The *Journal of Cotton Science 22:60–74 (2018)*
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MOLECULAR BIOLOGY AND PHYSIOLOGY

Seed-Fiber Ratio, Seed Index, and Seed Tissue and Compositional Properties of Current Cotton Cultivars

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ABSTRACT

Because of the continual efforts to breed cotton for increased fiber yield, several seed/fiber compositional properties have likely shifted over the decades. Conversations with breeders, ginners, and oil processers have identified several concerns, including smaller seed size, weaker hulls, increased seed and hull fragment contamination of fiber, and reduced seed oil and protein levels—all of which directly affect the economic value of the crop. To better understand these changes, field cotton samples of current cultivars were collected from areas around Stoneville, MS; Lubbock, TX; and Las Cruces, NM. The samples were ginned and cleaned to determine seed-to-fiber ratio, seed index, and the proportions of linter, hull, and kernel tissues. Kernels were then analyzed for oil, protein, and gossypol. Results from the three-year study (2014 through 2016) indicated that the average seed-to-fiber ratio was 1.41 ± 0.11 (range: 1.19–1.61, as is basis) and has declined compared with data sets published prior to 1950. Of the varieties included in the study, seed index averaged 9.75 ± 0.99 g (range: 8.08–11.8 g, as is basis) and also showed an overall decline compared with early published data. Seed tissue proportions have changed less, although a decrease in the percentage of linters was apparent. The average level of seed oil and protein does not appear to have changed much over the years, although oil levels were very low for a few individual cultivars.

Over many decades, selective breeding of the cotton plant has resulted in dramatically increased fiber yields. These efforts, however, may have come with consequences for the seed, and a number of complaints have been voiced by ginners and oil processors regarding changes in seed quality. Weaker seed, smaller seed size, and reduced oil and protein levels have all been discussed.

Seed quality affects ginners, textile manufacturers, and oil processers in a number of ways. Weak seed is a problem for both fiber and seed processors, as ginning and handling operations result in hull fragments that contaminate the fiber making it more difficult to clean and process. Concomitantly, damaged seed is more prone to moisture uptake and oil degradation during storage, which causes a direct loss of extractable oil and oil refining problems. Small seed size is a special concern for ginners, as the seed is usually taken as the payment for ginning. In addition to less seed produced per bale of ginned fiber, losses might be amplified if whole seed and seed pieces exit the gin stand with the motes or in the fiber cleaning operations. Small seed size also affects the oil processor's ability to recover the linters (small unginnable fibers) and dehull the seed. Low oil levels are a direct loss for the oil processors, and low protein levels reduce the amount of hulls that can be left with the kernels during oil extraction, making it more costly to prepare a standard 41% protein meal.

Values for seed properties were frequently obtained in the early years of studying oil processing, and a number of these studies are discussed in chapters in A.E. Bailey's book "Cottonseed and Cottonseed Products" (see e.g., chapters by Lund, 1948; and Tharp, 1948). However, since this publication, limited studies have focused on these properties, although the expectations are that some of these values have changed due to the intense breeding for increased fiber yield. To try to better understand the magnitude of these differences, this survey was undertaken to derive seed property values for current commercial cultivars and to compare these values with those discussed in the early literature.

METHODS

Field cotton samples were collected with the help of the Agricultural Research Service (ARS) cotton gin laboratories located in Stoneville, MS, Lubbock, TX, and Las Cruces, NM. After removing the bulk of

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the stem, burr, and leaf debris, three pounds of each sample was ginned on a ten-saw laboratory-scale gin, and the fiber and seed fractions were collected and weighed. Fiber moisture was determined by a modified ARS method for ginned fiber (ARS, 1972). Five grams of each fiber sample was weighed into a tall weighing bottle and dried in a convection oven at 105°C for 90 min. The bottles were then capped and placed in a room temperature desiccator (20 min) before weighing. Seed moisture was determined by the American Oil Chemists' Society (AOCS) Official Method Aa 3-38 (AOCS, 1998) on ten g samples, which were dried at 130°C for three hr, then allowed to reach room temperature in a desiccator (20 min) before weighing. The fiber was cleaned by two passes on a Shirley Analyzer (Manchester, UK). Seed-to-fiber ratio was calculated after accounting for the trash level determined by the cleaner, and seed index (gram weight of 100 seed) was determined by weighing.

Seed were dissected to determine the percentage of linters (i.e., short unginnable fibers), hulls, and kernels. Whole seed was analyzed for linter content by AOCS Official Method Aa 7-55 (AOCS, 1998), which uses a modest acid treatment followed by agitation to brush the linters free of the seed. The procedure determines the linter content by weight difference, and then corrects the moisture to an 8% level (typical of fiber and linter moisture levels at ambient conditions). Approximately 20 g of fuzzy whole seed was then hand cut to separate the kernel fraction from the hull–linter fraction, and both fractions were weighed. The percentage of hulls was then determined by difference.

Protein and moisture were measured on the hull–linter and kernel fractions, and the oil, protein, gossypol, and moisture contents were measured on the kernel tissue. For these tests, the hull–linter samples were ground with a Wiley laboratory mill, and the kernels were chopped with a Braun hand-held food chopper, both samples ground to pass through a 20 mesh sieve.

Gossypol was measured by high pressure liquid chromatography with the AOCS Recommended Practice Ba 8-99, and protein was determined by combustion with a LECO (St. Joseph, MI, USA) model FP-628 Truspec nitrogen analyzer. Both measurements were made on an as is basis. Moisture was determined on the ground kernel and hull–linter fractions by the AOCS Official Method Ba 2a-38 for cottonseed meal (oven drying at 130°C for two hr), which was used to calculate protein and gossypol values of these fractions on a moisture free basis.

To determine the crude oil level in kernels, ground kernel tissue was first freeze-dried with a benchtop lyophilizer for three to four days. The oil was then extracted with a Foss (Eden Prairie, MN, USA) Soxtec analyzer with petroleum ether (three g samples, 15 min immersion cycle and three hr extraction cycle), and the recovered oil was determined by weighing. The kernel moisture level was then used to calculate the results on an as is basis.

Seed gossypol level was based on the kernel results as there is no detectable gossypol in either the hulls or the fiber. Seed oil was determined from the kernel oil values and the percentage of seed kernel tissue with a small adjustment to account for the expected level of extractable lipid in the linters and hulls, which amounts to less than 1% in each tissue (Tharp, 1948). Seed protein was calculated from the protein levels measured for both the hull–linter and kernel tissues.

All analyses were conducted on three replicates of each cultivar. Most analytical determinations were made in duplicate, with the average taken as the value for the replicate. Seed index was averaged from three 100 seed weight determinations for each replicate. For each property measured, the data was analyzed for year and location differences with ANOVA and the Tukey mean comparison test ($\alpha = 0.05$).

All results were obtained on an as is basis and on a moisture free (dry weight) basis. Unless otherwise stated, values discussed in the work refer to an as is basis. Individual cultivar values on an as is basis are provided in Supplemental Tables S1-S9. Comparable values on a dry weight basis are provided in Supplemental Tables S10–S18.

RESULTS

A total of eleven field cotton samples were collected for the 2014 season. One *Gossypium barbadense* cultivar (DP340) was included. One *G. hirsutum* cultivar, STV5458, was collected from two locations. All were grown under irrigated conditions. In 2015, thirteen samples were analyzed. Three of these were grown in dryland conditions; the others were grown under irrigation. The STV4946 and DP1044 cultivars were grown in two locations. In 2016, 22 samples were collected from the three regions. All samples were grown under irrigated conditions. One sample, DP1522, was grown in both the Las Cruces and Lubbock regions, and DP340 Pima cultivar was again collected from Las Cruces.

Production statistics indicated that the cultivars tested contributed significant United States (U.S.) acreage over the three years of study (USDA, 2014, 2015, 2016). The cultivars represented 26.5% of the acres planted in 2014, 27.8% of the acres planted in 2015, and 48.9% of the acres planted in 2016. Hence, these samples should be fairly representative of the cotton cultivars seen by ginners, although the set is limited in that only three regions were sampled and the number of samples from each region was variable.

A few location and year differences were detected by ANOVA analysis. When evaluated by location, samples from Las Cruces had a higher seed-to-fiber ratio than the other two locations, and samples from Lubbock had a smaller average seed index compared with the other locations (Table 1). When evaluated by year, 2016 samples had a significantly lower seed-to-fiber ratio than did samples from the prior two years, and 2014 had a higher average seed index compared with the latter two years. There were no differences in the percentage of linters by year (Table 2), but Las Cruces had increased linters compared to the other two locations. Compared with the earlier years, the percentage of seed hull was greater in 2016, and this occurred with a concomitant decrease in the percentage of kernel tissue. Oil and gossypol levels were significantly reduced for Stoneville produced seed compared with the other locations (Table 3), and correspondingly, the protein levels were higher for this location.

Table 1. Seed-to-fiber ratio and seed index summary statistics for cotton varieties produced from 2014-2016 (as is basis) [z]

	Seed-to-fiber ratio	Seed index, g
Complete sample population (2014-2016)		
Ave. ± std. dev.	1.41 ± 0.11	9.75 ± 0.99
Low	1.195	8.08
High	1.609	11.75
ANOVA by year		
2014	1.45 ± 0.15 A	10.4 ± 1.2 A
2015	1.44 ± 0.10 A	9.48 ± 0.79 B
2016	1.38 ± 0.09 B	9.58 ± 0.85 B
ANOVA by location		
Las Cruces	1.49 ± 0.14 A	10.3 ± 1.2 A
Lubbock	1.38 ± 0.07 B	9.24 ± 0.65 B
Stoneville	1.42 ± 0.11 B	10.1 ± 1.0 A

[z] One-way ANOVA analysis. Different letters within a block of a row indicate significant difference by Tukey multiple comparison method with $\alpha = 0.05$.

Table 2. Linter, hull, and kernel summary statistics for cotton varieties produced from 2014-2016 (as is basis) [z]

	Linter, %	Hull, %	Kernel, %
Complete sample population (2014-2016)			
Ave. ± std. dev.	10.7 ± 1.7	36.6 ± 2.0	52.7 ± 2.7
Low	6.20	32.4	46.6
High	14.6	40.2	58.4
ANOVA by year [y]			
2014	10.6 ± 1.4 A	35.4 ± 2.4 B	54.1 ± 3.1 A
2015	10.2 ± 1.6 A	35.7 ± 1.1 B	54.1 ± 1.7 A
2016	11.0 ± 2.0 A	37.8 ± 1.9 A	51.2 ± 2.4 B
ANOVA by location [y]			
Las Cruces	12.3 ± 2.5 A	35.8 ± 1.8 A	51.9 ± 4.0 A
Lubbock	10.3 ± 1.7 B	37.0 ± 2.2 A	52.7 ± 2.7 A
Stoneville	10.6 ± 1.4 AB	36.4 ± 2.1 A	53.0 ± 2.4 A

[z] Values exclude the DP340 PIMA cultivar.

[y] One-way ANOVA analysis. Different letters within a block of a row indicate significant difference by Tukey multiple comparison method with $\alpha = 0.05$.

Table 3. Oil, protein, and gossypol summary statistics for cotton varieties produced from 2014-2016 (as is basis) [z]

	Oil, %	Protein, %	Gossypol, %
Complete sample population (2014-2016)			
Ave. ± std. dev.	17.6 ± 2.0	20.7 ± 1.6	0.74 ± 0.14
Low	12.7	16.7	0.44
High	22.4	24.6	0.98
ANOVA by year			
2014	18.7 ± 2.2 A	20.1 ± 1.4 B	0.74 ± 0.13 A
2015	17.5 ± 1.3 B	21.4 ± 2.2 A	0.65 ± 0.13 B
2016	17.1 ± 1.9 B	20.5 ± 1.0 B	0.79 ± 0.13 A
ANOVA by location			
Las Cruces	18.6 ± 2.4 A	20.2 ± 0.9 B	0.83 ± 0.12 A
Lubbock	18.1 ± 1.7 A	20.2 ± 1.3 B	0.78 ± 0.13 A
Stoneville	16.7 ± 1.6 B	21.4 ± 1.8 A	0.65 ± 0.11 B

[z] One-way ANOVA analysis. Different letters within a block of a row indicate significant difference by Tukey multiple comparison method with $\alpha = 0.05$.

The seed-to-fiber ratio from the three years of study varied from 1.20 to 1.61 with an average value of 1.41 ± 0.11 (Table 1). This represents a marked reduction compared with values discussed in the early literature. For example, from a 1901 presentation to the Texas Cottonseed Crushers' Association discussing the seed contribution to crop value, McCollum uses a value of two pounds of cotton seed per pound of cotton fiber (McCollum, 1948). In his book “Cottonseed Products”, Thornton (1932) notes that “for every 5 pounds of lint there will be produced 9 pounds of seeds”, giving a seed-to-fiber ratio of 1.8. Production records compiled by the Departments of Agriculture and Commerce from 1930 to 1946 yield seed-to-fiber ratios ranging between 1.60 and 1.78 (Lund, 1948). The average value over these years was 1.74. The average value obtained from this study is also lower that the value of 1.5 that is often cited in current literature (e.g., Dowd, 2015) but is roughly in line with averaged values reported in recent years of the Regional High Quality (RHQ) component of the National Cotton Variety Trials (NCVT), which averaged 1.46 between 2011 and 2015 (ARS, 2017).

The change in seed-to-fiber ratio appears to be due to more than simply increased fiber yield but also decreased seed mass. The average seed index of the samples within this survey was 9.8 ± 1.0 g. This result is roughly in line with recent seed indices reported as part of the RHQ-NCVT data, which averaged 9.9 g over the last five years. This compares with cultivar averages between 11 and 12 g in early studies (Garner et al., 1914; Fraps, 1916; Tharp, 1948) and an average value of 12.6 ± 1.1 from the 1964 RHQ-NCVT data, indicating that a ~10–30% reduction has occurred over the past several decades. Twelve cultivars had seed indices below 9.0 in this survey. For comparison, DP555, a cultivar that caused well known ginning difficulties, had location averaged seed indices between 7.5 and 8.7 g for the 2002 to 2007 years it was included in the RHQ-NCVT data.

There was relatively little repeat or overlap data for the cultivars tested during the three years of this survey (30 cultivars in the 46 samples). However, some overlap was present. Although there was insufficient data to consider an analysis of individual cultivars by year or location, there were indications of environmental effects among the results of these samples. For instance, STV5458 grown in 2014 showed marked property differences between the Lubbock and Stoneville locations (Table S1). Given that this cultivar was developed for the Delta region, it might be expected that productivity of this cultivar would be lower in Lubbock, which was realized with a lower seed-to-fiber ratio and a dramatically smaller seed index (Table S1). Also, given the almost 30% drop in seed size and the smaller 8% reduction in seed-to-fiber ratio, it is apparent that this cultivar must have also yielded considerably less fiber in Lubbock. Although less pronounced than the differences shown for STV5458, STV4946 grown in 2015 also showed different properties in the two locations. Again the seed-fiber ratio and seed index was reduced for the Lubbock location compared with the Stoneville location (Table S2). DP1522 was produced in 2016 in both Lubbock and Las Cruces, and differences were apparent in the two samples; in this case the Lubbock sample had a greater seed-to-fiber ratio and a larger seed index than did the Las Cruces sample (Table S3). Hence, significant differences in properties were observed for seed grown in different locations.

In contrast with the location differences, year-to-year differences within the same cultivar were less apparent. For instance, DP340 was sampled in both 2014 and 2016. This Pima cultivar showed little difference in seed-to-fiber ratio and seed index between the two years (Tables S1 and S3). FM1944 grown in Stoneville for all three years also showed relative little variation (Tables S1–S3). STV4946 produced in Stoneville in 2015 and 2016 showed only a modest difference in seed-to-fiber ratio and no apparent difference in seed index (Tables S2 and S3).

The average proportion of linters, hull, and kernel fractions appeared to be less different from early reports than were the seed index and seed-to-fiber ratio results (Table 2). For instance, the average kernel mass was 52.7% compared with averages that ranged from 50.2 to 58.1% from a handful of studies spanning the period of 1906 to 1944 (Tharp, 1948). Excluding the Pima cultivar, which skewed the results due to its low levels of linters, the range of kernel values varied from 46.6 to 58.4% in this work, which is almost exactly the low and high range of values recorded from the combined early studies.

The percentage of seed linters, however, appeared to be reduced compared with early reports. These reports give average values for this property ranging between 12.2 and 13.8% (Pope and Ware, 1945; Thomas and Gerdes, 1945; Martin and Thomas, 1946; Bradham and Whitten, 1948), compared with the average value of 10.7% obtained from the *G. hirsutum* 2014–2016 seed. Rarely in early studies were samples noted with linter levels less than 9.0%, whereas samples with this level or less linters are quite common within this dataset. This change seems to be a result of selecting plants for increased fiber, likely promoting the retention of plants with improved fiber elongation genetics thereby reducing the number of non-elongated trichomes and possibly reducing the metabolic resources available to support linter development.

If the percentage of linters is slightly reduced and the percentage of kernels is roughly the same, then the percentage of hull would be slightly increased. Hence, concerns of greater seed damage during ginning do not appear to be related to reduced hull mass. This, however, does not mean that the composition of hulls has not changed or that other metabolic or genetic effects have not influenced hull or seed strength.

For the 2014–2016 produced seed, the percentage of oil and protein in the kernels was typical of many prior reports. Over all of the samples, oil averaged 17.6 ± 2.0% and protein averaged 20.7 ± 1.6% on a fuzzy seed as is weight basis, compared to mean values of 17.7% oil and 20.8% protein reported by Tharp (1948). The Oil Mill Gazetteer in the 1940s reported average monthly seed oil and ammonia results from several states, and these averages typically ranged between 17 and 20% for crude oil and from 3.5 to 4.0% ammonia (or 18–21% protein), which gives a slightly greater mean value for oil and a slightly lesser value for protein than obtained in this work. Similarly in a report by Bradham and Whitten (1948), the average oil level for ten varieties grown in seven locations was 19.7% crude oil and 18.9% protein. While some early reports seem in line with current results, some reports appear to have slightly greater levels of oil and protein than found in this work. Overall, it is difficult to conclude that there has been any substantial shift in average oil or protein values due to sustained breeding efforts.

Whole seed gossypol levels averaged 0.74% on the same basis, which is toward the high end of values typically measured by the authors. With an average kernel content of 53%, this translates to a kernel level of 1.4% (gossypol is frequently reported on a kernel basis), which is a little higher than the 0.8–1.2% typically observed for kernel gossypol levels. The relatively high levels appear to result because most samples included in this work were grown with irrigation, which is known to have a pronounced positive effect on seed gossypol level (Stansbury et al, 1956; Pettigrew and Dowd, 2011). The two cultivars grown under both dryland and irrigated conditions in 2015, DP1044 and NG4111, showed this effect, with irrigation increasing gossypol levels by 15 and 30%, respectively (Table S8). As gossypol methods were not yet available before the late 1950s, no direct comparisons can be made for this property.

DISCUSSION

By comparing properties of currently grown cultivars and similar data from the early literature, it appears that the seed has changed with the continual breeding for increased fiber yield. Further evidence for this can be found in the 50 years of data from the NCVT. From any given year or even any 10 or 20 year span, variations can be large and trends difficult to discern. But when evaluated over the history of the trials, a gradual downward trend is observed for both seed-to-fiber ratio and seed index (Fig. 1). Average values from the early RHQ-NCVT data (1960s) are not far removed from the literature data discussed above, e.g., the early average seed-to-fiber ratio of around 1.7 from the trials is in the middle of the range of 1.64 and 1.78 calculated from seed and fiber production statistics of the Commerce and Agriculture Department in the 1930s and 1940s (Tharp, 1948). Averaged seed indices greater than 12 were also observed in the 1964 NCVT data, similar to early survey reports. Likewise, the data from the cultivars studied here yield ranges and average values similar to those reported in recent RHQ-NCVT results.

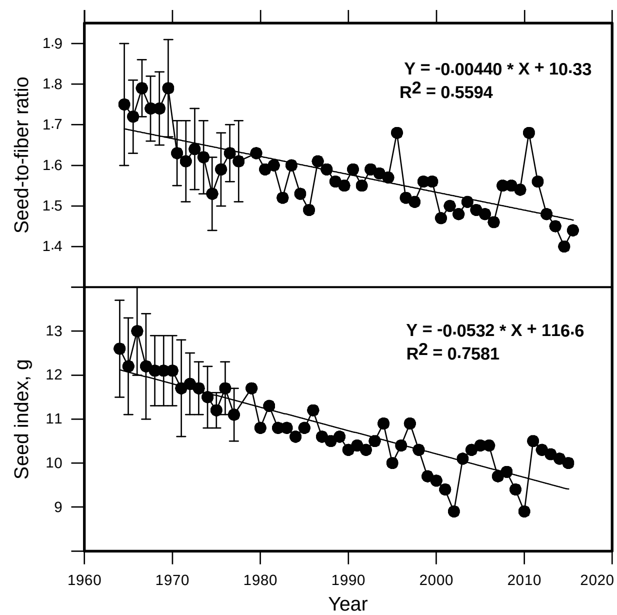

Fig. 1. Variation in seed-to-fiber ratio and seed index from National Cotton Variety Trial data (1964 to 2015). Data is the averaged cultivar data for the Regional High Quality Trials. Standard deviations are shown on the early year data as an indication of the variation among of cultivars within the annual sampling.

Some care must be taken when comparing different studies and in evaluating the early literature. The literature in some cases is unclear about the basis of values (i.e., as is weight basis, dry weight basis, or at an adjusted fixed moisture level). Additionally, it can be difficult to determine if early seed indices were expressed on a whole seed or linter free basis. In some cases the basis could be figured out by context or by the magnitude of other values presented in the report, but at times this was impossible, in which case the dataset was not considered. In many cases, we relied on the data and studies noted by Tharp (1948), as it was apparent his evaluation of prior work involved similar issues, and he would have been closer to these studies and more familiar with his contemporary authors.

Additionally, procedures have varied over the years. Protein, for example, was routinely determined by ammonia evolution from Kjeldahl combustion in early days, whereas combustion to nitrogen gas is standard today. Both of these approaches have the same basis, i.e., to determine the total amount of nitrogen in the sample. Hence, there should be little systemic difference due to this change. A protein-to-nitrogen conversion factor of 6.25 was used in this work as it was standard for most protein estimates in the early years, although it has been argued that a conversion value of 5.9–6.0 is more appropriate for cotton seed because of its relatively high level of arginine (Dowd and Wakelyn, 2010). Methods to determine crude oil have also changed, evolving from Butt-tube extractors, to repetitive immersion Soxhlet extractors or immersion-extraction systems (e.g., like a Soxtec apparatus), and even more recently to accelerated extractors under pressure. Again, the basic approach has not changed, extraction of the components soluble in hexane or petroleum ether, although there is likely more variability in these results because of different immersion times, sample preparation differences, sample moisture levels, etc. We have chosen to use a Soxtec extractor for this work, which submerges dried ground tissue under the solvent for a period of time then percolates the solvent through the sample. This approach had the advantage of being reproducible at a small scale (average reproducibility: 1–2 %), which was helpful to reduce the amount of hand dissecting of kernels needed to get good data.

Making fair comparisons of seed-to-fiber ratio also required some consideration. Early estimates of seed-to-fiber ratio discussed in this work would most likely have been based on fiber and seed production numbers or experimental studies where bolls were handpicked. Also, breeding studies, which frequently report a percent fiber, e.g. as is reported in the NCVT data, are usually based on hand-picked 50 boll cotton samples. Because these samples would have been largely debris free, these numbers were used directly. In contrast, the implementation of machine harvesting in the 1940–60s (Hughs, et al., 2010) dramatically increased the amounts of plant debris in field cotton samples. Because of this effect, it is difficult to estimate seed-to-fiber ratios from reported gin turn out values that range from 32 to 38%, as large amounts of trash are removed during ginning. To account for the debris in the samples used here, the ginned fiber samples were run through a Shirley cleaner.

Environment and growing conditions would be expected to have some influence on the seed properties measured here, and may be reflective in the location and year differences observed in Tables 1-3. Several agronomy studies on fiber yield and properties have included results on seed index. Meredith et al (2012) report that environment accounted for 82% of the variation in seed index from seven years of NCVT data. In contrast, a number of earlier studies have noted that considerably less than half of the seed index variation (18 to 28%) was due to environment (Meredith 2003; Blanche et al., 2006, Campbell et al. 2011). In potted plants, Wang et al. (2016) noted significant smaller seed with drought conditions, while Pettigrew (2010) noted a significant difference in the seed size of irrigated plants compared with dryland plants for only two years within a four year study. Similarly, Pettigrew and Zeng (2014) noted a significant difference in seed size between irrigated and dryland plants for only one year of a four year study. Added fertilizer generally appears to increase seed index (Pettigrew and Zeng, 2014) but planting early does not (Pettigrew, 2010). Stansbury and coworkers (1956) reported on the influence of rainfall on the oil, protein, and gossypol values of the seed, noting that seed oil and gossypol levels are increased when rainfall amounts are elevated, and correspondingly protein levels are reduced. This trend seems to be present in the location data (Table 3), where the lower oil and gossypol levels and greater protein levels were observed in seed from the Stoneville location. Whether this difference was due to rainfall or irrigation or if other factors were also contributing is unclear. Finally, although the ANOVA results suggest differences in environment, these results are based on a limited number of varieties for the Las Cruces location, which may have influenced the results.

While the average oil and protein compositional values seem little changed from prior reports, some individual compositional results were surprising. The whole seed oil level was less than 14% for two samples grown in 2016 (Table S9). DP1614, produced in Stoneville, and FM1830, produced in Lubbock, had crude oil levels of 12.7 and 13.2%, respectively, on whole seed as is basis. FM1830 was reported in the 2015 RHQ-NCVT where its oil content was 16.2%. However, from discussions with the associated analytical laboratory (Eurofins USA), we believe these numbers are reported on a linter-free basis at a reduced moisture level of about 3%, which would correspond to a 13.8% oil level on an as is whole seed basis. Hence, these values are in reasonable agreement. Low oil levels are of direct concern for oil processors but also seed producers because seed oil content is positively correlated with seedling viability (Snider et al., 2014). This trend should be monitored in the future.

Smaller seed size can be particularly troublesome for ginners, who frequently take the seed as the principal part of their payment. Lower seed-to-fiber ratio translates into less seed per bale produced. For instance, at the 2017 Beltwide Cotton Conferences, multiple ginners commented that they are frequently seeing seed yields less than 600 pounds per bale, which roughly translates to seed-to-fiber recovery ratio of 1.2 (assuming a 500 pound bale) down from amounts closer to 800 pounds per bale or a seed-to-fiber recovery ratio of 1.6.

Ginners believe that additional seed loss might be occurring as they have observed increased seed exiting the gin in the motes and fiber cleaning operations. Because the 1.2 seed-to-fiber recovery ratio is lower than the current average seed-to-fiber ratio of 1.4, additional factors may be affecting seed yields. Small seed may be capable of passing through the ribs of gin stands, and would then be lost during subsequent lint cleaning operations. If this is occurring, then it seems that there may be a critical seed size that results in accelerated losses. At present, only a rough estimate can be made of this size, but given the problems with the problematic DP555 cultivar with average RHQ-NCVT seed indices between 7.5 and 8.7 g, the number of current cultivars with seed indices <9 g, and the current complaints of ginners, this critical seed index size may be around 8.5 g.

Damaged or broken seed may also contribute to losses. Greater seed damage may result from inherently weaker seed, and cultivars prone to mechanical damage are known. However, if weaker seed are produced today, it is not apparent from the percentage of seed hull, which is roughly the same as in early reports. Increased gin speed is well known to increase seed damage (Delouche, 1986). With the pressure to gin seed cotton faster, ginning speed may also be a contributing factor to increased seed damage and accelerated seed loss.

SUMMARY

Seed cotton varieties from the 2014–2016 growing seasons were evaluated for a number of seed-fiber traits and compositional properties. Seed-fiber ratio averaged 1.41 ± 0.11, which is dramatically lower than values reported from early reports. Correspondingly, seed index has also fallen, indicating that the breeding of cotton for increased fiber yield appears to have resulted in substantive changes in seed size. A reduction in the amount of cottonseed linters was also apparent. Significant changes in the proportions of the hull and kernel fractions, and in the seed oil and protein levels were not observed. The scale of the changes to the seed-to-fiber ratio and seed index appears to have significant detrimental effects for ginning operations.

ACKNOWLEDGEMENTS

The authors thank Rick Byler (ARS), Greg Holt (ARS) and Ed Hughs (ARS) for providing seed cotton samples and Ellen Keene (ARS) for help in collecting early NCVT data.

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Table S1. Seed/fiber ratio and seed indices for cotton cultivars grown in 2014 (as is basis).

Variety - Location	Dryland / Irrigated	Seed/fiber ratio	Seed index, g
DP340 - PIMA - Las Cruces	Irrigated	1.56 ± 0.00	11.75 ± 0.03
DP1044 - Stoneville	Irrigated	1.54 ± 0.01	11.13 ± 0.25
DP1219 - Lubbock	Irrigated	1.37 ± 0.01	8.46 ± 0.11
DP1321 - Stoneville	Irrigated	1.28 ± 0.02	9.88 ± 0.33
FM1944 - Stoneville	Irrigated	1.54 ± 0.01	11.13 ± 0.25
FM2484 - Lubbock	Irrigated	1.23 ± 0.01	9.49 ± 0.13
PHY339 - Las Cruces	Irrigated	1.57 ± 0.01	11.62 ± 0.22
PHY565 - Las Cruces	Irrigated	1.50 ± 0.02	9.39 ± 0.08
STV4946 - Stoneville	Irrigated	1.39 ± 0.02	11.22 ± 0.33
STV5458 - Lubbock	Irrigated	1.40 ± 0.04	8.59 ± 0.06
STV5458 - Stoneville	Irrigated	1.51 ± 0.01	11.39 ± 0.11

Table S2. Seed/fiber ratio and seed indices for cotton cultivars grown in 2015 (as is basis).

Variety - Location	Dryland / Irrigated	Seed/fiber ratio	Seed index, g
Acala1517-08 – Las Cruces	Irrigated	1.60 ± 0.02	9.62 ± 0.15
DP1044 - Lubbock	Dryland	1.32 ± 0.02	8.49 ± 0.08
DP1044 - Lubbock	Irrigated	1.47 ± 0.02	8.74 ± 0.09
DP1321 - Stoneville	Irrigated	1.39 ± 0.01	9.47 ± 0.10
FM1944 - Stoneville	Irrigated	1.56 ± 0.01	10.42 ± 0.08
FM9180 - Lubbock	Dryland	1.44 ± 0.02	9.04 ± 0.14
NG4111 - Lubbock	Dryland	1.33 ± 0.02	8.56 ± 0.09
NG4111 - Lubbock	Irrigated	1.46 ± 0.01	9.62 ± 0.03
PHY444 - Stoneville	Irrigated	1.31 ± 0.02	10.67 ± 0.18
PHY499 - Stoneville	Irrigated	1.34 ± 0.01	9.40 ± 0.12
STV4946 - Lubbock	Irrigated	1.46 ± 0.05	9.72 ± 0.15
STV4946 - Stoneville	Irrigated	1.52 ± 0.02	10.88 ± 0.10
STV5289 - Stoneville	Irrigated	1.54 ± 0.01	8.59 ± 0.06

Table S3. Seed/fiber ratio and seed indices for cotton cultivars grown in 2016 (as is basis).

Variety - Location	Dryland / Irrigated	Seed/fiber ratio	Seed index, g
CP3475 - Lubbock	Irrigated	1.38 ± 0.01	9.64 ± 0.07
DG3385 – Las Cruces	Irrigated	1.31 ± 0.01	9.78 ± 0.24
DP340 - PIMA - Las Cruces	Irrigated	1.61 ± 0.02	11.50 ± 0.13
DP1321 - Stoneville	Irrigated	1.37 ± 0.02	9.84 ± 0.08
DP1522 - Las Cruces	Irrigated	1.26 ± 0.02	8.73 ± 0.07
DP1522 – Lubbock	Irrigated	1.44 ± 0.01	9.07 ± 0.11
DP1612 - Lubbock	Irrigated	1.41 ± 0.03	9.32 ± 0.07
DP1614 - Stoneville	Irrigated	1.20 ± 0.01	8.08 ± 0.07
FM1830 - Lubbock	Irrigated	1.28 ± 0.03	8.44 ± 0.05
FM1911 - Lubbock	Irrigated	1.26 ± 0.02	10.90 ± 0.23
FM1944 - Stoneville	Irrigated	1.51 ± 0.01	10.31 ± 0.14
NG3405 - Lubbock	Irrigated	1.33 ± 0.01	8.95 ± 0.09
NG3406 - Lubbock	Irrigated	1.34 ± 0.00	8.86 ± 0.01
NG3517 - Lubbock	Irrigated	1.43 ± 0.02	9.48 ± 0.12
NG4545 - Lubbock	Irrigated	1.36 ± 0.02	8.90 ± 0.10
PHY243 - Lubbock	Irrigated	1.45 ± 0.01	10.43 ± 0.05
PHY308 - Lubbock	Irrigated	1.49 ± 0.00	9.78 ± 0.14
PHY333 - Lubbock	Irrigated	1.39 ± 0.01	9.34 ± 0.13

Table S3. (continued)

Variety - Location	Dryland / Irrigated	Seed/fiber ratio	Seed index, g
PHY444 - Stoneville	Irrigated	1.28 ± 0.01	9.69 ± 0.17
PHY499 - Stoneville	Irrigated	1.30 ± 0.01	9.40 ± 0.21
STV4946 - Stoneville	Irrigated	1.43 ± 0.02	11.10 ± 0.16
STV5289 - Stoneville	Irrigated	1.46 ± 0.00	9.08 ± 0.02

Table S4. Proportion of cottonseed linter, hull and kernel tissues from cotton cultivars grown in 2014 (as is basis).

Variety - Location	Dryland / Irrigated	Linter	Hull	Kernel
DP340 - PIMA - Las Cruces	Irrigated	3.1 ± 0.2	36.4 ± 0.6	60.5 ± 0.5
DP1044 - Stoneville	Irrigated	10.8 ± 0.3	34.8 ± 0.6	54.4 ± 0.5
DP1219 - Lubbock	Irrigated	12.6 ± 0.4	35.0 ± 0.4	52.4± 0.1
DP1321 - Stoneville	Irrigated	10.7 ± 0.7	37.5 ± 0.9	51.8 ± 0.2
FM1944 - Stoneville	Irrigated	9.7 ± 0.1	40.0 ± 0.3	50.2 ± 0.3
FM2484 - Lubbock	Irrigated	9.7 ± 0.1	34.6 ± 0.6	55.7 ± 0.6
PHY339 - Las Cruces	Irrigated	9.3 ± 0.2	33.4 ± 0.4	57.4 ± 0.3
PHY565 - Las Cruces	Irrigated	13.3 ± 0.4	37.2 ± 0.9	49.5 ± 0.5
STV4946 - Stoneville	Irrigated	10.1 ± 0.7	36.0 ± 0.8	53.9 ± 0.6
STV5458 - Lubbock	Irrigated	8.8 ± 0.4	32.8 ± 0.3	58.4 ± 0.4
STV5458 - Stoneville	Irrigated	10.5 ± 0.3	32.4 ± 0.4	57.1 ± 0.3

Table S5. Proportion of cottonseed linter, hull, kernel tissues from cotton cultivar grown in 2015 (as is basis).

Variety - Location	Dryland / Irrigated	Linter	Hull	Kernel
Acala1517-08 - Las Cruces	Irrigated	9.9 ± 0.2	35.3 ± 0.6	54.8 ± 0.4
DP1044 - Lubbock	Dryland	11.5 ± 0.4	34.8 ± 0.2	53.7 ± 0.4
DP1044 - Lubbock	Irrigated	12.6 ± 0.4	35.2 ± 0.5	52.2 ± 0.5
DP1321 - Stoneville	Irrigated	11.4 ± 0.6	36.6 ± 0.1	52.0 ± 0.5
FM1944 - Stoneville	Irrigated	11.2 ± 0.4	37.9 ± 0.2	50.9 ± 0.6
FM9180 - Lubbock	Dryland	10.4 ± 0.7	36.5 ± 0.9	53.1 ± 0.4
NG4111 - Lubbock	Dryland	8.6 ± 0.1	34.9 ± 0.5	56.5 ± 0.4
NG4111 - Lubbock	Irrigated	9.7 ± 0.4	34.6 ± 0.5	55.7 ± 0.3
PHY444 - Stoneville	Irrigated	6.4 ± 0.5	37.7 ± 0.9	55.9 ± 0.4
PHY499 - Stoneville	Irrigated	9.3 ± 0.9	34.4 ± 1.0	56.3 ± 0.3
STV4946 - Lubbock	Irrigated	11.0 ± 0.5	35.8 ± 0.4	53.2 ± 0.2
STV4946 - Stoneville	Irrigated	10.4 ± 0.5	35.5 ± 0.6	54.2 ± 0.2
STV5289 - Stoneville	Irrigated	9.7 ± 0.1	35.5 ± 0.0	54.9 ± 0.2

Table S6. Proportion of cottonseed linter, hull, kernel tissues from cotton cultivars grown in 2016 (as is basis).

Variety - Location	Dryland / Irrigated	Linter	Hull	Kernel
CP3475 - Lubbock	Irrigated	9.8 ± 0.3	37.7 ± 0.8	52.5 ± 0.5
DG3385 – Las Cruces	Irrigated	14.6 ± 0.2	35.1 ± 0.7	50.3 ± 0.7
DP340 - PIMA - Las Cruces	Irrigated	3.8 ± 0.2	41.0 ± 0.1	59.0 ± 0.1
DP1321 - Stoneville	Irrigated	12.9 ± 0.5	35.9 ± 0.5	51.2 ± 0.3
DP1522 – Las Cruces	Irrigated	14.4 ± 0.3	38.0 ± 0.8	47.6 ± 0.6
DP1522 - Lubbock	Irrigated	11.4 ± 0.6	39.4 ± 1.6	49.2 ± 1.0
DP1612 - Lubbock	Irrigated	10.0 ± 0.5	39.3 ± 0.7	50.6 ± 0.6
DP1614 - Stoneville	Irrigated	11.1 ± 0.3	39.9 ± 0.5	49.0 ± 0.4
FM1830 - Lubbock	Irrigated	13.3 ± 0.2	40.2 ± 0.4	46.6 ± 0.2
FM1911 - Lubbock	Irrigated	6.2 ± 0.4	40.2 ± 0.6	53.6 ± 0.6
FM1944 - Stoneville	Irrigated	11.9 ± 0.6	39.6 ± 0.2	48.6 ± 0.6
NG3405 - Lubbock	Irrigated	11.4 ± 0.3	39.4 ± 0.9	49.2 ± 0.6

Table S6. (continued)

Variety - Location	Dryland / Irrigated	Linter	Hull	Kernel
NG3406 - Lubbock	Irrigated	11.1 ± 0.8	39.8 ± 0.5	49.1 ± 0.3
NG3517 - Lubbock	Irrigated	9.5 ± 0.2	37.4 ± 0.1	53.1 ± 0.2
NG4545 - Lubbock	Irrigated	9.5 ± 0.1	39.0 ± 0.2	51.5 ± 0.3
PHY243 - Lubbock	Irrigated	8.4 ± 0.3	36.8 ± 0.4	54.8 ± 0.6
PHY308 - Lubbock	Irrigated	11.6 ± 0.6	36.7 ± 0.4	51.7 ± 0.3
PHY333 - Lubbock	Irrigated	8.6 ± 0.4	37.3 ± 0.7	54.1 ± 0.6
PHY444 - Stoneville	Irrigated	10.6 ± 1.0	36.1 ± 0.8	53.3 ± 0.2
PHY499 - Stoneville	Irrigated	12.0 ± 0.1	35.0 ± 0.3	53.1 ± 0.4
STV4946 - Stoneville	Irrigated	11.2 ± 0.4	34.5 ± 0.2	54.4 ± 0.6
STV5289 - Stoneville	Irrigated	11.5 ± 0.4	36.2 ± 0.4	52.3 ± 0.1

Table S7. Percentage of seed oil, protein, and gossypol for 2014 cultivars (as is basis).

Variety - Location	Dryland / Irrigated	Oil	Protein	Gossypol
DP340 - PIMA - Las Cruces	Irrigated	22.1 ± 0.7	19.8 ± 0.3	0.88 ± 0.01
DP1044 - Stoneville	Irrigated	18.2 ± 0.3	20.8 ± 0.2	0.68 ± 0.02
DP1219 - Lubbock	Irrigated	17.4 ± 0.1	20.5 ± 0.3	0.60 ± 0.01
DP1321 - Stoneville	Irrigated	16.9 ± 0.1	19.4 ± 0.2	0.67 ± 0.02
FM1944 - Stoneville	Irrigated	15.8 ± 0.1	21.1 ± 0.3	0.51 ± 0.00
FM2484 - Lubbock	Irrigated	22.4 ± 0.1	16.7 ± 0.2	0.87 ± 0.01
PHY339 - Las Cruces	Irrigated	20.4 ± 0.4	20.6 ± 0.3	0.96 ± 0.01
PHY565 - Las Cruces	Irrigated	16.2 ± 0.2	19.3 ± 0.1	0.72 ± 0.01
STV4946 - Stoneville	Irrigated	17.4 ± 0.3	19.8 ± 0.3	0.74 ± 0.02
STV5458 - Lubbock	Irrigated	20.4 ± 0.1	21.9 ± 0.2	0.61 ± 0.02
STV5458 - Stoneville	Irrigated	19.3 ± 0.1	21.6 ± 0.1	0.84 ± 0.02

Table S8. Percentage of seed oil, protein, and gossypol for 2015 cultivars (as is basis).

Variety - Location	Dryland / Irrigated	Oil	Protein	Gossypol
Acala1517-08 - Las Cruces	Irrigated	18.3 ± 0.5	21.8 ± 0.7	0.61 ± 0.04
DP1044 - Lubbock	Dryland	18.6 ± 0.2	20.0 ± 0.6	0.65 ± 0.02
DP1044 - Lubbock	Irrigated	17.7 ± 0.1	19.4 ± 0.4	0.75 ± 0.02
DP1321 - Stoneville	Irrigated	16.1 ± 0.1	21.3 ± 0.2	0.53 ± 0.03
FM1944 - Stoneville	Irrigated	15.0 ± 0.3	22.6 ± 0.3	0.44 ± 0.01
FM9180 - Lubbock	Dryland	18.4 ± 0.2	20.7 ± 0.2	0.55 ± 0.01
NG4111 - Lubbock	Dryland	18.2 ± 0.2	23.4 ± 0.1	0.66 ± 0.02
NG4111 - Lubbock	Irrigated	18.2 ± 0.2	21.7 ± 0.2	0.84 ± 0.00
PHY444 - Stoneville	Irrigated	17.3 ± 0.3	22.6 ± 0.2	0.56 ± 0.02
PHY499 - Stoneville	Irrigated	16.7 ± 0.2	24.6 ± 0.2	0.57 ± 0.02
STV4946 - Lubbock	Irrigated	18.1 ± 0.2	19.2 ± 0.6	0.83 ± 0.03
STV4946 - Stoneville	Irrigated	19.6 ± 0.3	16.7 ± 0.1	0.83 ± 0.02
STV5289 - Stoneville	Irrigated	15.7 ± 0.0	24.7 ± 0.1	0.61 ± 0.02

Table S9. Percentage of seed oil, protein, and gossypol for 2016 cultivars (as is basis).

Variety - Location	Dryland / Irrigated	Oil	Protein	Gossypol
CP3475 - Lubbock	Irrigated	18.2 ± 0.2	20.2 ± 0.2	0.88 ± 0.00
DG3385 – Las Cruces	Irrigated	17.0 ± 0.2	19.5 ± 0.1	0.94 ± 0.04
DP340 - PIMA - Las Cruces	Irrigated	21.0 ± 0.2	21.1 ± 0.2	0.87 ± 0.00
DP1321 - Stoneville	Irrigated	16.3 ± 0.1	21.0 ± 0.4	0.68 ± 0.00
DP1522 – Las Cruces	Irrigated	15.5 ± 0.3	19.8 ± 0.2	0.79 ± 0.03
DP1522 - Lubbock	Irrigated	16.2 ± 0.5	19.8 ± 0.3	0.80 ± 0.02

Table S9. (continued)

Variety - Location	Dryland / Irrigated	Oil	Protein	Gossypol
DP1612 - Lubbock	Irrigated	17.4 ± 0.4	19.6 ± 0.3	0.85 ± 0.02
DP1614 - Stoneville	Irrigated	12.7 ± 0.1	23.1 ± 0.3	0.62 ± 0.01
FM1830 - Lubbock	Irrigated	13.2 ± 0.2	21.0 ± 0.2	0.56 ± 0.01
FM1911 - Lubbock	Irrigated	18.8 ± 0.4	20.7 ± 0.2	0.82 ± 0.02
FM1944 - Stoneville	Irrigated	15.4 ± 0.3	20.1 ± 0.2	0.51 ± 0.01
NG3405 - Lubbock	Irrigated	16.6 ± 0.2	19.3 ± 0.3	0.79 ± 0.02
NG3406 - Lubbock	Irrigated	16.4 ± 0.2	19.3 ± 0.1	0.78 ± 0.01
NG3517 - Lubbock	Irrigated	19.0 ± 0.3	19.8 ± 0.1	0.90 ± 0.00
NG4545 - Lubbock	Irrigated	18.1 ± 0.2	19.5 ± 0.1	0.96 ± 0.01
PHY243 - Lubbock	Irrigated	19.8 ± 0.2	20.1 ± 0.2	0.98 ± 0.02
PHY308 - Lubbock	Irrigated	17.7 ± 0.1	20.6 ± 0.2	0.75 ± 0.02
PHY333 - Lubbock	Irrigated	18.8 ± 0.2	21.0 ± 0.2	0.98 ± 0.02
PHY444 - Stoneville	Irrigated	16.7 ± 0.1	22.3 ± 0.1	0.63 ± 0.02
PHY499 - Stoneville	Irrigated	16.7 ± 0.1	22.2 ± 0.1	0.69 ± 0.02
STV4946 - Stoneville	Irrigated	17.9 ± 0.3	20.8 ± 0.3	0.78 ± 0.02
STV5289 - Stoneville	Irrigated	17.0 ± 0.3	21.0 ± 0.2	0.78 ± 0.02

Table S10. Seed/fiber ratio and seed indices for cotton cultivars grown in 2014 (dry weight basis).

Variety - Location	Dryland / Irrigated	Seed/fiber ratio	Seed index, g
DP340 - PIMA - Las Cruces	Irrigated	1.54 ± 0.00	10.8 ± 0.01
DP1044 - Stoneville	Irrigated	1.50 ± 0.01	10.06 ± 0.20
DP1219 - Lubbock	Irrigated	1.33 ± 0.01	7.64 ± 0.10
DP1321 - Stoneville	Irrigated	1.26 ± 0.02	8.96 ± 0.29
FM1944 - Stoneville	Irrigated	1.50 ± 0.01	10.06 ± 0.20
FM2484 - Lubbock	Irrigated	1.21 ± 0.01	8.60 ± 0.11
PHY339 - Las Cruces	Irrigated	1.58 ± 0.01	10.87 ±0.21
PHY565 - Las Cruces	Irrigated	1.49 ± 0.02	8.68 ± 0.05
STV4946 - Stoneville	Irrigated	1.36 ± 0.02	10.15 ± 0.29
STV5458 - Lubbock	Irrigated	1.37 ± 0.04	7.78 ± 0.05
STV5458 - Stoneville	Irrigated	1.48 ± 0.00	10.38 ± 0.05

Table S11. Seed/fiber ratio and seed indices for cotton cultivars grown in 2015 (dry weight basis).

Variety - Location	Dryland / Irrigated	Seed/fiber ratio	Seed index, g
Acala1517-08 – Las Cruces	Irrigated	1.57 ± 0.02	8.94 ± 0.13
DP1044 - Lubbock	Dryland	1.28 ± 0.02	7.76 ± 0.07
DP1044 - Lubbock	Irrigated	1.42 ± 0.02	8.04 ± 0.08
DP1321 - Stoneville	Irrigated	1.33 ± 0.01	8.63 ± 0.08
FM1944 - Stoneville	Irrigated	1.50 ± 0.01	9.51 ± 0.08
FM9180 - Lubbock	Dryland	1.39 ± 0.02	8.29 ± 0.12
NG4111 - Lubbock	Dryland	1.29 ± 0.02	7.80 ± 0.07
NG4111 - Lubbock	Irrigated	1.43 ± 0.01	8.94 ± 0.02
PHY444 - Stoneville	Irrigated	1.26 ± 0.01	9.68 ± 0.15
PHY499 - Stoneville	Irrigated	1.28 ± 0.01	8.56 ± 0.11
STV4946 – Lubbock	Irrigated	1.42 ± 0.05	8.96 ± 0.14
STV4946 - Stoneville	Irrigated	1.47 ± 0.02	9.93 ± 0.10
STV5289 - Stoneville	Irrigated	1.48 ± 0.01	7.81 ± 0.05

Table S12. Seed/fiber ratio and seed indices for cotton cultivars grown in 2016 (dry weight basis).

Variety - Location	Dryland / Irrigated	Seed/fiber ratio	Seed index, g
CP3475 – Lubbock	Irrigated	1.35 ± 0.01	8.88 ± 0.06
DG3385 – Las Cruces	Irrigated	1.28 ± 0.01	8.96 ± 0.21
DP340 - PIMA - Las Cruces	Irrigated	1.57 ± 0.02	10.57 ± 0.12
DP1321 - Stoneville	Irrigated	1.34 ± 0.02	9.00 ± 0.07
DP1522 - Las Cruces	Irrigated	1.22 ± 0.01	7.97 ± 0.06
DP1522 – Lubbock	Irrigated	1.40 ± 0.02	8.35 ± 0.10
DP1612 – Lubbock	Irrigated	1.38 ± 0.03	8.59 ± 0.07
DP1614 - Stoneville	Irrigated	1.16 ± 0.01	7.35 ± 0.06
FM1830 – Lubbock	Irrigated	1.24 ± 0.03	7.74 ± 0.05
FM1911 – Lubbock	Irrigated	1.23 ± 0.02	10.02 ± 0.21
FM1944 - Stoneville	Irrigated	1.47 ± 0.01	9.54 ± 0.12
NG3405 – Lubbock	Irrigated	1.30 ± 0.01	8.27 ± 0.09
NG3406 – Lubbock	Irrigated	1.31 ± 0.00	8.18 ± 0.01
NG3517 – Lubbock	Irrigated	1.39 ± 0.02	8.79 ± 0.12
NG4545 – Lubbock	Irrigated	1.33 ± 0.02	8.25 ± 0.09
PHY243 – Lubbock	Irrigated	1.43 ± 0.01	9.64 ± 0.04
PHY308 – Lubbock	Irrigated	1.46 ± 0.02	9.01 ± 0.13
PHY333 – Lubbock	Irrigated	1.37 ± 0.01	8.60 ± 0.12
PHY444 – Stoneville	Irrigated	1.25 ± 0.01	8.96 ± 0.15
PHY499 – Stoneville	Irrigated	1.27 ± 0.01	8.62 ± 0.19
STV4946 - Stoneville	Irrigated	1.40 ± 0.02	10.21 ± 0.15
STV5289 - Stoneville	Irrigated	1.42 ± 0.00	8.41 ± 0.01

Table S13. Proportion of cottonseed linter, hull and kernel tissues from cotton varieties grown in 2014 (dry weight basis).

Variety		Linter	Hull	Kernel
DP340 – PIMA - Las Cruces	Irrigated	3.1 ± 0.2	35.5 ± 0.7	61.4 ± 0.7
DP1044 - Stoneville	Irrigated	11.0 ± 0.4	33.9 ± 0.6	55.1 ± 0.6
DP1219 - Lubbock	Irrigated	12.7 ± 0.4	34.2 ± 0.4	53.2 ± 0.2
DP1321 - Stoneville	Irrigated	10.9 ± 0.7	36.4 ± 0.7	52.7 ± 0.1
FM1944 - Stoneville	Irrigated	9.9 ± 0.1	39.1 ± 0.5	51.0 ± 0.5
FM2484 - Lubbock	Irrigated	9.8 ± 0.1	33.5 ± 0.4	56.7 ± 0.4
PHY339 - Las Cruces	Irrigated	9.4 ± 0.2	32.6 ± 0.3	58.1 ± 0.3
PHY565 - Las Cruces	Irrigated	13.5 ± 0.4	36.4 ± 0.8	50.1 ± 0.3
STV4946 - Stoneville	Irrigated	10.3 ± 0.7	35.0 ± 0.9	54.7 ± 0.7
STV5458 - Lubbock	Irrigated	8.9 ± 0.4	31.8 ± 0.1	59.3 ± 04
STV5458 - Stoneville	Irrigated	10.6 ± 0.3	31.4 ± 0.4	58.0 ± 0.2

Table S14. Proportion of cottonseed linter, hull, kernel tissues from cotton varieties grown in 2015 (dry weight basis).

Variety		Linter	Hull	Kernel
Acala1517-08 - Las Cruces	Irrigated	10.0 ± 0.2	34.3 ± 0.6	55.7 ± 0.5
DP1044 - Lubbock	Dryland	11.6 ± 0.4	33.9 ± 0.3	54.5 ± 0.36
DP1044 - Lubbock	Irrigated	12.6 ± 0.5	34.3 ± 0.5	53.1 ± 0.5
DP1321 - Stoneville	Irrigated	11.5 ± 0.6	35.6 ± 0.1	52.9 ± 0.5
FM1944 - Stoneville	Irrigated	11.3 ± 0.4	37.0 ± 0.2	51.7 ± 0.6
FM9180 - Lubbock	Dryland	10.5 ± 0.7	35.5 ± 0.9	54.2 ± 0.4
NG4111 - Lubbock	Dryland	8.6 ± 0.1	34.0 ± 0.6	57.5 ± 0.5
NG4111 - Lubbock	Irrigated	9.7 ± 0.4	33.5 ± 0.5	56.8 ± 0.3
PHY444 - Stoneville	Irrigated	6.5 ± 0.5	36.4 ± 0.9	57.1 ± 0.4
PHY499 - Stoneville	Irrigated	9.4 ± 0.9	33.5 ± 1.0	57.1 ± 0.3

Variety		Linter	Hull	Kernel
STV4946 - Lubbock	Irrigated	11.0 ± 0.5	34.7 ± 0.5	54.3 ± 0.3
STV4946 - Stoneville	Irrigated	10.5 ± 0.5	34.5 ± 0.5	55.1 ± 0.2
STV5289 - Stoneville	Irrigated	9.7 ± 0.1	34.6 ± 0.1	55.7 ± 0.2

Table S15. Proportion of cottonseed linter, hull, kernel tissues from cotton varieties grown in 2016 (dry weight basis).

Variety		Linter	Hull	Kernel
CP3475 - Lubbock	Irrigated	9.8 ± 0.3	36.7 ± 0.8	53.5 ± 0.5
DG3385 - Las Cruces	Irrigated	14.6 ± 0.2	34.2 ± 0.6	51.2 ± 0.7
DP340 - PIMA - Las Cruces	Irrigated	3.8 ± 0.2	36.2 ± 0.3	60.1 ± 0.1
DP1321 - Stoneville	Irrigated	12.9 ± 0.5	35.1 ± 0.5	52.0 ± 0.3
DP1522 - Las Cruces	Irrigated	14.6 ± 0.3	37.2 ± 0.8	48.2 ± 0.6
DP1522 - Lubbock	Irrigated	11.4 ± 0.6	38.5 ± 1.5	50.1 ± 0.9
DP1612 - Lubbock	Irrigated	10.0 ± 0.4	38.4 ± 0.7	51.6 ± 0.6
DP1614 - Stoneville	Irrigated	11.1 ± 0.3	39.4 ± 0.4	49.5 ± 0.3
FM1830 - Lubbock	Irrigated	13.3 ± 0.2	39.4 ± 0.4	47.3 ± 0.1
FM1911 - Lubbock	Irrigated	6.2 ± 0.4	39.1 ± 0.6	54.7 ± 0.7
FM1944 - Stoneville	Irrigated	11.8 ± 0.6	38.9 ± 0.3	49.3 ± 0.4
NG3405 - Lubbock	Irrigated	11.4 ± 0.4	38.4 ± 1.0	50.2 ± 0.6
NG3406 - Lubbock	Irrigated	11.1 ± 0.8	38.9 ± 0.6	50.0 ± 0.3
NG3517 - Lubbock	Irrigated	9.4 ± 0.2	36.6 ± 0.1	54.0 ± 0.3
NG4545 - Lubbock	Irrigated	9.5 ± 0.1	38.0 ± 0.2	52.5 ± 0.3
PHY243 - Lubbock	Irrigated	8.4 ± 0.3	35.8 ± 0.4	55.8 ± 0.6
PHY308 - Lubbock	Irrigated	11.6 ± 0.6	35.8 ± 0.4	52.6 ± 0.3
PHY333 - Lubbock	Irrigated	8.6 ± 0.4	36.2 ± 0.7	55.2 ± 0.6
PHY444 - Stoneville	Irrigated	10.5 ± 1.0	35.3 ± 0.9	54.2 ± 0.2
PHY499 - Stoneville	Irrigated	11.9 ± 0.0	34.2 ± 0.4	53.9 ± 0.4
STV4946 - Stoneville	Irrigated	11.2 ± 0.4	33.5 ± 0.2	55.4 ± 0.6
STV5289 - Stoneville	Irrigated	11.5 ± 0.4	35.5 ± 0.5	53.0 ± 0.1

Table S16. Percentage of seed oil, protein, and gossypol for 2014 cultivars (dry weight basis).

Variety		Oil	Protein	Gossypol
DP340 – PIMA - Las Cruces	Irrigated	24.0 ± 0.8	21.7 ± 0.3	0.97 ± 0.01
DP1044 - Stoneville	Irrigated	19.8 ± 0.3	22.9 ± 0.2	0.75 ± 0.02
DP1219 - Lubbock	Irrigated	18.8 ± 0.1	22.5 ± 0.3	0.65 ± 0.01
DP1321 - Stoneville	Irrigated	18.5 ± 0.1	21.5 ± 0.2	0.75 ± 0.02
FM1944 - Stoneville	Irrigated	17.2 ± 0.1	23.3 ± 0.3	0.57 ± 0.01
FM2484 - Lubbock	Irrigated	24.3 ± 0.1	18.3 ± 0.3	0.96 ± 0.01
PHY339 - Las Cruces	Irrigated	22.2 ± 0.5	22.5 ± 0.3	1.06 ± 0.01
PHY565 - Las Cruces	Irrigated	17.6 ± 0.3	21.2 ± 0.1	0.79 ± 0.02
STV4946 - Stoneville	Irrigated	18.8 ± 0.4	21.9 ± 0.4	0.81 ± 0.03
STV5458 - Lubbock	Irrigated	22.1 ± 0.2	23.9 ± 0.3	0.67 ± 0.03
STV5458 - Stoneville	Irrigated	21.1 ± 0.1	23.8 ± 0.2	0.93 ± 0.02

Table S17. Percentage of seed oil, protein, and gossypol for 2015 cultivars (dry weight basis).

Variety		Oil	Protein	Gossypol
Acala1517-08 - Las Cruces	Irrigated	19.8 ± 0.5	23.8 ± 0.8	0.67 ± 0.04
DP1044 - Lubbock	Dryland	20.1 ± 0.3	21.9 ± 0.6	0.72 ± 0.02
DP1044 - Lubbock	Irrigated	19.1 ± 0.1	21.1 ± 0.4	0.81 ± 0.02
DP1321 - Stoneville	Irrigated	17.4 ± 0.2	23.3 ± 0.2	0.58 ± 0.03

Table S17. (continued)

Variety		Oil	Protein	Gossypol
FM1944 - Stoneville	Irrigated	16.1 ± 0.3	24.8 ± 0.2	0.50 ± 0.01
FM9180 - Lubbock	Dryland	19.9 ± 0.2	22.6 ± 0.2	0.60 ± 0.01
NG4111 - Lubbock	Dryland	19.5 ± 0.3	25.3 ± 0.1	0.71 ± 0.02
NG4111 - Lubbock	Irrigated	19.6 ± 0.2	23.7 ± 0.2	0.92 ± 0.00
PHY444 - Stoneville	Irrigated	18.6 ± 0.3	24.8 ± 0.3	0.61 ± 0.03
PHY499 - Stoneville	Irrigated	18.1 ± 0.3	27.0 ± 0.1	0.63 ± 0.02
STV4946 - Lubbock	Irrigated	19.5 ± 0.2	20.9 ± 0.7	0.90 ± 0.03
STV4946 - Stoneville	Irrigated	21.2 ± 0.3	18.3 ± 0.1	0.91 ± 0.02
STV5289 - Stoneville	Irrigated	16.9 ± 0.1	26.9 ± 0.2	0.66 ± 0.02

Table S18. Percentage of seed oil, protein, and gossypol for 2016 cultivars (dry weight basis).

Variety		Oil	Protein	Gossypol
CP3475 - Lubbock	Irrigated	19.6 ± 0.2	21.9 ± 0.2	0.95 ± 0.00
DG3385 – Las Cruces	Irrigated	18.3 ± 0.2	21.2 ± 0.1	1.03 ± 0.04
DP340- PIMA - Las Cruces	Irrigated	22.6 ± 0.2	23.1 ± 0.2	0.95 ± 0.01
DP1321 - Stoneville	Irrigated	17.4 ± 0.1	22.8 ± 0.5	0.74 ± 0.00
DP1522 – Las Cruces	Irrigated	16.8 ± 0.4	21.7 ± 0.3	0.87 ± 0.04
DP1522 - Lubbock	Irrigated	17.3 ± 0.5	21.4 ± 0.2	0.86 ± 0.01
DP1612 - Lubbock	Irrigated	18.6 ± 0.5	21.3 ± 0.2	0.93 ± 0.03
DP1614 - Stoneville	Irrigated	13.6 ± 0.0	25.1 ± 0.2	0.67 ± 0.00
FM1830 - Lubbock	Irrigated	14.2 ± 0.2	22.8 ± 0.4	0.61 ± 0.01
FM1911 - Lubbock	Irrigated	20.2 ± 0.4	22.5 ± 0.3	0.90 ± 0.02
FM1944 - Stoneville	Irrigated	16.4 ± 0.2	21.7 ± 0.2	0.55 ± 0.01
NG3405 - Lubbock	Irrigated	17.8 ± 0.3	21.0 ± 0.3	0.86 ± 0.02
NG3406 - Lubbock	Irrigated	17.6 ± 0.2	21.0 ± 0.1	0.85 ± 0.01
NG3517 - Lubbock	Irrigated	20.2 ± 0.4	21.3 ± 0.1	0.97 ± 0.01
NG4545 - Lubbock	Irrigated	19.3 ± 0.2	21.1 ± 0.0	1.03 ± 0.01
PHY243 - Lubbock	Irrigated	21.2 ± 0.2	21.8 ± 0.8	1.06 ± 0.02
PHY308 - Lubbock	Irrigated	18.9 ± 0.2	22.3 ± 0.2	0.81 ± 0.02
PHY333 - Lubbock	Irrigated	20.2 ± 0.2	22.8 ± 0.2	1.06 ± 0.02
PHY444 - Stoneville	Irrigated	17.9 ± 0.1	24.1 ± 0.1	0.68 ± 0.02
PHY499 - Stoneville	Irrigated	17.9 ± 0.2	24.0 ± 0.2	0.75 ± 0.02
STV4946 - Stoneville	Irrigated	19.2 ± 0.3	22.6 ± 0.3	0.85 ± 0.02
STV5289 - Stoneville	Irrigated	18.1 ± 0.3	22.6 ± 0.3	0.84 ± 0.02