each HVI line. The average results range from 3.45 to 8.57 before calibration. It should be expected that the mean values of the cottons should be the same on each HVI line. However, even after calibration, there is still some variance between HVI lines, although it is significantly reduced.

Table III. Elongation within HVI lines

HVI Line	Uncalibrated Elongation (%)	Calibrated Elongation (%)
1	7.31	6.54
2	3.45	7.53
3	5.09	7.27
4	3.37	7.44
5	7.37	6.82
6	6.53	6.96
7	5.92	7.03
8	3.50	7.29
9	7.69	6.48
10	8.57	6.72
Average	5.88	7.01
CV(%)	38.65	23.93

The use of a two-point calibration for elongation via a pair of high- and low-elongation standards has significantly reduced the variance between HVI lines. This work allows elongation-to-break results to be compared between HVI lines, which in turn enables breeders and others to utilize elongation data from HVI lines in a way that previously had not been possible.

Single-point calibration

As previously mentioned, during the conduct of this research, Uster Technologies released Version 71 of the HVI 1000 software which provided for a single-point internal calibration of elongation. It is not documented exactly how the single-point calibration is utilized within the software, however, typically, a single point calibration is used to create a correction factor (F_c) as shown in Equation 2, and then the observed value is corrected with that factor, Equation 3. For example, this is how elongation is corrected during Stelometer testing (ASTM D1445, 2012). One challenge for this approach is selecting the appropriate calibration material. The Version 71 software was installed on a single HVI line during the round trial and tested with both the HEB and LEB materials as the single point (Figure 4).

$$F_c = C_s / C_o \qquad \text{(Equation 2)}$$

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

$$E_c = E_o F_c \qquad \text{(Equation 3)}$$

E_c = corrected elongation
E_o = observed elongation

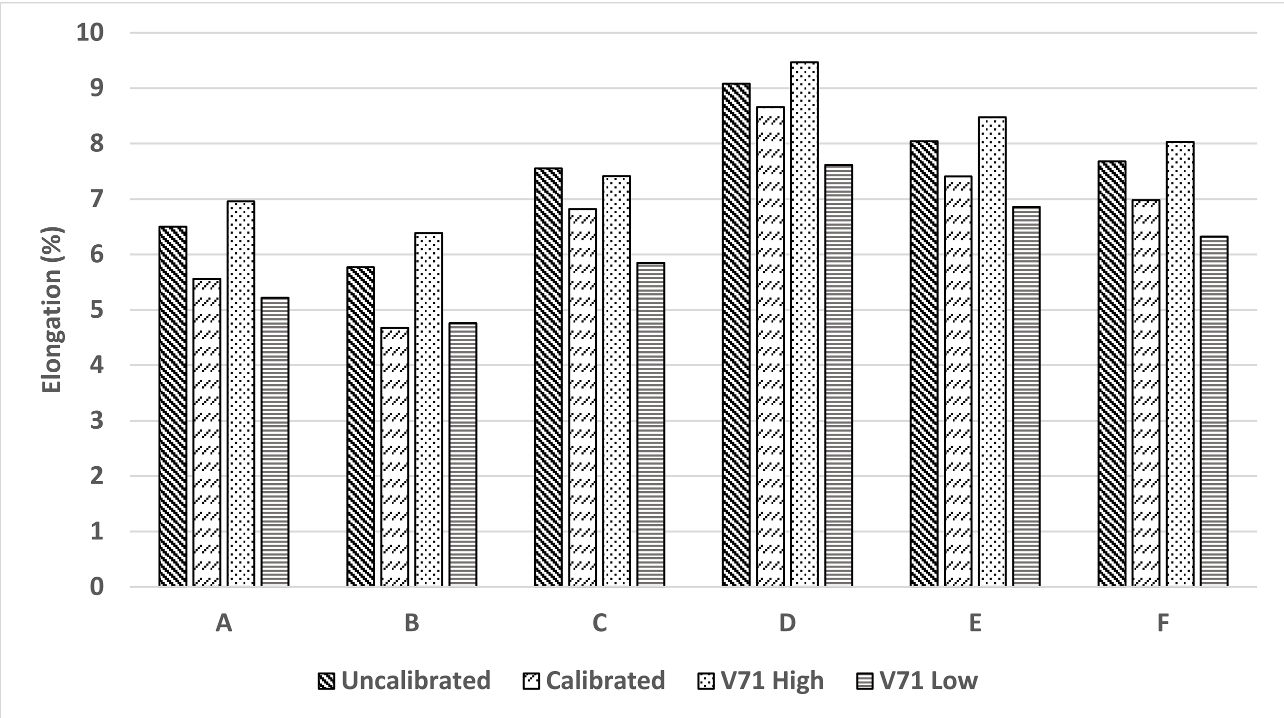

Figure 4. Comparison of calibration methods for a single HVI

As expected, the use of the single-point calibration raised the elongation value, in comparison to the uncalibrated elongation value when the high-elongation value was used and lowered the elongation value when the low-elongation material was used to calibrate. The two-point calibration routine can be seen to be more sensitive as for some samples the value is close to the single-point low calibrated value and for other samples, the value is closer to the single-point high calibrated value. Interestingly, cotton C was the only sample in which all calibration techniques resulted in a lower value than the raw measurement.

Conclusion

The development and implementation of HVI elongation standards were undertaken. This work allows for elongation measurements to be successfully and accurately compared between HVI lines. The ability to accurately measure elongation-to-break of cotton fibre bundles will enable cotton breeding programs to select for elongation and provide fibres that meet the ever-changing needs of the textile industry. As shown, the calibration techniques significantly reduced the variance between instruments. Implementation of HVI elongation standards can be performed outside of the HVI software in post-processing of the data merely by implementing routine testing of a high-elongation and a low-elongation standard.

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