SELECTION AND RESPONSE OF YIELD AND FIBER TRAITS IN UPLAND COTTON

A Thesis

by

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ABSTRACT

A dichotomy exists in the different aspects of cotton production and utilization. Lint yield is the most important factor for producers aiming to maximize profit while spinning mills are more concerned with the fiber quality characteristics at a good value. Simultaneously improving yield and fiber quality is essential to meet the demands of cotton producers and the textile industry; this remains difficult for cotton breeders due to the negative association between yield and fiber quality commonly observed. It has been shown that it is possible to break the negative associations and improve both yield and fiber quality traits. Determination of the precise relationship between these traits is important to understand for further breeding advancement. Four F_3 populations of upland cotton were grown and individual plants were harvested. The top 25 percent of plants were selected for three selection criteria, lint percent, fiber length and fiber strength, as well as an unselected control population. These selected populations were grown in randomized complete block designs in a dryland and irrigated environment. Yield and fiber quality data were collected and analyzed to ascertain relationships between traits when direct selection is applied. Significant differences in lint percent, fiber length, and fiber strength were observed mostly within the genotype and selection criteria. There was no difference observed in yield among the populations.

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NOMENCLATURE

HVI	High volume instrument
IPS	Individual plant selection
LG	Fiber length
LP	Lint percent
MAS	Marker assisted selection
NS	Non-selected
QTL	Quantitative trait loci
ST	Fiber strength
Q-score	Quality score
Sc	Selection criteria

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INTRODUCTION

Upland cotton (*Gossypium hirsutum* L.) is the predominant fiber crop in the United States, in particular Texas. According to the National Agricultural Statistics Service, the estimated 2016 Upland cotton in Texas produced a total of 8.10 million bales with an average cotton yield of 838.4 kilograms per hectare (USDA, 2017). The United States is the leading exporter of cotton with annual revenue of $120 billion (USDA-Foreign Agricultural Services, 2016). A dichotomy exists in the different aspects of cotton production and utilization. Lint yield is the most important factor for producers aiming to maximize profit. Cotton producers often interpret fiber quality as the fiber properties that the marketing system awards premiums or discounts. Textile mills are more concerned with the fiber quality characteristics of the raw product, rather than a pure volume standpoint, but they want this product at an affordable price. Importance of fiber quality differs to producers, marketers, and the consumers (May, 2002). Therefore, improvements of lint yield as well as fiber quality are essential for meeting demands of producers and the textile industry.

With international demand for high quality fibers, competition from synthetic fibers, and technological advancements in spinning methods, cotton breeders emphasize improvements in cotton fiber qualities. Two important and desirable fiber quality parameters are fiber length and strength because of the role each plays in optimizing textile processing efficiency as well as producing a high quality end-product. Strong and long fibers are important for efficient conversion of fiber into yarn, as well as the overall quality of yarn, particularly yarn tenacity.

While high-quality cotton fiber is desirable, lint yield usually is the most important factor for cotton production systems aiming to maximize profit. Several cotton yield components affect the final lint yield such as number of open bolls per plant, boll weight, number of seeds per boll, and lint percentage. One of the most important and easily measured yield components of cotton is lint percent, which is the proportion of lint weight to the seed cotton weight. Lint percent is commonly used in cotton breeding programs because it is easily obtained from ginning, highly heritable (Desalegn et al., 2009), and highly correlated to lint yield (Tang et al., 1996).

Several researchers have described the negative association between lint yield and fiber quality, making simultaneous improvement of these two difficult (Al-Jibouri, 1958; Hinze et al, 2011; Ulloa, 2006). Previous studies demonstrate a strong and significant negative correlation between fiber length and strength with lint percent (Desalegn et al., 2009; Karademir et al., 2010; Ulloa and Meredith 2000). Studies by Al-Jibouri (1958) and Meredith and Bridge (1971) provided evidence that the greatest significant negative association was between fiber strength and lint yield. Various genetic factors have been proposed as the reason for these negative associations including genetic linkage and pleiotropy (Culp and Harrell, 1975). Although there is strong evidence of a negative genetic association between fiber quality and lint yield, some cotton breeders have been successful in breaking these linkages through modified intermating and selection (Culp and Harrell, 1973) and recurrent selection (Clement et al., 2012). Research suggests using large recombinant populations can allow for the assembly of favorable gene combinations to occur that could influence the simultaneous improvement of yield and fiber traits. The possibility of utilizing molecular markers for marker assisted selection for concurrent improvements of lint yield and fiber quality have been reported (Liu et al., 2017; Ning et al., 2014; Shen et al., 2005; Tang et al., 2015).

Since it has been shown that it is possible to break or weaken the negative associations and improve both yield and fiber quality traits, determination of these precise relationships during the selection process is important to understand for further breeding advancements. The purpose of this research is (1) evaluate the response in lint percent, fiber length and fiber strength under direct selection pressure and (2) compare the re-selected populations for yield and fiber quality performance under differing levels of abiotic stress.

LITERATURE REVIEW

Historically multiple types of cottons were grown around the United States. Full-season varieties were associated with longer fibers. When the boll weevil (*Anthonomus grandis*) invaded the U.S. cotton belt, later maturing varieties were abandoned in favor of shorter staple, earlier maturing upland cottons that were still able to produce cotton in the presence of boll weevils (Ware, 1936). However, after abandoning these later maturing varieties, textile manufacturers observed a lower fiber quality produced by these varieties causing the market demand for the fibers to decline (May, 1999). Subsequently, cotton breeders began to accentuate improving fiber quality in these earlier maturing varieties. The mechanization of the textile industry as well as international demand for longer stapled cotton has contributed to fiber quality characteristics becoming a point of emphasis for U.S. cotton breeding programs.

There are two major types of spinning methods: rotor spinning and ring spinning. Rotor spinning is quick and can spin the fibers into yarn and used with coarse fibers. Rotor spinning is used because it results in more yarn produced in less time while requiring less labor and less pre-spinning preparation procedures (Faerber, 1995). Ring spinning has limited spindle speed which causes a lower production rate, and produces fine fibers by pulling the fibers between rollers which are spun around a rotating spindle. Since cotton buyers are emphasizing fiber quality in purchase decisions, spinning processes require stricter fiber profiles in order to economically produce high quality yarn (May, 2002). Ring spinning requires longer fibers that are more uniform (Price,

1990) and produces finer yarns while rotor spinning requires higher strength values (Deussen, 1992) due to its more aggressive procedure. Aside from rotor and ring spinning, air-jet spinning is a newer spinning method that requires longer and finer fibers for optimal processing (Bhortakke et al., 1997). Air-jet spinning is the process of making yarn through which the use of rollers and pressurized air spin individual fibers into the desired product (Grosberg et al., 1987). Technological advancements in the textile industry show that values defining high fiber quality vary according to spinning methods (Chapp, 1995); this highlights the importance of improving multiple fiber properties in order for cotton to capture additional value in the market place.

Fiber quality properties are important for evaluation of the overall value of the raw cotton product and accurate measurement of fiber properties such as strength and length. Cotton grading evolved from subjective human classers to the High Volume Instrument (HVI™) system and Advanced Fiber Information System (AFIS). Although AFIS is a more in-depth fiber analysis, it is not widely due to its relatively high cost. HVI testing is currently the most commonly used instrument to measure fiber properties because of its cost effectiveness, reliability, and speed. HVI is an instrument that mechanically tests a combed fiber bundle containing approximately 2,000 to 2,500 fibers (Ellison and Rogers, 1995). The HVI system was adopted by the U.S. Department of Agriculture in 1969 (Hsieh, 1999; Ramey, 1999) as the basis of cotton classification systems; for measurements of fiber properties for marketing purposes (Hake et al., 1990) that allows a comparatively thorough fiber profile to be measured on the same fiber sample (Taylor, 1986). HVI uses a fibrosampler to take a subsample of cotton and uses it to create a beard of parallel fibers (Hertel, 1940) that lab technicians optically scan for fiber quality parameters (Kelly et al., 2012). HVI measures five fiber parameters: upper half mean length (UHML), fiber strength, elongation, micronaire, and length uniformity index. The system can also quantify color and leaf trash. UHML is defined as the average length of the longest half of fibers in the sample (Ramey, 1999) and widely used as the standard to determine fiber length (Smith et al., 2009). There are four classes of fiber length for upland cotton: short (<21 mm), medium (22-25 mm), medium-long (26-28 mm) and long (29-34 mm) (Cotton Incorporated, 2012). Values of fiber strength are determined by clamping a bundle of fibers and measuring force required to break the bundle of fibers. Fiber strength can be classified into five categories: weak (<225.6 kN m kg^{-1}), intermediate (235.4-245.2 kN m kg^{-1}), average (255.0-274.6 kN m kg^{-1}), strong (284.4-294.2 kN m kg^{-1}), and very strong (>304.0 kN m kg^{-1}).Elongation is determined when the bundle strength is being tested. Fiber elongation is measured from the distance traveled by the clamps before the bundle of fibers break. The scale for fiber elongation: very low (<5), low (5.0-5.8), average (5.9-6.7), high (6.8-7.6), and very high (>7.6). Micronaire is an air permeability measurement of compressed cotton fibers, which is used to estimate fiber maturity and fineness (Hake et al., 1990). Micronaire is a fiber parameter that is not maximized, but rather a certain range is desired (3.5-4.9). Fiber micronaire above or below this range is discounted which increases as the micronaire measurements fall further way from the desirable range. Length uniformity index is the ratio of the average length to the UHML, often reported as a percentage. Length uniformity can be characterized into five categories: very low (<77%), low (77-79%), intermediate (80-82%), high (83-85%), and very high (>85%). Aside from these five parameters, HVI also measures trash content by using a camera to scan over the sample to determine the percentage of trash (Xu et al., 1997).

Depending on the current market, price premiums may be given for fiber quality traits. Premium prices related to certain fiber parameter values are established by the U.S. government loan program and based on the US Commodity Credit Cooperation loan value (Bourland et al., 2010). Loan values vary in regards to base loan rate and fiber quality parameters such as fiber length and strength, micronaire, and the length uniformity index. Premium prices are currently based on fiber lengths greater than 27.0 mm, fiber strength equivalent to or greater than 290 kN m kg^{-1}, ,micronaire values within 3.7 and 4.2, and a length uniformity index greater than 82.0 (USDA Farm Service Agency, 2016).

Fiber quality defines the overall quality of the cotton crop since over 95% of the value of cotton comes from the fiber. (National Cotton Council, 1999). Fiber length and strength are important fiber traits that affect the fibers' conversion into yarn, as well as the subsequent quality of the yarn (May, 2002). Strong and long fibers are desired for modern textile industry due to the importance each plays in producing a high-quality product as well as the optimization of textile processing efficiency. Fiber length and strength affect spinning efficacy, and the stronger fibers can withstand more vigorous and rapid spinning methods. Dependent upon the spinning method used, the importance of fiber parameters varies. Rotor spinning prioritizes fiber strength over fineness and length, whereas ring spinning ranks fiber length over strength and fineness. (Deussen, 1992). Strong fibers lead to the production of more durable fabrics such as denim, while longer fiber lengths allow for finer yarns to be spun and, in turn, softer and finer fabrics. Long fibers are also preferred for the making of knitting yarns and other low-twist yarns. Fiber length influences yarn production and overall yarn quality, impacting yarn strength, uniformity, and hairiness (Pan et al., 2001). Fiber length also is related to yarn fineness (Moore, 1996). Numerous studies demonstrated a significant relationship between fiber length and strength with yarn strength (Faulkner et al., 2012; Ȕreyen and Kadoğlu, 2006). Fiber strength is a predictor of yarn strength (Steadman, 1997). Yarn strength is a fundamental yarn property impacting textile performance and a partial determinant of durability of fabric produced with a specific yarn quality (Zeidman and Sawhney, 2002). As fiber length increases, so does the surface area availability for twisting and mechanical friction to bind individual fibers together, which results in stronger yarn. Moreover, the additional surface area from longer fibers reduces the number of twists required to produce a given yarn strength. Fine fibers promote yarn strength by allowing for more fibers per cross section of yarn (Constable et al., 2015).

Additional fiber properties such as micronaire, length uniformity, and elongation are essential for several reasons. These various fiber quality properties each play a different role that is significant to the spinning performance and usage in the textile industry. Micronaire is an important fiber parameter to cotton classers and spinners (Heap, 2000). Micronaire is often used as an indirect method to estimate fiber fineness and maturity. With respect to fiber fineness, micronaire can predict the spinning efficacy and yarn thickness; while regarding maturity, it influences dye uptake. High micronaire

(>4.9) and low micronaire values (<3.5) are undesirable for spinning because a high value indicates that the fiber is coarse and a low micronaire value usually indicates immature fibers. Since two factors (fineness and maturity) are incorporated into micronaire, a low micronaire can indicate immature fibers or fine fibers that have adequate maturity. Thus micronaire has been considered inadequate in estimating fineness due to the significant influence of maturity that is found in micronaire (Abbott et al., 2009; Clement et al., 2012). Low micronaire values due to immature fibers can cause uneven dye patterns since these fibers do not readily absorb dye. Fiber maturity affects the fiber color, both before and after dye application (Lord and Heap, 1988; Smith, 1991). Low micronaire value cottons are more likely to form neps, which are small entanglements of fibers that reduce the processing efficiency (Hebert et al., 1988). Neps can cause breakages in the fiber as well as white specks, both of which are undesired to the textile industry. As mentioned earlier, the length uniformity index can be defined the ratio of the average length to the UHML. It affects the yarn strength and evenness as well as the spinning efficiency. Length uniformity is related to the low short fiber index, which is the percent by weight of fibers shorter than 13mm (Constable et al., 2015). Short fibers are undesired since they represent a loss in being combed out and contribute to a lower uniformity index. Fiber elongation is the degree of elasticity in fiber or ability of fiber to stretch before breaking, and elongation contributes to spinning efficacy and yarn quality. Backe (1996) demonstrated that increased fiber elongation was associated with improved yarn properties for spinning, in particular yarn strength and evenness. Fiber elongation is important for measuring the work-to-break values

(Benzina et al., 2007) which is the amount of energy needed to break a fiber (Hequet et al., 2014), and an important contributing factor to the processing performance (Meredith, 1945).

Cotton plant breeding studies have demonstrated that fiber quality traits tend to be moderate to highly heritable (>50%) and quantitatively inherited (Meredith and Bridge, 1972; Meredith 1984). Breeding efforts have led to steady gains in increased fiber strength and length (May, 1999; Sasser and Shane, 1996). Fiber strength has increased .44% annually (Taylor et al., 1995) and fiber length has increased on average .08 mm per year (Bowman and Gutierrez, 2003). Advances in fiber length remain a complex issue because there is a distribution of fiber lengths in fiber samples taken from the cotton bales. The variation in fiber quality can be contributed from the genotype, the environment, or an interaction between these two (Bradow et al., 1997). The growth and development of cotton as well as the indeterminate growth pattern also leads to variability in fiber quality. Length of cotton fibers differ within the same plant due to boll position, within the same boll due to individual seed nutrients, and within the same seed due to the position of the fibers on the seed (Braden and Smith, 2004; Clouvel et al., 1998; Copur et al., 2010). Because of this innate variability, there is not an absolute value that is considered for fiber length in a sample.

The growth and development of fiber is affected by many of the same factors that influence plant growth (Constable and Bange, 2007). Temperature and irrigation can impact seed and fiber growth and development (Bradow and Davidonis, 2000).

Temperature impacts fiber quality because of its influence on fiber elongation and fiber thickening (Wang et al., 2014). Lower temperatures result in lower fiber lengths (Zheng et al., 2012) and possible undesired micronaire values. Environmental factors as well as the genotype cause variations in the duration of the fiber growth period and the maximum elongation rate (Gipson and Ray, 1969). Environmental changes that occur near anthesis can hinder fiber initiation as well as delay fiber elongation. If suboptimal environmental conditions such as soil-water deficiency were to occur during the fiber elongation phase, it could shorten the elongation period or cause the rate of fiber elongation to decrease (Hearn, 1976) and thus reduce fiber length. Also, water deficiency that occurs during the latter of the flowering period negatively impacts fiber length (Hearn, 1976). Research suggests that climate and management practices affect fiber length more so than fiber strength (Constable and Bange, 2007); however, both are strongly affected by irrigation (Mert, 2005; Ritchie et al., 2004). Multiple studies demonstrated that optimal irrigation positively influenced fiber length (Grimes et al., 1969; Spooner et al., 1958) and strength (Basal et al., 2009). While optimal irrigation is desired, untimely rainfall or irrigation can lead to reductions in fiber quality and lint yield (Parvin et al., 2005). Regarding land management and planting practices, plant density (Bednarz et al., 2006), planting date, and soil nutrition influence variability in fiber quality (Feng et al., 2011). Davidonis et al. (2004) demonstrated that an improper planting date had a negative impact on fiber quality, with an earlier planting date resulting in higher fiber quality and yields. Nutrient deficiencies can have a significant impact upon fiber length (Sawan et al., 2006); in particular potassium deficiencies (Read et al., 2006) because potassium is essential for the maintenance of cell turgor by osmotic regulation (Dhindsa et al., 1975). High weed densities and competition from these weeds can impact overall fiber quality. The timing of harvest can also have a negative impact on fiber length and strength. Numerous studies have examined the influence of early and late harvests on cotton fiber quality (Snipes and Baskin, 1994; Williford, 1992). Delayed harvests expose the lint to rainfall or humidity, which lowers lint yield and the overall fiber quality as well as increases the chance of microbial damage (Bednarz et al., 2004). Studies show that in addition to the timing of harvest, harvest practices also can have an impact upon fiber qualities. It has been demonstrated that using a cotton picker harvester instead of a cotton stripper harvester can often lead to better fiber quality (Faulkner, 2008; McAlister III and Rogers, 2005) because fewer fibers from immature bolls are harvested and seedcotton has less trash. In conjunction with the type of harvester used, the timing of defoliation prior to harvest is known to impact fiber properties; defoliating too early or too late could cause an undesirable micronaire value (Faircloth et al., 2004), resulting in too low or high of a value. Previous studies suggest that early defoliation can lead to significant reductions in micronaire (Kerby et al., 1992) because of the termination of carbohydrates that are needed for fiber thickening (Gwathmey et al. 2004; Siebert et al. 2006). The possibility of regrowth and late flowering also negatively influences fiber quality by increasing leaf trash contents. Regrowth also causes lower micronaire values due to the immature fibers from the newest bolls formed. Post-harvest processing such as ginning can have an influence on fiber quality; however, the quality of the cotton that is ginned is mostly reflective of the quality of the cotton that is brought to the gin.

Although high-quality fibers usually are desirable, lint yield is the main consideration in most cotton production systems. There are multiple components of yield that contribute to the final lint yield such as boll weight, number of seeds per boll, and number of bolls per plant. An important yield component is lint percent, the proportion of lint weight to the seed cotton weight. Lint percent is affected by the number of seeds per boll, seed size, the amount of lint per seed, and the boll size (Culp and Harrell, 1975). Meredith (1984) reported that the lint percent contributed to 70-90% of the variation present in lint yield. Lint percent can be highly correlated to lint yield (r=.94) (Desalegn et al., 2009), is highly heritable (Tang and Watson, 1996), and easily obtained when seed cotton samples are ginned, which makes it a commonly used yield component in most cotton breeding programs.

Simultaneous improvement of lint yield and fiber quality is important but remains challenging for cotton breeders due to the negative associations between yield and fiber quality that is commonly observed when investigating these traits (Al-Jibouri, 1958; Hinze et al., 2011; McCall et al., 1986; Meredith and Bridge, 1971). The degree of the negative association between fiber quality and lint yield varies widely on genotype (Constable and Bange, 2007). Studies suggest that as lint yield is increased, lint percentage increases while the fiber length and strength decrease (Miller and Rawlings, 1967). Research shows negative correlation coefficients between lint percent and fiber strength and length are large and significant (Desalegn et al., 2009; Karademir et al., 2010; Ulloa and Meredith, 2000). Studies completed by Al-Jibouri (1958) and Meredith and Bridge (1971) gave evidence that the most significant negative association was between lint yield and fiber strength, with the degree of the relationship depending on the genotype. Multiple genetic factors have been proposed as the reason for these negative associations including pleiotropy and genetic linkage (Culp and Harrell, 1975). Studies completed by Miller and Rawlings (1967) gave evidence that linkage was the primary cause for the negative association between fiber quality and yield; however, a study done by Scholl and Miller (1976) proposed that pleiotropy was the main cause of the negative correlation. The use of molecular techniques could help verify the sources of this negative genetic association. QTL clustering have been reported in upland cotton (He et al., 2007; Ning et al., 2014; Said et al., 2013; Shen et al., 2005), which could be the linkage of genes and QTL.

Although there is proof of a negative genetic association between lint yield and fiber quality, cotton breeding programs have been effective in breaking these linkages through modified intermating and selection (Culp and Harrell, 1973), as well as recurrent selection (Clement et al., 2012). Meredith and Bridge (1971) were able to decrease the degree of the negative association between fiber strength and lint yield through intermating. Miller and Rawlings (1967) used recurrent selection; their data exhibited a significant negative association between fiber strength and lint yield in the base population, but a non-significant association in the fourth cycle of recurrent selection. Clement et al. (2012) concluded that recurrent selection could be used to more effectually assemble the desirable alleles associated with fiber traits and lint yield, which can weaken negative relationships. Research by Clement et al. (2015) suggested that if selection was done early for lint yield and fiber quality, then the undesired lines could be discarded so that chosen lines would be assessed in further generations.

Researchers suggest that enhancements in fiber and yield traits simultaneously have been challenging because of the quantitative inheritance of fiber traits that could possibly be mitigated with the usage of genomic tools, such as molecular markers, for marker assisted selection (MAS) (Rahman et al., 2002; Asif et al., 2006; Jauhar 2006). MAS requires extensive mapping of quantitative trait loci (QTL) in order to be implemented and requires the development of markers that are tightly linked to the QTL (Yabe et al., 2013). Researchers should test the QTL of interest in numerous environments and evaluate the QTL's stability related to phenotypes across populations and environments (Kumar et al., 2012). Therefore validation studies are often performed to verify if a QTL is effective in differing genetic backgrounds (Landridge et al., 2001). Finding specific QTL that control the phenotypic expression of fiber properties could be utilized to improve fiber traits in breeding programs.

Development of QTL mapping in upland cotton has been challenging due to the fact that the genome of cotton is large and complex (Zhang et al., 2015) and the genetic background of cotton is narrow (Nie et al., 2016). Research done by Lu and Myers

(2002) and Tyagi et al. (2014) found genetic similarities exceeding 90% among upland cotton varieties evaluated using either simple sequence repeats (SSRs) or random amplification of polymorphic DNA (RAPD) (Smith et al., 2017). Due to low genetic polymorphism of upland cotton, multiple interspecific maps (between G. *barbadense* and G. *hirsutum*) have been constructed in order to study QTL for fiber quality traits (Lacape et al., 2013; Li et al., 2012; Yu et al.,2014). Hundreds of QTLs have been reported in the literature to be related to fiber quality (Said et al., 2013; Yu et al., 2013); however, most of these were found in interspecific populations (Chen et al.., 2009; Kumar et al., 2012; Mei et al., 2004). Consequently, many of these QTL have been considered of little value for utilization for MAS in upland cotton (Liang et al., 2013). Moreover, utilizing the QTLs identified in interspecific populations and transferring them into another species can pose the possibility of linkage drag (Shang et al., 2015).

The identification and mapping of stable fiber quality QTL with moderate to high effects is essential for successful improvements in fiber quality using MAS. However, difficulty of obtaining stable QTL across populations or environments has been reported in the literature (Shen et al., 2005; Mei et al., 2004; Zhang et al., 2009), and the QTL identified for fiber traits tend to vary across environments (Shang et al., 2015). Wang et al. (2015) found difficulty obtaining common QTL among cotton populations and suggested that phenotyping under multiple environments was necessary to use QTL for MAS in an effective manner. Out of the 57 fiber quality QTL detected by Tan et al. (2015), only 11 QTL were detected in two or more environments. Moreover, some of the

QTL with large effects were detected in only one environment. Aside from finding major and stable QTL, some of the challenges that cotton breeders may encounter when using MAS to improve fiber quality and yield include: overestimation of QTL effects (Bohn et al., 2001; Hoeschele and VanRaden, 1993; Lande and Thompson, 1990; Melchinger et al., 1998), failure to detect small effect QTL, and the QTL detected in a mapping population might not be accountable for the variation seen in a breeding program (Strauss et al., 1992).

Although using MAS poses many challenges to plant breeders, there have been reports of finding stable QTL related to fiber quality and lint yield in upland cotton. For example, Tang et al. (2015) detected eight fiber quality QTL across multiple years that were considered stable. Ning et al. (2014) identified a stable QTL (*qFL-D11-1*) for fiber length that explained 10.02–25.34% of the phenotypic variation, and also identified stable fiber strength QTL *(qFS-D3-1)* that explained 4.5–17.6% of the phenotypic variation. Tan et al. (2015) also identified two stable fiber strength QTL, (qFS07.1) and (qFS14.1), which were detected in five and three environments, respectively. There also have been reports of some stable yield QTL obtained, including *(qBS-D8-1)* and *(qLP-D6-1)* (Shen et al., 2006). Although these above examples show the potential of using MAS for improvements of lint yield and fiber quality, with the implications given, MAS should not supplant traditional methods but rather be incorporated as a tool to improve efficiency of selection in a plant breeding program.

It is possible to break or weaken the negative associations and improve both lint yield and fiber quality traits using traditional breeding methods. Determination of these precise relationships during the selection process is important to understand for further breeding advancements. Objectives of this research are: (1) evaluate the response in lint percent, fiber length and fiber strength under direct selection pressure in four different genotypes and (2) compare the re-selected populations for yield and fiber quality performance under differing levels of abiotic stress.

MATERIALS AND METHODS

Individual Plant Selections

Four F_2 populations (pedigrees: (08WZ-51/08WZ-39)F1/10 WG-24; 09 WJ-37/10 WD-08; 09 WJ-37/11 HA-27; 10 WD-08 /11 HA-14) were grown in 2015 near College Station, Texas. These four populations differed in lint percent, fiber length and strength values (Table 3.1).

Table 3.1 F_2 population preliminary parameters, College Station, TX (2015)

Line	Pedigree	Lint Percent	Fiber Length (mm)	Fiber Strength (kN m kg^{-1})
SH13021	(08WZ-51/08WZ-39)F1/10 WG-24	39.3	29.0	334
SH13024	09 WJ-37/10 WD-08	37.8	32.0	338
SH13028	09 WJ-37/11 HA-27	38.8	31.2	367
SH13031	10 WD-08 /11 HA-14	40.2	30.5	351

In 2016 these same four populations were grown as F3s near College Station, Texas. 16 rows (12m x 1m) of each population (four rows across four replications) were grown with standard agronomic practices for this region. Plants were spaced at a distance of .4-.5 m. From every plot, 25 plants were randomly selected by selecting the first 25 consecutive plants and hand harvested for a total of 400 selected plants in each population (1,600 total). After harvest, seed cotton was weighed and ginned using saw gins. After ginning, lint was weighed. Lint percent for each plant is calculated from the ratio between seedcotton weight and lint weight, using the formula: $\frac{lint\ weight}{seed\ cotton\ weight}$ x 100. Fiber samples from the 1,600 IPSs were sent to the Texas Tech University's Fiber and Biopolymer Research Institute at Lubbock, Texas, to obtain fiber length and fiber strength measurements from HVI.

The best six plants from each plot based on lint percent, fiber length or fiber strength were selected for advancement in the project to create new populations. The plants were ranked by performance in the desired trait. This selection process was employed for all populations. Selected IPSs based on each trait were bulked together. The remaining four rows (one from each replication) were used as a control "non-selected", and all 25 IPSs from these rows were bulked. These selections and controls were re-designated as 16 (three traits, one control by four populations) new populations (Table 3.2).

In 2017, the same plant selection process as described was conducted on the next generation (F4) of the re-designated populations.

Table 3.2 Individual Plant Selections (IPS) re-designated population names

	Selection Criteria			
	Non-selected	Lint %	Fiber Length	Fiber Strength
Line				
SH13021	NS-01	LP-01	LG-01	ST-01
SH13024	NS-02	LP-02	LG-02	ST-02
SH13028	NS-03	LP-03	LG-03	ST-03
SH13031	NS-04	LP-04	LG-04	ST-04

Yield Trials

In 2017, yield trials of the 16 re-designated populations were conducted near College Station, Texas. Yield trials were conducted in a randomized complete block design with four replications. One trial was conducted with irrigation, and one was conducted without irrigation. From each plot, 30-boll samples were hand harvested in both yield trials, and measurements of lint percent, fiber length and fiber strength were obtained in the same method as described earlier for the IPSs. Micronaire, length uniformity, and elongation measurements were measured with HVI. Plots were harvested with a mechanical cotton picker harvester and seed cotton was weighed to estimate lint yield.

Data Analysis

In 2016, the IPSs were analyzed based on selection criteria and its effect on the selected trait and the other traits. Percent differences in means of lint percent, fiber length, and fiber strength were calculated in order to quantify the effects of selection pressure and this was repeated with the 2017 IPSs.

Fiber and yield data were analyzed using SAS v.9.4 (SAS v.9.4, SAS Institute, 2015). Data from 2017 dryland and irrigated yield trials were analyzed using PROC GLM procedure with the selection criteria as a fixed effect. Combined analysis of yield data using PROC GLM was performed and all effects were fixed. Correlation analysis were performed using the PROC CORR procedure. For further evaluation of fiber quality in yield trials, the Q-score developed by Bourland (2010) was utilized to create a criteria for fiber quality by integrating fiber length, micronaire, length uniformity, and strength, with the weights of the four parameters: 50%, 25%, 15%, and 10% respectively.

RESULTS AND DISCUSSION

Individual Plant Selections

In 2016, IPSs were taken to evaluate response in lint percent, fiber length and fiber strength under direct selection pressure in four genotypes. The evaluation of the selection pressures and its effects were based on the average values for lint percent, fiber length, and fiber strength and the percent differences in means that occur in each trait (Table 4.1, 4.2, 4.3). The populations will be referenced by their re-designated names (Table 3.2).

Table 4.1 Lint percent means of IPSs (2016)

Line	Criteria	n	Lint %		CV, %	% change
SH13021(F_3)	Unselected	100	38.1	b†	14.9	-
	Lint %	24	39.8	a	3.6	4.5
	Fiber length	24	37.6	b	4.2	-1.3
	Fiber strength	24	37.7	b	5.3	-1.1
SH13024(F_3)	Unselected	100	35.0	bc	7.2	-
	Lint %	24	37.4	a	2.5	6.9
	Fiber length	24	33.4	c	6.4	-4.6
	Fiber strength	24	35.9	ab	8.5	2.6
SH13028(F_3)	Unselected	100	36.2	b	13.4	-
	Lint %	24	38.9	a	3.0	7.5
	Fiber length	24	35.9	b	5.5	-0.8
	Fiber strength	24	35.8	b	12.3	-1.1
SH13031(F_3)	Unselected	100	37.6	b	5.5	-
	Lint %	24	40.2	a	3.0	6.9
	Fiber length	24	37.5	b	6.9	-0.3
	Fiber strength	24	38.5	ab	5. 7	2.4

†Means followed with the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.2 Fiber length means of IPSs (2016)

Line	Criteria	n	Length(mm)		CV, %	% change
SH13021(F_3)	Unselected	100	30.2	b†	3.9	-
	Lint %	24	29.9	b	3.2	-1.0
	Fiber length	24	32.0	a	1.6	6.0
	Fiber strength	24	30.2	b	3.4	0.0
SH13024(F_3)	Unselected	100	33.0	b	3.8	-
	Lint %	24	32.8	b	4.2	-0.6
	Fiber length	24	34.8	a	3.2	5.5
	Fiber strength	24	33.0	b	5.7	0.0
SH13028(F_3)	Unselected	100	32.5	b	3.1	-
	Lint %	24	32.0	b	3.8	-1.5
	Fiber length	24	33.8	a	1.9	4.0
	Fiber strength	24	32.5	b	3.4	0.0
SH13031(F_3)	Unselected	100	31.5	b	3.9	-
	Lint %	24	30.9	b	3.9	-1.9
	Fiber length	24	33.3	a	3.0	5.7
	Fiber strength	24	32.0	b	3.3	1.6

†Means followed with the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.3 Fiber strength means of IPSs (2016)

Line	Criteria	n	Fiber Strength (kN m kg^{-1})		CV, %	% change
SH13021(F_3)	Unselected	100	307	b[†]	5.6	-
	Lint %	24	309	b	6.2	0.7
	Fiber length	24	313	b	6.0	2.0
	Fiber strength	24	334	a	4.0	9.0
SH13024(F_3)	Unselected	100	306	b	4.8	-
	Lint %	24	305	b	6.5	-0.3
	Fiber length	24	308	b	4.8	0.7
	Fiber strength	24	330	a	4.5	7.7
SH13028(F_3)	Unselected	100	319	b	5.9	-
	Lint %	24	324	ab	6.5	1.5
	Fiber length	24	314	b	5.3	-1.5
	Fiber strength	24	337	a	3.5	5.9
SH13031(F_3)	Unselected	100	316	b	5.0	-
	Lint %	24	315	b	5.6	-0.3
	Fiber length	24	320	b	5.2	1.2
	Fiber strength	24	335	a	2.0	6.2

[†]Means followed with the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.4 Analysis of variance of IPSs, College Station, Texas (2016)

		Lint %	Fiber Length	Fiber Strength
Source	**df**	**Mean Square**		
Rep	3	4.90*	0.0004	5.294**
Selection criteria	3	26.91**	0.0192**	19.350**
Genotype	3	32.34**	0.0354**	4.519**
Sc*genotype	9	1.20	0.0002	0.452
Error	45	1.16	0.0003	0.626

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

The 2016 IPS data showed differences in lint percent, fiber length and strength. (Table 4.4). Differences among selection criteria and genotype were significant for all three traits. There was not an interaction effect, but we did observe differences among genotypes.

In 2016, among the populations the average lint percent ranged from 33.4%-40.2%, LG-02 and LP-04 had the lowest and highest lint percent respectively (Table 4.1). The populations selected for lint percent exhibited an average range of 37.4%-40.2%, with LP-03 displaying the largest percent increase in lint percent mean (7.5% increase). Lint percent declined in all populations when the primary selection criterion was fiber length (0.3-4.6% decrease). SH13031(F_3) exhibited the lowest percent change in lint percent when selecting for fiber length and SH13024(F_3) exhibited the largest percent decrease when selected for fiber length. SH13021(F_3) and SH13028(F3) showed approximately a 1% decrease in lint percent mean when selected for either fiber length and fiber strength. SH13024(F_3) and SH13031(F_3) exhibited approximately a 2% increase in lint percent mean when selected for fiber strength. As seen by Table 4.1, the population exhibiting the largest percent increase in lint percent does not necessarily equate to having the highest end value for that trait.

The fiber length mean ranged from 29.9 to 34.8 mm, LP-01 and LG-02 exhibited the lowest and highest fiber lengths respectively (Table 4.2). The populations selected for fiber length exhibited an average range of 32.0 to 34.8 mm, with LG-01 exhibiting the largest percent increase in fiber length mean (6.0%). All four genotypes showed a percent decrease in fiber length when selected for lint percent (.6-1.9% decrease), with LP-04 exhibiting the largest percent decrease. SH13021(F_3), SH13024(F_3), and SH13028(F_3) showed no percent change in fiber length mean when selected for fiber strength and SH13031(F_3) exhibited a percent increase in mean when selected for fiber strength (1.6% increase).

Fiber strength mean ranged from 305-337 kN m kg^{-1}, and LP-02 and ST-03 displayed the lowest and highest fiber strength respectively (Table 4.3). The populations selected for fiber strength exhibited an average range of 330-337 kN m kg^{-1}, with ST-01 exhibiting the largest percent increase in fiber strength mean (8.96% increase). In comparison to the other selection pressures, selecting for fiber strength resulted in the largest percent increase of the end value for that trait. In SH13021(F_3) and SH13028(F_3) when selected for lint percent, these exhibited a percent increase in fiber strength mean, and SH13024(F_3) and SH13031(F_3) exhibited a percent decrease in fiber strength mean. In three of the genotypes, there was a percent increase in fiber strength mean when selected for fiber length. In opposition to these findings, SH13028(F_3) exhibited a percent decrease in fiber strength mean when selected for fiber length.

Table 4.5 Lint percent means of IPSs (2017)

Line	Criteria	n	Lint %		CV, %	% change
SH13021(F_4)	Unselected	87	38.5	b[†]	5.9	-
	Lint %	20	42.6	a	4.3	10.7
	Fiber length	24	38.0	b	4.2	-1.3
	Fiber strength	22	38.0	b	6.1	-1.3
SH13024(F_4)	Unselected	95	36.9	b	6.2	-
	Lint %	24	39.8	a	2.5	7.9
	Fiber length	19	33.1	c	5.5	-10.3
	Fiber strength	24	35.7	b	6.9	-3.3
SH13028(F_4)	Unselected	100	37.2	b	6.0	-
	Lint %	19	40.8	a	4.9	9.7
	Fiber length	23	36.2	b	5.9	-2.7
	Fiber strength	22	37.3	b	4.9	0.3
SH13031(F_4)	Unselected	100	37.6	c	5.6	-
	Lint %	21	41.8	a	2.8	11.2
	Fiber length	24	37.9	c	5.3	0.8
	Fiber strength	24	39.8	b	5.5	5.9

[†]Means followed with the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.6 Fiber length means of IPSs (2017)

Line	Criteria	n	Length (mm)		CV, %	% change
SH13021(F_4)	Unselected	87	29.7	b†	3.8	-
	Lint %	20	28.7	c	4.6	-3.4
	Fiber length	24	32.0	a	1.2	7.7
	Fiber strength	22	30.5	b	4.9	2.7
SH13024(F_4)	Unselected	95	32.0	b	4.0	-
	Lint %	24	30.5	c	2.8	-4.7
	Fiber length	19	35.1	a	2.6	9.7
	Fiber strength	24	32.3	b	6.4	0.9
SH13028(F_4)	Unselected	100	31.2	b	4.1	-
	Lint %	19	30.9	b	6.0	-1.0
	Fiber length	23	33.5	a	1.2	7.4
	Fiber strength	22	30.7	b	3.6	-1.6
SH13031(F_4)	Unselected	100	30.5	c	4.1	-
	Lint %	21	30.5	c	5.5	0
	Fiber length	24	33.0	a	3.1	8.2
	Fiber strength	24	31.5	b	3.1	3.3

†Means followed with the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.7 Fiber strength means of IPSs (2017)

Line	Criteria	n	Strength (kN m kg^{-1})		CV, %	% change
SH13021(F_4)	Unselected	87	315	b†	5.0	-
	Lint %	20	305	b	7.2	-3.1
	Fiber length	24	329	b	4.9	4.4
	Fiber strength	22	350	a	3.3	11.24
SH13024(F_4)	Unselected	95	310	b	4.7	-
	Lint %	24	312	b	6.3	0.7
	Fiber length	19	331	a	4.9	6.7
	Fiber strength	24	343	a	2.9	10.8
SH13028(F_4)	Unselected	100	322	b	5.6	-
	Lint %	19	321	b	6.8	-0.3
	Fiber length	23	327	b	4.4	1.5
	Fiber strength	22	360	a	2.9	11.9
SH13031(F_4)	Unselected	100	320	b	5.3	-
	Lint %	21	314	b	7.1	-1.9
	Fiber length	24	336	a	6.7	5.2
	Fiber strength	24	345	a	3.0	8.0

†Means followed by the same letter are not different (α=0.05, Duncan MRT);means within section are compared

Table 4.8 Analysis of variance of IPSs, College Station, TX (2017)

		Lint %	Fiber Length	Fiber Strength
Source	**df**		**Mean Square**	
Rep	3	1.63	0.0009	1.35
Selection criteria	3	67.43**	0.0486**	44.37**
Genotype	3	31.96**	0.0193**	2.23
Sc*genotype	9	3.35**	0.0020**	1.62
Error	45	1.08	0.0004	1.09

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

In 2017, IPSs were repeated on the next generation (F4) of the re-designated populations to further evaluate the response in lint percent, fiber length, and fiber strength under direct selection pressure. Evaluation of selection pressures was based on the average values for lint percent, fiber length, and fiber strength and the percent differences in means that occur in each trait (Table 4.5, 4.6, 4.7).

The 2017 IPS data showed significant differences in lint percent, fiber length and strength (Table 4.8).The selection criteria, genotype, and sc*genotype interaction were significant for lint percent and fiber length. Regarding fiber strength, only the selection criteria was significant.

In terms of lint percent, the average ranged from 33.1-42.6% and LG-02 and LP-01 showed the lowest and highest lint percent respectively (Table 4.5). Consistent with the previous year, LG-02 displayed the lowest lint percent. The populations selected for lint percent varied from 39.8-42.6% and the percent increases in lint percent are greater than in 2016 (7.9-11.2% increase), with LG-04 displaying the largest percent increase. SH13024(F_4) displayed the largest percent decrease in lint percent mean when selected for fiber length or strength (10.3% and 3.3% respectively). Consistent with 2016, SH13021(F_4) exhibited approximately a 1% decrease in lint percent mean when selected for either fiber length or strength. Also similar to 2016, SH13031(F_4) exhibited a percent increase in the average lint percent when selected for fiber strength.

The average fiber length ranged from 28.7-35.1 mm (Table 4.6). Consistent with 2016, LP-01 and LG-02 exhibited the lowest and highest fiber length means respectively. The populations selected for fiber length exhibited a range of 32-35.1 mm, with LG-02 exhibiting the largest percent increase (9.7%). In this case, the population with the largest percent increase exhibited the highest fiber length among all other populations. SH13021(F_4), SH13024(F_4), and SH13031(F_4) displayed a percent increase in fiber length with a selection pressure of fiber strength (.9-3.3%), with ST-04 showing the largest percent increase in fiber length mean when selected for fiber strength. SH13021(F4), SH13024(F4), and SH13028(F4) exhibited a negative percent change in the average fiber length when selected for lint percent, while SH13031(F_4) exhibited no percent difference.

In terms of fiber strength, the average ranged from 305-360 kN m kg^{-1}, LP-01 and ST-03 exhibited the lowest and highest fiber strength respectively (Table 4.7). Consistent with 2016, ST-03 displayed the highest fiber strength mean. The populations with selection pressure of fiber strength exhibited a range of 343-360 kN m kg^{-1}, with ST-03 exhibiting the largest percent increase among all populations (11.9%). In this case, the population with the largest percent increase in fiber strength mean exhibited the highest fiber strength. All genotypes exhibited a percent increase in fiber strength when selected for fiber length (1.5-6.7%), and LG-02 displayed the largest percent increase in fiber strength among the other populations selected for fiber length. Consistent with 2016, selecting for fiber strength resulted in the largest percent increase of that trait (8.0-11.9%).

Table 4.9 Correlation analysis of lint percent and fiber length of IPSs

	Lint Percent					
Fiber Length	**2016**					
	NS-01	**LP-01**	**LG-01**	**ST-01**	**NS-02**	**LP-02**
	-.1083	-.3370	-.0930	-.5221	-.2736	-.2437
	.2833	*.1073*	*.6655*	*.0089*	*.0059*	*.2511*
	LG-02	**ST-02**	**NS-03**	**LP-03**	**LG-03**	**ST-03**
	-.6641	-.6626	-.1647	-.3703	.1612	.0158
	.0004	*.0004*	*.1015*	*.0749*	*.4517*	.9417
	NS-04	**LP-04**	**LG-03**	**ST-04**		
	-.3556	-.0855	.0755	-.4235		
	.0003	*.6913*	*.7261*	*.0392*		
	2017					
	NS-01	**LP-01**	**LG-01**	**ST-01**	**NS-02**	**LP-02**
	-.0645	.3664	.1231	-.5846	-.3068	-.5348
	.5527	*.1120*	*.5666*	*.0043*	*.0025*	*.0071*
	LG-02	**ST-02**	**NS-03**	**LP-03**	**LG-03**	**ST-03**
	-.3276	-.5278	-.4000	-.5379	-.3864	-.0716
	.1710	*.0080*	*<.0001*	*.0175*	*.0686*	*.7514*
	NS-04	**LP-04**	**LG-04**	**ST-04**		
	-.4483	-.4615	-.4607	-.2609		
	<.0001	*.0352*	*.0235*	*.2182*		

The correlation value and p-value are beneath each population, respectively.

Table 4.10 Correlation analysis of lint percent and fiber strength of IPSs

	Lint Percent					
	2016					
Fiber Strength	**NS-01**	**LP-01**	**LG-01**	**ST-01**	**NS-02**	**LP-02**
	-.0420	.2845	.4635	.2026	.2432	-.2641
	.6782	*.1779*	*.0225*	*.3425*	*.0148*	*.2124*
	LG-02	**ST-02**	**NS-03**	**LP-03**	**LG-03**	**ST-03**
	-.1328	.2735	-.1647	-.2207	.3794	-.0009
	.5363	*.1960*	*.1015*	*.3001*	*.0674*	.9966
	NS-04	**LP-04**	**LG-03**	**ST-04**		
	.0188	.0045	.0832	.4786		
	.8525	*.9832*	*.6990*	*.0180*		
	2017					
	NS-01	**LP-01**	**LG-01**	**ST-01**	**NS-02**	**LP-02**
	.0511	-.2375	-.1067	-.0407	-.1662	.1116
	.6383	*.3134*	*.6197*	*.8572*	*.1075*	*.6037*
	LG-02	**ST-02**	**NS-03**	**LP-03**	**LG-03**	**ST-03**
	-.3117	-.4319	.1829	-.8385	.0586	-.1465
	.1939	*.0350*	*.0686*	*<.0001*	*.7905*	*.5153*
	NS-04	**LP-04**	**LG-04**	**ST-04**		
	-.2502	-.4236	-.1282	-.1805		
	.0120	*.0557*	*.5505*	*.3987*		

The correlation value and p-value are beneath each population, respectively.

Table 4.11 Correlation analysis of fiber length and strength of IPSs

Fiber Strength	Fiber Length					
	2016					
	NS-01	**LP-01**	**LG-01**	**ST-01**	**NS-02**	**LP-02**
	.2744	.0338	-.3261	.0143	.2938	.3198
	.0057	*.8755*	*.1199*	*.9471*	*.0030*	*.1277*
	LG-02	**ST-02**	**NS-03**	**LP-03**	**LG-03**	**ST-03**
	.2971	-.2075	.0596	-.0062	.0484	.2435
	.1585	*.3305*	*.5559*	*.9770*	*.8222*	*.2515*
	NS-04	**LP-04**	**LG-03**	**ST-04**		
	.2257	.0156	.2935	-.2402		
	.0240	*.9424*	*.1640*	*.2583*		
	2017					
	NS-01	**LP-01**	**LG-01**	**ST-01**	**NS-02**	**LP-02**
	.2816	.1031	-.1689	.2167	.1527	-.0905
	.0082	*.6653*	*.4300*	*.3328*	*.1395*	*.6742*
	LG-02	**ST-02**	**NS-03**	**LP-03**	**LG-03**	**ST-03**
	.4376	.5080	.3669	.5639	-.1763	.0521
	.0610	*.0113*	*.0002*	*.0119*	*.4210*	*.8178*
	NS-04	**LP-04**	**LG-04**	**ST-04**		
	.4375	.3680	.1948	.4047		
	<.0001	*.1007*	*.3618*	*.0498*		

The correlation value and p-value are beneath each population, respectively.

Correlation analysis of 2016 and 2017 IPSs were performed to ascertain relationships among selection pressures (lint percent, fiber length and strength). Positive and negative correlations were observed between the traits depending on genotype and selection criteria.

Consistent with previous reports in the literature (Desalegn et al., 2009; Karademir et al., 2010), there was a negative correlation between lint percent and fiber length in 2016 and 2017 (Table 4.9). In 2016, six of the sixteen populations showed a negative correlation and the population's with the highest negative correlations were ST-02 and LG-02 (r=-.66**). Two populations (LG-02 and ST-04) displayed a negative correlation in 2016 but no correlation in 2017. There were negative relationships between lint percent and fiber length noticed in 2017. Since fiber length is influenced by the environment (Constable and Bange 2007), it is possible that the environment caused a larger range of fiber length values in 2017.

In 2016, three populations (LG-01, NS-02, and ST-04) displayed a significant positive correlation between lint percent and fiber strength (Table 4.10). This disagrees with the common findings of a negative association between lint percent and fiber strength (Desalegn et al., 2009). However in 2017, these significant positive correlations were not present and these populations did not express a negative correlation. In 2017, there was a negative correlation between lint percent and fiber strength in some of the populations (ST-02, LP-03, and LP-04). This finding was consistent with previous reports in the literature (Karademir et al., 2010, Ulloa and Meredith 2000). LP-02 showed the strongest negative correlation between lint percent and fiber strength (r=-.84).

Consistent with the findings of Desalegn et al., (2009) and Karademir et al., (2010), there was a positive correlation between fiber length and strength in some of the populations (Table 4.11). In 2016, three populations (NS-01, NS-02, NS-04) displayed a slightly positive correlation between lint percent and fiber strength, with NS-02 displaying the strongest correlation (r=.29**). Two populations (NS-01 and NS-04) displayed a positive correlation in 2016 but no correlation in 2017. In 2017, six populations displayed a positive correlation, with LP-03 showing the strongest correlation (r=.56). This was the only population selected for lint percent that displayed a positive correlation between fiber length and strength.

Table 4.12 Analysis of variance of selection pressures of irrigated yield trial, College Station, TX (2017)

		Lint %	Fiber Length	Fiber Strength
Source	**df**	**Mean Square**		
Rep	3	0.92**	0.0011	6.749**
Selection criteria	3	10.12**	0.0085**	8.355**
Genotype	3	13.99**	0.0318**	4.907*
Sc*genotype	9	1.85*	0.0007	1.551
Error	45	0.72	0.0004	1.389

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Table 4.13 Analysis of variance of lint yield of irrigated yield trial, College Station, TX (2017)

Source	df	Mean Square
Rep	3	355,773**
Selection criteria	3	13,781
Genotype	3	50,106
Sc*genotype	9	30,279
Error	45	49,061

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Table 4.14 Mean separation of lint percent of genotypes, irrigated trial

Line	Lint %	
SH13021($F_{3:}F_4$)	39.9	a†
SH13031($F_{3:}F_4$)	39.4	a
SH13028($F_{3:}F_4$)	38.4	b
SH13024($F_{3:}F_4$)	37.8	b

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.15 Mean separation of lint percent of selection pressures, irrigated trial

Selection Criteria	Mean (%)	
Lint percent	40.0	a†
Fiber strength	38.8	b
Non-selected	38.6	bc
Fiber length	38.1	c

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.16 Mean separation of lint percent within genotypes, irrigated trial

SH13021(F_3:F_4)		SH13024(F_3:F_4)		SH13028(F_3:F_4)		SH13031(F_3:F_4)	
Selection							
LP	40.9 a†	LP	38.7 a	LP	39.5 a	LP	40.7 a
LG	40.3 ab	NS	38.1 a	NS	38.7 ab	ST	40.1 ab
ST	39.5 bc	ST	37.9 a	ST	37.9 b	NS	38.9 bc
NS	38.8 c	LG	36.6 b	LG	37.6 b	LG	37.9 c

†Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Yield Trials

2017 irrigated yield trial showed differences in lint percent, fiber length and strength among entries. Differences among selection criteria and genotypes were significant for lint percent, fiber length and strength (Table 4.12) and there was a sc*genotype interaction for lint percent. However, there were no differences in lint yield regardless of selection criteria or genotype (Table 4.13). One factor that may have caused no differences in lint yield is 'Hurricane Harvey'. In August 2017, approximately .56 m of rainfall occurred in College Station, Texas. Rain fell continuously upon the trial for five days. The excessive rainfall caused lower bolls to be damaged or destroyed. Previous research suggests that excess rainfall when bolls begin to open can cause a reduction in lint yield (Williford et al., 1995, Parvin et al., 2005).

Differences in lint percent were noticed among genotypes, selection criteria, and within genotypes (Table 4.14, 4.15, 4.16). As expected, the selection criteria of lint percent showed the highest lint percent mean (Table 4.15). All genotypes exhibited differences (Table 4.16), and SH13021($F_{3:}F_4$) and SH13031($F_{3:}F_4$) showed the largest degree of differences Even though these genotypes displayed the largest degree of differences, the lowest lint percent was exhibited by LG-02 (36.6%). The average lint percent ranged from 36.6%-40.9%. Among all the populations, LP-01, LP-04, and LG-01 displayed the highest lint percent average (40.9%, 40.7%, and 40.3% respectively).

Regarding fiber length, differences were noticed among genotype and selection criteria (Table 4.17 and 4.18). Even though the sc*genotype interaction effect was not a source of variation (Table 4.12), differences within the genotypes were observed (Table 4.19). SH13021($F_{3:}F_4$), SH13024($F_{3:}F_4$), and SH13028($F_{3:}F_4$) displayed differences in fiber length within the genotype. The average fiber length ranged from 29.7-34.3 mm, with LP-01 exhibiting the lowest fiber length. The populations displaying the highest fiber length were LG-02 and LG-03 (34.3 and 33.3 mm respectively). Premiums are given to fiber lengths greater than 27 mm and all sixteen populations would receive a premium in the cotton marketplace.

Differences in fiber strength were noticed among the genotype and selection criteria (Table 4.20 and 4.21). Sc*genotype interaction was not a significant source of variation but differences within the genotype were still observed (Table 4.22). Three of the four genotypes displayed differences in fiber strength. In SH13024($F_{3:}F_4$) the population selected for fiber length (LG-02) resulted in the highest fiber strength within that genotype; however, no differences in fiber strength were observed within that genotype. The mean fiber strength ranged from 310-346 kN m kg^{-1}, with LP-01and ST-03 displaying the lowest and highest fiber strength values respectively. Premiums are awarded cotton with strength exceeding 290 kN m kg^{-1}.All populations in this study exceeded that threshold.

Table 4.17 Mean separation of fiber length of genotypes, irrigated trial

Line	**Length (mm)**
SH13024($F_{3:}F_4$)	32.9 a[†]
SH13028($F_{3:}F_4$)	32.0 b
SH13031($F_{3:}F_4$)	31.2 c
SH13021($F_{3:}F_4$)	30.3 d

[†]Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.18 Mean separation of fiber length of selection pressures, irrigated trial

Selection Criteria	**Fiber Length (mm)**
Fiber length	32.5 a[†]
Non-selected	31.4 b
Fiber strength	31.4 b
Lint %	31.2 b

[†]Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.19 Mean separation of fiber length within genotypes, irrigated trial

SH13021(F_3:F_4)		SH13024(F_3:F_4)		SH13028(F_3:F_4)		SH13031(F_3:F_4)	
Selection							
LG	31.0 a†	LG	34.3 a	LG	33.3 a	LG	31.5 a
NS	30.2 ab	NS	32.8 b	NS	31.8 b	LP	31.2 a
ST	30.2 ab	ST	32.5 b	ST	31.5 b	ST	31.2 a
LP	29.7 b	LP	32.5 b	LP	31.5 b	NS	31.0 a

†Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.20 Mean separation of fiber strength of genotypes, irrigated trial

Line	Mean (kN m kg^{-1})	
SH13031($F_{3:}F_4$)	336	a†
SH13028($F_{3:}F_4$)	335	ab
SH13024($F_{3:}F_4$)	328	bc
SH13021($F_{3:}F_4$)	326	c

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.21 Mean separation of fiber strength of selection pressures, irrigated trial

Selection Criteria	Mean (kN m kg^{-1})	
Fiber strength	339	a†
Fiber length	335	a
Lint %	326	b
Non-selected	325	c

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.22 Mean separation of fiber strength within genotypes, irrigated trial

SH13021(F_3:F_4)		SH13024(F_3:F_4)		SH13028(F_3:F_4)		SH13031(F_3:F_4)	
Selection							
ST	336 a[†]	LG	336 a	ST	346 a	ST	344 a
LG	330 a	ST	331 a	LG	336 ab	LG	340 ab
NS	328 ab	LP	327 a	LP	332 ab	LP	335 ab
LP	310 b	NS	316 a	NS	329 b	NS	327 b

[†]Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Treatments in the 2017 dryland yield trial had differences in lint percent, fiber length and strength traits (Table 4.23). Selection criteria, genotype, and sc*genotype interaction were different for lint percent and fiber length. Only the genotype effect was found to be significant for fiber strength. As observed in the irrigated trial, there were no differences in lint yield regardless of selection criteria or genotype (Table 4.24).

Significant differences in lint percent were noticed among genotypes, selection criteria, and the four new populations within each genotype (Table 4.25, 4.26, 4.27). Three of the four genotypes exhibited differences in lint percent among populations within the genotype. Consistent with the irrigated trial, SH13021($F_{3:}F_4$) and SH13031($F_{3:}F_4$) showed the largest degree of differences among the selected populations within the genotype. The average lint percent ranged from 38.5-42.3% and is a higher range of values compared to the irrigated yield trial. Among all populations, ST-03 exhibited the lowest average lint percent. Consistent with the irrigated yield trial, LP-01 exhibited the highest lint percent overall (42.3%). It was interesting to find that the second highest lint percent was exhibited by ST-04 (41.4%) but it was not different from LP-04.

Regarding fiber length, significant differences were noticed among the genotype, selection criteria, and within the genotypes (Table 4.28, 4.29, 4.30). Three of the genotypes exhibited significant differences in fiber length within the genotype. SH13024($F_{3:}F_4$) exhibited the largest degree of differences within the genotype. The average fiber length values ranged from 29.3-32.3 mm, which is a lower range of values compared to the irrigated yield trial. Previous research suggests that irrigation strongly influences final fiber length (Hearn 1976; Ramey 1986), which suggests why the dryland trial had a lower range of fiber length values. Consistent with the irrigated trial the populations displaying the highest fiber length were LG-02 and LG-03 (32.3 and 32.0 mm respectively). Cotton from all populations would receive a premium since fiber length exceeded 27 mm.

Significant differences were noticed among the genotypes for fiber strength (Table 4.31). SH13021($F_{3:}F_4$) is the only one that showed differences in fiber strength within the genotype (Table 4.32). From the ANOVA, genotype effect was a significant source of variation, which due to the differences of fiber strength in SH13021($F_{3:}F_4$). The average fiber strength values ranged from 308-340 kN m kg^{-1}, which is a lower range of values compared to the irrigated yield trial. Among all populations, LP-03 exhibited the highest fiber strength. The lowest fiber strength value was exhibited by NS-02. All populations had fiber strength measurements in the premium range.

Table 4.23 Analysis of variance of selection criteria of dryland yield trial, College Station, TX (2017)

		Lint %	Fiber Length	Fiber Strength
Source	**df**	**Mean Square**		
Rep	3	4.789**	0.0042**	2.55
Selection criteria	3	7.323**	0.0062**	3.20
Genotype	3	7.015**	0.0184**	13.49**
Sc*genotype	9	2.919**	0.0001*	1.68
Error	45	0.996	0.0007	1.87

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Table 4.24 Analysis of variance of lint yield of dryland yield trial, College Station, TX (2017)

Source	df	Mean Square
Rep	3	20,819
Selection criteria	3	12,032
Genotype	3	3,966
Sc*genotype	9	21,269
Error	45	44,702

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Table 4.25 Mean separation of lint percent of genotypes, dryland trial

Line	Mean (%)
SH13021(F_{3}:F_{4})	40.7 a†
SH13031(F_{3}:F_{4})	40.3 a
SH13024(F_{3}:F_{4})	39.5 b
SH13028(F_{3}:F_{4})	39.3 b

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.26 Mean separation of lint percent of selection pressures, dryland trial

Selection Criteria	Mean (%)
Lint %	41.0 a†
Fiber length	39.7 b
Non-selected	39.7 b
Fiber strength	39.5 b

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.27 Mean separation of lint percent within genotypes, dryland trial

SH13021(F_3:F_4)		SH13024(F_3:F_4)		SH13028(F_3:F_4)		SH13031(F_3:F_4)	
Selection							
LP	42.3 a[†]	LP	40.5 a	LP	40.1 a	ST	41.4 a
LG	40.7 b	NS	40.0 ab	LG	39.7 a	LP	41.0 ab
NS	40.6 b	LG	38.8 b	NS	38.8 a	LG	39.7 bc
ST	39.2 c	ST	38.7 b	ST	38.5 a	NS	39.2 c

[†]Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.28 Mean separation of fiber length of genotypes, dryland trial

Line	Mean (mm)
SH13028(F_3:F_4)	31.2 a†
SH13024(F_3:F_4)	31.2 a
SH13031(F_3:F_4)	30.2 b
SH13021(F_3:F_4)	29.5 c

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.29 Mean separation of fiber length of selection pressures, dryland trial

Selection Criteria	Mean (mm)
Fiber length	31.2 a†
Fiber strength	30.5 b
Non-selected	30.5 b
Lint %	30.0 b

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.30 Mean separation of fiber length within genotypes, dryland trial

SH13021(F_3:F_4)		SH13024(F_3:F_4)		SH13028(F_3:F_4)		SH13031(F_3:F_4)	
Selection							
LG	30.0 a†	LG	32.3 a	LG	32.0 a	LG	30.7 a
ST	29.7 a	ST	31.5 ab	LP	31.2 ab	NS	30.7 a
LP	29.0 b	NS	30.7 bc	NS	31.2 ab	ST	30.0 a
NS	29.0 b	LP	30.2 c	ST	30.5 b	LP	29.7 a

†Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.31 Mean separation of fiber strength of genotypes, dryland trial

Line	Mean (kN m kg^{-1})
SH13031(F_3:F_4)	333 a†
SH13028(F_3:F_4)	332 a
SH13021(F_3:F_4)	320 b
SH13024(F_3:F_4)	314 b

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.32 Mean separation of fiber strength within genotypes, dryland trial

SH13021(F_3:F_4)		SH13024(F_3:F_4)		SH13028(F_3:F_4)		SH13031(F_3:F_4)	
Selection							
LG	331 a†	ST	320 a	LP	340 a	ST	336 a
ST	326 ab	LG	318 a	ST	335 a	LG	333 a
NS	314 bc	LP	310 a	LG	326 a	LP	332 a
LP	310 c	NS	308 a	NS	324 a	NS	331 a

†Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.33 Combined analysis of 2017 irrigated and dryland yield trials, College Station, TX

			Lint %	Fiber Length	Fiber Strength	Lint Yield
Effect	**Num df**	**Den df**			**F Value**	
Irrigation	1	6	12.6**	23.2**	3.3	26.2**
Rep(irrigation)	6	90	3.3**	4.9**	2.9**	4.0**
Selection criteria	3	90	18.8**	26.4**	6.6**	0.3
Irrigation*sc	3	90	1.6	0.5	0.5	0.2
Genotype	3	90	22.9**	86.7**	10.3**	0.5
Irrigation*genotype	3	90	1.7	5.0**	1.0	0.7
Sc*genotype	9	90	4.1**	2.4*	1.4	0.8
Irrigation*sc*genotype	9	90	1.5	1.5	0.6	0.4

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Combined analysis of 2017 irrigated and dryland yield data shows irrigation was significant for lint percent, fiber length, and lint yield (Table 4.33). Research shows that irrigation strongly influences fiber growth and fiber length (Hearn, 1976), which may explain as to why irrigation was significant for fiber length. Selection criteria and genotype were both significant for lint percent, and fiber length and strength. However no significant irrigation*sc interactions were noticed. There was a significant irrigation*genotype and sc*genotype interaction for fiber length. Sc*genotype interaction was also significant for lint percent.

Table 4.34 Analysis of variance of HVI fiber properties—micronaire, uniformity (%) and elongation of irrigated yield trial, College Station, TX (2017)

		Micronaire	**Uniformity**	**Elongation**
Source	**df**	**Mean Square**		
Rep	3	0.0288	1.923	3.267**
Selection criteria	3	0.2088**	1.143	0.308
Genotype	3	0.9271**	1.007	1.386**
Sc*genotype	9	0.0647**	0.695	0.629*
Error	45	0.0208	0.872	0.254

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Table 4.35 Mean separation of micronaire within genotypes, irrigated trial

SH13021(F_3:F_4)		**SH13024(F_3:F_4)**		**SH13028(F_3:F_4)**		**SH13031(F_3:F_4)**	
Selection							
LG	5.0 a	LP	4.7 a	ST	5.1 a	LP	5.1 a
LP	5.0 a	NS	4.6 a	LP	4.9 a	NS	5.0 ab
ST	4.9 a	ST	4.6 a	LG	4.9 a	ST	5.0 ab
NS	4.8 a	LG	4.3 b	NS	4.8 a	LG	4.9 b

†Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.36 Mean separation of elongation within genotypes, irrigated trial

SH13021(F_3:F_4)		SH13024(F_3:F_4)		SH13028(F_3:F_4)		SH13031(F_3:F_4)	
Selection							
LP	6.5 a	LP	7.8 a	NS	6.6 a	NS	7.1 a
ST	6.5 a	LG	6.8 b	LG	6.4 a	LG	6.5 a
NS	6.4 a	ST	6.7 b	ST	6.2 a	ST	6.5 a
LG	6.1 a	NS	6.5 b	LP	6.1 a	LP	6.3 a

†Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.37 Analysis of variance of HVI fiber properties— micronaire, uniformity, (%) and elongation of dryland yield trial, College Station, TX (2017)

		Micronaire	Uniformity	Elongation
Source	**df**	**Mean Square**		
Rep	3	0.0288	2.132*	2.901**
Selection criteria	3	0.2088**	0.592	0.309
Genotype	3	0.9271**	4.509**	1.839**
Sc*genotype	9	0.0647**	0.773	0.448*
Error	45	0.0208	0.679	0.228

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Table 4.38 Mean separation of length uniformity of genotypes, dryland trial

Line	Mean (%)	
SH13028($F_{3:}F_4$)	86.1	a[†]
SH13031($F_{3:}F_4$)	85.7	a
SH13021($F_{3:}F_4$)	85.7	a
SH13024($F_{3:}F_4$)	84.9	b

[†]Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.39 Mean separation of elongation of genotypes, dryland trial

Line	Mean	
SH13024($F_{3:}F_4$)	7.3	a[†]
SH13031($F_{3:}F_4$)	6.8	b
SH13021($F_{3:}F_4$)	6.7	bc
SH13028($F_{3:}F_4$)	6.5	c

[†]Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.40 Mean separation of micronaire within genotypes, dryland trial

SH13021($F_{3:}F_4$)		SH13024($F_{3:}F_4$)		SH13028($F_{3:}F_4$)		SH13031($F_{3:}F_4$)	
Selection							
NS	5.2 a†	LP	4.9 a	ST	5.2 a	LP	5.4 a
LP	5.1 a	ST	4.7 a	NS	5.1 b	ST	5.3 ab
LG	5.1 a	NS	4.6 ab	LP	5.1 b	NS	5.1 bc
ST	5.0 a	LG	4.4 b	LG	4.9 c	LG	5.0 c

†Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Regarding additional HVI fiber properties, significant differences in micronaire and elongation were observed in the irrigated yield trial (Table 4.34). However, there were no significant differences observed in length uniformity. Genotype and sc*genotype interaction were significant for micronaire and elongation. The selection criteria was also significant for micronaire. Since there was a sc*genotype interaction for micronaire and elongation, significant differences within the genotype were noticed in both traits. Regarding micronaire, SH13024($F_{3:}F_4$) and SH13031($F_{3:}F_4$) exhibited significant differences within the genotype (Table 4.35).The micronaire values ranged from 4.3-5.1, with low (<3.5) and high (>4.9) micronaire values being undesirable. LG-02 displayed the lowest micronaire value of 4.3 and the only population that exhibited a micronaire value close to the premium range. With respect to elongation, only SH13024($F_{3:}F_4$) exhibited significant differences within the genotype (Table 4.36).

Significant differences in micronaire, length uniformity, and elongation were noticed in the dryland yield trial (Table 4.37). Genotype was significant for micronaire, uniformity, and elongation. Since genotype was the only significant source of variation for length uniformity and elongation, significant differences among genotypes were noticed (Table 4.38 and 4.39). The selection criteria and sc*genotype interaction were also significant for micronaire. Significant differences within the genotype were observed for micronaire (Table 4.40). Regarding micronaire, SH13024($F_{3:}F_4$), SH13028($F_{3:}F_4$), and SH13031($F_{3:}F_4$) displayed significant differences within the genotype. The micronaire values ranged from 4.4-5.4, and LG-02 displayed the lowest micronaire value (4.4), which was consistent with the irrigated trial.

Table 4.41 Analysis of variance of Q-score of irrigated yield trial, College Station, TX (2017)

Source	df	Mean Square
Rep	3	0.0339**
Selection criteria	3	0.0829**
Genotype	3	0.4001**
Sc*genotype	9	0.0106
Error	45	0.0081

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Table 4.42 Mean separation of Q-score of selection pressures, irrigated yield trial

Selection Criteria	Q-score	
Fiber length	67.2	a†
Non-selected	56.8	b
Fiber strength	53.6	b
Lint %	50.7	b

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

Table 4.43 Mean separation of Q-score within genotypes, irrigated yield trial

SH13021(F_3:F_4)			SH13024(F_3:F_4)			SH13028(F_3:F_4)			SH13031(F_3:F_4)		
Selection											
LG	48.1[†]	a	LG	91.7	a	LG	77.2	a	LG	51.7	a
NS	44.9	ab	NS	75.5	b	NS	60.0	ab	ST	47.8	a
ST	41.8	ab	ST	74.8	b	LP	55.6	b	NS	47.2	a
LP	32.3	b	LP	68.8	b	ST	50.1	b	LP	46.0	a

[†]Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.44 Analysis of variance of Q-score of dryland yield trial, College Station, TX (2017)

Source	df	Mean Square
Rep	3	0.0645**
Selection criteria	3	0.1069**
Genotype	3	0.2648**
Sc*genotype	9	0.0230*
Error	45	0.0101

* and ** = Significant at 0.05 and 0.01 level of probability, respectively

Table 4.45 Mean separation of Q-score within genotypes, dryland yield trial

SH13021(F_3:F_4)			SH13024(F_3:F_4)			SH13028(F_3:F_4)			SH13031(F_3:F_4)		
Selection											
LG	50.0	a†	LG	84.5	a	LG	76.2	a	LG	54.9	a
ST	46.3	a	ST	68.3	ab	LP	64.6	a	NS	54.5	a
LP	33.7	b	NS	64.5	b	NS	63.9	ab	ST	43.7	a
NS	31.9	b	LP	53.0	b	ST	49.7	b	LP	37.8	a

†Means followed by the same letter are not different (α=0.05, Duncan MRT); means within section are compared

Table 4.46 Mean separation of Q-score of selection pressures, dryland yield trial

Selection Criteria	Q-score	
Fiber length	66.4	a†
Non-selected	53.7	b
Fiber strength	52.0	b
Lint %	47.3	b

†Means followed by the same letter are not different (α=0.05, Duncan MRT)

For further evaluation of fiber quality in yield trials, the Q-score developed by Bourland (2010) was utilized to create a criteria for fiber quality by integrating the weighted values of four HVI properties into a single numerical index. These include: fiber length, micronaire, length uniformity, and strength, with the weights of the four parameters: 50%, 25%, 15%, and 10% respectively.

2017 irrigated yield trial shows significant differences in Q-score (Table 4.41) Selection criteria and genotype were both significant sources of variation. Selecting for fiber length resulted in the highest Q-score mean (Table 4.42), which is to be expected since the Q-score had fiber length weighted as 50%. Even though there was not a significant sc*genotype interaction, significant differences within the genotype can be observed (Table 4.43). SH13021($F_{3:}F_4$), SH13024($F_{3:}F_4$), and SH13028($F_{3:}F_4$) exhibited significant differences in the Q-score within the genotype. The Q-score ranged from 32.3-91.7, with LP-01 and LG-02 displaying the lowest and highest Q-score, respectively.

2017 dryland yield trial shows significant differences in Q-score (Table 4.44). The selection criteria, genotype, and sc*genotype were significant. Significant differences within the genotype were noticed (Table 4.45). Consistent with the irrigated trial, the same three genotypes displayed significant differences in Q-score within the genotype. The Q-score ranged from 31.9-84.5, with NS-01 and LG-02 displaying the lowest and highest Q-score, respectively. As expected, selecting for fiber length resulted in the highest Q-score mean (Table 4.46).

CONCLUSION

This project had two objectives: (1) to evaluate the response in investigated traits (lint percent, fiber length and strength) under direct selection pressure and (2) to compare the re-selected populations for yield and fiber quality performance under differing levels of abiotic stress. With respect to the first objective, it is well known that a negative association between fiber quality and lint yield exists. Furthermore, that a negative association exists between fiber length and strength and lint percent. However it should be noted that the degree of the negative association is population specific and each genotype does not respond the same to the selection pressure; which highlights the importance of determining relationships among desired traits during the selection process for breeding advancements. When selecting for fiber length and strength, a corresponding drop in lint percent was noticed depending on the genotype. Furthermore, negative correlations between fiber length and strength and lint percent were noticed, varying among populations and the year. There were more significant correlations of fiber length and lint percent noticed in 2017 than 2016, which could be due to the environment causing more variability in fiber length and thus resulting in significant correlations being inconsistent. Significant positive correlations between fiber length and strength were also noticed in some populations, suggesting simultaneous improvements in fiber length and strength in these populations.

The second objective that this project was to compare re-selected populations for yield and fiber quality performance under differing levels of soil-water deficit stress. No significant differences in yield regardless of the selection criteria or genotype were noticed in the dryland and irrigated yield trials (Table 4.13 and 4.24), which was possibly due to the excess rainfall from Hurricane Harvey. Significant differences in lint percent and fiber length and strength were noticed mostly within genotype, depending on the selection criteria (Table 4.16, 4.19, 4.22). Thus the degree of the differences in lint percent, fiber length and strength varied among the four genotypes. This further highlights that each population did not respond the same from the selection pressure in 2016. Among all the populations, LP-01 displayed the highest lint percent in the dryland and irrigated yield trial. All sixteen populations in both of the yield trials exhibited fiber length and strength values that would constitute premiums given the current market.

REFERENCES

Abbott, A., G. Higgerson, R. Long, S. Lucas, G. Naylor, C. Tischler, and M. Purmalis. 2009. An Instrument for Determining the Average Fiber Linear Density (Fineness) of Cotton Lint Samples. Textile Research Journal 80(9):822—833.

Al-Jibouri, H.A., P.A. Miller, and H.F. Robinson. 1958. Genotypic and Environmental Variances and Covariances in an Upland Cotton Cross of Interspecific Origin1. Agronomy Journal 50(10): 633—636.

Asif, M., M. Rahman and Y. Zafar. 2006. Genotyping Analysis of Six Maize (Zea mays L.) Hybrids using DNA Fingerprinting Technology. Pakistan Journal of Botany 38(5): 1425—1430.

Backe, E. E. 1996. The importance of cotton fiber elongation on yarn quality and weaving performance. *In* C.H. Chewning Jr. (ed.) Proceedings of the Ninth Annual Cotton Inc. Engineered Fiber Selection System Conference. Cary, NC, May. pp. 1—13.

Basal, H., N. Dagdelen, A. Unay, and E. Yilmaz. 2009. Effects of Deficit Drip Irrigation Ratios on Cotton (Gossypium hirsutumL.) Yield and Fibre Quality. Journal of Agronomy and Crop Science 195(1): 19—29.

Bednarz, C., R. Nichols, and S. Brown. 2006. Plant Density Modifies Within-Canopy Cotton Fiber Quality. Crop Science 46(2): 950—956.

Bednarz, C.W., W.D. Shurley, and W.S. Anthony. 2004. Losses in yield, quality, and profitability of cotton from improper harvest timing. Agronomy Journal 94(5):1004—1011.

Benzina, H., E. Hequet, N. Abidi, J. Gannaway, J. Drean, and O. Harzallah. 2007. Using Fiber Elongation to Improve Genetic Screening in Cotton Breeding Programs. Textile Research Journal 77(10): 770—778.

Bhortakke, M.K., T. Nishimura, and T. Matsuo. 1997. High speed yarn production with air-jet apinning: effects of some fiber parameters. Textile Research Journal 67(2):101—108.

Bohn, M., S. Groh, M.M. Khairallah, D.A. Hoisington, H.F. Utz, and A.E. Melchinger. 2001. Re-evaluation of the prospects of marker-assisted selection for improving insect resistance against Diatraea spp. in tropical maize by cross validation and independent validation. Theoretical and Applied Genetics 103(6-7): 1059—1067.

Bourland, F. M., R. Hogan, D.C. Jones, and E. Barnes. 2010. Development and utility of Q-score for characterizing cotton fiber quality. Journal of Cotton Science 14:53—63.

Bowman, D. T., and A. Gutiérrez. 2003. Sources of fiber strength in the US upland cotton crop from 1980 to 2000. Journal of Cotton Science 7(4):164—169.

Braden, C., and C. W. Smith. 2004. Fiber length development in near-long staple upland cotton. Crop Science 44(5):1553—1559.

Bradow, J.M., L.H. Wartelle, P.J. Bauer, and G.F. Sassenrath-Cole. 1997. Small-sample cotton fiber quality quantitation. Journal of Cotton Science 1(1):48—60.

Bradow, J.M, and G.H. Davidonis 2000. Quantitation of fiber quality and the cotton production-processing interface: a physiologists perspective. Journal of Cotton Science 4(1):34—64.

Chen, H., N. Qian, W. Guo, Q. Song, B. Li, F. Deng, C. Dong, and T. Zhang. 2009. Using three overlapped RILs to dissect genetically clustered QTL for fiber strength on Chro.D8 in Upland cotton. Theoretical and Applied Genetics 119(4): 605—612.

Clement, J., G. Constable, W. Stiller, and S. Liu. 2012. Negative associations still exist between yield and fibre quality in cotton breeding programs in Australia and USA. Field Crops Research 128: 1—7.

Clement, J., G. Constable, W. Stiller, and S. Liu. 2015. Early generation selection strategies for breeding better combinations of cotton yield and fibre quality. Field Crops Research 172: 145—152.

Clouvel, P., E. Goze., R. Sequeira, J. Dusserre and M. Cretenet. 1998. Variability of cotton fiber quality. *In* Proceedings of the 2nd World Cotton Research Conference—New Frontiers in Cotton. Athens, Greece. pp 963—966.

Constable, G.A., and M.P. Bange. 2007. Producing and preserving fiber quality: from the seed to the bale. *In* Stephens, M. (ed.) Proceedings of the World Cotton Research Conference. Lubbock, TX, September. pp 10—14.

Constable, G., D. Llewellyn, S. Walford, and J. Clement. 2015. Cotton breeding for fiber quality improvement. *In* V.Cruz and D.Dierig (eds.) Industrial Crops. Springer, New York, NY. pp 191—232.

Copur, O., İ. H. Birgül, H. Haliloğluand , and V. Beyyavaş 2010. The effect of different harvesting times on seed-set efficiency in cotton (Gossypium hirsutum L.) varieties. African Journal of Biotechnology 9(40):6654—6659.

Cotton Incorporated. 2012. Rating of fiber properties. www.cottoninc.com/fiber/quality/US-Fiber-Chart/Ratings-OfFiber-Properties/

Culp, T. W., and D.C Harrell. 1973. Breeding methods for improving yield and fiber quality of upland cotton (Gossypium hirsutum L.). Crop Science 13(6): 686—689.

Culp, T. W., and D.C. Harrell. 1975. Influence of lint percentage, boll size, and seed size on lint yield of upland cotton with high fiber strength. Crop Science 15(6):741—746.

Davidonis, G. H., A.S. Johnson, J.A. Landivar, and C.J. Fernandez. 2004. Cotton Fiber Quality is Related to Boll Location and Planting Date. Agronomy Journal 96(1): 42—47.

Desalegn, Z., N. Ratanadilok, and R. Kaveeta. 2009. Correlation and Heritability for Yield and Fiber Quality Parameters of Ethiopian Cotton (Gossypium hirsutum L.) Estimated from 15 (diallel) Crosses. Kasetsart Journal of Natural Sciences 43(1):1—11.

Deussen, H. 1992. Improved Cotton Fiber Properties: The Textile Industry's Key to Success in Global Competition. *In* C.R. Benedict and G.M. Jividen (ed.) Proceedings Cotton Fiber Cellulose: Structure, Function, and Utilization Conference. Nashville, TN. pp 43—63. National Cotton Council, Memphis, TN.

Dhindsa, R. S., C.A. Beasley, and I.P. Ting. 1975. Osmoregulation in Cotton Fiber: Accumulation of Potassium and Malate during Growth. Plant Physiology 56(3): 394—398.

Ellison, M. and C. Rogers. 1995. Cotton fiber quality: Characterization, selection, and optimization. National Textile Center Annual Report.

Faerber, C. 1995. Future demands on cotton fiber quality in the textile industry. *In* D.A. Richter and J. Armour (ed.) Proceedings of Beltwide Cotton Conference. San Antonio, Texas, January. pp 1449—1454. National Cotton Council, Memphis, TN.

Faircloth, J. C., K.L. Edmisten, R. Wells, and A.M. Stewart. 2004. Timing defoliation applications for maximum yields and optimum quality in cotton containing a fruiting gap. Crop Science 44(1): 158—164.

Faulkner, W. 2008. Comparison of Picker and Stripper Harvesters on Irrigated Cotton on the High Plains of Texas.

Faulkner, W.B., E.F. Hequet, J. Wanjura, and R. Boman. 2012. Relationships of cotton fiber properties to ring-spun yarn quality on selected High Plains cottons. Textile Research Journal 82(4): 400—414.

Feng, L., V.B. Bufon, C.I. Mills, E. Hequet, J.P. Bordovsky, W. Keeling, and C.W. Bednarz. 2011. Effects of Irrigation, Cultivar, and Plant Density on Cotton Within-Boll Fiber Quality. Agronomy Journal 103(2): 297—303.

Gipson, J. R. and L.L. Ray. 1969. Fiber Elongation Rates in Five Varieties of Cotton (Gossypium hirsutum L.) as Influenced by Night Temperature 1. Crop Science 9(3): 339—341.

Grimes, D.W., H. Yamada, and W.L. Dickens. 1969. Functions of Cotton (Gossypium hirsutum L.) Production from Irrigation and Nitrogen Fertilization variables: I. Yield and Evapo-transpiration. Agronomy Journal 61(5):769—773.

Grosberg, P., W. Oxenham, and M Miao. 1987. The Insertion of 'Twist' into Yarns by Means of Air-jets. Part I: An Experimental Study of Air-jet Spinning. Journal of the Textile Institute 78(3):189—203.

Gwathmey, C. O., C.W. Bednarz, D.D. Fromme, E.M. Holman, and D.K. Miller. 2004. Response to defoliation timing based on heat-unit accumulation in diverse field environments. Journal of Cotton Science 8:142—153.

Hake, K., B. Mayfield, H. Ramey, and P. Sasser. 1990. Producing quality cotton. Cotton Physiology Education Program, National Cotton Council, Memphis, TN.

He, D.H., Z.X. Lin, X. Zhang, Y.C. Nie, X.P. Guo, Y. Zhang, and W. Li. 2007. QTL mapping for economic traits based on a dense genetic map of cotton with PCR-based markers using the interspecific cross of Gossypium hirsutum × Gossypium barbadense. Euphytica 153(1–2): 181—197.

Heap, S.A. 2000. The Meaning of Micronaire. *In* Proceedings of the 25th International Cotton Conference. Breman, Germany. pp 97—107. ITMF, Zurich, Switzerland.

Hearn, A.B. 1976. Response of cotton to nitrogen and water in a tropical environment. III. Fibre quality. Journal of Agricultural Science 86(2): 257—269.

Hebert, J.J., E.K. Boylston, and D.P. Thibodeaux. 1988. Anatomy of a Nep. Textile Research Journal 58(7): 380—382.

Hequet, E. F., B. Kelly, and J. Dever. 2014. Breeding for better fiber elongation: A key to improve yarn tensile properties. *In* Proceedings of the International Cotton Conference. Breman, Germany.

Hertel, K. L. 1940. A Method of Fibre-Length Analysis Using the Fibrograph. Textile Research Journal 10(12): 510—520.

Hinze, L.L., B.T. Campbell, and R.J. Kohel. 2011. Performance and combining ability in cotton (*Gossypium hirsutum* L.) populations with diverse parents. Euphytica 181: 115—125.

Hoeschele, I., and P.M. VanRaden. 1993. Bayesian analysis of linkage between genetic markers and quantitative trait loci. I. Prior knowledge. Theoretical and Applied Genetics 85(8): 953—960.

Hsieh, Y.L. 1999. Structural Development of Cotton Fibers and Linkage to Fiber Quality. *In* Basra A.S. (ed). Cotton fibers: Developmental biology, quality improvement, and textile processing. Food Products Press, New York, NY. pp. 137–165.

Jauhar, P.P. 2006. Modern biotechnology as an integral supplement to conventional plant breeding: The prospects and challenges. Crop Science 46(4):1841—1859.

Karademir, E., C. Karademir, R. Ekininci, and O. Gencer. 2010. Relationship between yield, fiber length and other fiber-related traits in advanced cotton strains. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 38(3): 111—115.

Kelly, C. M., E.F. Hequet, and J. Dever. 2012. Interpretation of AFIS and HVI fiber property measurements in breeding for cotton fiber quality improvement. Journal of Cotton Science 16:1—16.

Kerby, T. A., J. Supak, J.C. Banks, and C. Snipes. 1992. Timing defoliations using nodes above cracked boll. *In* Proceedings of the Beltwide Cotton Conference. San Antonio, Texas, January. pp 155—156.

Kumar, P., R. Singh, E.L. Lubbers, X. Shen, A.H. Paterson, B.T. Campbell, and P.W. Chee. 2012. Mapping and validation of fiber strength quantitative trait loci on chromosome 24 in upland cotton. Crop Science 52(3): 1115—1122.

Lacape, J. M., G. Gawrysiak, T.V. Cao, C. Viot, D. Llewellyn, S. Liu, and O. Palai. 2013. Mapping QTLs for traits related to phenology, morphology and yield components in an inter-specific Gossypium hirsutum× G. barbadense cotton RIL population. Field Crops Research 144: 256—267.

Lande, R., and R. Thompson. 1990. Efficiency of marker-assisted selection in the improvement of quantitative traits. Genetics 124(3):743—756.

Li, X., D. Yuan, H. Wang, X. Chen, B. Wang, Z. Lin, and X. Zhang. 2012. Increasing cotton genome coverage with polymorphic SSRs as revealed by SSCP. Genome 55(6): 459—470.

Liu, X., T. Zhonghua, J. Wang, T. Wu, Z. Zhang, X. Deng, X. Fang, Z. Tan, I. Ali, D. Liu, J. Zhang, D. Liu, F. Liu, and Z. Zhang. Enriching an intraspecific genetic map and identifying QTL for fiber quality and yield component traits across multiple environments in Upland cotton (Gossypium hirsutum L.). Molecular Genetics Genomics 292: 1281—1306.

Liang, Q., C. Hu, H. Hua, Z. Li, and J. Hua. 2013. Construction of a linkage map and QTL mapping for fiber quality traits in upland cotton (Gossypium hirsutum L.). Chinese Science Bulletin 58(26): 3233—3243.

Lord, E., and S.A. Heap. 1988. The origin and assessment of cotton fibre maturity. International Institute for Cotton, Technical Research Division, Manchester, England.

Lu, H., and G. Myers. 2002. Genetic relationships and discrimination of ten influential upland cotton varieties using RAPD markers. Theoretical and Applied Genetics 105(2-3): 325—331.

May, O.L. 1999. Genetic variation in fiber quality. *In* Basra A.S. (ed.) Cotton fibers: Developmental biology, quality improvement, and textile processing. Food Products Press, New York, NY. pp 183—229.

May, O.L. 2002. Quality improvement of upland cotton (Gossypium hirsutum L.). Journal of Crop Production 5(1-2): 371—394.

McAlister III, D. D., and C.D. Rogers. 2005. The effect of harvesting procedures on fiber and yarn quality of ultra-narrow-row cotton. Journal of Cotton Science 9:15—23.

McCall, L.L., L.M. Verhalen, and R.W. McNew. 1986. Multidirectional selection for fiber strength in upland cotton. Crop Science 26(4): 744—750.

Mei, M., N.H. Syed, W. Gao, P.M. Thaxton, C.W. Smith, D.M. Stelly, and Z.J. Chen. 2004. Genetic mapping and QTL analysis of fiber-related traits in cotton (Gossypium). Theoretical and Applied Genetics 108(2):280—291.

Mert, M. 2005. Irrigation of cotton cultivars improves seed cotton yield, yield components and fibre properties in the Hatay region, Turkey. Acta Agriculturae Scandinavica 55(1): 44—50.

Melchinger, A. E., H.F. Utz, and C.C. Schön. 1998. Quantitative trait locus (QTL) mapping using different testers and independent population samples in maize reveals low power of QTL detection and large bias in estimates of QTL effects. Genetics 149(1): 383—403.

Meredith, R. 1945. The Tensile Behavior of Raw Cotton and other Textile Fibers. Journal of Textile Institute Transactions 36(5):107—130.

Meredith, W.R. 1984. Quantitative genetics. In Kohel, R.J. and Lewis, C.F. (eds.) Cotton, Agronomy Monographs 24. ASA, CSSA, and SSSA, Madison, WI. pp 131—150.

Meredith, W.R., and R.R. Bridge. 1971. Breakup of linkage blocks in cotton, *Gossypium hirsutum* L. Crop Science 11(5): 695—698.

Meredith, W. R. and R. R. Bridge. 1972. Heterosis and gene action in cotton (Gossypium hirsutum L.). Crop Science 12(3):304—310.

Miller, P. A., and J.O. Rawlings. 1967. Selection for increased lint yield and correlated responses in upland cotton, Gossypium hirsutum L. Crop Science 7(6):637—640.

Moore, J. F. 1996. Cotton classification and quality. *In* Glade, E.H., Meyer, L.A. and Stults, H., (eds.) The cotton industry in the United States. U.S. Government Print Office, Washington D.C. pp 51—57.

National Cotton Council. 1999. Cotton: Profile of a resourceful industry. <http://www.cotton.org/ncc/education/profile.pdf>.

Nie, X., C. Huang, C. You, W. Li, W. Zhao, C. Shen, B. Zhang, H. Wang, Z. Yan, and Z. Lin. 2016. Genome-wide SSR-based association mapping for fiber quality in nation-wide upland cotton inbreed cultivars in China. BMC Genomics 17(1): 352.

Ning, Z.Y., H. Chen, H.X. Mei, and T.Z. Zhang. 2014. Molecular tagging of QTLs for fiber quality and yield in the upland cotton cultivar Acala-Prema. Euphytica 195(1): 143—156.

Pan, N., T. Hua, and Y. Qiu. 2001. Relationship between fiber and yarn strength. Textile Research Journal 71(11): 960—964.

Parvin, D. W., S.W. Martin, F. Cooke, and B.B. Freeland. 2005. Effect of Harvest Season Rainfall on Cotton Yield. Journal of Cotton Science 9(3): 1408—1417.

Price, J. 1990. Cotton breeding directions: The yarn producer's viewpoint. ICAC Recorder 8:12—15.

Rahman, M., M. Asif, I. Ali, Z. Hayder, K.A. Malik, and Y. Zafar. 2002. DNA markers studies in cotton.

Ramey, H.H. 1986. Stress influences on fiber development. *In* J.R. Mauney and J.McD. Stewart (eds) Cotton Physiology. The Cotton Foundation, Memphis, TN. pp 351—359.

Ramey, H.H., Jr. 1999. Classing of fiber. *In* C.W. Smith and J.T. Cothren (eds.) Cotton: Origin, History, Technology, Production. John Wiley & Sons, Inc., New York, NY. pp 709—727.

Read, J. J., K.R. Reddy, and J.N. Jenkins. 2006. Yield and fiber quality of upland cotton as influenced by nitrogen and potassium nutrition. European Journal of Agronomy 24(3):282—290.

Ritchie, G. L., C.W. Bednarz, P.H. Jost, and S.M. Brown. 2004. Cotton growth and development. Bulletin 1252.

Said, J. I., Z. Lin, X. Zhang, M. Song, and J. Zhang. 2013. A comprehensive meta QTL analysis for fiber quality, yield, yield related and morphological traits, drought tolerance, and disease resistance in tetraploid cotton. BMC Genomics 14(1): 776.

Sasser, P.E. and J.L. Shane. 1996. Crop quality–a decade of improvement. *In* Proceedings of the Beltwide Cotton Conference. Nashville, TN. pp 9—12.

Sawan, Z. M., M.H. Mahmoud, and A.H. El-Guibali. 2006. Response of yield, yield components, and fiber properties of Egyptian cotton (Gossypium barbadense L.) to nitrogen fertilization and foliar-applied potassium and mepiquat chloride. Journal of Cotton Science 10:224—234.

Scholl, R. L., and P.A. Miller. 1976. Genetic association between yield and fiber strength in upland cotton. Crop Science 16(6):780—783.

Shang, L., Q. Liang, Y. Wang, X. Wang, K. Wang, A. Abduweli, M. Lingling, S. Cai, and J. Hua. 2015. Identification of stable QTLs controlling fiber traits properties in multi-environment using recombinant inbred lines in Upland cotton (Gossypium hirsutum L.). Euphytica 205(3): 877—888.

Shen, X., W. Guo, X. Zhu, Y. Yuan, Y.Z. John, R.J. Kohel, and T. Zhang. 2005. Molecular mapping of QTLs for fiber qualities in three diverse lines in Upland cotton using SSR markers. Molecular Breeding 15(2):169—181.

Shen, X.L., T.Z. Zhang, W.Z. Guo, X.F. Zhu, and X.Y. Zhang. 2006. Mapping fiber and yield QTLs with main, epistatic, and QTL × environment interaction effects in recombinant inbred lines of upland cotton. Crop Science 46(1): 61—66.

Siebert, J.D., B.R. Leonard, and A.M. Stewart. 2006. Cotton (Gossypium hirsutum L.) yield and fiber quality to insect-simulated and harvest-aid premature defoliation. Journal of Cotton Science 10:9—16.

Smith, B. 1991. A Review of the Relationship of Cotton Maturity and Dyeability. Textile Research Journal 61(3): 137—145.

Smith, C., E. Hequet, S. Hague, and D. Jones. 2017. Elite Fiber Quality Germplasm Lines of Upland Cotton: TAM 11K-13 ELSU, TAM 11T-08 ELSU-ESU, and TAM 11L-24 LSU. Journal of Plant Registrations 12(1): 112—117.

Smith, C., S. Hague, P. Thaxton, E. Hequet, and D. Jones. 2009. Registration of Eight Extra-Long Staple Upland Cotton Germplasm Lines. Journal of Plant Registrations 3(1): 81—85.

Snipes, C., and C. Baskin. 1994. Influence of Early Defoliation on Cotton Yield, Seed Quality, and Fiber Properties. Field Crops Research 37(2): 137—143.

Spooner, A., C. Caviness, and W. Spurgeon. 1958. Influence of Timing of Irrigation on Yield, Quality and Fruiting of Upland Cotton1. Agronomy Journal 50(2): 74—77.

Steadman, R.G. 1997. Cotton Testing. Textile Progress 27(1):1—63.

Strauss, S., R. Lande, and G. Namkoong. 1992. Limitations of molecular-marker-aided selection in forest tree breeding. Canadian Journal of Forest Research 22(7): 1050—1061.

Tan, Z., X. Fang, S. Tang, J. Zhang, D. Liu, Z. Teng, L. Li, H. Ni, F. Zheng, D. Liu, T. Zhang, A. Paterson, and Z. Zhang. 2015. Genetic map and QTL controlling fiber quality traits in upland cotton (Gossypium hirsutum L.). Euphytica 203(3): 615—628.

Tang, B., J.N. Jenkins, C.E. Watson, J.C. McCarty, and R.G. Creech. 1996. Evaluation of genetic variances, heritability, and correlations for yield and fiber properties among cotton F2 hybrid population. Euphytica 91(3): 315—322.

Tang, S., Z. Teng, T. Zhai, X. Fang, F. Liu, D. Liu, J. Zhang, and Z. Zhang. 2015. Construction of genetic map and QTL analysis of fiber quality traits for Upland cotton (Gossypium hirsutum L.). Euphytica 201(2):195—213.

Taylor, R. 1986. Cotton Tenacity Measurements with High Speed Instruments. Textile Research Journal 56(2): 92—101.

Taylor, R.A., L.C. Godbey, D.S. Howle, and O.L. May. 1995. Why we need a standard strength test for cotton variety selection. *In* Proceedings of the Beltwide Cotton Conference. San Antonio, TX, January. pp 1175—1178.

Tyagi, P., M.A. Gore, D.T. Bowman, T.B. Campbell, J.A. Udall, and V. Kuraparthy. 2014. Genetic diversity and population structure in the US upland cotton (*Gossypium hirsutum* L.) Theoretical and Applied Genetics 127(2):283—295.

Ulloa, M. 2006. Heritability and correlations of agronomic and fiber traits in an okra-leaf upland cotton population. Crop Science 46(4): 1508—1514.

Ulloa, M. and W. R. Meredith 2000. Genetic linkage map and QTL analysis of agronomic and fiber quality traits in an intraspecific population. Journal of Cotton Science 4(3):161—170.

Ǘreyen, M.E., and H. Kadoğlu. 2006. Regressional estimation of ring cotton yarn properties from HVI fiber properties. Textile Research Journal 76(5): 360—366.

USDA Farm Service Agency. 2016. Price support. https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/Price-Support/pdf/2016/2016.cotton.premiun.discounts.pdf

USDA–Foreign Agricultural Service. 2016. Cotton: World markets and trade. https://www.fas.usda.gov/data/cottonworld-markets-and-trade

USDA National Agricultural Statistics Service. 2017. Cotton Production. https://www.nass.usda.gov/Statistics_by_State/Texas/Publications/Texas_Crop_Reports/2017/spr_cotton_prod_05_2017.pdf

Wang, H., C. Huang, H. Guo, X. Li, W. Zhao, B. Dai, Z. Yan, and Z. Lin. 2015. QTL mapping for fiber and yield traits in upland cotton under multiple environments. PLoS One 10(6):1—14.

Wang, X., L. Zhang, J.B. Evers, L. Mao, S. Wei, X. Pan, X. Zhao, and Z. Li. 2014. Predicting the effects of environment and management on cotton fibre growth and quality: a functional–structural plant modelling approach. AoB Plants 6(1).

Ware, J. 1936. Plant breeding and the cotton industry. *In* Yearbook of Agriculture. USDA, Washington. pp 657—744.

Williford, J.R. 1992. Influence of Harvest Factors on Cotton Yield and Quality. Transactions of the ASAE 35(4): 1103—1107.

Williford, J.R., F.T Cooke Jr, D. F. Cailouet, and S. Anthony. 1995. Effect of Harvest Timing on Cotton Yield and Quality. *In* Proceedings of the Beltwide Cotton Conference. San Antonio, TX. pp. 633-635.

Xu, B., C. Fang, R. Huang, and M. Watson. 1997. Chromatic image analysis for cotton trash and color measurements. Textile Research Journal 67(12): 881—890.

Yabe, S., R. Ohsawa, and H. Iwata. 2013. Potential of Genomic Selection for Mass Selection Breeding in Annual Allogamous Crops. Crop Science 53(1): 95—105.

Yu, J., S. Jung, C.H. Cheng, S. Ficklin, T. Lee, P. Zheng, D. Jones, R. Percy and D. Main. 2013. CottonGen: a genomics, genetics and breeding database for cotton research. Nucleic Acids Research 42(D1): D1229—D1236.

Yu, J., M. Ulloa, S. Hoffman, R.J. Kohel, A. Pepper, D. Fang, R.G. Percy, and J. Burke. 2014. Mapping genomic loci for cotton plant architecture, yield components, and fiber properties in an interspecific (*Gossypium hirsutum* L. × *G. barbadense* L.) RIL population. Molecular Genetics and Genomics 289(6): 1347—1367.

Yu, J., K. Zhang, S. Li, S. Yu, H. Zhai, M. Wu, X. Li, S. Fan, M. Song, D. Yang, Y. Li, and J. Zhang. 2013. Mapping quantitative trait loci for lint yield and fiber quality across environments in a Gossypium hirsutum× Gossypium barbadense backcross inbred line population. Theoretical and applied genetics 126(1): 275—287.

Zeidman, M., and P Sawhney. 2002. Influence of fiber length distribution on strength efficiency of fibers in yarn. Textile Research Journal 72(3): 216—220.

Zhang, T., Y Hu, W Jiang, L Fang, X Guan, J. Chen, J. Zhang, C. Saski, and Z. Chen. 2015. Sequencing of allotetraploid cotton (*Gossypium hirsutum* L. acc. TM-1) provides a resource for fiber improvement. Nature Biotechnology 33(5): 531—537.

Zhang, Z., M. Hu, J. Zhang, D. Liu, J. Zheng, K. Zhang, W. Wang, and Q. Wan. 2009. Construction of a comprehensive PCR-based marker linkage map and QTL mapping for fiber quality traits in upland cotton (Gossypium hirsutum L.). Molecular Breeding 24(1): 49—61.

Zheng, M., Y. Wang, K. Liu, H. Shu, and Z. Zhou. 2012. Protein expression changes during cotton fiber elongation in response to low temperature stress. Journal of Plant Physiology 169(4): 399—409.