BREEDING FOR BETTER FIBER ELONGATION: A KEY TO IMPROVING YARN TENSILE PROPERTIES

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Cotton breeding programs must deliver fibres that perform better in textile manufacturing in order to compete effectively with various man-made fibres and with international growths of cotton. While strength (tenacity) of cotton fibres is a focus of these programs, the elongation of the fibres is not. Yet, it is the strength/elongation properties that determine the amount of energy (often called the work-to-break) required to break either a fibre or a yarn and work-to-break is critically important to processing performance.
Producers depend on breeders to develop elite varieties with a potential to produce fibre with improved tensile properties. Breeding for improved HVI strength without considering elongation does not always lead to an improvement in the total work-to-break. Substantial tensile property improvements can be made by breeding for both strength and elongation.

Developing the cotton fibre of the future depends on developing methods to select for fibre elongation. It is possible to use a single HVI instrument to make transformative changes in cotton fibre quality. Unfortunately, the lack of HVI calibration standards inhibits the interpretation of the elongation parameter across multiple instruments. Requiring a single HVI to test all entries limits the use of HVI elongation as a breeding parameter. Therefore, the creation of HVI calibration standards for elongation is imperative for the development of cotton varieties able to serve the needs of high-value markets.

Cotton breeding programs must deliver fibres that perform better in textile manufacturing in order to compete effectively with various man-made fibres and with international growths of cotton (Meredith et AL., 1991). While strength (tenacity) of cotton fibres is a focus of these programs (May et al., 1999), the elongation of the fibres is not. Yet, it is the strength/elongation properties that determine the amount of energy (often called the work-to-break) required to break either a fibre or a yarn and work-to-break is critically important to processing performance (Meredith, 1945). Work-to-break is especially important at three junctures:

- **Ginning** – The cleaning and removal of fibres from the seeds create stresses that break fibres which lack sufficient strength and elongation, resulting in elevated short fibre content (SFC).
- **Opening and Carding** – These indispensable steps prior to spinning achieve the final cleaning of the fibres and arranges them into a continuous bundle of parallel fibres (called a sliver). The Short Fibre Content (SCF) generated by these mechanical processes is negatively correlated with fibre strength and elongation.

- **Weaving** – Forming the spun yarns into a fabric on a weaving machine provides the ultimate test of yarn performance. Low levels of yarn breakage are required for achieving both the requisite weaving efficiency and fabric quality. Weaving has always been an abrasive and stressful process, but the speeds of modern weaving machines have magnified these problems.

Given the demands made on yarns in weaving, it is clearly inadequate to rely on the traditional concept of tenacity to achieve desired performance levels. Yet, most of the cotton breeding industry is relying only on the HVI bundle strength of cotton fibres and ignores elongation. The main reason for this lack of interest in elongation is the absence of HVI calibration cottons for elongation (Benzina et al., 2007). Typically, results from multiple HVIs across multiple days are used to evaluate entries in breeding programs. HVI measurements are calibrated across instruments using USDA cotton calibration standards making it possible to compare results from different instruments over a long period of time. In addition, cotton testing laboratories use cottons of known values throughout the day to check for a possible drift in measurements over time. While calibration cottons are available for most HVI fibre properties, none are available for HVI elongation (Benzina et al., 2007). This prevents the comparison of elongation measurements between separate HVI instruments and over time.

It is well known that yarn quality depends on a combination of many fibre properties (El Mogahzy et al., 1990). Cotton breeders, when making selections, can only improve yarn quality by taking into account the complete fibre quality profile. When considering tensile properties, a slight negative trend between tenacity and elongation has been observed between cotton bales of diverse backgrounds (May et al. 1998). In a sampling of 547 wild-type cotton cultivars, a slight yet significant negative relationship was observed (R^2=0.131; Figure 1). Similarly, a sampling of 567 commercial bales revealed an identical slight negative trend (R^2=0.251; Figure 2). Nevertheless, the low coefficient of determination should make it possible to improve both tenacity and elongation. For improving tensile properties based on HVI measurements, the situation is somewhat difficult because in addition to the negative correlation reported above, HVI elongation lacks calibration cotton standards. Therefore, it has been largely overlooked as a parameter for developing new cotton varieties.

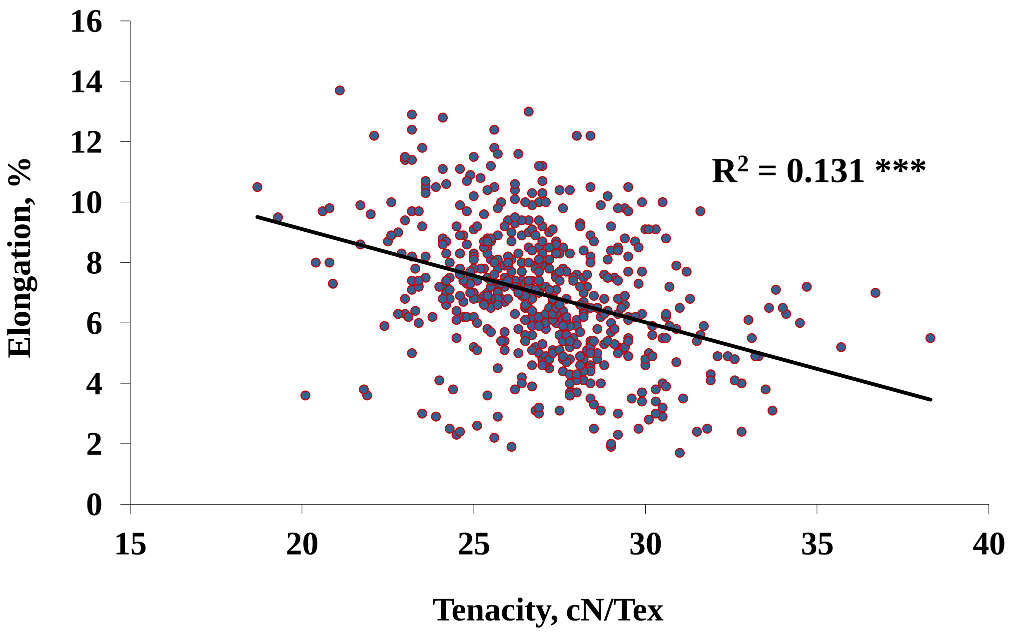


Figure 1. Elongation vs. HVI tenacity. 547 wild-type cotton samples

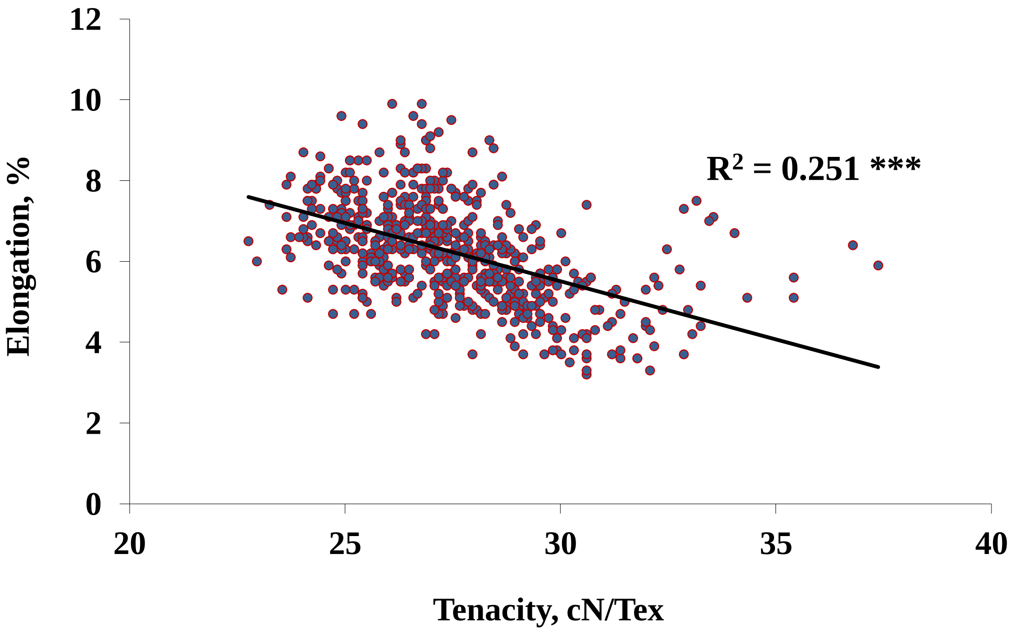


Figure 2. Elongation vs. HVI tenacity. 567 commercial varieties

This paper reports on the potential benefit of using HVI elongation for developing varieties with improved tensile properties. In the first experiment, the slight negative relationship between bundle tenacity and elongation is investigated. The need for calibration standards when comparing between HVIs is demonstrated in the second experiment. The third experiment characterizes the stability of the HVI elongation measurement. Experiment four demonstrates the potential advantage of using HVI elongation and the impact of improved elongation on yarn quality. Finally, the results from a breeding program based on HVI Elongation from a single instrument are presented.

Experiment 1: Is it possible to improve fibre strength and elongation simultaneously?

HVI provides fibre bundle tensile properties. A beard of fibres is clamped and broken to assess fibre bundle tenacity and elongation. However, bundle test measurements may not be the best indicator of spinning performance as stress on individual fibres leads to breakage during industrial processing. Thus, it is important to establish the within sample relationship between individual fibre tenacity and elongation.

The 104 cotton fibre maturity reference bales developed at the Fiber and Biopolymer Research Institute in Lubbock, TX (Hequet et al., 2006) exhibit a slight negative relationship between bundle force-to-break and elongation. A subset of 32 bales was selected to investigate the relationship between individual fibre force to break and elongation. A total of 450 fibres (150 fibres x 3replications) from each of the 32 bales were tested on a FAVIMAT tensile tester at a 3mm gauge length. FAVIMAT provides the force-to-break, elongation, and work-to-break of individual cotton fibres.

The within sample relationship between individual fibre elongation and force-to-break for two representative bales are illustrated in Figures 3 and 4. A significant positive relationship between individual fibre force-to-break and elongation within sample can be observed. Fibres that have higher force to break tend to have higher elongation.

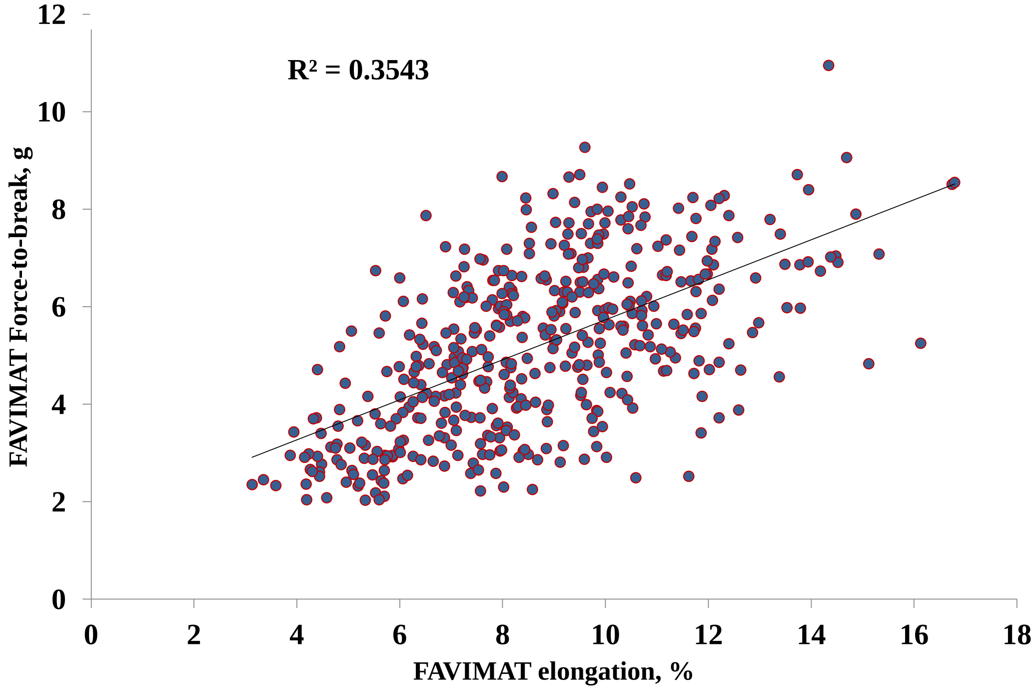


Figure 3. Bale 2684: Relationship between elongation and force-to-break (individual fibres)

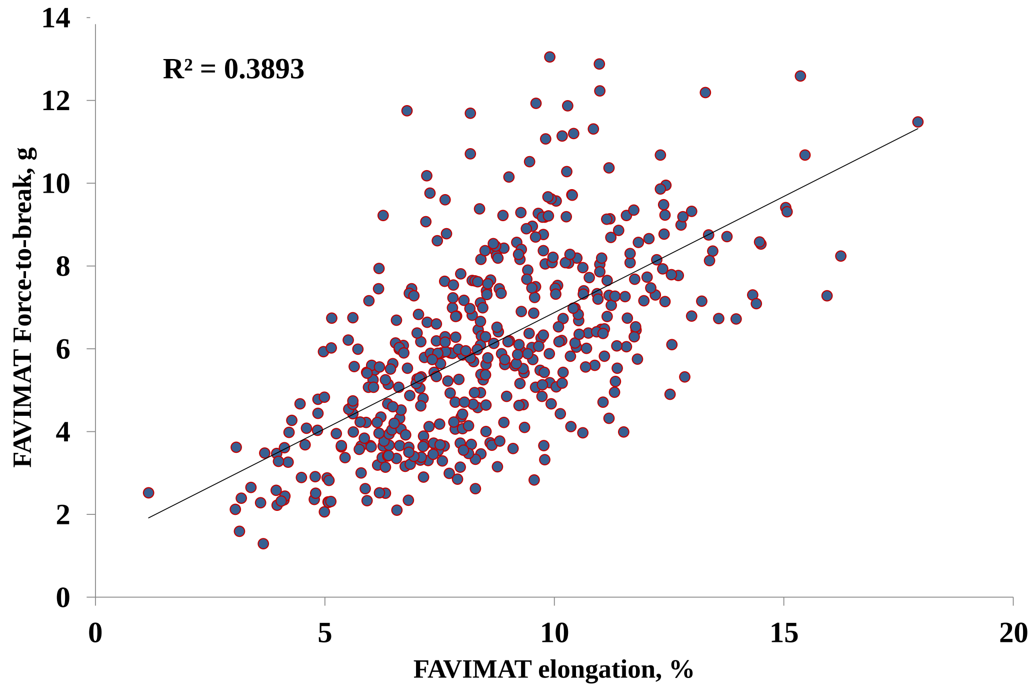


Figure 4. Bale 3004: Relationship between elongation and force-to-break (individual fibers)

The same type of relationship was observed for all the bales tested. Figure 5 summarizes the correlation of individual fibre force-to-break (Blue) and tenacity (Red) with individual fibre elongation. There is a positive relationship for every one of the sampled bales. Individual fibres with high force-to-break and tenacity tend to also exhibit higher levels of fibre elongation.

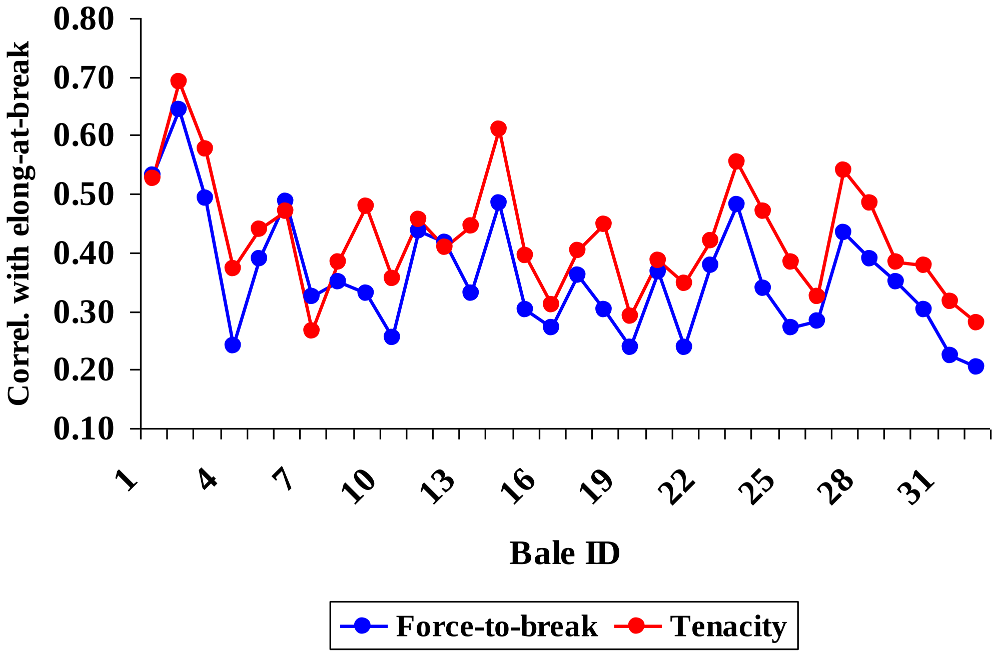


Figure 5. Correlation between force-to-break, tenacity, and elongation-at-break: 32 bales (individual fibres)

Contrary to the slight negative correlation between bundle strength and elongation, individual fibres with high strength tend to exhibit higher elongation. This indicates that both fibre elongation and force-to-break may be improved without compromising each other. Improvements of both force-to-break and elongation will lead to fibres with improved work-to-rupture. It is therefore important to establish if variability in fibre elongation is sufficient for genetic gain.

The variability of force-to-break and elongation exhibited by the 32 sample bales is illustrated in Figures 6 and 7. The normalized dynamic range of the average individual fibre force-to-break among the 32 bales is 20.6%. The normalized dynamic range for the average individual fibre elongation of 56% is much greater than the one for force-to-break. This is not surprising because, despite the parameter's importance, fibre elongation is not typically considered in cotton breeding. A wide dynamic range indicates a large potential for genetic gain for individual fibre elongation. All things being equal, selecting for individual fibre elongation offers a potentially more efficient means for improving the total work-to-rupture of cotton fibre when compared to tenacity. However, individual fibre elongation measurement with FAVIMAT is time consuming and is not well suited for breeding.

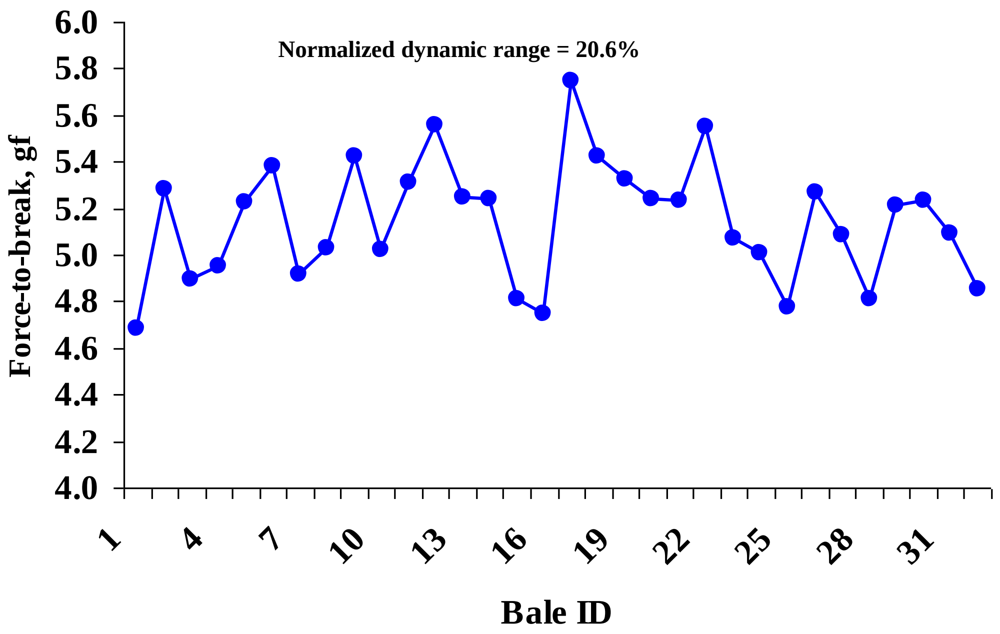


Figure 6. FAVIMAT Force-to-break: 32 bales – Normalized dynamic range: 20.6%

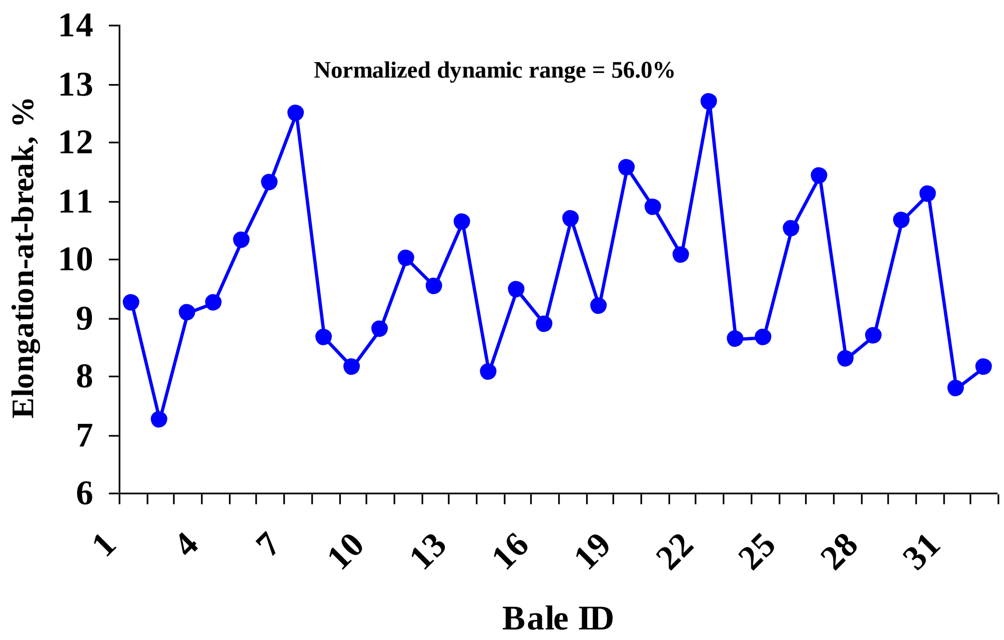


Figure 7. FAVIMAT Elongation-at-break: 32 bales – Normalized dynamic range: 56.0%

In contrast, HVI provides breeders with an expedient and affordable measure of fibre bundle tensile properties. HVI fibre bundle strength is commonly used in many breeding programs. HVI could be used to improve elongation if bundle measurements were related to individual fibre elongation. Average FAVIMAT individual fibre elongation for a sample accounts for 80% of the variability in HVI bundle elongation (Figure 8). Despite the slight negative correlation between HVI force-to-break and HVI elongation, these results indicate that HVI elongation has potential as a selection criterion for improving the total work to rupture.

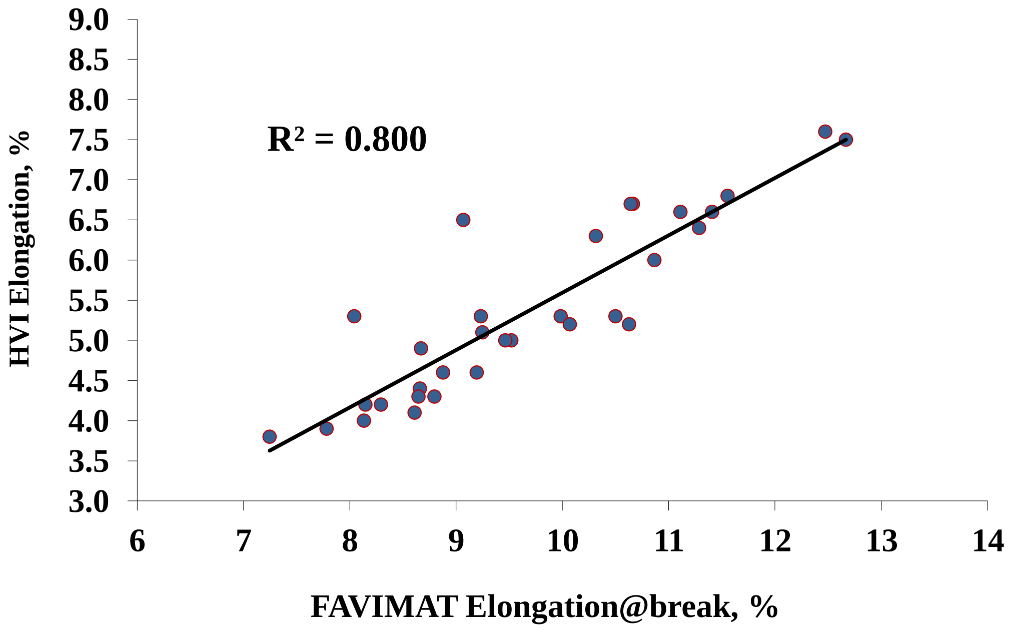


Figure 8. Relationship FAVIMAT – HVI. Elongation-at-break. R^2 = 0.80

The total work-to-break of a fibre or bundle is a function of both the load required to break and the elongation before rupture. This relationship for any fibre bundle is represented by a unique stress strain curve. While the stress strain curve is unavailable from HVI, the total work to break should be proportional to the product tenacity*elongation. A combination of both tenacity and elongation accounts for 89.4% of the variability in work-to-break among the 32 sample bales (Figure 9). Therefore, improving both elongation and tenacity should result in an improvement in the total work required to break the fibres.

Figure 10 illustrates a potential pitfall of omitting elongation as a selection criterion. The horizontal axis is HVI tenacity, the vertical axis is work-to-break, and the upward sloping lines trace the impacts of alternative HVI elongation values. The total work-to-break of the sample is determined by selecting a combination of HVI tenacity and elongation.

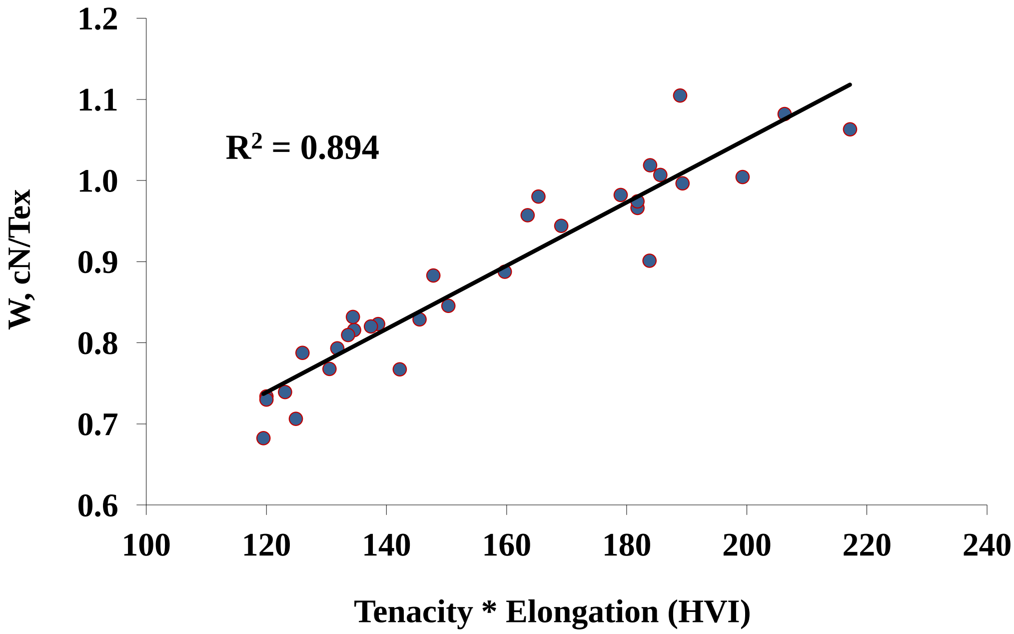


Figure 9. Work of rupture W vs. HVI Tenacity * Elongation. R^2 = 0.894

The red dot in Figure 10 represents the control line and has a Tenacity of 24cN/Tex with an elongation of 6%. The green and the black dots represent potential selections. The black dot represents a selection based solely on HVI tenacity, while ignoring elongation. The green dot is an entry that offers no improvement in tenacity and may potentially be overlooked.

The entry represented by the black dot at 28cN/Tex exhibits a 4 cN/Tex improvement in HVI tenacity over the control. The entry represented by the green dot has the same HVI tenacity as the control. If HVI tenacity is the only tensile property considered, the entry represented by the black dot would be favoured.

However, the entry represented by the black dot exhibits a 1% reduction in HVI elongation compared to the control while the entry represented by the green dot exhibits a 2% increase. A 2% increase in elongation is a very realistic improvement based on the differences observed in the experimental bales (Figure 6). While the entry represented by the black dot would be favoured in a screening considering only HVI tenacity, it has a 20% reduction in total work-to-break. Despite no improvement in tenacity, the entry represented by the green dot exhibits a 30% improvement in total work-to-break over the control. Thus, the entry represented by the green dot has a greater improvement in work-to-break and should be favoured.

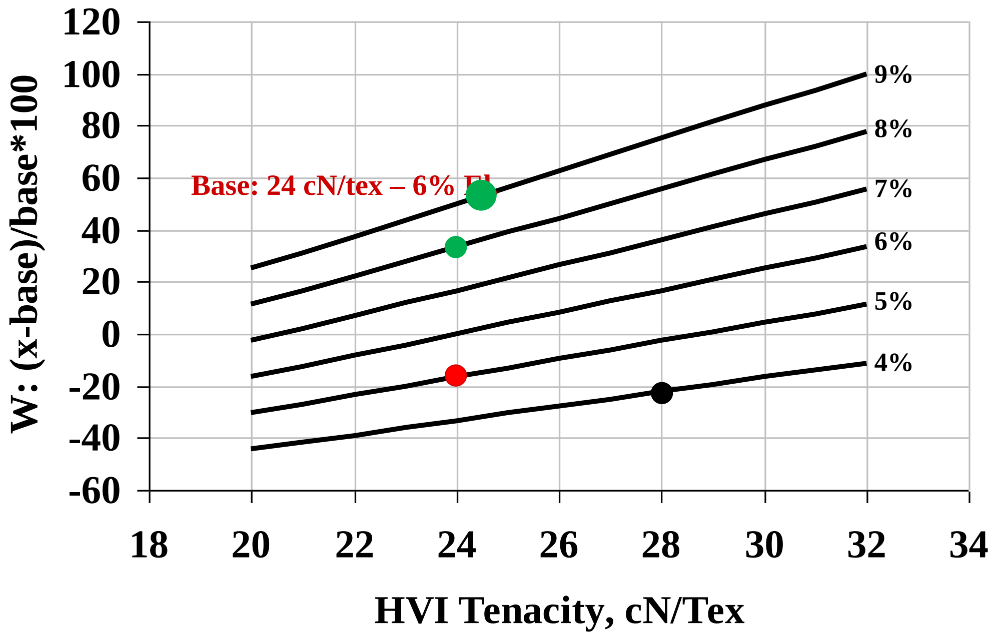


Figure 10. Estimated HVI work-of-rupture W vs. HVI Tenacity for selected elongations

These results show that both tenacity and elongation must be considered when improving work-to-break. Ignoring one parameter may compromise improvement in the total work-to-break. HVI elongation relates well to the average individual fibre elongation for the 32 bales considered here. However, HVI lacks calibration cottons for elongation. Before HVI can be used as a selection parameter, it is important to establish that HVI elongation is repeatable between machines and the measurement is stable over time.

Experiment 2: *Is HVI assessment of fibre elongation reliable between instruments without cotton calibration standards? What are the implications for cotton breeding programs?*

Entries in a breeding program are classified with many HVI systems. Each HVI must be calibrated for reliable comparison between instruments. In this experiment, 8 cotton bales were selected in order to represent a wide range of strength and elongation for comparison between HVI systems. Fibres from each bale were homogenized in preparation for repeated HVI testing. The homogenized fibre from each cotton bale was sampled 8 times a day for testing on 3 different HVI systems (4-4-10). This protocol was repeated for 36 days.

The 36 day moving average is summarized for one of the HVIs in Figures 11 and 12. The moving average over the 36 days reveals that the measurement for HVI tenacity is very repeatable during the testing period (Figure 11). HVI elongation is slightly more variable but it is still acceptable. This shows that HVI provides measurements of strength and elongation that could be used in a breeding program.

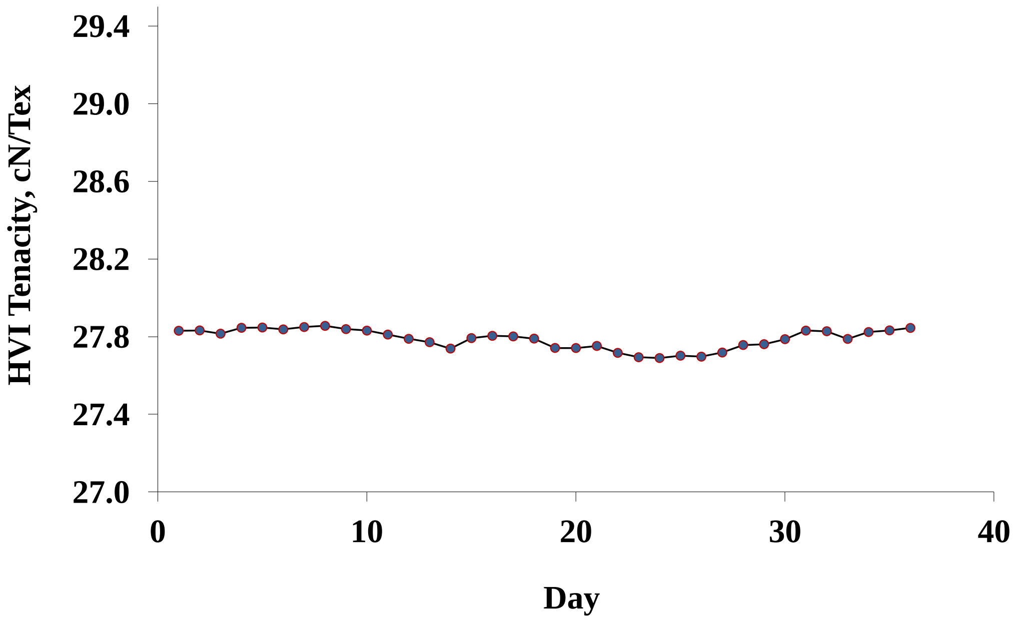


Figure 11. Exponentially weighed moving average for HVI tenacity

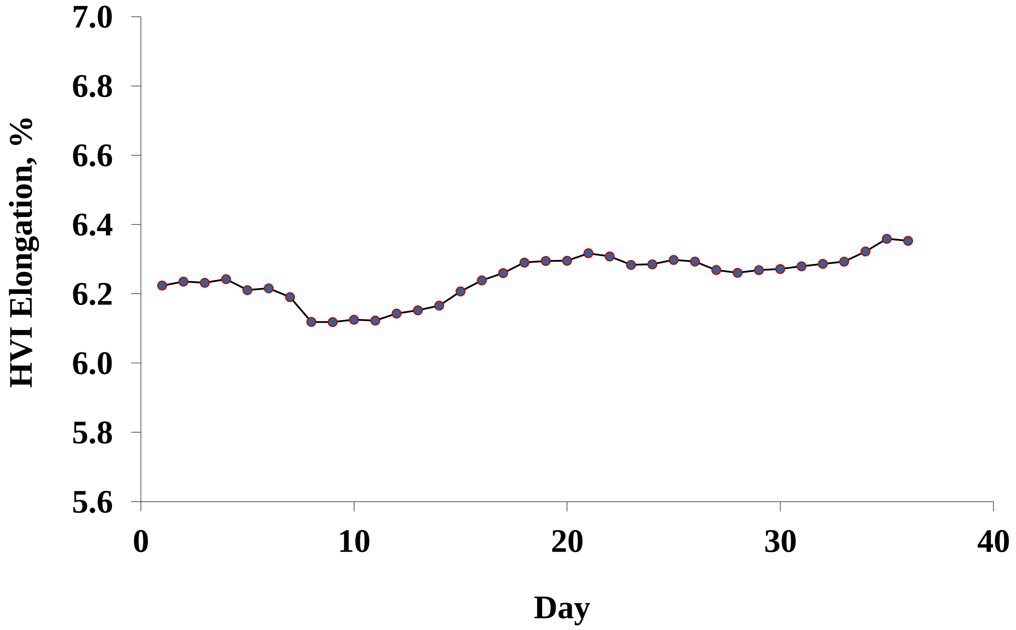


Figure 12. Exponentially weighed moving average for HVI elongation

The repeatability across HVI instruments is shown in Figures 13 and 14. HVI tenacity is highly repeatable across HVI instruments (Figure 13). Strength measurements from HVI 1 can be directly compared to HVI 2, and to HVI 3, i.e., the slopes are not statistically different. Bundle strength of a cotton sample can be reliably assessed across HVI instruments allowing for multiple HVI instruments in screening for HVI tenacity.

HVI elongation is not as stable across multiple HVI instruments. There is a level shift in the measurement of HVI elongation between the HVI systems in this experiment. HVI elongation should not be compared across multiple instruments without calibration standards.

These results demonstrate that the measurement of HVI elongation is repeatable enough for use in a breeding program. However, the lack of calibration standard makes it difficult to compare HVI elongation across multiple HVI instruments. The next experiment will consider the possibility of using a single HVI instrument in order to evaluate entries for improved tensile properties despite not having calibration standards.

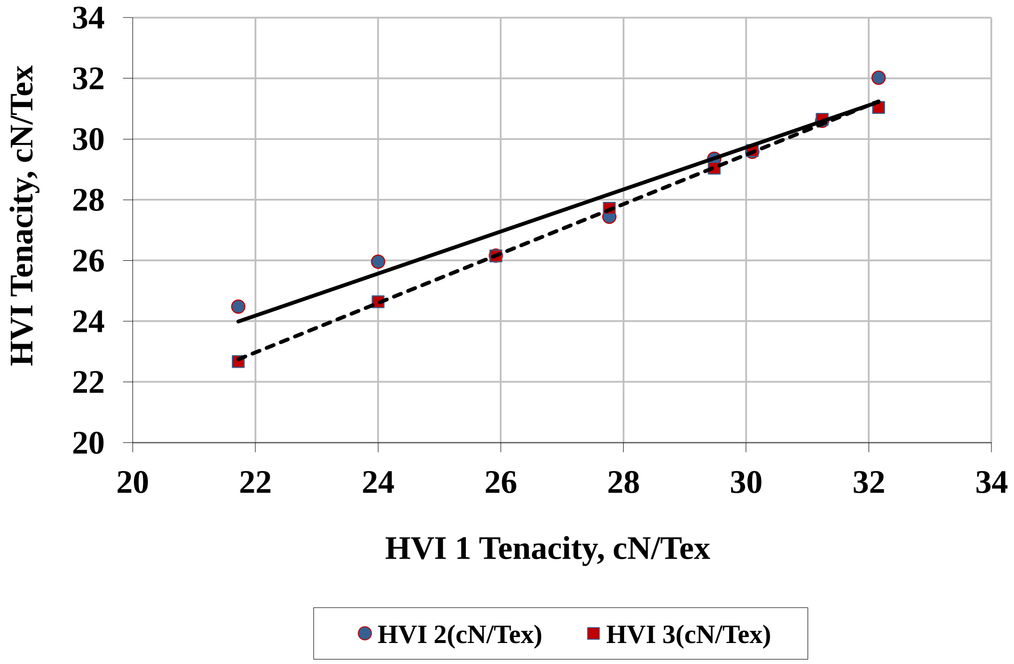


Figure 13. Tenacity HVI 2 and HVI 3 vs. HVI 1

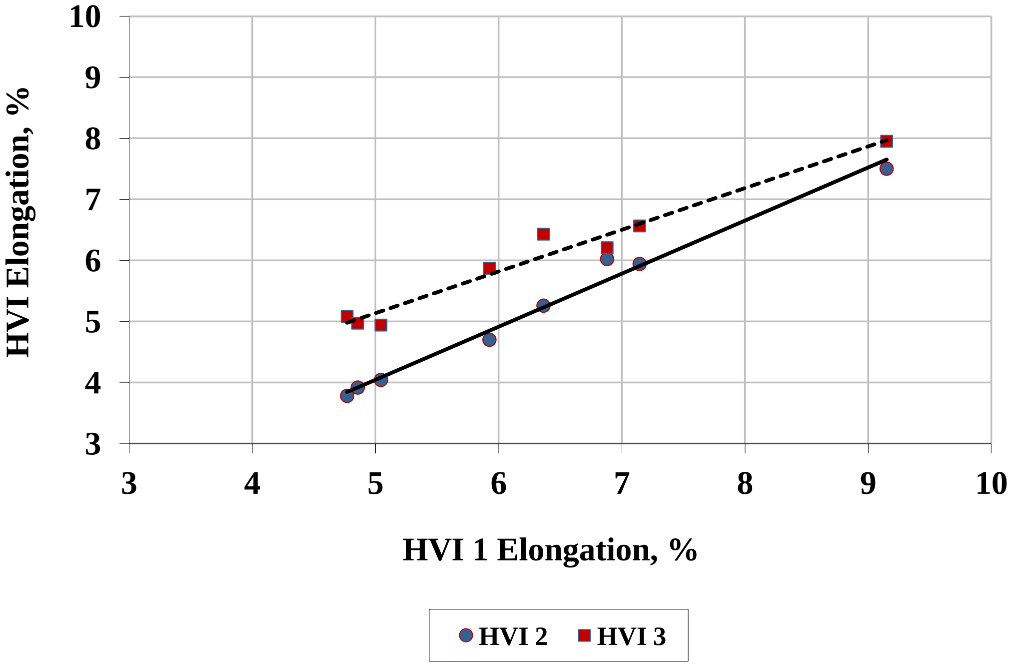


Figure 14. Elongation HVI 2 and HVI 3 vs. HVI 1

Experiment 3: *Repeatability of HVI tensile properties - Is it possible to rely upon HVI elongation as a selection parameter?*

The previous experiment established the repeatability of the HVI elongation measurement. However, a shift in the level of HVI elongation when measured with separate instruments illustrates the need for calibration standards. Without calibration standards available, it is necessary to consider an alternative approach for developing varieties with improved tensile properties.

A level shift in the measurement can be avoided by utilizing a single HVI instrument for breeding and check cottons (in-house standards) to verify that no drift occurred during the testing period. Three bales were selected with a wide range of strength and elongation in order to investigate the possibility of utilizing a single HVI instrument for evaluating elongation. The bales were homogenized according to the ICCS (International Cotton Calibration Standard committee) protocol. Card web was produced from each of the three bales. The card web was sampled and tested on HVI (4 micronaire readings, 4 colour readings, and 10 length/strength readings). This protocol was repeated 6 times a day for 3 days.

The repeatability of HVI tenacity during the testing period can be seen in Figure 15. The HVI instrument consistently ranks the bales based on HVI strength over the 18 measurements. The coefficient of variation (CV%) of the measurement is a mean standardized measurement of standard deviation. It is desirable to utilize measurements that exhibit a low CV%. The CV% of HVI tenacity is very good, i.e., well below 5% (Figure 16).

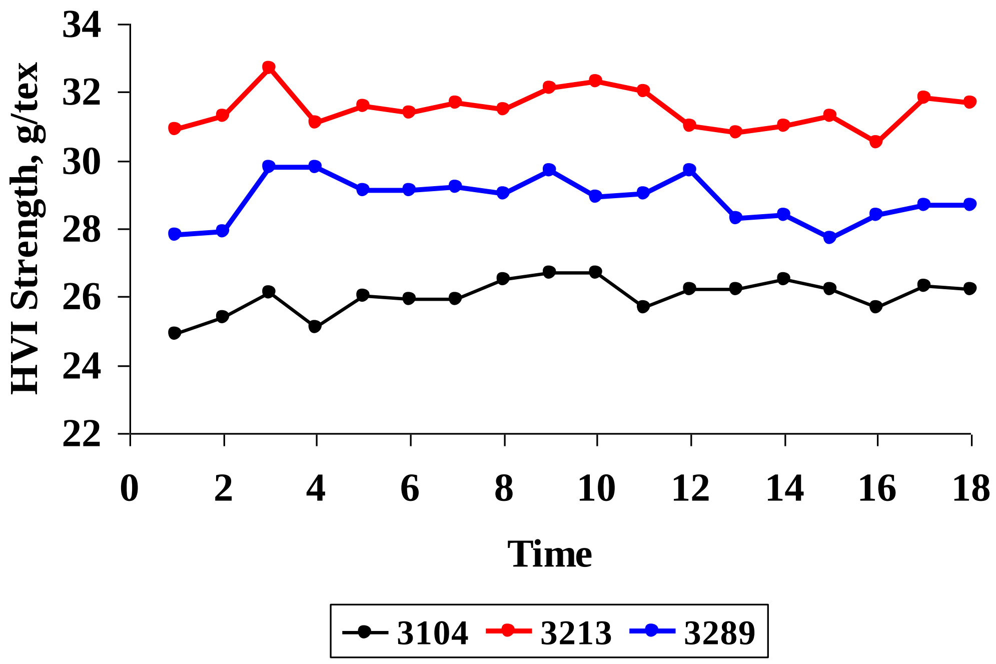


Figure 15. Repeatability of HVI tensile properties

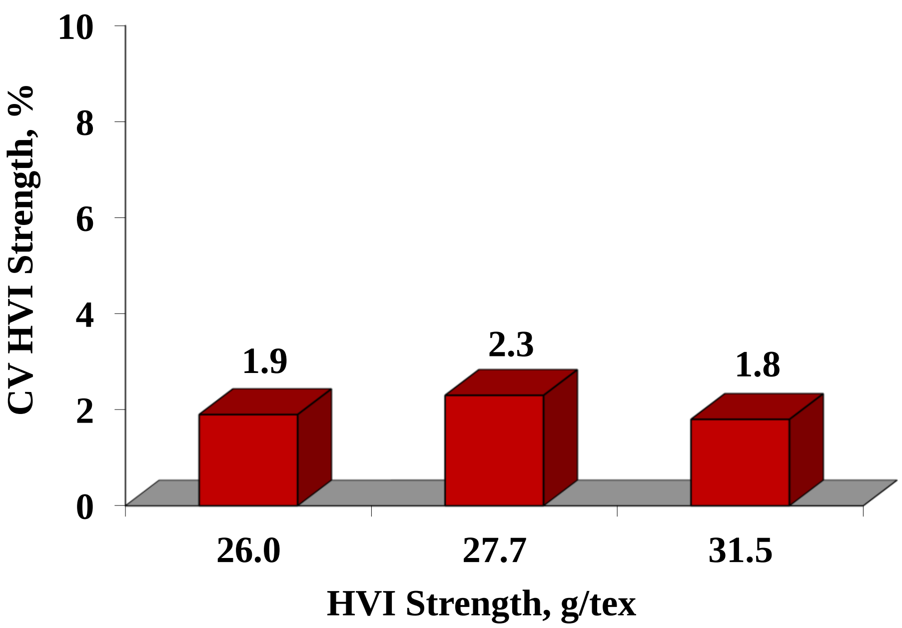


Figure 16. Repeatability of HVI tensile properties (CVs)

The repeatability of HVI elongation is illustrated in Figure 17. The lack of check cotton is apparent as there is a slight drift in the measurement of the high elongation cotton. The CV% for HVI elongation is higher than desirable.

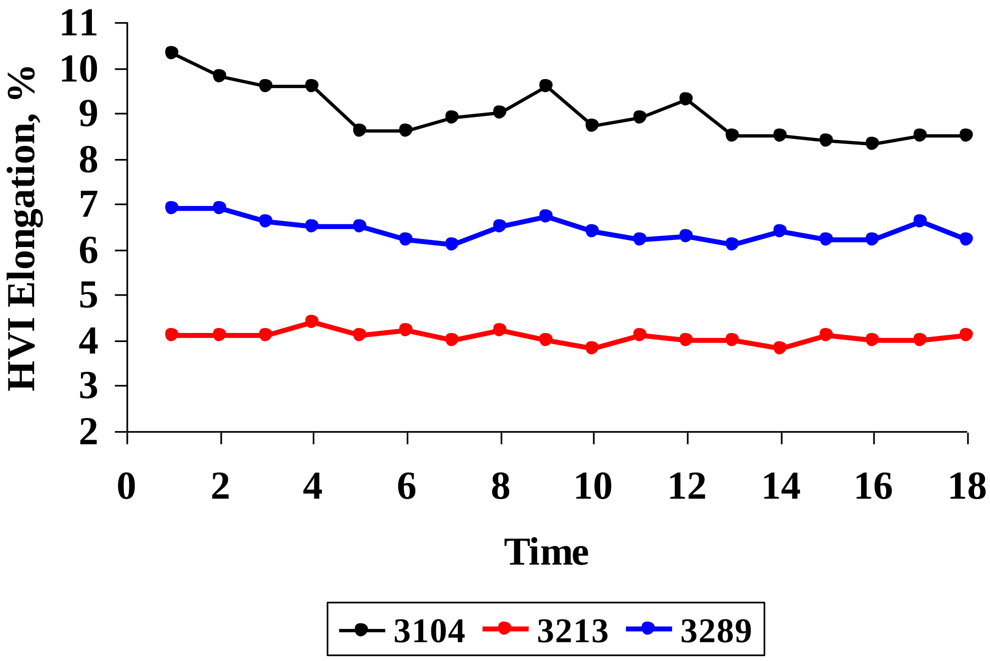


Figure 17. Repeatability of HVI tensile properties

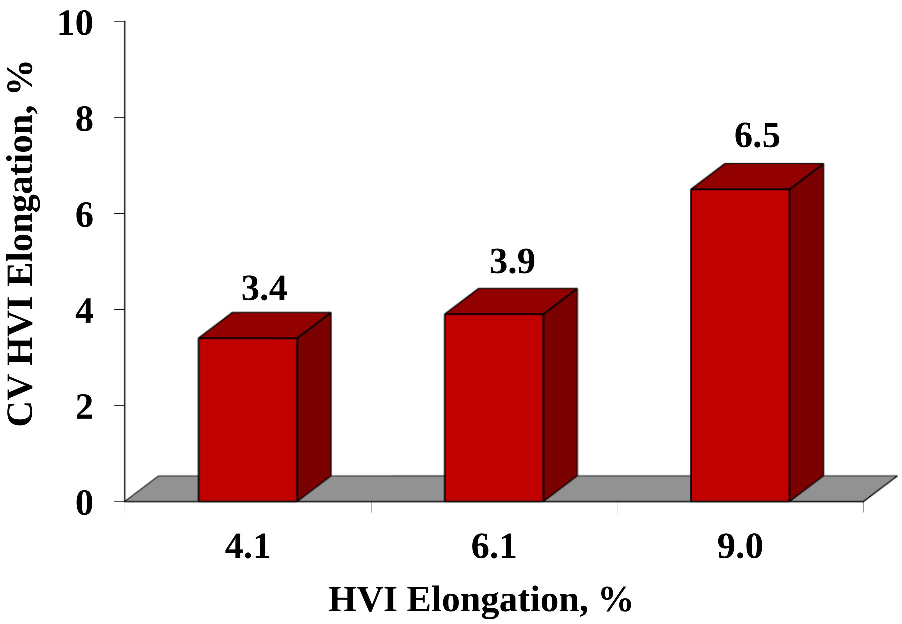


Figure 18. Repeatability of HVI tensile properties (CVs)

HVI tenacity is highly repeatable and exhibits a suitable CV%. On the other hand, HVI elongation may have a slight drift and is more variable than is desired. Despite the high CV%, the measurement of HVI elongation should be sufficient for identifying entries with low, medium, and high elongation. The next experiment will investigate the potential impact of improving HVI elongation on yarn quality.

Experiment 4: *Does HVI elongation translate into better yarn tensile properties?*

Cotton is primarily traded on international markets as a raw material used in the production of ring-spun yarns. Ring-spun yarns are used in premium textiles. Producers depend on breeders to develop lines that perform well in high value international markets. This experiment is used to investigate whether an improvement in HVI elongation will lead to an improvement in ring-spun yarn quality.

A set of 21 cultivars were selected for this experiment. The cultivars were planted with 2 field replicates at the Texas A&M Agrilife Research station in Lubbock, TX. The plots were stripper harvested and saw ginned in preparation for spinning. A sample of lint from each plot was tested on HVI (4-4-10) and AFIS (5 reps of 3,000 fibres).

30Ne carded ring-spun yarn was produced out of the lint from each plot (Suessen Fiomax 1000). The tensile properties of the produced yarns were evaluated on a Tensorapid. Yarn imperfections were evaluated on a Uster Tester 3 (UT3).

Both HVI Strength and HVI Elongation are highly repeatable between field replications (Figure 19 and 20). Field replications share 78% of the variation in HVI Strength and 91.4% of the variation in HVI Elongation. Yarn quality is also highly repeatable between field replications (Figure 21 and 22). Field replications share 94.0% of the variation in yarn tenacity and 70.0% of the variation in yarn elongation. This large degree of repeatability indicates that there is a strong genetic factor to these fibre and yarn properties. It is likely that the traits considered here are highly heritable.

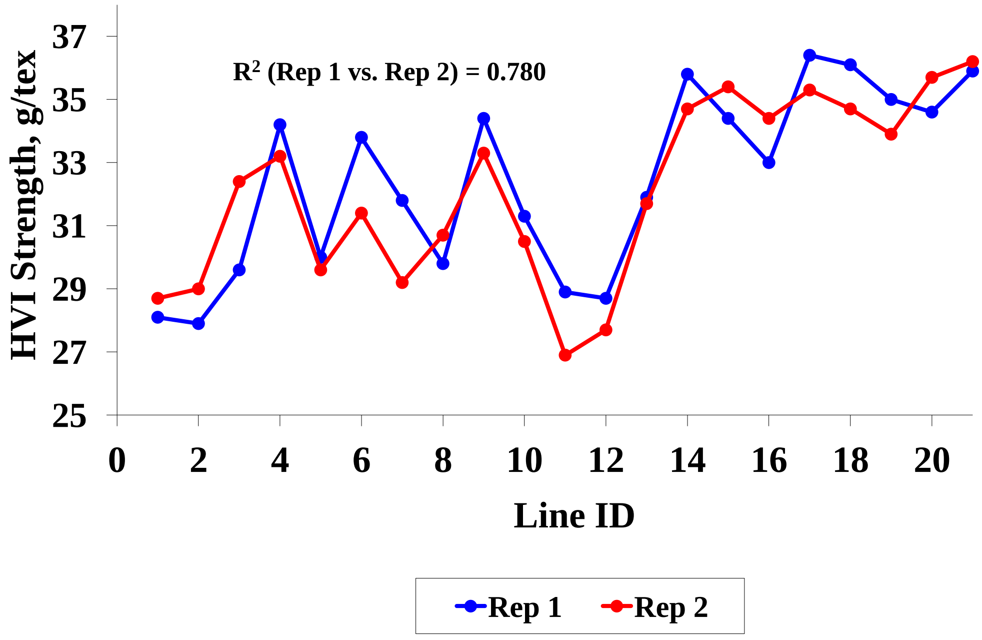


Figure 19. HVI Strength among cultivars and field replications. R^2=0.78

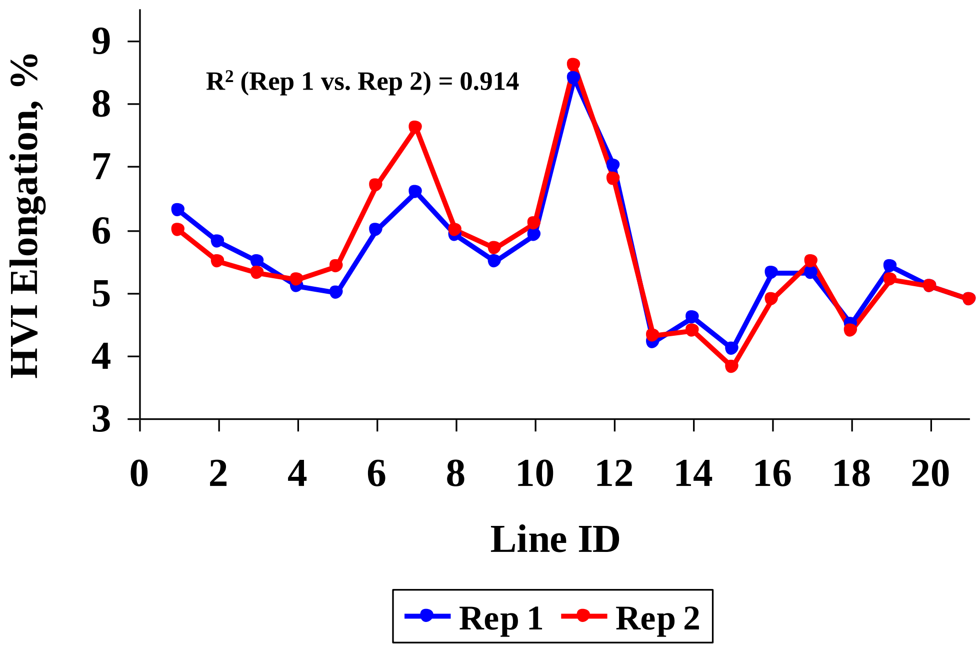


Figure 20. HVI elongation among cultivars and field replications. R^2=0.914

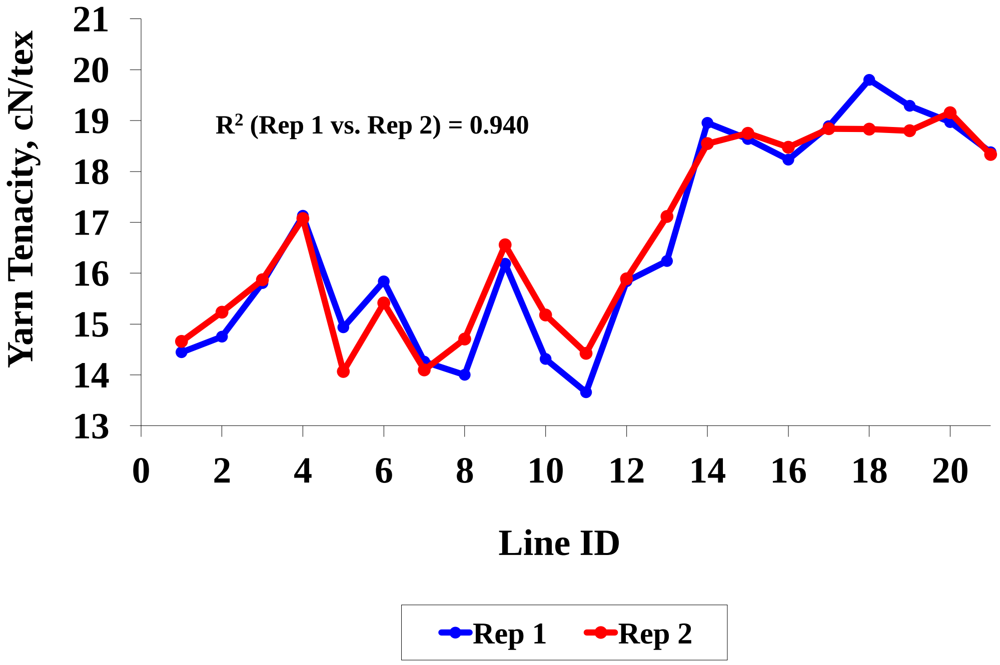


Figure 21. Yarn tenacity among cultivars and field replications. R^2=0.940

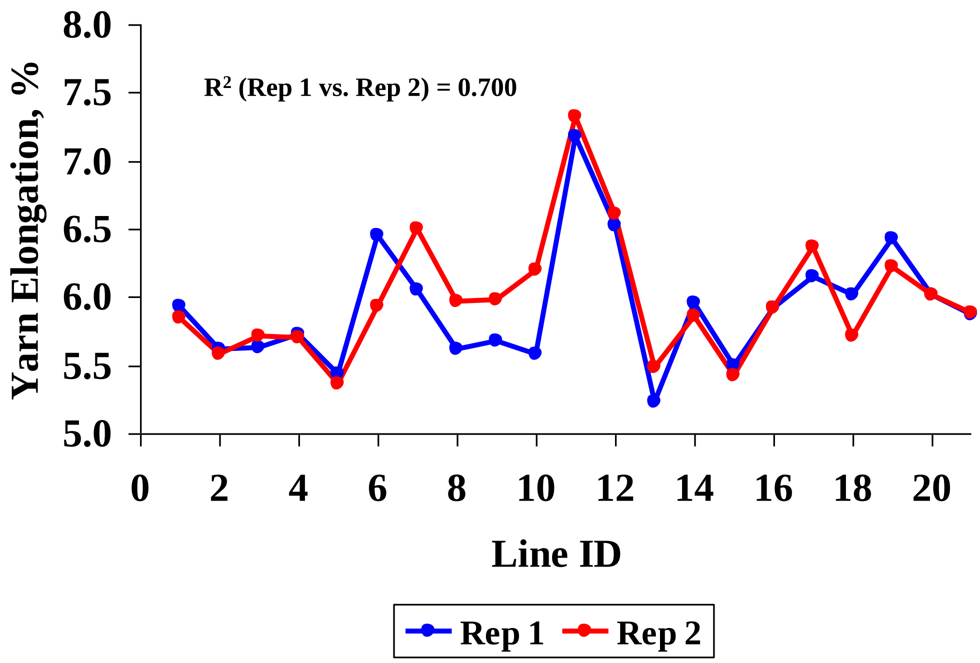
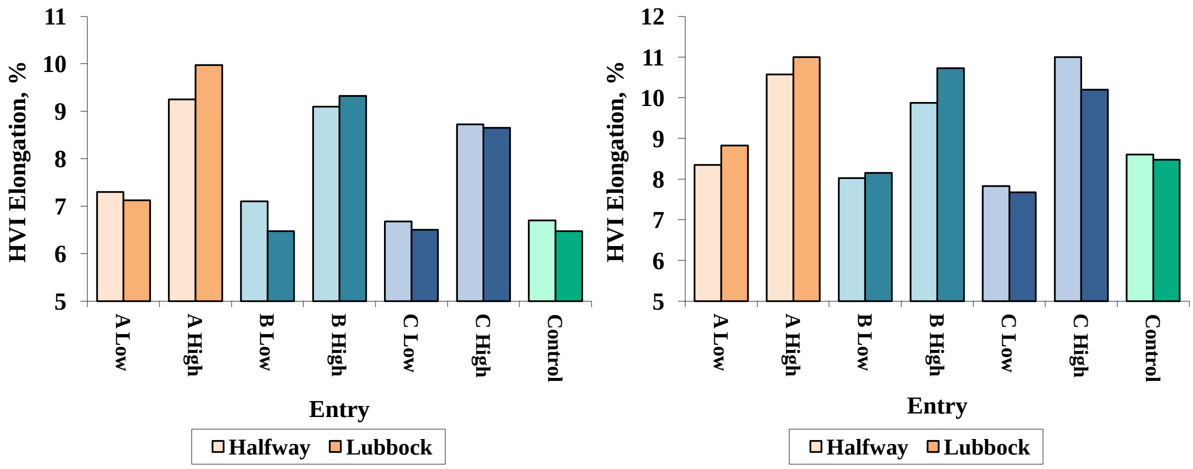


Figure 22. Yarn elongation among cultivars and field replications. R^2=0.70

Experiment 4: *Breeding for elongation to improve fibre and yarn quality*

A proof-of-concept breeding program was conducted by Dr. Dever at the Texas A&M Agrilife Research station in Lubbock, TX. Variability in HVI elongation was created with 25 crosses. Divergent selection was used to create pairs of lines exhibiting high and low HVI elongation while keeping other HVI parameters as similar as possible. Three divergent pairs were produced and tested in 2 locations with 4 replications. The results presented here are from two consecutive years of testing (2011 and 2012).

The divergent selection protocol created 3 pairs of entries. For each pair, we obtained one entry with high elongation and one with low elongation. A control was used in both locations. Figure 23 confirms that the divergent selection protocol was effective.



Year: 2011 **Year: 2012**

Figure 23. HVI Elongation of the three pairs of entries plus the control in two locations. Each colour represents a pair of entries with low and high elongation all other fibre properties being about constant.

The impact on HVI tenacity provides a contrast to HVI Elongation. There is little difference between HVI tenacity between the high and low elongation for the three pairs of entries (Figure 24).

The slight negative correlation between HVI strength and elongation (Figures 1 and 2) seems to imply improvements in HVI elongation may have a negative impact on HVI strength. This divergent selection scheme clearly demonstrates improvements in HVI elongation can be achieved without negatively impacting HVI strength.

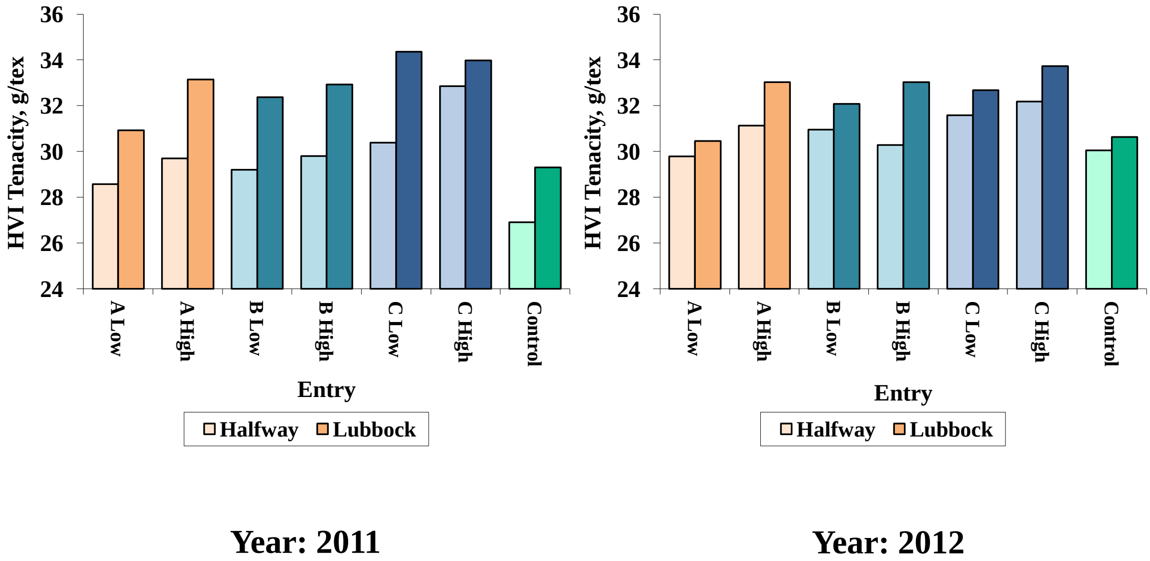


Figure 24. HVI tenacity of the three pairs of entries plus the control in two locations. Each colour represents a pair of entries with low and high elongation all other fibre properties being about constant.

Fibre bundle elongation has a large impact on yarn elongation. Divergent lines with high elongation result in ring-spun cotton yarns with high elongation (Figure 25). HVI elongation has a very small impact on yarn tenacity, if any. Yarns produced with high elongation entries do not exhibit improvements in yarn tenacity (Figure 26). Work-to-break is a function of both elongation and tenacity. Improvements in HVI elongation directly translate into ring-spun yarns with improved work-to-break (Figure 27). It is quite remarkable to achieve after just two cycles of selection such an improvement in work-to-break (for the best entry +62.1% in 2011 and +50.2% in 2012 versus the control).

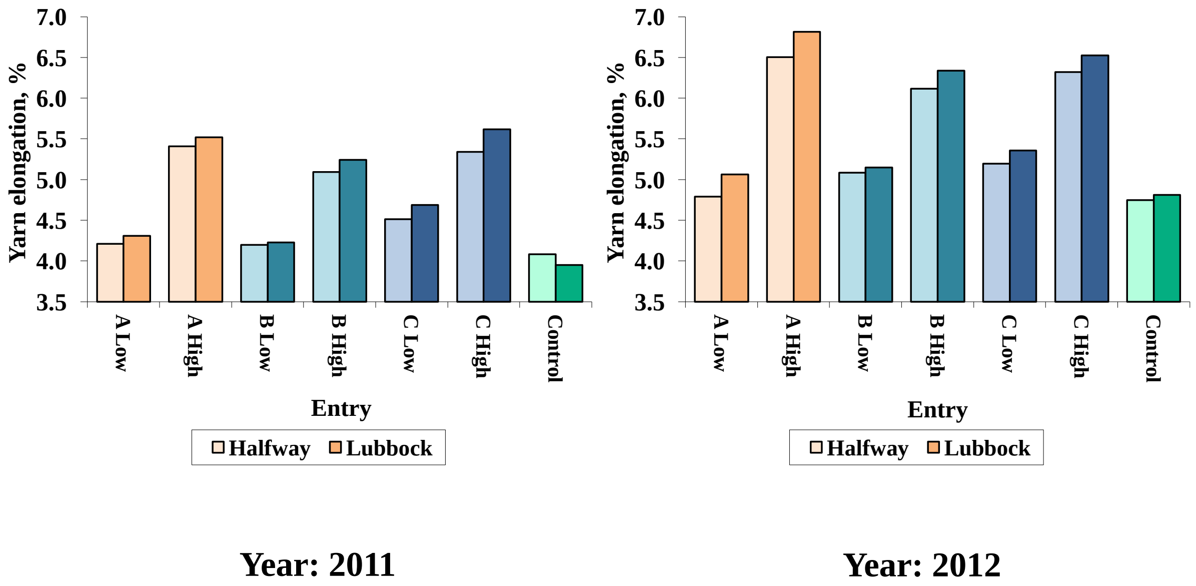


Figure 25. Yarn Elongation of the three pairs of entries plus the control in two locations. Each colour represents a pair of entries with low and high elongation all other fibre properties being about constant.

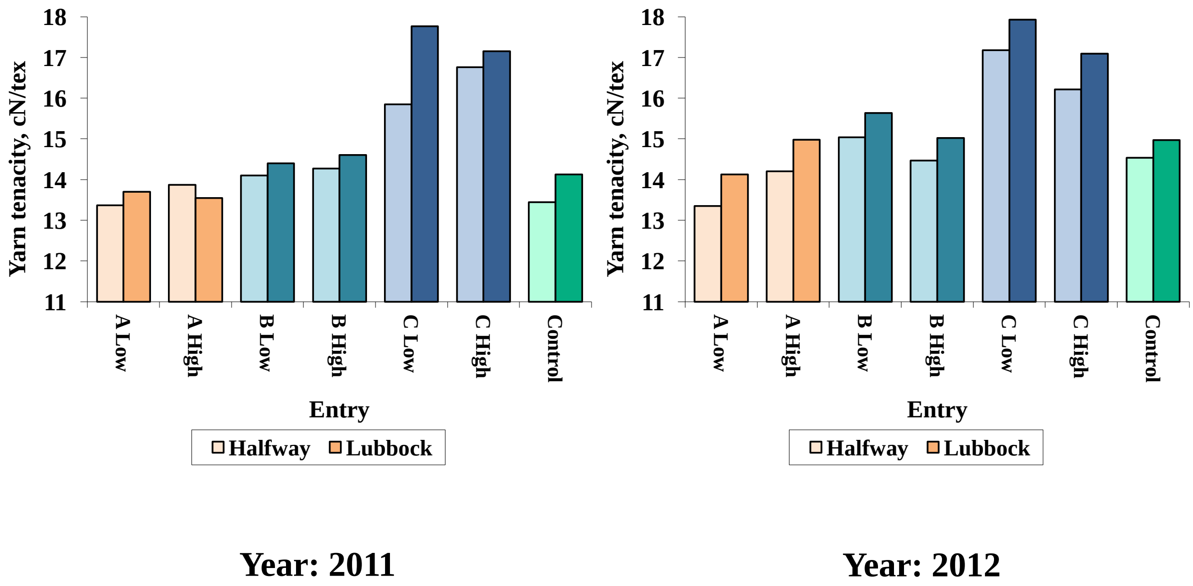
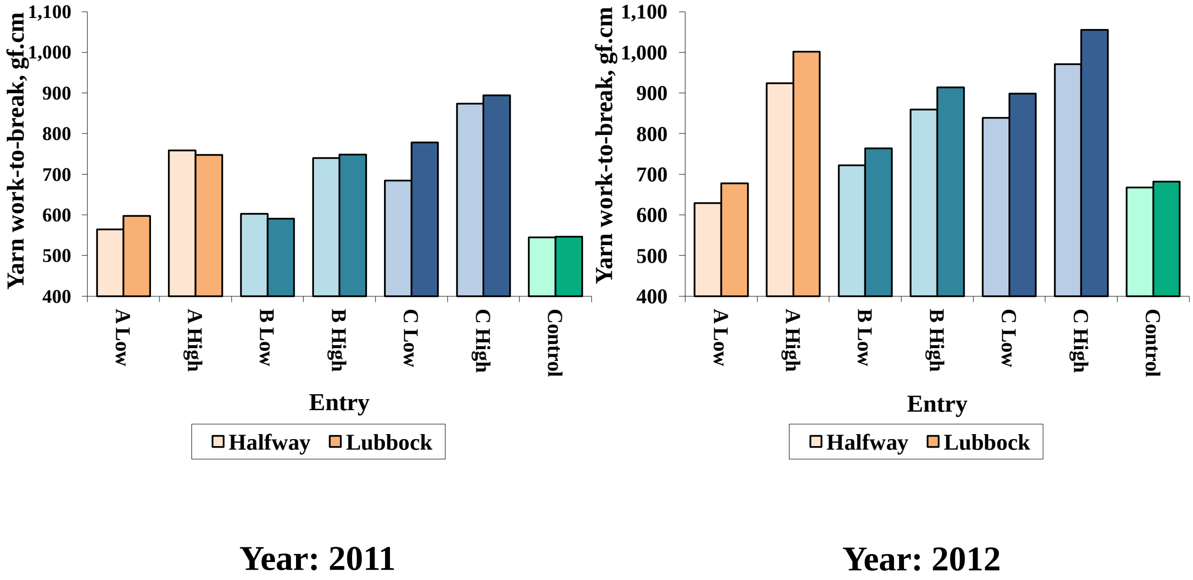


Figure 26. Yarn Tenacity of the three pairs of entries plus the control in two locations. Each colour represents a pair of entries with low and high elongation all other fibre properties being about constant.



Best entry (C High): + 62.1% in 2011 and +50.2% in 2012 versus control

Figure 27. Work-to-Break of the three pairs of entries plus the control in two locations. Each colour represents a pair of entries with low and high elongation all other fibre properties being about constant.

Yarn quality improvements from HVI elongation extend beyond yarn tensile properties. Fibre with high elongation requires more work-to-break and will resist breakage better during processing. Therefore, entries with high elongation tend to have lower short fibre content than entries with low elongation (Figure 28). Excessive short fibre content leads to more yarn defects. This is illustrated in Figure 29 where a significant relationship between yarn elongation and number of thick places in the yarn is depicted. The same trend was observed for all yarn defects. Yarns that have higher elongation tend to have fewer defects.

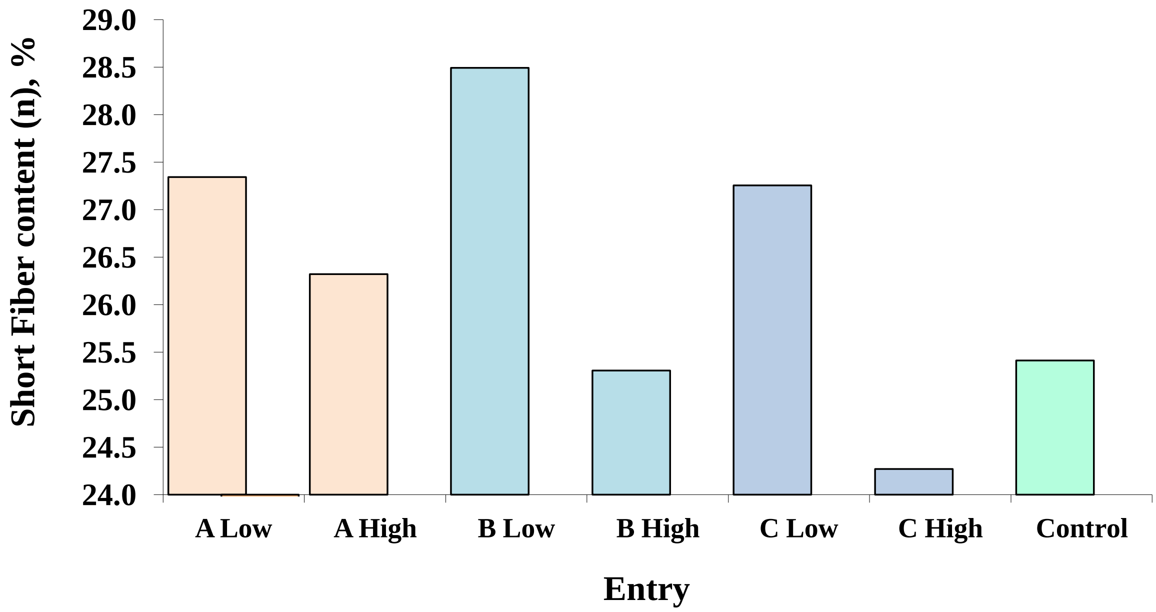


Figure 28. AFIS Short Fibre Content by Number of the three pairs of entries plus the control in two locations. Each colour represents a pair of entries with low and high elongation all other fibre properties being about constant.

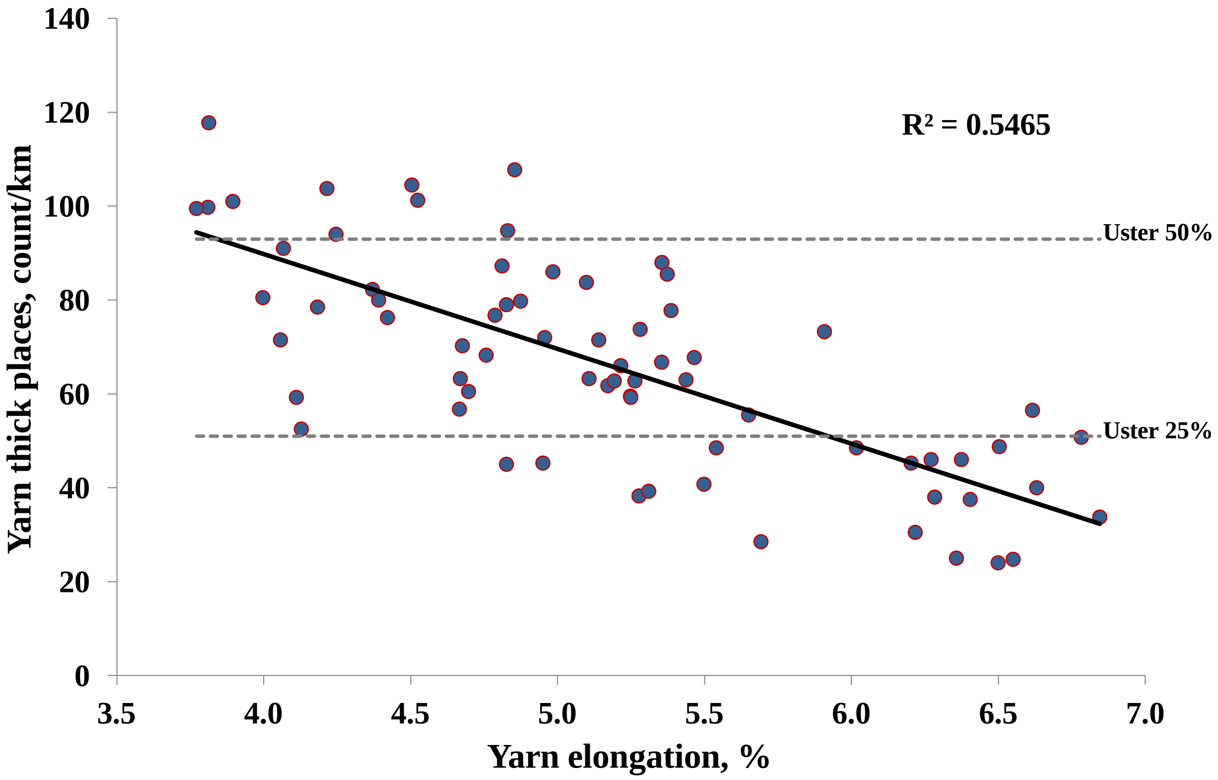


Figure 29. Yarn elongation vs. Thick Places

CONCLUSION

Producers depend on breeders to develop elite varieties with a potential to produce fibre with improved tensile properties. Breeding for improved HVI strength without considering elongation does not always lead to an improvement in the total work-to-break. Substantial tensile property improvements can be made by breeding for both strength and elongation.

Individual fibre elongation and tenacity within a sample have a strong positive relationship. It is therefore possible to develop cotton fibres that are both strong and exhibit high elongation. However, individual fibre testing is too slow and expensive for use as a selection method. HVI provides an assessment of fibre bundle elongation along with the standard output. The measurement is reasonably repeatable and stable over time. HVI elongation relates well to the average individual fibre elongation and has the potential for use as a selection parameter in developing varieties with superior spinning performance.

Developing the cotton fibre of the future depends on developing methods to select for fibre elongation. It is possible to use a single HVI instrument to make transformative changes in cotton fibre quality. Unfortunately, the lack of HVI calibration standards inhibits the interpretation of the elongation parameter across multiple instruments.

Requiring a single HVI to test all entries limits the use of HVI elongation as a breeding parameter. Therefore, the creation of HVI calibration standards for elongation is imperative for the development of cotton varieties able to serve the needs of high-value markets.

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