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# AGRONOMY AND SOILS

## Yield, Fiber Quality, and Textile Outcomes from In-Field Blending of Cotton Seed at Planting

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### ABSTRACT

**Cotton is a highly variable natural material that is routinely blended during textile processing to create a uniform product. Harvesting and ginning can introduce some blending before the mill. Blending earlier in the supply chain could produce a more consistent and predictable product. There has been limited research on the benefits of in-field blending of cotton cultivars, especially from a textile perspective. Experiments were conducted over two seasons to determine the economic and performance impacts of in-field blending. The seed of three cultivars with different quality parameters were blended in combinations of two cultivars at 25% increments before planting. Crop maturity, lint yield, fiber quality, and textile processing were evaluated for both years. Some combinations resulted in differences in micronaire, fineness (linear density), and fiber length, which mostly followed the blend rates of the constituent cultivars. Although there were some statistical differences, no functional differences were observed for yield, textile processing, or textile quality. The most significant result was the movement of one set of blends from the base range of micronaire to the premium range. The results showed that in-field blending of cultivars could be done without harming quality or resultant textiles, as long as the cultivars are carefully selected for similar seed characteristics and maturation timing. Individual producers will have to determine if the benefits and risks are worthwhile for their specific situation.**

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Cotton is one of the world's most important textile fibers. Most uses of cotton require the fiber to be spun into yarn and then converted to fabric. The spinning performance and yarn quality of cotton depend upon several fiber properties, including fiber length, length uniformity, strength, fineness (linear density), and maturity (Delhom et al., 2017). Fiber yield and quality are influenced by many factors and thus, can be quite variable. The natural variation of cotton is one of the properties that gives cotton superior handle and feel. However, this variation in quality also presents challenges for a spinning mill that has a goal of producing consistent products in a predictable manner. Producing consistent, uniform fiber quality, through improved crop genetics, crop management, harvesting, and ginning is the primary challenge for the cotton industry to remain competitive against manmade fibers.

Agronomic factors such as planting date (Davidonis et al., 2004), cultivar selection, irrigation (Guinn et al., 1981), weather, harvest preparation and timing (Bednarz et al., 2002), and harvest method (Faulkner et al., 2011; van der Sluijs et al., 2015), as well as other factors, contribute to increasing the natural variability present in cotton. Upon harvesting, the quality and uniformity of cotton are not yet fixed as the ginning process also has a large impact on final quality (Armijo et al., 2019; Mangialardi et al., 1988).

Spinning mills blend cotton bales in an effort to obtain consistent, uninterrupted, and continuous mill operations while producing a uniform end product using the same concept, which is the basis for blending samples during testing (Lund, 1953; Wakeham et al., 1954). Blending is typical amongst all natural fiber processors and is not a challenge faced solely by cotton mills (Coplan and Klein, 1956). Initially, blending was based on human judgment utilizing only fiber length and grade (Landstreet and Simpson, 1956; Regnery, 1952; Williams and Towery, 1946). The advent of instrument testing of cotton for blending purposes began in the 1940s with the development of airflow-based techniques to measure fiber fineness (Hertel and Craven, 1951). In the 1950s, researchers began to experiment with utilizing fineness or micronaire, as it is understood today, as an additional fiber property to control bale selection for blending (Regnery, 1952; Mayne et al., 1960).

Blending bales by fineness did not result in loss of processing efficiencies and could improve the quality of the yarn produced (Fiori et al., 1959;). However, blending cottons with large differences in fineness revealed fiber migration issues as finer and coarser fibers tend to segregate during drawing and spinning (Anandijiwala et al., 1999; Zurek et al., 1979). Some of the issues caused by blending fibers with large differences in fineness can be alleviated by incorporating a gradient of micronaire values instead of just high and low (Mayne et al., 1960). These early studies did not include fabric formation or dyeing studies, so the potential consequences of dyeing issues from mixing cottons of significantly different maturity or fineness values were not assessed (Zurek et al., 1979; Bailey, 2002).

Currently, the most effective blending of cotton does not occur in the field or gin but at the spinning mill. Spinning mills blend multiple bales in a laydown to provide enough material of consistent quality to the processing equipment. Utilizing a mixed laydown allows fibers to be intimately mixed during the opening and cleaning process before carding (Lund, 1953; Mayne et al., 1960; McCreight et al., 1997). An alternative to blending in a laydown is to perform the blending on the drawframe. Blending on the drawframe prevents preferential removal of fibers during the carding process and allows for control over the location of fiber types in the sliver; however, the intimate blending created by the laydown is more effective at averaging out fiber qualities (Anandjiwala et al., 1999). Numerous computer modeling efforts have been pursued to guide the selection of bales to be included in a particular laydown (El Moghazy et al., 2004; Sheikh and Lanjewar, 2010).

It is reasonable to consider that the earlier in the cotton supply chain that blending occurs, the more effective it will be, such as in the blowroom versus the drawframe. The earliest possible point blending can occur is in the field at the time of planting. Several efforts have explored the idea of mixing cottonseed at planting. Although simple in concept, the mixing of cottonseed does add logistical challenges related to the selection and handling of the seed to be mixed. The earliest of these, in 1977, examined increasing yield through five separate experiments at three locations with numerous mixtures of upland cotton varieties; however, all the efforts failed to exceed monoculture yields (Innes and Jones, 1977). Faircloth and colleagues conducted a three-year study utilizing 50/50 blends of several different upland cottons with the goal to improve overall lint quality without decreasing yield. Yield and micronaire results were inconsistent while fiber length followed in-step with the blend ratios (Faircloth et al., 2003). The Faircloth study utilized two approaches to blending: mixing seed before planting and alternating rows. Another study used a wider range of blends and chose to blend a high-quality low-yield cultivar with a lower quality high-yield cultivar while ensuring both cultivars had similar seed size. In general, length was improved, uniformity was reduced, yields correlated with the blend rates, but no economic gains were realized (Bechere et al., 2008).

The introduction of transgenic cotton led to an attempt to blend transgenic and non-transgenic seeds of the same cultivar at various rates to investigate the efficacy of *Bt* mixes against bollworms. The inclusion of non-transgenic cotton in any blend resulted in increased insect damage (Agi et al., 2001). Mixing transgenic cotton technologies may be accompanied by various legal requirements and restrictions, which must be investigated before commercial application (Faircloth et al., 2003).

Recently one study investigated the feasibility of blending cottons of different qualities at the point of ginning (van der Sluijs et al., 2019). This study had the advantage of measuring fiber quality before determining the blends and was able to realize an increase of up to \$0.023/kg (\$5.32 per 227 kg (500 lbs) bale) for the producer.

Although the concept of in-field blending of cultivars is not new, one aspect needed to understand the value of this approach is to ascertain how this approach affects textile performance. The objective of this research was to investigate blending two cultivars of seed at the time of planting in different proportions to determine whether blends could improve fiber yield, quality, or textile performance.

## MATERIALS AND METHODS

**Field Cultural Practices.** Cotton was planted in 2009-10 and 2010-11 at the Australian Cotton Research Institute (ACRI), in Narrabri, New South Wales, Australia (30°18’ S, 149°48’ E). The location is a semiarid environment with gray vertosol (Isbell, 2002). Three cultivars were used in these experiments, which differed in inherent quality and yield (Table 1). The three Upland (*Gossypium hirstum* L.) cultivars were all bred by the Commonwealth Scientific and Industrial Research Organization (CSIRO) Australia and included two commercially available cultivars at the time of study: Sicot 71BR and Sicot 71BRF and one experimental cultivar (66643-231BRF). Cultivars contained transgenic Bollgard II and Roundup-Ready traits. All cultivars have normal leaf shape, medium-to-late crop maturity, and a compact growth habit. Twelve seed mixtures were prepared prior to planting each year, which were generated to create the proportions listed in Table 2, based on plant numbers established in the field. Seed mixtures were generated by seed mass adjusted for seed index (number of seed per 100 g). Treatment proportions included 100% of a single cultivar and relative proportions of 25/75%, 50/50%, and 75/25% in binary combinations with the other cultivars.

The 12 treatment combinations were planted in a randomized complete block design with four replications. Ten-meter-long plots were planted on one meter row-spacing with eight rows on 15 October 2009 (10 x 8m), and four rows on 21 October 2010 (10 x 4m). Each experiment was established and grown with full irrigation using nonlimiting nitrogen and thorough insect control as described in Hearn and Fitt (1992). Nitrogen was applied as anhydrous ammonia, injected below and to the side of the plant line, four weeks before planting at rates estimated to provide optimal yields. The rate of nitrogen was determined on the basis of a nitrogen replacement program that accounts for nitrogen use in previous cotton crops (Rochester, 2007). Established plant population was 12 plants per square meter. Treatments were monitored for crop maturation, where crop maturity was defined as the number of days after planting (DAP) when 60% of bolls were open (DAP60) (Gwathmey et al., 2016). Seed cotton was harvested three weeks after application of harvest aids at 60% open bolls. At harvest, one central row of cotton from each plot was harvested with a modified spindle basket cotton picker (Deere and Company, Moline, IL) equipped with a single harvester head with the capacity to capture and tag small amounts of cotton. One sub-sample of approximately one kg of seed cotton was taken from each plot and ginned using a 20-saw gin (Continental Eagle, Prattville, AL) at ACRI to determine lint turn out (%) and lint yield (kg/m$^2$). Ginning was performed without pre-cleaning or lint cleaning and produced approximately 400 g of lint per experimental plot.

**Table 1. Inherent average yield and fiber quality of cultivars utilized in this study.**

| Cultivar | Seed Index | Yield | UHML[z] | Strength | Micronaire | Uniformity |
|---|---|---|---|---|---|---|
| | (seeds/100 g) | (kg/ha) | (mm) | (cN/tex) | | (%) |
| A - Sicot 71BR | 10.14 | 2700 | 30.0 | 30.4 | 4.70 | 84.0 |
| B - Sicot 71BRF | 9.84 | 3300 | 31.4 | 30.1 | 4.40 | 84.0 |
| C - 66643-231BRF | 8.44 | 2900 | 31.6 | 31.2 | 4.77 | 84.5 |

[z] **UHML: Upper Half Mean Length**

**Table 2. Cultivar blend treatments established in the field (%).**

| Cultivar Blend | Treatment Blend | Cultivar A Sicot 71BR | Cultivar B Sicot 71BRF | Cultivar C 66643-231BRF |
|---|---|---|---|---|
| A | 100 | 100 | 0 | 0 |
| B | 100 | 0 | 100 | 0 |
| C | 100 | 0 | 0 | 100 |
| A/B | 25/75 | 25 | 75 | 0 |
| A/B | 50/50 | 50 | 50 | 0 |
| A/B | 75/25 | 75 | 25 | 0 |
| A/C | 25/75 | 25 | 0 | 75 |
| A/C | 50/50 | 50 | 0 | 50 |
| A/C | 75/25 | 75 | 0 | 25 |
| B/C | 25/75 | 0 | 25 | 75 |
| B/C | 50/50 | 0 | 50 | 50 |
| B/C | 75/25 | 0 | 75 | 25 |

**Fiber and Yarn Quality.** Lint samples were transported to the USDA Agricultural Research Service in New Orleans, LA for fiber quality and spinning analyses. All fiber quality testing was performed after conditioning samples as per ASTM D1776-20 (2020). Cotton classification values were assessed with five measurements per sample on a Uster 1000 High Volume Instrument (HVI) (Knoxville, TN). Samples were characterized for length, maturity, and fineness on a Uster AFIS Pro (Knoxville, TN) with three replications of 5,000 fibers each. Maturity, fineness, and ribbon width measurements were taken with the Cottonscope instrument (BSC Electronics, Ardross, WA, Australia) (Long et al., 2010) using three replications of 50 mg sub-samples.

Samples were subjected to miniature-scale processing and spinning trials using the protocol reported by Manandhar and Delhom (2018) on 60 g sub-samples of lint. Yarn quality was assessed for each sample by producing two bobbins of 20 tex (Ne 30) ring-spun yarn with a 3.8 twist multiple. Yarn strength was tested using a skein break (ASTM D1578-93) and single-end breaks with tests bobbin (ASTM D2256-10). Yarn evenness was assessed using a Uster Tester 4 (Knoxville, TN) at 100m/min for one minute per bobbin using the criteria of ASTM D1425-14 (2020).

**Data Analysis.** Fiber quality assessment, processing trials, and yarn testing was carried out in a complete random design by crop year. The experimental design was constructed using Genstat 9 (Lawes Agricultural Trust, IACR, Rothamsted, UK). Statistical analyses were performed using Minitab 19 (State College, PA, USA). Generalized linear modeling (GLM) was used to test for differences between treatments. Analyses were performed independently on each set of binary blends. Seed blends were treated as fixed effects, while crop year and plot replicates were treated as random factors. Significant differences were identified using Fisher's Least Significant Difference (LSD) means comparison at $P < 0.05$.

## RESULTS AND DISCUSSION

**Crop Maturity, Yield, and Lint Turnout.** The timing of crop maturation is a major factor influencing yield and fiber quality of a crop. Blending cultivars could potentially create inconsistent crop maturities, which could affect the production of a uniform crop. Published data on cultivars chosen for this experiment reported similar crop maturities when grown under the same conditions (Bange et al., 2010). The cultivars were selected to reduce complications of achieving non-uniform crop maturity, so the lack of differences in DAP60 was not unexpected and confirmed the selection of cultivars (Table 3). Cultivar A and B were significantly different in terms of both yield and turnout, with their blends largely following the trend of the proportions of the parent cultivars. Similar results were found for lint turnout of blends with cultivar A and C. Yields for the A and C blends were more variable, with the 50/50 blend resulting in the highest yield. There were no significant differences for yield or turnout between cultivars B and C, so it is not unexpected that there were no significant differences between the B and C blends.

**Fiber Quality.** Cultivars used for this study had historical differences in fiber quality traits (Table 1). Cultivars A and B differed in micronaire and length but not strength or length uniformity index, while cultivar C differed from cultivar A largely in terms of length and strength. Cultivar B differed from cultivar C in terms of micronaire and strength but not length or uniformity. Results from both years largely upheld those trends (Table 4).

Blends with cultivar A showed significant differences for fiber length parameters. The upper half mean length (UHML) from HVI and the upper quartile length (UQL) from AFIS both showed significant differences with the inclusion of the longer cultivars (B or C) in the blends. The effect of the blend on length parameters followed the blend levels in a similar manner as previous investigations (Bechere et al., 2008; Faircloth et al., 2003). Although longer fiber lengths were improved with the blends, there was no reduction in the percentage of fibers less than 12.7 mm, i.e., short fiber content (SFC). Neither short fiber content by weight (data not shown) nor short fiber content by number, SFCn (Table 4) revealed any significant differences. Short fiber content is important to spinning mills as shorter fibers do not contribute to yarn strength and may adversely impact yarn quality by increasing hairiness (Tallant et al., 1960; Thibodeaux et al., 2008). Short fibers weigh less than longer fibers within a given sample, so it is expected that the percentage of short fibers will be higher when expressed as a percentage of the number of fibers in a sample rather than by weight, therefore the number based short fiber content is a more sensitive measure to determine if there were significant differences in short fiber content.

**Table 3. Mean crop maturity, yield, lint yield, and lint turnout %.**

| Cultivar | Blend | DAP60[z] | Machine Picked Lint Yield | Lint Turnout |
|---|---|---|---|---|
| | | | ($kg/m^2$) | (%) |
| A | 100 | 171 | 0.269 c | 40.8 d |
| A/B | 75/25 | 171 | 0.306 ab | 41.3 c |
| A/B | 50/50 | 168 | 0.285 bc | 41.6 bc |
| A/B | 25/75 | 174 | 0.324 a | 41.7 ab |
| B | 100 | 169 | 0.329 a | 42.1a |
| A | 100 | 171 | 0.269 b | 40.8 b |
| A/C | 75/25 | 172 | 0.306 ab | 41.3 ab |
| A/C | 50/50 | 173 | 0.317 a | 41.9 ab |
| A/C | 25/75 | 166 | 0.270 b | 42.1 ab |
| C | 100 | 169 | 0.291 ab | 42.3 a |
| B | 100 | 169 | 0.329 | 42.1 |
| B/C | 75/25 | 169 | 0.317 | 41.4 |
| B/C | 50/50 | 168 | 0.310 | 42.6 |
| B/C | 25/75 | 171 | 0.322 | 41.9 |
| C | 100 | 169 | 0.291 | 42.3 |

**Treatment means represent both years. Means within a column, by blend components, followed by the same letter are not significantly different according to Fishers LSD ($P < 0.05$). Means with no letter have no significant difference.**

**[z] DAP60 is days after planting where 60% of the bolls are open.**

**Table 4. Mean fiber quality for cultivar blends.**

| Cultivar | Blend | Micronaire | UHML[z] | Uniformity | Strength | UQLw[y] | SFCn[x] | Fineness | IFC[w] |
|---|---|---|---|---|---|---|---|---|---|
| | | | (mm) | (%) | (cN/tex) | (mm) | (%) | (mtex) | (%) |
| A | 100 | 4.58 | 30.6 c | 84.6 | 31.8 ab | 32.3 c | 19.7 | 170 | 5.17 |
| A/B | 75/25 | 4.58 | 31.2 bc | 84.3 | 31.3 b | 33.2 b | 19.1 | 172 | 4.92 |
| A/B | 50/50 | 4.47 | 31.7 ab | 84.5 | 32.0 ab | 33.6 ab | 20.1 | 171 | 4.80 |
| A/B | 25/75 | 4.45 | 31.9 a | 84.1 | 32.1 a | 34.1 a | 20.5 | 170 | 5.00 |
| B | 100 | 4.36 | 32.2 a | 84.3 | 31.6 ab | 34.2 a | 23.1 | 168 | 5.51 |
| A | 100 | 4.58 | 30.6 b | 84.6 | 31.8 | 32.3 b | 19.7 | 170 b | 5.19 |
| A/C | 75/25 | 4.65 | 30.8 b | 83.9 | 31.5 | 32.8 b | 22.4 | 174 ab | 5.31 |
| A/C | 50/50 | 4.53 | 31.9 a | 84.3 | 31.6 | 34.3 a | 22.3 | 175 a | 5.32 |
| A/C | 25/75 | 4.56 | 32.0 a | 84.1 | 31.8 | 34.3 a | 26.1 | 176 a | 6.21 |
| C | 100 | 4.66 | 32.3 a | 84.5 | 32 | 34.5 a | 20.4 | 176 a | 4.75 |
| B | 100 | 4.36 b | 32.2 | 84.3 | 31.6 | 34.2 ab | 23.1 | 168 b | 5.53 |
| B/C | 75/25 | 4.45 b | 32.0 | 84 | 31.5 | 33.8 b | 28.5 | 172 ab | 6.84 |
| B/C | 50/50 | 4.39 b | 32.5 | 84.6 | 32 | 34.5 ab | 24.3 | 169 b | 6.01 |
| B/C | 25/75 | 4.44 b | 32.2 | 84.4 | 31.8 | 35 a | 20.2 | 172 ab | 4.91 |
| C | 100 | 4.66 a | 32.3 | 84.5 | 32 | 34.5 ab | 20.4 | 176 a | 4.75 |

**Treatment means represent both years. Means within a column, by blend components, followed by the same letter are not significantly different according to Fishers LSD ($P < 0.05$). Means with no letter have no significant difference.**

**[z] UHML: Upper Half Mean Length**

**[y] UQLw: Upper Quartile Length, by weight**

**[x] SFCn: Short Fiber Content, by number**

**[w] IFC: Immature Fiber Content**

Blends of cultivars A and B showed some minor differences in fiber strength between the blends, but no blends were significantly different from either cultivar A or B alone. No other differences in strength were observed (Table 4).

The blends of cultivars A and C showed differences in fineness as measured by both AFIS (Table 4) and Cottonscope (Table 5). AFIS measurements found cultivar C to be coarser than cultivar A. Inclusion of cultivar C resulted in coarser fibers than when cultivar A was planted by itself. Cottonscope measurements revealed differences within blends of A and C but did not detect differences between cultivar A and C. Although fineness is important as a limiting factor in the production of fine count yarns (Fiori and Brown, 1951), differences detected were not of practical concern due to the relatively narrow range of fineness.

As shown in Table 1, the primary difference between cultivars B and C was micronaire. Cultivar B and C differed significantly in micronaire and AFIS fineness (Table 4) but not Cottonscope fineness (Table 5). Unlike differences between A and C, these differences were at a practical and significant level. The inclusion of any amount of cultivar B with cultivar C resulted in significantly lower micronaire than cultivar C alone. This reduction in micronaire moved the cotton quality from the base range of micronaire (3.5 to 4.9) to the premium range of micronaire (3.8 to 4.5) (CottonInfo, 2020), which resulted in a premium for the producer and a more desirable bale for spinning mills. Micronaire is an indirect measure of both fiber fineness (perimeter and cross-sectional area) and maturity (development of cellulose in the secondary cell wall) (Montalvo, 2005). There were no differences for fiber maturity (Table 5) or immature fiber content (IFC, Table 4); however, there were significant differences in the ribbon width of the fibers (Table 5), with cultivar B being narrower than C. Blends of B and C fell between the constituent parents for ribbon width except for the 25% B, 75% C blend, which had a lower ribbon width than any other sample.

Improper mixing of fine and coarse fibers can lead to appearance defects in fabrics due to the number of fibers in a cross-section of yarn being greater when finer fibers are present. A large difference in the number of fibers in a cross-section of yarn can make a dyed fabric appear darker due to the increased total surface area of fibers in the yarn, however, these results do not indicate that this would be an issue. Differences in cellulose content (maturity) can create differences in dye uptake and lead to the appearance of defects in textile products (Bailey, 2002). The lack of differences in maturity (Table 5) was an indicator that none of the blends were likely to cause defects due to dye uptake.

**Table 5. Crop quality as measured by Cottonscope**

| Cultivar | Blend | Maturity Ratio | Fineness | Ribbon Width |
|---|---|---|---|---|
| | | | (mtex) | |
| A | 100 | 0.85 | 196 | 15.71 a |
| A/B | 75/25 | 0.85 | 201 | 15.45 b |
| A/B | 50/50 | 0.83 | 209 | 15.43 b |
| A/B | 25/75 | 0.84 | 198 | 15.36 bc |
| B | 100 | 0.83 | 198 | 15.14 c |
| A | 100 | 0.85 | 196 b | 15.71 a |
| A/C | 75/25 | 0.86 | 209 ab | 15.50 b |
| A/C | 50/50 | 0.89 | 202 b | 15.48 b |
| A/C | 25/75 | 0.86 | 220 a | 15.43 b |
| C | 100 | 0.84 | 193 b | 15.53 ab |
| B | 100 | 0.83 | 198 | 15.14 d |
| B/C | 75/25 | 0.83 | 198 | 15.33 bc |
| B/C | 50/50 | 0.84 | 200 | 15.29 cd |
| B/C | 25/75 | 0.85 | 202 | 14.49 ab |
| C | 100 | 0.84 | 193 | 15.53 a |

**Treatment means represent both years. Means within a column, by blend components, followed by the same letter are not significantly different according to Fishers LSD (*P* < 0.05). Means with no letter have no significant difference.**

**Textile Processing.** Raw material is chosen by spinning mills to provide the necessary traits to produce yarn of the desired quality at the lowest cost. Processing trials revealed few significant differences in yarn quality between treatments with the A and C cultivars or the B and C cultivars. Yarns produced using proportions of cultivars A and B revealed some differences in the uniformity (CV%) of mass as well as the number of thin places, thick places, and neps. Thin places and thick places are short term variations in yarn thickness by 50% of average yarn diameter; for neps, the short-term variation is 200% of average yarn diameter. Although there was variation in the yarn imperfections for the blends, only the 75% A and 25% B treatment showed a significant difference from the parent cultivars (Table 6).

Yarn elongation-to-break showed significant differences between yarns produced from 100% cultivar C and any addition of blended cultivar B, but not cultivar A (Table 6). The difference in yarn elongation corresponds to differences in micronaire and fineness (Table 4) and may be due to increased slippage between fibers when the yarn is placed under tension. Differences in fiber diameter or ribbon width (Table 5) will alter surface area contact between fibers in the yarn cross-section leading to higher elongation when cultivar B fibers are introduced to cultivar C. The elongation results matched the findings of Broughton (1992) in relating yarn elongation changes to fiber friction within a yarn.

Yarn production efficiency is also an important consideration for a spinning mill. Any increases in waste or loss of production from ends-down (broken yarns during spinning) increases costs for the mill. A mass balance was performed during opening, cleaning, and carding operations while ends-down (yarn breakages) were tracked during spinning trials, as shown in Table 7. No differences were found for either processing efficiency parameter except processing waste for treatments with cultivars B and C. Processing efficiency was greater for treatments with a majority of cultivar B, which corresponds with the pattern of increased short fiber content (Table 4). All treatments experienced some ends-down during spinning, but none were greater than 0.86 ends down per 1,000 spindle hours, which is well within acceptable limits for the textile industry (Prendzova, 2000). However, it should be noted that all cultivars in the study are known for acceptable quality parameters and spinnability so this result indicates no unexpected fiber interactions during spinning.

**Table 6. Mean yarn quality.**

| Cultivar | Blend | Skein Strength | Yarn Tenacity | Yarn Elongation | Mass CV[z] | Thin Places -50% | Thick Places +50% | Neps +200% |
|---|---|---|---|---|---|---|---|---|
| | | (mN/tex) | (cN/tex) | (%) | (%) | (/km) | (/km) | (/km) |
| A | 100 | 65.5 | 14.9 | 7.29 ab | 20.5 a | 231 a | 813 a | 290 ab |
| A/B | 75/25 | 66.5 | 16.2 | 7.7 a | 18.9 b | 88 b | 540 b | 216 b |
| A/B | 50/50 | 72.7 | 15.3 | 7.13 b | 19.6 ab | 149 ab | 701 ab | 265 ab |
| A/B | 25/75 | 72.2 | 15.2 | 7.23 ab | 20 ab | 130 ab | 783 a | 283 ab |
| B | 100 | 71.7 | 15.6 | 7.25 ab | 20.4 a | 154 ab | 831 a | 331 a |
| A | 100 | 65.5 | 14.9 | 7.29 ab | 20.5 | 231 | 813 | 290 |
| A/C | 75/25 | 65.6 | 14.9 | 7.21 b | 20.4 | 201 | 849 | 331 |
| A/C | 50/50 | 72.7 | 15.8 | 7.53 ab | 19.8 | 134 | 795 | 331 |
| A/C | 25/75 | 75 | 15.5 | 7.43 ab | 19.9 | 127 | 803 | 309 |
| C | 100 | 70.9 | 15.9 | 7.71 a | 19.6 | 126 | 794 | 307 |
| B | 100 | 71.7 | 15.6 | 7.25 bc | 20.4 | 154 | 831 | 331 |
| B/C | 75/25 | 68.4 | 15.4 | 7.48 ab | 20.4 | 176 | 951 | 361 |
| B/C | 50/50 | 67.8 | 15.1 | 7.29 bc | 20.4 | 183 | 863 | 309 |
| B/C | 25/75 | 71.2 | 15.6 | 7.07 c | 19.9 | 152 | 848 | 356 |
| C | 100 | 70.9 | 15.9 | 7.71 a | 19.6 | 126 | 794 | 307 |

**Treatment means represent both years. Means within a column, by blend components, followed by the same letter are not significantly different according to Fishers LSD ($P < 0.05$). Means with no letter have no significant difference.**

**[z] CV is the coefficient of variation.**

**Table 7. Mean yarn production efficiency.**

| Cultivar | Blend | Processing Waste[z] | Ends-Down[y] |
|---|---|---|---|
| | | (%) | (/k-hr) |
| A | 100 | 10.9 | 0.34 |
| A/B | 75/25 | 10.5 | 0.86 |
| A/B | 50/50 | 9.7 | 0.28 |
| A/B | 25/75 | 10.7 | 0.13 |
| B | 100 | 10.8 | 0.59 |
| A | 100 | 10.9 | 0.34 |
| A/C | 75/25 | 11.1 | 0.16 |
| A/C | 50/50 | 9.5 | 0.38 |
| A/C | 25/75 | 10.5 | 0.36 |
| C | 100 | 9.5 | 0.22 |
| B | 100 | 10.8 ab | 0.59 |
| B/C | 75/25 | 11.3 a | 0.19 |
| B/C | 50/50 | 10.2 ab | 0.39 |
| B/C | 25/75 | 9.9 b | 0.25 |
| C | 100 | 9.5 b | 0.22 |

**Treatment means represent both years. Means within a column, by blend components, followed by the same letter are not significantly different according to Fishers LSD ($P < 0.05$). Means with no letter have no significant difference.**

**[z] Processing waste, reported in percentage, is the total loss during conversion from fiber to yarn**

**[y] Ends-down are yarn breakages during spinning reporter per 1,000 spindle hours**

**Economic Analysis.** Yield and turnout differences corresponded with proportions of the parent cultivars, so an economic benefit due to increased yield was not realized. There were minor fiber quality differences that were evaluated for economic value using the USDA cotton loan premiums and discounts (USDA, 2019). Color grade and leaf content were not evaluated in this trial as those properties are impacted by the harvesting and ginning method (Bednarz et al., 2002). A base color grade of 31 and leaf grade of 3 was used for the economic analysis to represent the base target of Australian cotton. Micronaire of all seed mixes ranged between 4.4 and 4.7, which is in the base range for micronaire, so no premiums or discounts from the USDA cotton loan chart apply. The fiber length, strength, and uniformity index of all samples in the trials qualified for premiums. All samples qualified for the same premiums, so no economic benefit was identified from mixing seeds at the time of planting. However, for the international market, micronaire is specified in several groups with the base group (G5) range of 3.5 to 4.9. Within G5, in Australia, the premium range is designated from 3.8 to 4.5 (CottonInfo, 2020). Cultivar A and C fell outside this premium range, while cultivar B fell within the range. All treatments with any proportion of cultivar B resulted in micronaire within the international premium range that are likely to provide an economic benefit on the international market.

## CONCLUSIONS

No significant benefits or reductions in yield were found from the in-field blending of seed in these experiments. The only fiber quality trait of direct economic benefit to the producer, which was significantly altered by in-field blending of seed was micronaire, with resultant bales likely more easily to market. These results largely follow those from previous experiments (Bechere et al., 2008; Faircloth et al., 2003; and Innes and Jones, 1977). The few differences in fiber quality observed were expected and generally followed the proportionally blended combinations of the constituent varieties.

When short fiber content increased, waste during textile processing increased, as expected. No negative impact was found on the resultant textile product quality. The lack of differences in fiber maturity is indicative that there would also be no dye uptake differences in the resultant textiles. Although no direct economic benefit was immediately identified in these results, intimate blending of quality in the field can only further increase the level of blending realized through harvesting, ginning, and blending in the spinning mill. More uniform and predictable cotton will more readily compete with manmade fibers in the spinning mill. The improvement of micronaire from base to premium grades may potentially provide an economic benefit to the producer and result in a more uniform and well blended textile product. In-field blending of carefully selected cultivars did not result in any reduction in yield or quality. Individual producers will have to decide if the potential benefit is worth the logistical efforts and risks of blending seed at planting. Additional work would be needed to further quantify the selection criteria for seed which could be blended with minimal risk. It is understood that seed should be of similar size, suited for the same growing conditions, and have the same maturation level, but other factors may come in to play that have not yet been identified and studied.

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## REFERENCES

Agi, A.L., J.S. Mahaffey, J.R. Bradley, Jr., and J.W. Van Duyn. 2001. Efficacy of seed mixes of transgenic *Bt* and non-transgenic cotton against bollworm, *Helicoverpa zea* Boddie. J. Cotton Sci. 5(2):74-80.

Anandjiwala, R.D., B.C. Goswami, C.K. Bragg, and J.D. Bargeron. 1999. Structure-property relationship of blended cotton yarns made from low and high tenacity fibers. Textile Res. J. 69(2):129-138. https://doi.org/10.1177/004051759906900208

ASTM D1425-14. 2020. Standard test method for evenness of textile strands using capacitance testing equipment. ASTM Intl. West Conshohocken, PA.

ASTM D1578-93. 2016. Standard test method for breaking strength of yarn in skein form. ASTM Intl. West Conshohocken, PA.

ASTM D1776-20. 2020. Standard practice for conditioning and testing textiles. ASTM Intl. West Conshohocken, PA.

ASTM D2256-10. 2015. Standard test method for tensile properties of yarns by the single-strand method. ASTM Intl. West Conshohocken, PA.

Bailey, D.L. 2002. Methods to prevent barré in knitted fabric. p. 17. *In* Proc. of 15th EFS Conferences, Memphis, TN.

Bange, M.P., G.A. Constable, D.B. Johnston, and D. Kelly. 2010. A method to estimate the effects of temperature on cotton micronaire. J. Cotton Sci. 14(3):164-172.

Bechere, E. A. Alexander, D.L. Auld, and C.P. Downer. 2008. Effect of cultivar blends on fiber quality, lint yield, and gross return of upland cotton in West Texas. J. Cotton Sci. 12(1):8-15.

Bednarz, C.W., W.D. Shurley, and W.S. Anthony. 2002. Losses in yield, quality, and profitability of cotton from improper harvest timing. Agron. J. 94(5):1004-1011. https://doi.org/10.2134/agronj2002.1004

Broughton Jr., R.M., Y.E. El Mogahzy, and D.M. Hall. 1992. Mechanism of yarn failure. Textile Res. J. 62(3):131-134. https://doi.org/10.1177/004051759206200302

Coplan, M.J. and W.G. Klein. 1955. A study of blended woolen structures. Part I: Statistics of the ideal random blended yarn. Textile Res. J. 25(9):743-755. https://doi.org/10.1177/004051755502500901

CottonInfo. 2020. Fibre quality [Online]. https://www.cottoninfo.com.au/fibre-quality (Verified on 11 December 2020).

Davidonis, G.H., A.S. Johnson, J.A. Landivar, and C.J. Fernanadez. 2004. Cotton fiber quality is related to boll location and planting date. Agron. J. 96(1):42-47. https://doi.org/10.2134/agronj2004.4200

Delhom, C.D., V.B. Martin, and M.K. Schreiner. 2017. Textile industry needs. J. Cotton Sci. 21(3):210-219.

El Mogahzy, Y.E, R. Farag, F. Abdelhady, and A. Mohamed. 2004. An integrated approach to analyzing the nature of multicomponent fiber blending. Part II: Experimental analysis of structural and attributive blending. Textile Res. J. 74(9):767-775. https://doi.org/10.1177/004051750407400904

Faircloth, J.C., K. Edmisten, R. Wells, and A. Stewart. 2003. Planting cotton cultivar mixtures to enhance fiber quality. J. Cotton Sci. 7(3):51-56.

Faulkner, W.B., J.D. Wanjura, E.F. Hequet, R.K. Boman, B.W. Shaw, and C.B. Parnell. 2011. Evaluation of modern cotton harvest systems on irrigated cotton: fiber quality. Appl. Eng. in Ag. 27(4):507-513. https://doi.org/10.13031/2013.38197

Fiori, L.A. and J.J. Brown. 1951. Effects of cotton fiber fineness on the physical properties of single yarns. Textile Res. J. 21(10):750-757. https://doi.org/10.1177/004051755102101008

Fiori, L.A., G.L. Louis, and J.E. Sands. 1959. Blending cottons differing widely in maturity. Part I: Effect on properties of single yarns. Textile Res. J. 29(9):706-716. https://doi.org/10.1177/004051755902900906

Fiori, L.A., G.L. Louis, and J.E. Sands. 1961. Blending cottons differing in fiber bundle break elongation. Part I: Effect on properties of combed single yarns. Textile Res. J. 31(1):43-51. https://doi.org/10.1177/004051756103100107

Guinn, G., J.R. Mauney, and K.E. Fry. 1981. Irrigation scheduling and plant population effects on growth, bloom rates, boll abscission, and yield of cotton. Agron. J. 73(3):529-534. https://doi.org/10.2134/agronj1981.00021962007300030030x

Gwathmey, C.O., M.P. Bange, and R. Brodrick. 2016. Cotton crop maturity: A compendium of measures and predictors. Field Crops Res. 191:41-53. https://doi.org/10.1016/j.fcr.2016.01.002

Hearn, A.B. and G.P. Fitt. 1992. Cotton cropping systems. p. 85-142. *In* C.J. Pearson (ed.) Ecosystems of the World. Elsevier, New York, NY.

Hertel, K.L. and C.J. Craven. 1951. Cotton fineness and immaturity as measured by the arealometer. Textile Res. J. 21(11):765-774. https://doi.org/10.1177/004051755102101101

Innes, N.L. and G.B. Jones. 1977. Performance of seed mixtures and multilines of Upland cotton in Uganda. J. Agric. Sci. 88(1):47-54. https://doi.org/10.1017/S002185960003375X

Isbell, R.F. 2002. The Australian soil classification. CSIRO Publ., Melbourne, Australia.

Landstreet, C.B. and D.M. Simpson. 1956. Irregularities in fiber properties of cotton in commercial mill mixes. Agron. J. 48(10):463-466. https://doi.org/10.2134/agronj1956.00021962004800100008x

Long, R.L., M.P. Bange, S.G. Gordon, and G.A. Constable. 2010. Measuring the maturity of developing cotton fibers using an automated polarized light microscopy technique. Textile Res. J. 80(5):463-471. https://doi.org/10.1177/0040517509343784

Lund, G.V. 1953. Fiber blending. Textile Res. J. 24(8):759-764. https://doi.org/10.1177/004051755402400813

Mayne, Jr., S.C., W.T. Mathews, Jr., and E.E. Berkley. 1960. Effects of blending cottons by fineness on cotton costs, processing efficiency, and yarn quality. Textile Res. J. 30(4):268-276. https://doi.org/10.1177/004051756003000404

Manandhar, R. and C.D. Delhom. 2018. Miniature spinning: An improved cotton research tool. J. Cotton Sci. 22(2):126-135.

Mangialardi, G.J., J.D. Bargeron III, and S.T. Rayburn. 1988. Gin-stand feed rate effects on cotton quality. Trans of ASAE. 31(6):1844-1850. https://doi.org/10.13031/2013.30945

McCreight, D.J., R.W. Feil, and J.H. Booterbaugh. 1997. Short staple yarn manufacturing. Carolina Academic Press.

Montalvo, Jr., J.G. 2005. Relationships between micronaire, fineness, and maturity. Part I. Fundamentals. J. Cotton Sci. 9(2):81-88.

Prendzova, M. 2000. The effect of cotton yarn properties on yarn end breakage. Intl. J. Polymeric Mater. 47(4):701-707. https://doi.org/10.1080/00914030008031325

Rochester, I.J. 2007. Nutrient uptake and export from an Australian cotton field. Nutrient cycling in Agroecosystems. 77(3):213-223. https://doi.org/10.1007/s10705-006-9058-2

Regnery, W. 1952. Blending of cotton by fineness determination and other applications of research in mill operations. Textile Res. J. 22(1):49-52. https://doi.org/10.1177/004051755202200107

Sheikh, R.A. and U.A. Lanjewar. 2010. Decision support system for cotton bales blending using genetic algorithm. Int. J. of Computer Appl. 8(1):28-34. https://doi.org/10.5120/1177-1608

Simpson, J. and L.A. Fiori. 1974. Effect of mixing cottons differing in micronaire reading and carding variables on cotton sliver quality, yarn properties, and end breakage. Textile Res. J. 44(5):327-331. https://doi.org/10.1177/004051757404400501

Tallant, J.D., L.A. Fiori, and C.B. Landstreet. 1960. The effect of short fibers in a cotton on its processing efficiency and product quality: Part II: Yarns made by miniature spinning techniques from differentially ginned cotton. Textile Res. J. 30(10):792-795. https://doi.org/10.1177/004051756003001008

Thibodeaux, D.P., H. Senter, J.L. Knowlton, D. McAlister., and X. Cui. 2008. The impact of short fiber content on the quality of cotton ring spun yarn. J. Cotton Sci. 12(4):368-377.

USDA. 2019. 2019 Cotton premiums and discounts [Online]. Available at: https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/Price-Support/pdf/2019/2019%20Cotton%20Premiums%20and%20Discounts.pdf (Verified on 22 June 20).

van der Sluijs, M.H.J., R.L. Long, and M.P. Bange. 2015. Comparing cotton fiber quality from conventional and round module harvesting methods. Textile Res. J. 85(9):987-997. https://doi.org/10.1177/0040517514540770

van der Sluijs, M.H.J., C.D. Delhom, J.D. Wanjura, and G.A. Holt. 2019. A preliminary investigation into the feasibility of gin blending. J. Cotton Sci. 23(1):97-108.

Wakeham, H., W.P. Virgin, and N. Spicer. 1954. Cotton quality and fiber properties Part I: Effect of mechanical blending on cotton fiber properties. Textile Res. J. 24(9):802-809. https://doi.org/10.1177/004051755402400903

Williams, S. and J.D. Towery. 1946. A study of cotton blending. Textile Res. J. 16(2):61-73. https://doi.org/10.1177/004051754601600202

Zurek, W., I. Sobieraj, and T. Tresowska. 1979. Properties of blend yarns. Textile Res. J. 49(8):438-444. https://doi.org/10.1177/004051757904900802