DEGREE OF WHITENESS AND MATURITY AMONG WORLD COTTON CULTIVARS

A Thesis

by

KENDRA LYN GREGORY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2012

Major Subject: Plant Breeding

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Approved by:

Co-chairs of Committee,	C. Wayne Smith
	Eric F. Hequet
Committee Member,	J. Tom Cothren
Head of Department,	David D. Baltensperger

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ABSTRACT

Degree of Whiteness and Maturity among World Cotton Cultivars. (May 2012)

Kendra Lyn Gregory, B.S., Abilene Christian University; B.A., Abilene Christian University

Co-Chairs of Advisory Committee: Dr. C. Wayne Smith
Dr. Eric F. Hequet

Increased US export of cotton and global competition necessitates that plant breeders continue to improve fiber properties of upland cotton, *Gossypium hirsutum* (L.). Cotton cultivars having whiter fibers and more mature fibers are desirable due to decreased processing costs. TAM B182-33 ELS (Extra Long Staple) germplasm line of upland cotton, and Tamcot CAMD-E, a short staple obsolete cultivar were crossed with 36 cultivars representing unique germplasm pools from China (12 cultivars), west and central Africa (7 cultivars), south Africa (10 cultivars), and the United States (7 cultivars) that represent distinct germplasm pools. Parents and F_1s were grown in College Station, TX, in a Line x Tester design during the summers of 2010 and 2011. Seedcotton was harvested by hand (to avoid the presence of thrash particles in the lint that could bias the color measurements), deburred and allowed to dry in limited light. Cotton samples were ginned on a laboratory saw gin, separated into 2.00 gram subsamples, and color measurements were taken using a Konica-Minolta CR-310 reflectance colorimeter. Absolute color measurements were obtained in two color systems (tristimulus XYZ and CIE L*a*b*). At the Fiber and Biopolymer Research

Institute (FBRI) in Lubbock, TX, 50.0 mg samples of the 38 parents and F_1s were used to determine maturity ratio (MR), ribbon width (RbWth) and micronaire (Mic) on a Cottonscope®. The fibers were cut into 2.0 mm snippets and immersed in an aqueous solution containing a surfactant and NaCl. Approximately, 20,000 snippets per entry were analyzed for MR, RbWth and Mic in the Cottonscope® using polarized light. General and specific combining abilities for all the variables were calculated from the data collected.

Despite the evident genetic variation from this study for the degree of fiber whiteness, the difficulties in the phenotypic screening of this trait and its importance relative to other fiber traits are problematic. At this time, it is not advisable to begin a cotton breeding program based upon degree of fiber whiteness. Genetic variation also existed for MR, RbWth and Mic among the distinct germplasm pools utilized in this study, but it is not advisable to begin a breeding program based on RbWth or Mic. However, a cotton breeding program to improve MR would be feasible, especially with fast and repeatable measurements from the Cottonscope®.

DEDICATION

To Daniel Jernigan

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Smith, my co-chair, Dr. Hequet and my other committee member, Dr. Cothren, for their guidance and support throughout the course of this research. They have effectively prepared me for an exciting career as a plant breeder.

Thanks also to my colleagues and the Soil and Crop Sciences department faculty and staff for making my time at Texas A&M University a memorable and educational experience. I also want to extend my gratitude to Cotton Incorporated, which provided funding for this research project.

Finally, thanks to my mother and father for their encouragement and to my fiancé for his great patience and love. Also thanks be to God for His goodness and unfailing love.

NOMENCLATURE

USDA	United States Department of Agriculture
HVI	High Volume Instrument
NIST	National Institution of Standardization and Technology
CIE	International Commission on Illumination
AMS	Agricultural Marketing Service
SFC	Short Fiber Content
MR	Maturity Ratio
Mic	Micronarie
UV	Ultraviolet
AFIS	Advanced Fiber Information System
RbWth	Ribbon Width
FIAS	Fiber Image Analysis System
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CCD	Charged Coupled Device
GCA	General Combining Ability
SCA	Specific Combining Ability
PI	Plant Inventory
PVP	Plant Variety Protection
FBRI	Fiber and Biopolymer Research Institute
ANOVA	Analysis of Variance

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CHAPTER I

INTRODUCTION

Cotton Color Measurements

Cotton, *Gossypium hirsutum* L., color is influenced by numerous environmental factors including weathering, insects, fungi, bacteria, and contact with cotton leaves, soil, oils or greases in the machinery (2001). Color can be affected by higher levels of moisture or temperature during storage of either seedcotton or cotton fibers after ginning. As a result of weathering and bacterial or fungal activity (under high moisture conditions) cotton becomes grayer and the fiber strength may be reduced. This leads to poorer processing efficiency and lower dye uptake. Whiter cottons are preferable since such fiber logically would result in textile manufacturers reducing use of bleaching agents and other finishing chemicals prior to dyeing, resulting in lower production costs and a more environmentally friendly product. The marketing of "greener" textile products may be favorable for textile manufacturers.

Cotton color grading, prior to the invention of the Nickerson-Hunter cotton colorimeter, was accomplished by trained United States Department of Agriculture (USDA) cotton color graders. The number and description of the various cotton color grades and classes have changed over the years. The United States Cotton Standards Act in 1923, established nine grades of white cotton (good ordinary, strict good ordinary, low middling, strict low middling, middling, strict middling, good middling, strict good middling and middling fair) and seven color classifications for upland cotton (white,

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This thesis follows the style and format of Crop Science.

blue-stained, gray, spotted, yellow-tinged, light-stained and yellow-stained) (Brown, 1927). The color classifications for upland cotton were decreased to only six classes by 1938 (gray, extra white, white, spotted, tinged and yellow-stained) (Brown, 1938). These upland cotton color classifications were decreased again by 1962 to only five classes (white, light spotted, spotted, tinged and yellow-stained), but sub-categories of gray and light gray were used to denote differences in leaf content in the white class (Kohel and Lewis, 1984). Since 1993, the USDA has maintained 25 official color grades for upland cotton, with five substandard color grades (Table 1). However, only 15 of the color grades have physical standards applied to them; the remaining grades are strictly descriptive standards and as such, are somewhat more subjective in nature (2001).

Table 1. United States Department of Agriculture (USDA) cotton color grading standards.

Grade	White	Light-spotted	Spotted	Tinged	Yellow-stained
Good Middling	11*	12	13	---	---
Strict Middling	21*	22	23*	24*	25
Middling	31*	32	33*	34*	35
Strict low Middling	41*	42	43*	44*	---
Low Middling	51*	52	53*	54*	---
Strict Good Ordinary	61*	62	63*	---	---
Good Ordinary	71*	---	---	----	---
Below Grade	81	82	83	84	85

*Physical standards maintained by the USDA.

Human cotton color classers began to be replaced, when Nickerson developed a disk colorimeter that was used to prepare cotton grade standards (Nickerson, 1931). This disk colorimeter gave color values in the Munsell space (value or lightness, and chroma), while hue was not included because cotton was considered to have a constant hue (Nickerson, 1931; Rodgers et al., 2008). Later on, the Nickerson-Hunter reflectance colorimeter was developed in 1948 to replace human cotton classers. It was standardized for readings on a 2-D scale for Rd (reflectance) and +b (yellowness) values that would classify the cotton sample into one of the USDA color grades (Nickerson et al., 1950). Rd measures the degree of lightness or darkness, while +b measures the amount of yellowness or blueness in a cotton. In colorimetric machinery, Rd values range from 40 to 90%, while +b values range from 0 to 20 (Nickerson, 1951). The third measurement typically associated with color grading (redness or greenness) was discounted for inclusion in the cotton grading system because it was determined to not contribute to statistical correlations between the USDA cotton grades and the calibration standards.

A two digit coding system was developed to correspond to the traditional USDA cotton color grades. The first digit referred to the grade number associated with grade names (good middling, strict middling, middling, strict low middling, low middling, strict good ordinary, and good ordinary), and the second digit referred to the cotton color classes (white, light-spotted, spotted, tinged and yellow-stained). Since 2005, the USDA color grade includes subdivisions and a third digit that correspond to differences within each particular color grade or the color quadrant. A two digit color grade and a single-

digit color quadrant are reported by locating the intersection of the High Volume Instrument (HVI) Rd and +b values on a two dimensional plane (USDA, 2005) (Figure 1).

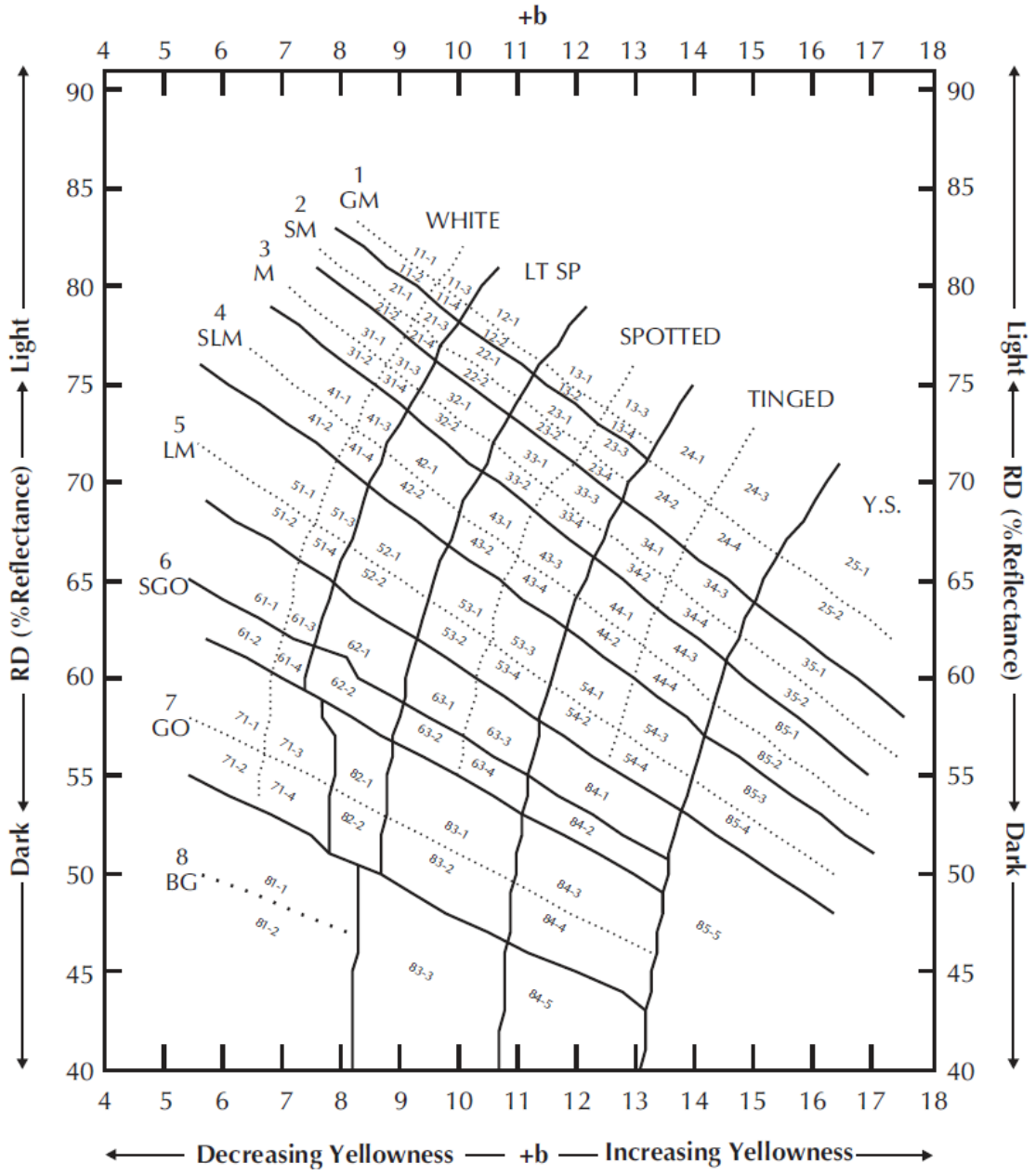

Figure 1. United States Department of Agriculture – Agricultural Marketing Service (USDA-AMS) High Volume Instrument (HVI) colorimeter chart.

While Rd and +b have been used in the United States for many years as cotton-specific color measurements, this color system is not as prominent in international cotton market where human grading is still prevalent. Other industries such as plastics, food science or man-made fiber textiles use more internationally accepted color systems. Of particular concern to those who work in the cotton industry is the fact that Rd and +b standards are not recognized officially by the National Institution of Standardization and Technology (NIST) (Rodgers et al., 2006; Rodgers et al., 2008). As such, there is no "traceability" associated with the cotton color standards that are maintained by the USDA. All US HVI colorimeters are standardized to a master colorimeter, which is housed in Memphis, TN, at the Cotton Program's Standardization and Engineering branch. This master HVI colorimeter is recalibrated to new calibration cottons and ceramic tiles every 3 or 4 years. Unfortunately, there is no concrete evidence that these cotton color standards used for calibration are not drifting from year to year.

Research has improved the consistency of cotton color classification and supports a switch to a more internationally recognized color system, such as the XYZ or L*a*b* system that was developed by the International Commission on Illumination (CIE). Statistically significant correlations between Rd and +b to the L*a*b* color system (including DE_{ab}*) and the L C H color system have been reported (Xu et al., 1998a; Rodgers et al., 2006; Rodgers et al., 2008; Matusiak and Walawska, 2010; Rodgers et al., 2010). Even though scientific evidence exists to support the transition of the cotton color grading system to a more well-known system (XYZ or L*a*b*), such change has not occurred. And yet with all these studies, the environmental influences on

cotton fiber samples were not partitioned out in order to better understand the genetic aspects associated with cotton whiteness.

Fiber Color Determination

A reflectance colorimeter was incorporated into the HVI machines during the 1970s, but it was not until the 1990s that the Rd and +b values were used by the USDA in cotton color classifications. A 227g sample of fibers are taken from every bale of US cotton, with which USDA Agricultural Marketing Service (AMS) Cotton Classing Offices determine HVI fiber properties (upper half mean length (UHML), length uniformity index (UI), fiber bundle strength, micronaire and color). The HVI reflectance colorimeter specifically measures the Rd and +b values associated with the cotton color classification because of the historic use of the Nickerson-Hunter reflectance colorimeter (Nickerson et al., 1950).

Despite the fact that the Rd and +b cotton color grading system has been widely adopted and used throughout the US since its inception, this color grading system is too specific to cotton color classification to have substantial meaning for those outside of the cotton or textile industry. The current standards for HVI cotton colorimeters are reference ceramic tiles provided by the USDA-AMS, which are not recognized by the NIST as scientifically appropriate standards (Rogers et al., 2008). Studies have been conducted to determine the feasibility of developing "traceable" cotton color standards (either ceramic tiles) by reporting inter-instrument agreement on a subset of spectrophotometers; while they demonstrated that inter-instrument agreement is possible, the use of glass between the cotton fibers and the machines diminished that

agreement (Rodgers et al., 2006; Shofner et al., 2006). The AMS system is a 2-D color grading system that does not take into consideration the redness or greenness component (Xu et al., 1998b). A more internationally recognized color grading system (XYZ or L*a*b*) for use in cotton color classification or HVI testing has been proposed by several researchers (Xu et al., 1998a; Xu et al., 1998b; Shofner et al., 2006; Rodgers et al., 2006; Rodgers et al., 2008; Rodgers et al., 2010). They suggested that the CIE L*a*b* color system should be used because of its already established usage in several international industries and because of its effectiveness in mathematically representing color as perceived by the human eye.

Three components are essential for the perception of light by a machine or a human eye. First, light, and its spectral energy, is required for color perception. Second, an object is required that in some way modifies the spectral energy. Objects of varying colors will modify the spectral energy in different manners, allowing for the perceptions of these differences. And third, a receptor (either an eye or a photodetector) is necessary to absorb the modified spectral energy and interpret it in a meaningful way (HunterLab, 2008). There exist a variety of color systems that mathematically represent aspects of the color of an object, and these color systems have been improved over time relative to their accuracy at representing color in numerical terms.

Most color systems attempt to address three specific aspects of color measurement: hue, lightness and saturation. Hue is the predominant color as it is perceived such as red, blue, green etc. Lightness or reflectance is how light or how dark the perceived color is, and saturation is a measurement of the color intensity or chroma

(Konica Minolta Sensing, 2007). Chromaticity incorporates both hue and chroma into two coordinates that may be plotted on a 2-D plane. The third variable typically corresponds to the lightness of the object in order to maintain precision in color measurement (Konica Minolta, 1991).

XYZ Color System

The XYZ tristimulus values were defined by the CIE in 1931 using color-matching functions $\bar{X}(\lambda), \bar{Y}(\lambda)$, and $\bar{Z}(\lambda)$. The mathematical formulas for most of the other CIE color systems are derived from the XYZ tristimulus color system (Konica Minolta, 1991). These color-matching functions are the tristimulus values from an equal energy spectrum overlaid as a function of a specific wavelength. The human eye and its perception of colors were the basis for the development of the color-matching functions in order to shift color measurements from a subjective art to a more objective science. Since the XYZ color system is a simple mathematical transformation of the earlier developed CIE RGB color system, the tristimulus variables, X, Y and Z do not have units. These color-matching functions are utilized for a viewing angle of 4° or less (Ohno, 2000). The following formulas are utilized to define the reflected color of an object:

$$X = K \int_{380}^{780} S(\lambda)\bar{X}(\lambda)R(\lambda)d\lambda$$

$$Y = K \int_{380}^{780} S(\lambda)\bar{Y}(\lambda)R(\lambda)d\lambda$$

$$Z = K \int_{380}^{780} S(\lambda)\bar{Z}(\lambda)R(\lambda)d\lambda$$

$$K = \frac{100}{\int_{380}^{780} S(\lambda)\bar{Y}(\lambda)d\lambda}$$

Where,

S(λ) = Relative spectral power distribution of the illuminant

$\bar{X}(\lambda), \bar{Y}(\lambda)$, and $\bar{Z}(\lambda)$ = color-matching functions for CIE 2° Standard Observer

R(λ) = Spectral reflectance of specimen (Konica Minolta Sensing, 2007).

CIE L*a*b* Color System

A number of different color systems were developed to adapt the tristimulus values via non-linear transformations to result in improved perception of colors (Rogers et al., 2008). A chromaticity diagram can be made by transforming the tristimulus XYZ values onto a unit plane, where X+Y+Z = 1 in a 2-D diagram. In this diagram, the color of an object is related as the coordinates (x, y) (Ohno, 2000). Unfortunately, this chromaticity diagram does not depict the color of an object uniformly because equal distances on the chromaticity diagram do not reflect equal differences in the color perceived (Konica Minolta, 1991). The color measurements are somewhat skewed in this non-uniform color system, which can lead to problems in color measurements and data interpretations.

The CIE also has developed several uniform color grading systems that more accurately represent the color perception of the human eye and minimize issues related to the non-uniform color systems. The L*a*b* system, developed by the CIE in 1976, is perhaps one of the most common uniform color systems; it utilizes a 3-D rather than a 2-D coordinate system. In the L*a*b* system, the L* represents lightness (or reflectance), a* represents red/green dimensions and b* represents yellow/blue dimensions. The L* values vary from black (0) to completely white (100), so it can be thought of as a

percentage. A positive a* value indicates a redder color, while a negative a* value indicates a greener color. A positive b* value indicates a yellower color, while a negative b* indicates a bluer color (Konica Minolta, 1991). The L*a*b* values are calculated from corresponding XYZ values of a given object and they are corrected for by the X_n, Y_n and Z_n tristimulus values of white point, which depends upon the illumination setting used during testing (Ohno, 2000). The following formulas are used to calculate the L*a*b* values from the corresponding XYZ values:

$$L^* = 116(\frac{X}{X_n})^{\frac{1}{3}} - 16$$

$$a^* = 500[(\frac{X}{X_n})^{\frac{1}{3}} - (\frac{Y}{Y_n})^{\frac{1}{3}}]$$

$$b^* = 200[(\frac{Y}{Y_n})^{\frac{1}{3}} - (\frac{Z}{Z_n})^{\frac{1}{3}}]$$

Where,

X, Y, and Z = tristimulus values XYZ of the object

X_n, Y_n and Z_n = tristimulus values XYZ of an ideal reflecting diffuser (Rogers et al 2008).

The X_n, Y_n and Z_n values depend upon the type of illumination used to measure the color of the object. North sky daylight or average daylight (C illumination) and average of noon daylight across the world (D65 illumination) are two of the most common illuminations used (HunterLab, 2008). The X_n, Y_n and Z_n values for C and D65 illumination are listed in Table 2.

Table 2. XYZ Tristimulus values for C and D65 illuminations.

Illumination	X_n	Y_n	Z_n
C	98.072	100.00	118.225
D65	95.045	100.00	108.892

Reflectance Spectrophotometer and Reflectance Colorimeter

The two primary methods of obtaining color measurements for opaque or semi-opaque objects (such as cotton fibers) are either a reflectance spectrophotometer or a reflectance colorimeter. A reflectance spectrophotometer typically will use polychromatic illumination (although some use monochromatic illumination) to separate the spectrum of light (between 400 nm and 700 nm) reflected from an object, relative to a predetermined standard (AATCC, 2006). The values for the tristimulus XYZ values and corresponding values in other color systems may be calculated based upon the reflectance values of the object, the spectrum of the illuminant used in the measurement and the observer values (Rodgers et al., 2008). In contrast, a reflectance colorimeter uses broad band filters (usually two or three between 400nm to 700nm) that are specifically designed for use with one illuminant and one observer angle to directly measure the tristimulus XYZ values (AATCC, 2006; Rogers et al., 2008; Rogers et al., 2010). With a colorimeter, it is not inherently possible to obtain reflectance spectrums at specific wavelengths of light, thus limiting the number of color measurements possible. However, the low production costs and portability of reflectance colorimeters make them a logical alternative to reflectance spectrophotometers for very specific color measurements.

Cotton Maturity Measurements

Cotton fiber whiteness depends upon the quantity of the pigments, the fiber diameter, and the wavelengths of light refracted from the cellulose deposition in the cell wall. Cotton fiber maturity is defined as the secondary cell wall development inside an individual cotton fiber relative to the fiber perimeter. Fiber maturity is heavily influenced by environmental conditions such as temperature, moisture, heat or drought stress. Even though fiber maturity is of great importance to the textile industry, as of yet a fast, inexpensive, and reliable indirect or direct measurement of maturity does not exist (Hequet et al., 2006). Immature fibers inherently are weaker than more mature fibers and have a tendency to break during mechanical processing, which increases short fiber content (SFC) and in turn increases negative parameters in yarn quality such as neps (entanglements of immature fibers), thick places, thin places and yarn hairiness (Xu et al., 2009). Immature fibers typically do not have enough cellulose to effectively uptake dye, causing white specks in the fabric produced (Damian and Xu, 2010).

Caustic Soda Swelling Test

Using the caustic soda swelling test to determine fiber maturity, cotton fibers are swollen in 18% caustic soda solution and divided into three groups based upon appearance under a microscope. Normal fibers are those fibers that are nearly solid, with no or an intermittent lumen and possess well-defined convolutions. Dead fibers have a continuous lumen, and a flat, nonconvoluted secondary cell wall thickening with a wall thickness less than one-fifth the fiber ribbon width. Thin-walled fibers are those fibers that do not meet the requirements for the other two groups. This test usually looks

at about 500 fibers and the results are reported in the average percentages of normal (N) and dead (D) fibers. The following equation relates degree of cell wall thickening (θ), with the Normal and Dead fibers:

$\theta = 0.577[\frac{N-D}{200} + 0.70]$ (Pierce and Lord, 1939)

The Maturity Ratio (MR) is [(N-D)/200 + 0.70] and also may be defined as the ratio of fibers with 0.5 (or more) circularity divided by the amount of fibers with 0.25 (or less) circularity. A MR of 1.0 indicates an average degree of secondary cell wall thickening of 0.577.

HVI: Micronaire

Micronaire (Mic) is a single measurement that is a combination of gravimetric fiber fineness and fiber maturity. Mic may be influenced by environmental conditions including sunlight, moisture, temperature and plant population density (2001). As a component of HVI testing, Mic is a relatively inexpensive and quick measurement. For upland cotton, Mic should be between 3.5 and 4.9, with the premium range between 3.7 to 4.2 (Smith and Cothren, 1999). Currently, the textile industry uses Mic to provide an approximation of a combined gravimetric fineness/maturity measurement. Mic is a nondestructive testing method. It determines the relationship between air flow and fiber linear density based upon the theory expounded by Darcy's Law, which was further refined by Kozeny (1927). Kozeny applied these physics theories to textiles by use of the following equation:

$S_0^2 = \left(\frac{1}{K}\right)\left(\frac{A\Delta P}{\mu LQ}\right)\left(\frac{\varepsilon^3}{(1-\varepsilon)^2}\right)$

Where,

S_0 = Specific particle surface in cm^2/cm^3

A = Area of the cross section of the specimen in cm^2

ΔP = Pressure difference across the ends of the specimen in g/cm^2

μ = Air viscosity at 20° C and 65% relative humidity in 10^{-6} poises

L = Length of the specimen in cm

Q = Rate of flow in cm^3/second

K = Constant which depends on the shape and arrangement of fibers, (K_0/ξ)

K_0 = Factor of shapes of section and flow channels

ξ = Constant factor for any arrangement of fibers

ε = porosity or proportion of space unoccupied by material (Hequet et al., 2006)

In essence, Mic is proportional to the inverse of the square of the specific surface of the cotton fibers because nearly every other variable in Kozeny's derived equation is considered to be a constant. Airflow is passed over the cotton sample, and the porosity is used to determine the Mic in the HVI machine (2001). If the cotton fibers are small, then the air flow will be decreased inside the testing chamber, and the fibers will have a lower Mic. On the other hand, if the cotton fibers are large, then the air flow will be increased, and the fibers will have a higher Mic. Lord (1956) was one of the first to establish the relationship between Mic and a product of cotton fiber maturity and fineness, using 100 reference cottons.

In practical terms for cotton breeding purposes, Mic is not a good representation of the complexity associated with the fiber quality trait of gravimetric fineness because it

is strongly impacted by the fiber maturity; Mic fails to distinguish between gravimetric fineness and maturity since the two fiber qualities are confounded (Morton and Wray, 2008; Xu et al., 2009). Hence, it is theoretically possible that two cotton bales can have the same Mic, but have entirely different fiber properties. A fiber sample with finer, more mature fibers could conceivably have the same Mic value as a fiber sample with coarser, immature fibers (Hequet et al., 2006; Abbott et al., 2010). Finer and more mature cotton fibers will produce a finer quality yarn (Abidi et al., 2007).

Image Analysis: Fiber Maturity and Perimeter

Microscopic image analysis of cotton fiber cross-sections provides the most accurate and direct measurement of fiber maturity and perimeter, and is used as the preferred reference method for fiber maturity (Hequet et al, 2006). When Pierce and Lord (1939) conducted research to determine a relationship between fiber maturity, gravimetric fineness and Mic, they established this relationship based upon two methods: measurements of swollen fibers treated with sodium hydroxide and gravimetric fineness determined by fibers that were cut into 1cm segments, weighted and counted.

When using image analysis for cross-sectional fiber maturity measurement, two discrete steps are involved: making the fiber cross-sections and the image analysis. Fiber cross-sectioning procedures must result in usable fiber samples that can be imaged by the appropriate computer software. The fiber cross-sections can be produced by embedding a bundle of parallel fibers in a mixture of hardening solution and polymer resin, such as methacrylate. The bundle of fibers in the methacrylate is then polymerized under ultraviolet (UV) light (Boylston et al., 1993; Boylston et al., 1995). The fiber cross-

sections are cut perpendicular to the longitudinal axis with a diamond knife into 1μm slices. A microscope and appropriate computer imaging software are used to determine the fiber maturity and cell wall perimeter via refracted light (Xu and Huang, 2004). Cross-sectional image analysis is a highly reproducible method of cotton fiber maturity measurement, but it is tedious, slow and expensive (Hequet et al., 2006). Thus, while this method of determining fiber maturity is important as a reference method for validation of other measurement methods, it is impractical to use it on a commercial scale.

AFIS: Maturity and Fineness

Advanced Fiber Information System (AFIS) provides a direct gravimetric method for measurement of cotton fiber fineness in units of mass per unit of length. AFIS measures fiber maturity using optical signals that are interpreted by computer algorithms to determine the size and shape of each individual fiber. It enables the testing of individual fibers in order to obtain more precise and accurate measurements. Despite the advantage of AFIS maturity and fineness to HVI Mic, AFIS is slower and more expensive. AFIS measurements are not feasible on a large industry-wide scale because of the impracticalities associated with its decreased speed and higher cost.

Longitudinal Measurements

In pursuit of a rapid, but accurate measurement of cotton fiber maturity that does not have the confounded problems associated with Mic, Xu et al. (2009) suggested that fiber maturity may be predicted by the fiber ribbon width (RbWth) (fiber convolution) and translucency (secondary cell wall thickness). Cotton fibers twist along their

longitudinal axes and when depicted in a 2-D image, the fiber convolutions will demonstrate large variations in RbWth. The more immature the fiber snippet is, the more variable its cross-section shape is (linear shape, U shape, etc.). It translates into greater variability in RbWth when projected in a 2-D image (Xu et al., 2009).

Fiber Image Analysis System (FIAS) is a microscopic image analysis system that was developed to measure both cross-sectional and longitudinal measurements of cotton fibers snippets (Damian and Xu, 2010). The sample preparation for the FIAS is automated and takes a matter of seconds instead of days for cross-sectional image analysis. Direct and indirect fiber fineness and maturity data may be obtained from the FIAS measurements. Xu et al. (2009) could not accurately predict θ based solely upon RbWth because RbWth is related to both fiber maturity and fiber diameter. Damian and Xu (2010) reported a lack of correlation between cross-sectional fiber maturity values and longitudinal measurements, which they attributed to the differences in preparation methods and the miscounted dead or immature fibers from cross-sectional image analysis. They proposed to either combine RbWth measurements with translucency or Mic values to obtain a better estimate of fiber maturity. However, such a confounded indirect measurement of maturity results in other problems already addressed in this work.

Cottonscope®

The Cottonscope® is a relatively new invention developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia (Rodgers et al., 2012). It uses polarized light to determine cotton fiber maturity on fiber snippets and

uses a computerized system to agitate an aqueous solution containing the snippets in order to assess cotton fiber fineness. While the Cottonscope® is still considered to be a prototype, it potentially will provide more accurate and repeatable measurements of cotton fiber maturity and fineness. A study conducted by Rodgers et al. (2012) determined that the Cottonscope® demonstrated good agreement with image analysis and microscopy methods for fiber fineness and maturity measurements. That information would be of value to cotton breeders as they develop new cultivars with enhanced fiber properties.

The precursor to the Cottonscope® was the Cottonscan™, also developed by the CSIRO. The Cottonscan™ utilized computer algorithms to measure the fiber linear density by directly measuring the total length of a known mass of cotton fiber fragments to extrapolate a mass per unit length (Abbott et al., 2010). In a study conducted by Abbott et al., the Cottonscan™ demonstrated a larger within-sample variation than between-machine effects and the only statistically significant differences between machines were found for extremely coarse cottons. The Cottonscan™ was upgraded to reduce the sample processing time (from 6 minutes to only 1 minute), and these upgrades did not adversely affect the performance (Abbott et al., 2011a; Abbott et al., 2011b; Abbott et al., 2011c). Unlike the Cottonscope®, the Cottonscan™ only measures fiber fineness and not MR, RbWth, and Mic.

The precursor to the Cottonscope® in measurement of cotton fiber maturity was the SiroMat™, also developed by CSIRO. It measures cotton fiber maturity through the use of polarized light microscopy (Long et al., 2010). Polarized light and the resulting

interference colors have been used to determine relative fiber maturity for some time, but this measurement of fiber maturity has been considered to be too subjective because the color assessments were human estimates (Schwarz and Hotte, 1935). The SiroMat™ (and now the Cottonscope®) overcame this subjectivity in testing by introducing a color charged couple device (CCD) camera and computer software with specially designed algorithms to assess the inference colors of the fiber snippets (Long et al., 2010).

General and Specific Combining Abilities

Sprague and Tatum first used general combining ability (GCA) "to designate the average performance of a line in hybrid combinations" and specific combining ability (SCA) "to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved" (1942). More specifically, GCA of a line should be understood as a deviation from the mean of all the mean performances of all of its crosses; thus, it is the average performance of all the F_1s with this specific line as one parent stated as a deviation from the overall average performance of every F_1 (Falconer and Mackay, 1996). The GCA of a given genotype has no practical meaning associated with it unless this genotype is compared in relation to other genotypes and the tester and environment are specified (Henderson, 1952). Unless the genotypes involved in an experiment have been chosen at random, GCA and SCA measurements are relative and solely dependent upon the genotypes involved in a particular mating design, such as a diallel or Line x Tester design (Griffing, 1956; Bartolome and Gregorio, 2003).

The GCA values obtained in an experiment generally reflect the additive variances of the lines involved for the traits of interest, while the SCA values obtained in an experiment generally reflect the dominant variances of the lines involved for the traits of interest (Sprague and Tatum, 1942). A larger GCA value indicates if a particular line is either better or worse than the overall average performance of the combined lines, thus indicating that the genes involved in the quantitative trait of interest are primarily additive in nature. A low SCA value indicates that the hybrid performed as it was expected to perform based upon the average GCA estimates of the two parents. On the other hand, a large SCA value indicates that a hybrid either performed better or worse than expected based upon the average GCA estimates of the two parents, leading to the conclusion that the genes involved in the quantitative trait of interest are primarily dominant or epistatic in nature. Fehr (1991) reported that top-cross tests, also known as Line x Tester designs, generally should be used in preliminary testing of germplasm to gauge the GCAs of the lines, while single-cross tests should be used in later generation testing to more accurately determine SCA estimates of specific superior hybrids.

As general and specific combining abilities are related in terms of a Line x Tester experimental design, their general definitions are as follows: GCA is the average performance of a line in all its hybrid combinations compared to the performance of all hybrids, while SCA is the deviation of the observed hybrid performance from the expected parental performance. The expected parental performance is defined using the GCAs of both parents (the average contribution of both parent 1 and parent 2 to the

hybrid) in addition to the average performance of all hybrids (Falconer and Mackay, 1996; Bartolome and Gregorio, 2003).

Research Objectives

1. Determine degree of whiteness, MR, RbWth, and Mic in the phenotypes of 36 world cultivars collected from 3 continents and their F_1 progenies.
2. Evaluate parents and F_1s in a Line x Tester design to determine general and specific combining abilities for the degree of whiteness, MR, RbWth, and Mic.

CHAPTER II

MATERIALS AND METHODS

The 36 parents used as females (or lines) in this study represent unique upland cotton germplasm pools from different geographic regions of the world. Of the accessions in the US cotton germplasm collection, 12 accessions from China, 7 accessions from west or central Africa, and 10 accessions from south Africa were chosen as representative of the genetic diversity from their specific geographic region. Table 3 lists the cultivars with their respective geographic regions and plant inventory (PI) numbers. All of these cultivars were added to the US cotton germplasm collection between 1953 and 2001. Non-transgenic commercial cultivars developed in the US were also included as representing recent germplasm that are currently under US Plant Variety Protection (PVP), except for Del Cerro an obsolete US cultivar, and as such are not currently available from the US Cotton Germplasm Collection (Hinze et al., 2012). These US commercial upland cultivars were developed after 1990, except Del Cerro.

Table 3. Plant Inventory (PI) numbers and Geographic groupings for 36 upland lines and 2 upland testers.

Genotype	Geographic area	PI number
	Females	
China 632	China	PI451750
Chung Mein-Jue #7	China	PI529467
Duck Shelter	China	PI452101
Jiangsu #3	China	PI452103
Kang Bin Chang Mienne	China	PI433732
Lintsing Sze Tze 4B	China	PI528889
Lishan Big Boll	China	PI452105
Nanging #12	China	PI529483
Pengze	China	PI529486
Shan 5245	China	SA-3203
Small Leaf	China	PI438958
Zhong Mian Suo 9 Hao	China	SA-3207
Allen 333	West Africa	PI392289
Allen 333-61 CB 4027	West Africa	PI529302
BJA 592	West Africa	PI529492
F 280	West Africa	PI529383
Funtua FT-5	West Africa	PI607222
PAN 575	West Africa	PI529385
Reba W 296	West Africa	PI529387
A 7215	South Africa	PI529054
A-637-33	South Africa	PI408999
ALA 70-11	South Africa	PI529332
Albacala 7	South Africa	PI529319
BPA 68 CB 4030	South Africa	PI529305
Komati	South Africa	PI607192
Limpopo	South Africa	PI607199
Marico (Smooth)	South Africa	PI607197
Sabie	South Africa	PI607193
UK 64	South Africa	PI407455
Acala 1517-99	US	PI612326
Del Cerro	US	PI414135
Deltapine 491	US	PI618609
Phytogen 72	US	PI617043
ST 474	US	PI578877
Tamcot 22	US	PI635877
Tejas	US	PI591047
	Males	
TAM B182-33 ELS	US	PI654362
Tamcot CAMD-E	US	PI529633

The two parents used as males, or testers, in this study were TAM B182-33 ELS (Extra long staple) and Tamcot CAMD-E. The US Cotton Germplasm Collection maintains historical records of its various accessions. However, the pedigrees and breeding histories of the parents (from Africa and China) used in this study as females, or lines, are nebulous and incomplete (Hinze et al., 2012). It is assumed that these accessions were derived from pedigree-type breeding programs. The genetic backgrounds of the US cultivars are well-documented and understood. In particular, the genetic backgrounds of the two testers are as follows:

TAM B182-33 ELS: TAM 94L-25/PSC 161 (Smith et al., 2009).
Tamcot CAMD-E: MDR.SP7-67/17M2/ / SP46-67/17M2 (Bird, 1979).

The parents were crossed during the summers of 2009 and 2010 in a Line x Tester mating design as described by Kempthorne (1957). All the parents and F_1 progenies were grown in a randomized complete block design with three replications at the Texas A&M University AgriLife Research Farm near College Station, TX, during the summers of 2010 and 2011. The parents and F_1s were planted on April 27, 2010 and on April 18, 2011, respectively, with skips replanted on May 10, 2011. Plots were a single row, 6.1m x 1.0m. After plant establishment, the plots were thinned to one plant approximately every 10cm. Soil type at Texas A&M University AgriLife Research Farm was a Westwood silt loam, a fine-silty, mixed thermic Fluventic Ustochrept, integraded with Ships clay, a very fine, mixed, thermic Udic Chromustert. Agronomic

practices common to cotton production in the region were utilized such as furrow irrigation and periodic pesticide and herbicide treatments.

Five boll samples per entry per replication were harvested as the bolls matured (defined as sutures cracked naturally or under human hand pressure). First position bolls between the 5^{th} and 10^{th} main stem fruiting branches (middle fruiting zone) were selected preferentially, yet a limited number of second position bolls were harvested as necessary to compensate for missing first position bolls. The bolls were harvested in this manner in order to minimize any environmental influences that could bias the color measurements and to avoid the presence of thrash particles in the lint. The bolls were deburred the night after harvest in limited light. Any bolls that had insect, bacterial or fungal damage (typified by yellowish or greenish tints to the cotton fibers) were discarded and replaced.

The seedcotton was allowed to air dry in limited light for at least 72 hours. The five bolls were combined and ginned on a table-top laboratory saw-gin without lint cleaners. Fibers were separated into 2.00g subsamples. Absolute color measurements were taken on a Konica-Minolta CR-310 reflectance colorimeter in two color systems (XYZ and L*a*b*) using D65 illumination. Each subsample of randomly oriented fibers was placed in a measurement container beneath 5 mm thick glass that applied constant pressure to the subsample. Use of a layer of glass is recommended when measuring cotton color to present a compressed surface to the measuring head (Rogers et al., 2010). Four repetitions of each subsample were measured. Each repetition was taken after a 90° rotation of the colorimeter measuring head. The values obtained from repetitions per

subsample and across subsamples per entry were averaged together before statistical analysis.

Calibration plate readings were taken between every eight experimental subsamples and two calibration cotton samples. Calibration plate readings were taken after ten subsample measurements in the following order: calibration plate, four experimental subsamples, one calibration cotton sample, four experimental subsamples, one calibration cotton sample and another calibration plate reading. The calibration cotton readings were averaged together for each consecutive day of testing to ensure the stability of the CR-310 reflectance colorimeter. The calibration plate readings were used to provide correction to the experimental subsample measurements by use of the following formula: $M - \left(\frac{PrCP+PoCP}{2}\right) - RV$, where

M = measured value of the subsample

PrCP = previous calibration plate reading

PoCP = post calibration plate reading

RV = reference value for calibration plate

Cotton fiber maturity measurements on all parents and F_1s from both consecutive years were taken at the Fiber and Biopolymer Research Institute (FBRI), based in Lubbock, TX, from January 9, 2011 to January 20, 2011 using the Cottonscope®. The cotton samples were allowed to equilibrate to the constant atmospheric conditions of the FBRI (20° C and 65% relative humidity) for a period of 48 hours. A sample of 50.0mg was utilized from each entry from both field years of the experiment. The fibers were cut using a guillotine system developed for the Cottonscan™ (Abbott et al., 2010;

Rodgers et al., 2012) into 2.0mm snippets and immersed in an aqueous solution containing a surfactant and NaCl. Approximately 20,000 snippets per entry were analyzed for MR, RbWth and Mic in the Cottonscope® using polarized light. An average value for each variable was obtained, and each sample was read by the Cottonscope® twice. These two replicates were averaged together to obtain a single data set for each variable. Since the Cottonscope® is a prototype machine, three calibration cottons were read with three repetitions at the start and conclusion of daily testing. The calibration cotton readings were averaged together for each consecutive day of testing to ensure the stability of the Cottonscope®, despite some daily fluctuations for the calibration cottons.

The General Linear models procedure of SAS was used to conduct the analysis of variance (ANOVA) with years, genotypes, lines and testers considered fixed effects (SAS Institute Inc., SAS 9.2, Cary, NC). GCAs for parents and SCAs for their F_1 progenies were obtained for XYZ and L*a*b* color systems and maturity measurements (MR, RbWth and Mic) from the means squares of the ANOVA. GCAs and SCAs were calculated using the formulas as described by Singh and Chaudhary (1979). The GCAs and SCAs were determined to be significant at a 95% confidence interval, if they fell outside of an interval including two times the appropriate standard errors as calculated by the formulas of Singh and Chaudhary (1979). The GCAs and SCAs were determined to be significant at a 99% confidence interval, if they fell outside of an interval including three times the appropriate standard errors.

Because only two testers were used in the experiments reported herein, if there was a significant Line x Tester interaction, then only the SCAs of the F_1 progenies are reported. The GCA values should not be calculated with only one tester represented in a data set, since the value would simply be a SCA. If there was not a significant Line x Tester interaction, then only the GCAs of the lines and testers are reported because the corresponding SCAs would not deviate from the expected F_1 values based upon the GCAs of both parents. GCA and SCA values combined over years give a more appropriate representation of the combining abilities of the different lines and testers as opposed to separating out GCA and SCA values based upon significant year interaction terms.

CHAPTER III

RESULTS AND DISCUSSION

Machinery Stability

Based on findings by Montgomery (1985), the exponentially weighted moving averages for L*, a*, b*, MR, RbWth, and Mic were obtained to document the accuracy of both the reflectance colorimeter and the Cottonscope® during the periods of testing. The exponentially weighted moving averages for L*, a*, b*, MR, RbWth, and Mic for 2010 and 2011 are shown in Figures 2-7. The two separate periods of color testing were combined to validate the overall calibration procedures which occurred between the two testing periods. The Cottonscope® testing for the cotton samples from both years occurred simultaneously, so an overall calibration procedure did not occur. By use of the exponentially weighted moving averages, both large and small drifts in the values of the calibration cottons are revealed. The overall trends in the stability of both the reflectance colorimeter and Cottonscope® confirm the experimental findings discussed herein. The boundary lines (dotted lines) above and below the mean (solid line) in all the figures correspond to three standard deviations away from the mean values. The intervals that encompass three standard deviations from the respective mean for all the variables are narrow (Table 4). These intervals were calculated using the following formula:$[(\mu + 3\sigma) - (\mu - 3\sigma)]$.

The trends of both L* and a* demonstrate some fluctuations among days of testing for the reflectance colorimeter, which may indicate some instability within the

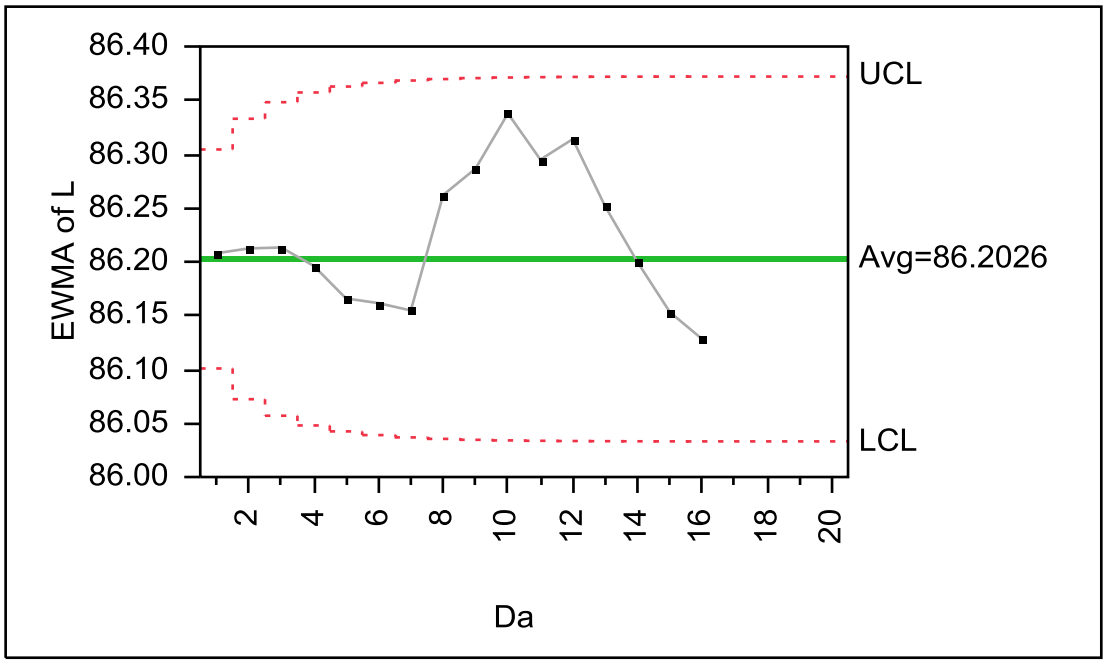

Figure 2. L*, reflectance, exponentially weighted moving averages versus time for standards analyzed on the Konica-Minolta CR-310 reflectance colorimeter.

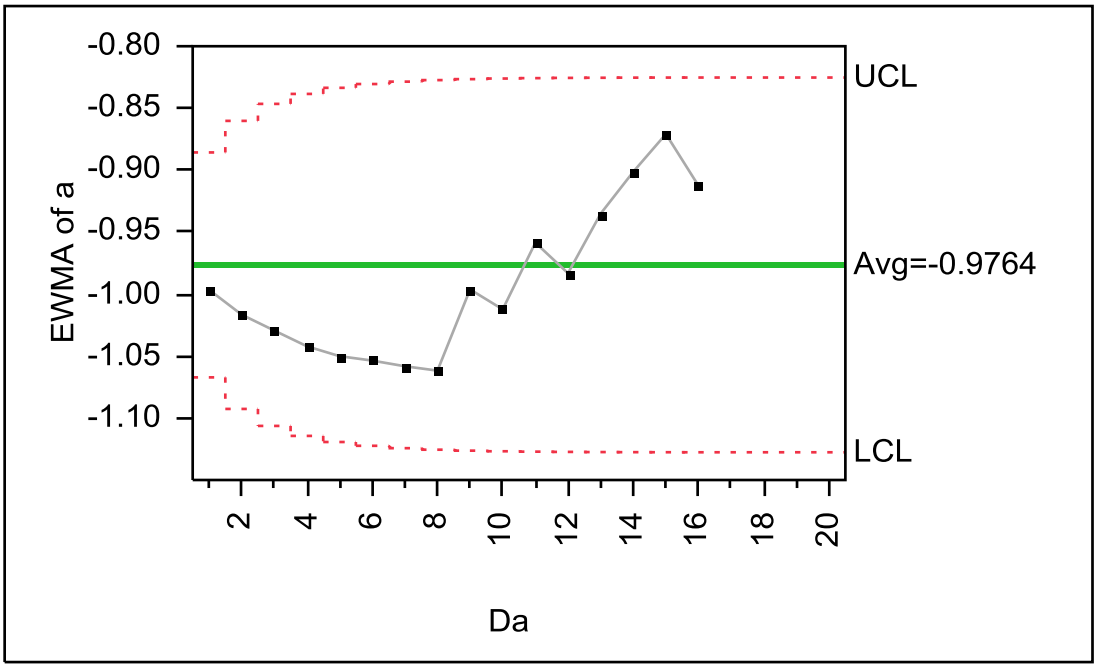

Figure 3. a*, redness/greenness, exponentially weighted moving averages versus time for standards analyzed on the Konica-Minolta CR-310 reflectance colorimeter.

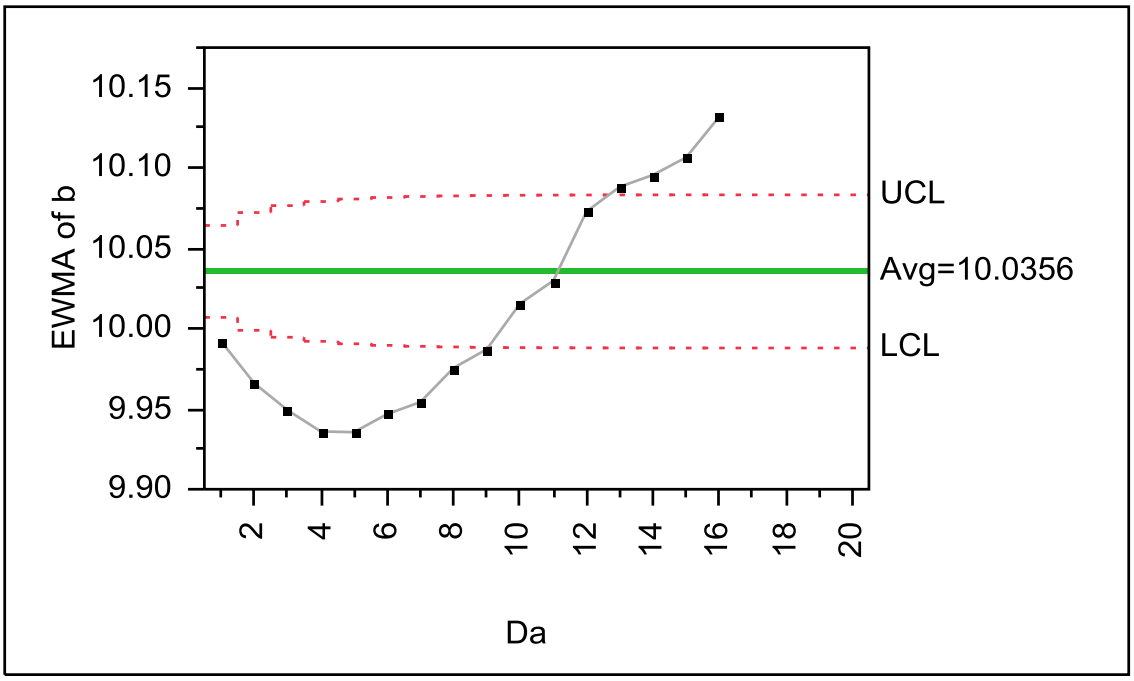

Figure 4. b*, yellowness/blueness, exponentially weighted moving averages versus time for standards analyzed on the Konica-Minolta CR-310 reflectance colorimeter.

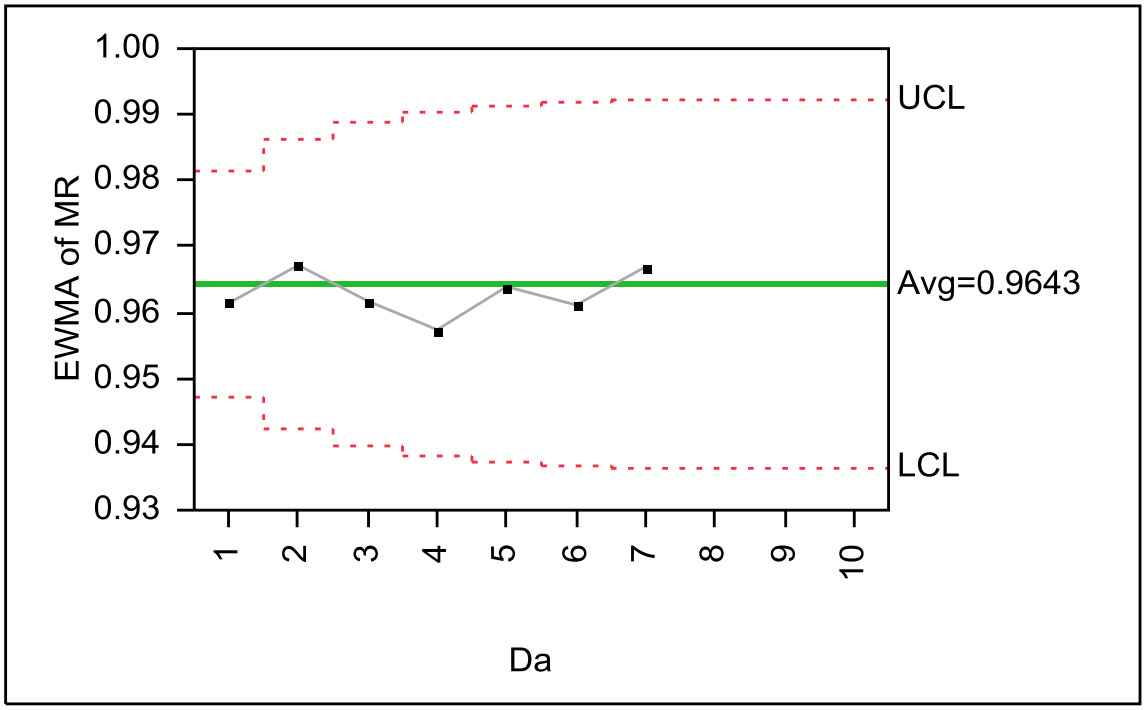

Figure 5. Maturity Ratio (MR) exponentially weighted moving averages versus time for standards analyzed on the Cottonscope®.

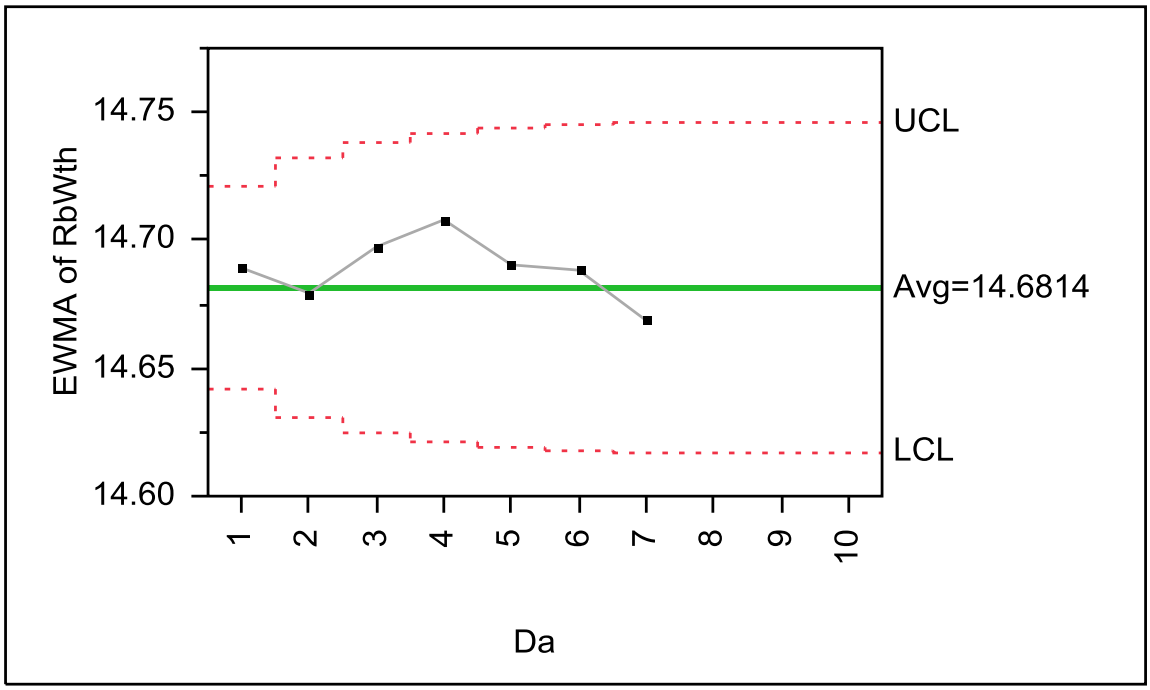

Figure 6. Ribbon-width (RbWth) exponentially weighted moving averages versus time for standards analyzed on the Cottonscope®.

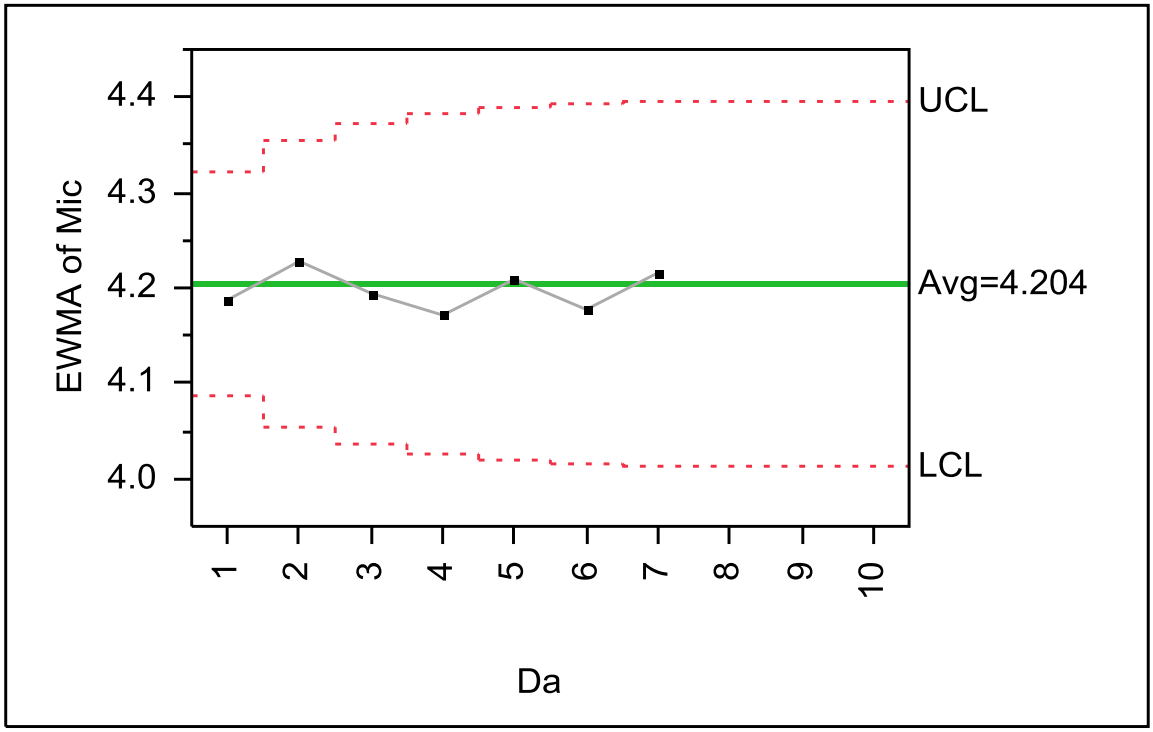

Figure 7. Micronaire (Mic) exponentially weighted moving averages versus time for standards analyzed on the Cottonscope®.

Table 4. Range of Konica-Minolta CR-310 reflectance colorimeter and Cottonscope® measurements for cotton standards.

Trait	Range
L*	1.24
	(σ = 0.21)
a*	0.96
	(σ = 0.16)
b*	0.80
	(σ = 0.13)
MR†	0.13
	(σ = 0.02)
RbWth	0.40
	(σ = 0.07 μm)
Mic	0.96
	(σ = 0.16)

† MR, Maturity Ratio; RbWth, Ribbon Width; Mic, Micronaire.

machine itself, but these fluctuations do not go beyond the bounds of the upper confidence limit (UCL) and lower confidence limit (LCL), making it reasonable to conclude that the colorimeter is consistent in measuring these color values. The trend for b* begins below the LCL at the start of testing in 2010 and ends above the UCL at the end of testing in 2011. It is difficult to definitively explain the reason for this trend in the exponentially weighted moving averages for b*, but perhaps the machine was not entirely stable for this color value. More likely, the calibration cottons may have yellowed in storage between the testing periods from 2010 to 2011 despite precautions taken to ensure the maintenance of the calibration cottons.

In contrast, the trends for MR, RbWth and Mic are extremely stable with minimal fluctuations around the mean lines. These results demonstrate the possibility for the Cottonscope® to be a reliable and efficient means of obtaining fiber maturity and fineness information as demonstrated by Rodgers et al. (2012). Although, as the Cottonscope® is simply a prototype, further calibration and standardization may be required before it has the potential to accurately measure fiber maturity and fineness without the increased preparation time and cost associated with AFIS testing.

XYZ Color System

The data sets for the tristimulus X, Y and Z values all failed to meet the underlying assumptions of homogeneity and normality for ANOVA. Therefore a data transformation (to the x^6) was applied to the data sets for X, Y and Z. These transformations resulted in nonsignificant p-values for the Bartlett and Shapiro-Wilks tests of homogeneity and normality.

All genotypes differed significantly ($p < 0.001$) for the tristimulus X, Y and Z values (Table 5). Specifically, the Parents, F_1s, and Parents vs. F_1s significantly differed ($p < 0.001$) for the X, Y and Z values. The ANOVA table did not reveal any significant genotype x year interactions, except for F_1s x year ($p < 0.05$) for tristimulus values X and Y as well as line x year ($p < 0.05$) for all the X, Y and Z values. The results were combined from both years for further analysis, but also the means were separated out by year based on the significant year interaction terms. For all three variables, the line x tester interaction was significant ($p < 0.05$), indicating that the 36 lines combined differently with the 2 testers in both years. Therefore, only the SCAs of the F_1s are

appropriate for discussion, since it would be duplicative to report also GCAs for the lines for each tester.

For both X and Y tristimulus values, line and tester were significant at $p < 0.05$. Yet for the Z values, line and tester were significant at $p < 0.01$ and $p < 0.05$, respectively. These significant values may be attributed to using the line x tester interaction term as an error term for line and tester, as described by Singh and Chaudhary (1979), which has fewer degrees of freedom. An error term with fewer degrees of freedom decreases the power to detect statistical differences among lines and testers. Due to the significance of genotype, parents, parents vs. F_1s and F_1s, it is logical to conclude that there is genetic variation for X, Y and Z among the 36 lines and 2 testers used in this experiment.

Table 5. Mean squares for tristimulus XYZ values for 38 world upland cultivars and their F_1 progeny grown under irrigated field culture near College Station, TX in 2010 and 2011.

Source	df	X	Y	Z
Year	1	199.7913	233.726	1761.1015 *
[Rep(Year)]†	4	105.7142	209.647	115.6400
Genotype	109	94.8260 ***	199.819 ***	136.5066 ***
Parents	37	137.3446 ***	291.157 ***	202.2335 ***
Parents vs F_1s	1	671.4745 ***	1341.892 ***	1015.4936 ***
F_1s	71	64.5466 ***	136.135 ***	89.8745 ***
Line	35	80.2717 *	169.631*	126.4068 **
Tester	1	272.7402 *	633.647 *	327.5176 *
[Line*Tester]	35	42.8731 *	88.424 *	46.5524 *
Genotype*Year	109	30.9806	62.979	33.5286
Parent*Year	37	23.7535	48.756	28.3914
Parent vs F_1s*Year	1	23.8869	47.107	48.2519
F_1s*Year	71	34.8468 *	70.614 *	35.9983
Line*Year	35	40.5422 *	81.489 *	43.1519 *
Tester*Year	1	19.7215	40.189	14.4381
Line*Tester*Year	35	29.5836	60.609	29.4608
Error	436	26.1246	52.862	27.7024

*, **, *** significant at $P < 0.05$, 0.01, and 0.001, respectively.
† Brackets indicate an error term.

Since there was a significant Line x Year interaction term for the X values, the means of lines were reported separately by year, while the tester X values were combined over years (Table 6). A 7215 (South Africa) had the numerically highest X mean as compared to all the cultivars in both 2010 and 2011. In 2010, A 7215 differed significantly compared to the eight other South African cultivars and was not different than A-637-33 (South Africa) ($p < 0.05$). Tejas (US) exhibited the highest X average of the US cultivars and, was significantly different than two other US cultivars. PAN 575 (West Africa) was statistically equal to or higher than three other West African cultivars. Among the Chinese cultivars, Lintsing Sze Tze 4B exhibited a numerically high X color value that was not different than eight other Chinese cultivars ($p < 0.05$). None of the cultivars from China, South Africa, West Africa or the US that had the numerically highest X color values for their respective region were different from one another ($p < 0.05$).

In 2011, A 7215 (South Africa) had a numerically high X value that was equal to or higher than five other South African cultivars ($p < 0.05$) (Table 6). Del Cerro (US) had the highest X mean of the US cultivars, and it differed significantly than Deltapine 491. F 280 (West Africa) had the numerically highest X value of the West African cultivars, differing significantly from two other West African cultivars. Nanging #12 of the Chinese cultivars exhibited a numerically high X value and, it was not significantly different than three other Chinese cultivars in 2011. All of the cultivars from China, South Africa, West Africa or the US that had the numerically highest X color values for their respective regions, in 2011, were not different from one another ($p < 0.05$).

Table 6. Average tristimulus X color values of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

		Year	
Lines	Region	2010	2011
A 7215	South Africa	63.07 a†	62.96 a
Tejas	US	62.83 ab	62.27 a-h
PAN 575	West Africa	62.76 a-c	62.77 ab
Lintsing Sze Tze 4B	China	62.46 a-d	61.21 i-l
A-637-33	South Africa	62.37 a-e	62.68 a-c
Del Cerro	US	62.34 a-e	62.40 a-f
Tamcot 22	US	62.31 a-e	61.68 d-l
F 280	West Africa	62.25 a-f	62.99 a
China 632	China	62.18 a-f	62.10 a-i
Acala 1517-99	US	62.13 a-f	62.29 a-h
Sabie	South Africa	62.05 b-g	62.02 b-i
Zhong Mian Suo 9 Hao	China	62.04 b-g	60.76 l
Chung Mein-Jue #7	China	61.99 b-g	62.27 a-h
Reba W 296	West Africa	61.93 b-g	61.98 b-j
Marico (Smooth)	South Africa	61.91 b-g	62.52 a-d
Jiangsu #3	China	61.83 b-h	60.97 k-l
Shan 5245	China	61.81 b-h	61.40 g-l
Phytogen 72	US	61.80 b-h	61.45 f-l
BPA 68 CB 4030	South Africa	61.78 c-h	62.08 b-i
Allen 333	West Africa	61.76 c-h	61.82 c-k
ST 474	US	61.64 d-h	61.73 d-l
UK 64	South Africa	61.55 d-h	61.35 h-l
Small Leaf	China	61.49 d-h	60.93 kl
Lishan Big Boll	China	61.46 d-h	62.36 a-f
Funtua FT-5	West Africa	61.43 d-h	62.32 a-g
Albacala 7	South Africa	61.43 d-h	62.49 a-e
Deltapine 491	US	61.42 d-h	61.01 j-l
Nanging #12	China	61.40 d-h	62.83 ab
BJA 592	West Africa	61.37 d-h	62.31 a-g
Komati	South Africa	61.37 d-h	62.39 a-f
ALA 70-11	South Africa	61.28 e-h	60.91 kl
Kang Bin Chang Mienne	China	61.25 f-h	61.24 i-l
Limpopo	South Africa	61.17 f-h	62.26 a-h
Pengze	China	61.17 f-h	61.75 c-l
Allen 333-61 CB 4027	West Africa	61.02 gh	62.33 a-g
Duck Shelter	China	60.63 h	61.55 e-l
Tester			
Tamcot CAMD-E	US	62.03 a	
TAM B182-33 ELS	US	61.73 b	

† Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD

The genetic variability that exists for enhanced X color values is not limited to a particular geographic region. Instead, this variability exists in specific cultivars unique to each region.

The two testers differed from each other for X as well ($p < 0.05$). The difference between Tamcot CAMD-E and TAM B182-33 ELS was only 0.30 units, so this difference, although significant, may not be of biological importance.

There was a significant F_1 x year interaction term for the X values, so the means of the F_1s were separated by year (Table 7). PAN 575 (West Africa), A 7215 (South Africa) crossed with TAM B182-33 ELS and Tamcot 22 crossed with Tamcot CAMD-E resulted in the highest X values among hybrid means for 2010. In 2011, A 7215 and Nanging #12 (China) crossed with Tamcot CAMD-E exhibited the numerically highest X values among all the hybrid combinations.

Table 7. Average tristimulus X color values of F_1s of 36 upland lines and 2 upland testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	TAM B182-33 ELS		Tamcot CAMDE	
		Year		Year	
		2010	2011	2010	2011
PAN 575	West Africa	63.93 a†	63.03 a-d	61.60 c-n	62.51 b-m
A 7215	South Africa	63.29 ab	61.73 d-w	62.86 a-d	64.18 a
Tejas	US	62.92 a-c	62.40 b-n	62.74 a-e	62.14 b-t
A-637-33	South Africa	62.69 a-f	62.91 b-e	62.05 a-n	62.45 b-n
Lintsing Sze Tze 4B	China	62.68 a-g	61.26 i-w	62.23 b-k	61.15 l-w
Acala 1517-99	US	62.66 a-g	62.03 d-e	61.60 c-n	62.56 b-l
Del Cerro	US	62.56 a-h	62.61 b-i	62.12 b-m	62.19b-t
Sabie	South Africa	62.41 b-i	61.94 d-v	61.68 c-n	62.11 c-t
China 632	China	62.19 b-k	61.71 d-w	62.16 b-l	62.49 b-m
Funtua FT-5	West Africa	62.10 b-n	62.29 b-q	60.77 k-o	62.34 b-p
Zhong Mian Suo 9 Hao	China	61.99 b-n	60.33 w	62.08 b-m	61.20 k-w
BPA 68 CB 4030	South Africa	61.94 b-n	61.91 d-v	61.63 c-n	62.24 b-s
ST 474	US	61.91 b-n	60.89 r-w	61.37 d-n	62.57 b-k
UK 64	South Africa	61.89 b-n	60.81 t-w	61.20 f-n	61.89 d-v
Phytogen 72	US	61.78 c-n	61.24 j-w	61.83 c-n	61.67 e-w
Jiangsu #3	China	61.72 c-n	60.88 r-w	61.93 b-n	61.05 m-w
Shan 5245	China	61.63 c-n	61.71 e-w	61.99 b-n	61.10 n-w
Allen 333	West Africa	61.60 c-n	61.38 h-w	61.93 b-n	62.25 b-r
F 280	West Africa	61.54 c-n	62.68 b-h	62.96 a-c	63.31 a-c
BJA 592	West Africa	61.50 c-n	62.72 b-g	61.24 e-n	61.89 d-v
Marico (Smooth)	South Africa	61.46 c-n	62.14 b-t	62.37 b-j	62.90 b-d
Deltapine 491	US	61.45 c-n	61.32 i-w	61.38 d-n	60.70 u-w
Pengze	China	61.43 d-n	61.83 d-v	60.90 i-o	61.67 e-w
Chung Mein-Jue #7	China	61.34 e-n	61.86 d-v	62.64 a-h	62.67 b-g
Tamcot 22	US	61.34 d-n	61.81 d-v	63.29 ab	61.56 g-w
Limpopo	South Africa	61.29 e-n	62.41 b-o	61.05 i-o	62.12 c-u
Reba W 296	West Africa	61.20 f-n	62.27 b-r	62.66 a-g	61.68 e-w
Kang Bin Chang Mienne	China	61.18 f-n	60.92 q-w	61.33 e-n	61.56 f-w
Komati	South Africa	61.17 f-n	62.09 c-u	61.56 c-n	62.69 b-h
Small Leaf	China	61.13 h-n	60.84 s-w	61.84 c-n	61.03 p-w
Allen 333-61 CB 4027	West Africa	60.90 i-o	61.75 d-w	61.14 g-n	62.90 b-e
Lishan Big Boll	China	60.82 j-o	61.87 d-v	62.10 b-m	62.85 b-f
Nanging #12	China	60.59 m-o	62.26 b-r	62.22 b-k	63.41 ab
Albacala 7	South Africa	60.47 l-o	62.39 b-n	62.40 b-j	62.58 b-j
ALA 70-11	South Africa	60.46 n-o	60.56 vw	62.10 b-m	61.26 j-w
Duck Shelter	China	59.33 o	61.00 p-w	61.94 b-n	62.10 c-u

† Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

Table 8. Average tristimulus Y color values of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

		Year	
Lines	Region	2010	2011
A 7215	South Africa	66.67 a†	66.56 a
Tejas	US	66.47 ab	65.77 a-g
PAN 575	West Africa	66.38 a-c	66.36 ab
A-637-33	South Africa	65.99 a-d	66.26 a-c
Lintsing Sze Tze 4B	China	65.95 a-e	64.58 h-k
Del Cerro	US	65.93 a-e	65.92 a-f
Tamcot 22	US	65.87 a-e	65.13 d-k
F 280	West Africa	65.81 a-f	66.57 a
Acala 1517-99	US	65.72 a-g	65.80 a-g
China 632	China	65.68 a-g	65.57 b-h
Sabie	South Africa	65.59 a-h	65.49 b-h
Zhong Mian Suo 9 Hao	China	65.57 b-h	64.13 k
Chung Mein-Jue #7	China	65.51 b-h	65.76 a-g
Marico (Smooth)	South Africa	65.48 b-h	66.07 a-d
Reba W 296	West Africa	65.47 b-h	65.44 b-i
Phytogen 72	US	65.32 d-i	64.88 f-k
Allen 333	West Africa	65.30 c-i	65.28 c-j
BPA 68 CB 4030	South Africa	65.30 c-i	65.56 b-h
Jiangsu #3	China	65.30 d-i	64.32 i-k
Shan 5245	China	65.30 d-i	64.81 g-k
ST 474	US	65.15 d-i	65.20 d-k
UK 64	South Africa	65.04 d-i	64.78 g-k
Lishan Big Boll	China	64.95 d-i	65.85 a-f
Albacala 7	South Africa	64.94 d-i	66.01 a-e
Small Leaf	China	64.94 d-i	64.32 jk
Deltapine 491	US	64.91 d-i	64.40 i-k
Funtua FT-5	West Africa	64.90 d-i	65.84 a-g
BJA 592	West Africa	64.89 d-i	65.85 a-f
Komati	South Africa	64.89 d-i	65.94 a-f
Nanging #12	China	64.88 d-i	66.36 ab
ALA 70-11	South Africa	64.80 e-i	64.28 jk
Kang Bin Chang Mienne	China	64.67 f-i	64.66 h-k
Pengze	China	64.64 g-i	65.20 d-k
Limpopo	South Africa	64.63 g-i	65.78 a-g
Allen 333-61 CB 4027	West Africa	64.46 hi	65.82 a-g
Duck Shelter	China	64.08 i	65.01 e-k
Tester			
Tamcot CAMD-E	US	65.55 a	
TAM B182-33 ELS	US	65.20 b	

† Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

Lines did not respond the same across years for Y as indicated by a significant Line x Year interaction, so Line means are reported separately for each year (Table 8). A 7215 (South Africa) had the numerically highest Y color value during 2010, and it differed significantly from seven other South African cultivars. Tejas (US) had the highest mean for Y among the US cultivars included in this study during 2010, which was equal to or higher than three other US cultivars ($p < 0.05$). PAN 575 (West Africa) had the numerically highest mean among the West African cultivars during 2010, which was significantly higher than three of the remaining six West African cultivars. Lintsing Sze Tze 4B (China) had the highest Y color value of the Chinese cultivars during 2010, and it was equal to or higher than eight other Chinese cultivars ($p < 0.05$). None of the cultivars that exhibited the numerically highest Y values for their respective regions differed significantly from one another in 2010.

In 2011, A 7215 (South Africa), once again, had the highest Y mean of the South African cultivars, which was equal to or higher than five other South African cultivars ($p < 0.05$) (Table 8). Del Cerro (US) had the highest mean of the US cultivars in 2011, and differed significantly from Deltapine 491 ($p < 0.05$). F 280 (West Africa) exhibited the highest average value for Y among the West African cultivars, differing significantly than two of the remaining West African cultivars. Nanging #12 (China) had the highest mean for Y of the Chinese cultivars in 2011. Nanging #12 also significantly differed from eight other Chinese cultivars. In 2011, none of the cultivars that had the highest Y color values for their respective regions differed significantly from one another. As with the tristimulus X color value, the genetic variability for the Y color value is not superior

in several cutlivars from any particular region. Instead, the genetics for improved Y color values can be found in a few cultivars from each region.

The testers differed significantly for Y also, although more similar in absolute values than some of the lines (Table 8). The difference between Tamcot CAMD-E and TAM B182-33 ELS is only 0.35, which is probably not of any significant biological importance.

A significant F_1 x Year interaction was found for the Y color value, so the F_1 means must be reported separately by year (Table 9). In 2010, PAN 575 (West Africa)/TAM B182-33 ELS, Tamcot 22 (US)/Tamcot CAMD-E and A 7215 (South Africa)/TAM B182-33 ELS had the highest means for Y as compared with all other hybrids. In constrast, A7215 (South Africa)/Tamcot CAMD-E, Nanging #12 (China)/Tamcot CAMD-E and F 280 (West Africa)/Tamcot CAMD-E had the highest means for Y as compared to the other hybrid combinations in 2011. It may be possible to develop cultivars with enhanced Y color values from some of these specific hybrid combinations.

Table 9. Average tristimulus Y color values of F_1s of 36 upland lines and 2 upland testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	TAM B182-33 ELS		Tamcot CAMDE	
		Year		Year	
		2010	2011	2010	2011
PAN 575	West Africa	67.62 a†	66.63 b-d	65.14 c-n	66.08 b-k
A 7215	South Africa	66.91 ab	65.20 e-u	66.43 a-e	67.92 a
Tejas	US	66.55 a-d	65.91 b-n	66.39 a-f	65.63 b-r
A-637-33	South Africa	66.33 a-g	66.51 b-e	65.66 b-m	66.01 b-l
Acala 1517-99	US	66.28 a-g	65.52 d-s	65.17 c-n	66.08 b-k
Lintsing Sze Tze 4B	China	66.21 a-i	64.63 j-u	65.69 b-l	64.53 k-u
Del Cerro	US	66.14 a-i	66.13 b-i	65.71 b-l	65.70 b-r
Sabie	South Africa	65.99 b-j	65.37 d-t	65.19 c-n	65.61 b-s
China 632	China	65.70 b-k	65.14 e-u	65.67 b-l	66.01 b-l
Funtua FT-5	West Africa	65.60 b-n	65.81 b-o	64.21 k-o	65.87 b-o
Zhong Mian Suo 9 Hao	China	65.51 b-n	63.65 u	65.62 b-n	64.62 j-u
BPA 68 CB 4030	South Africa	65.44 b-n	65.35 d-t	65.16 c-n	65.76 b-p
ST 474	US	65.42 c-n	64.28 p-u	64.88 e-n	66.12 b-j
UK 64	South Africa	65.41 c-n	64.17 r-u	64.66 h-n	65.38 d-t
Phytogen 72	US	65.28 c-n	64.64 j-u	65.36 c-n	65.13 e-u
Jiangsu #3	China	65.19 c-n	64.20 q-u	65.41 b-n	64.44 l-u
Allen 333	West Africa	65.10 c-n	64.79 h-u	65.51 b-n	65.76 b-p
Shan 5245	China	65.10 c-n	65.14 e-u	65.50 b-n	64.47 m-u
F 280	West Africa	65.01 d-n	66.21 b-h	66.61 a-c	66.93 a-c
BJA 592	West Africa	64.99 d-n	66.31 b-g	64.80 e-n	65.38 d-t
Marico (Smooth)	South Africa	64.98 d-n	65.65 b-r	65.99 b-j	66.50 b-e
Deltapine 491	US	64.94 e-n	64.74 i-u	64.89 e-n	64.07 s-u
Pengze	China	64.90 e-n	65.27 d-t	64.37 j-o	65.13 e-u
Chung Mein-Jue #7	China	64.82 f-n	65.32 d-t	66.20 a-i	66.19 b-i
Tamcot 22	US	64.81 f-n	65.25 d-u	66.94 ab	65.02 g-u
Limpopo	South Africa	64.78 g-n	65.98 b-m	64.48 j-o	65.59 c-s
Reba W 296	West Africa	64.67 h-n	65.75 b-p	66.27 a-h	65.12 e-u
Komati	South Africa	64.66 h-n	65.58 c-s	65.11 c-n	66.29 b-g
Kang Bin Chang Mienne	China	64.61 i-n	64.29 p-u	64.74 g-n	65.03 f-u
Small Leaf	China	64.54 j-o	64.19 q-u	65.33 c-n	64.45 n-u
Allen 333-61 CB 4027	West Africa	64.28 k-o	65.16 e-u	64.65 h-n	66.48 b-f
Lishan Big Boll	China	64.24 k-o	65.31 d-t	65.65 b-l	66.38 b-g
Nanging #12	China	63.95 1-o	65.72 b-q	65.81 b-k	66.99 ab
Albacala 7	South Africa	63.93 m-o	65.90 b-n	65.96 b-j	66.12 b-j
ALA 70-11	South Africa	63.93 m-o	63.90 tu	65.66 b-l	64.66 j-u
Duck Shelter	China	62.66 o	64.38 o-u	65.50 b-n	65.64 b-r

† Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

The Line x Year interaction for the Z color value was significant, so the line means were reported here separately by year (Table 10). In 2010, A 7215 (South Africa) had the numerically highest mean for Z as compared to the other South African cultivars, and it differed significantly than eight of the other South African cultivars. Tejas (US) had the highest mean for Z in relation to the US cultivars, and it was equal to or higher than two other US cultivars ($p < 0.05$). PAN 575 (West Africa) had the highest mean as compared to the other West African cultivars, which differed significantly than four other West African cultivars. Lintsing Sze Tze 4B (China) had the highest mean in 2010 of the Chinese cultivars, differing significantly than five other Chinese cultivars. In 2010, none of the cultivars that exhibited numerically higher Z color values for their respective regions were significantly different from each other.

In 2011, A 7215 (South Africa), once again, had the numerically highest mean for Z color value, and it differed significantly from five other South African cultivars (Table 10). Del Cerro (US) had the highest mean of the US cultivars, which differed significantly from Deltapine 491. F 280 (West Africa) had the highest mean as compared to the other West African cultivars, and it differed significantly than three other West African cultivars. Nanging #12 (China) had the numerically highest Z color value of the Chinese cultivars, and it was equal to or higher than three other Chinese cultivars ($p < 0.05$). In 2011, A 7215 differed from Del Cerro ($p < 0.05$), suggesting that the cultivars from the US have slightly inferior Z color values as opposed to South Africa.

Table 10. Average tristimulus Z color values of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

		Year	
Lines	Region	2010	2011
A 7215	South Africa	61.82 a†	62.07 a
Tejas	US	61.37 ab	60.97 b-g
A-637-33	South Africa	61.36 a-c	61.68 a-c
PAN 575	West Africa	61.35 a-d	61.66 a-c
Lintsing Sze Tze 4B	China	60.91 a-e	59.77 g-k
Tamcot 22	US	60.72 a-e	60.42 d-j
Del Cerro	US	60.69 a-e	61.07 b-f
BPA 68 CB 4030	South Africa	60.53 b-f	61.08 b-f
F 280	West Africa	60.51 b-f	61.88 ab
Marico (Smooth)	South Africa	60.51 b-f	61.60 a-c
Chung Mein-Jue #7	China	60.32 b-g	61.13 a-d
Acala 1517-99	US	60.19 c-h	60.87 b-h
Sabie	South Africa	60.19 c-h	60.69 c-i
Reba W 296	West Africa	60.19 c-h	60.64 c-i
China 632	China	60.13 e-h	60.59 c-i
Allen 333	West Africa	60.01 e-i	60.31 d-k
Shan 5245	China	60.01 e-i	59.95 f-k
Zhong Mian Suo 9 Hao	China	60.00 e-i	59.13 k
Albacala 7	South Africa	59.84 e-i	61.54 a-c
Lishan Big Boll	China	59.80 e-i	60.84 b-h
BJA 592	West Africa	59.79 e-i	61.08 a-e
UK 64	South Africa	59.74 e-i	59.98 d-k
Phytogen 72	US	59.70 e-i	60.10 d-k
ST 474	US	59.66 e-i	60.24 d-k
Jiangsu #3	China	59.65 e-i	59.23 jk
Deltapine 491	US	59.63 e-i	59.51 i-k
ALA 70-11	South Africa	59.42 f-i	59.22 jk
Funtua FT-5	West Africa	59.36 f-i	61.04 b-f
Limpopo	South Africa	59.33 f-i	61.08 b-f
Komati	South Africa	59.27 f-i	61.09 a-f
Small Leaf	China	59.23 g-i	59.26 jk
Pengze	China	59.22 g-i	60.38 d-k
Nanging #12	China	59.17 g-i	61.57 a-c
Kang Bin Chang Mienne	China	59.04 g-i	59.78 h-k
Duck Shelter	China	58.85 h-i	59.96 e-k
Allen 333-61 CB 4027	West Africa	58.81 i	60.69 c-h
Tester			
Tamcot CAMD-E	US	60.50 a	
TAM B182-33 ELS	US	60.12 b	

† Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

Table 11. Average tristimulus Z color values of F_1s of 36 upland lines and 2 upland testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	TAM B182-33 ELS	Tamcot CAMDE
PAN 575	West Africa	62.39 ab†	60.62 e-q
A-637-33	South Africa	61.88 a-d	61.16 c-j
Tejas	US	61.43 b-f	60.91 c-n
A 7215	South Africa	61.38 b-g	62.51 a
Del Cerro	US	61.00 c-l	60.75 e-p
BPA 68 CB 4030	South Africa	60.78 d-p	60.83 c-o
Acala 1517-99	US	60.65 e-q	60.41 e-t
BJA 592	West Africa	60.63 e-q	60.24 h-t
Marico (Smooth)	South Africa	60.59 e-q	61.52 a-e
Funtua FT-5	West Africa	60.57 e-s	59.84 m-v
Sabie	South Africa	60.52 e-s	60.36 f-t
F 280	West Africa	60.51 e-s	61.88 a-c
Lintsing Sze Tze 4B	China	60.50 e-s	60.18 h-u
Limpopo	South Africa	60.45 e-t	59.96 j-v
Albacala 7	South Africa	60.25 f-t	61.12 c-j
Reba W 296	West Africa	60.24 h-t	60.59 e-r
Chung Mein-Jue #7	China	60.14 h-u	61.30 c-h
Shan 5245	China	60.09 j-v	59.87 l-v
Tamcot 22	US	60.06 i-v	61.09 c-k
China 632	China	60.02 i-v	60.71 e-q
Pengze	China	59.99 j-v	59.61 o-v
Komati	South Africa	59.88 k-v	60.47 e-s
Deltapine 491	US	59.78 m-v	59.36 r-w
Allen 333	West Africa	59.74 n-v	60.58 e-r
UK 64	South Africa	59.68 o-v	60.04 j-v
Phytogen 72	US	59.67 o-v	60.12 i-u
Lishan Big Boll	China	59.67 o-v	60.97 c-m
ST 474	US	59.63 p-w	60.27 g-t
Nanging #12	China	59.55 p-w	61.19 c-i
Zhong Mian Suo 9 Hao	China	59.31 s-w	59.81 m-v
Jiangsu #3	China	59.24 t-w	59.64 o-v
Allen 333-61 CB 4027	West Africa	59.23 t-w	60.27 f-t
Kang Bin Chang Mienne	China	59.01 u-w	59.82 m-v
Small Leaf	China	58.97 u-w	59.53 q-w
ALA 70-11	South Africa	58.78 vw	59.85 m-v
Duck Shelter	China	58.26 w	60.55 e-r

† Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

The two testers differed significantly for the Z color value from both combined years (Table 10). The difference between Tamcot CAMD-E and TAM B182-33 ELS was only 0.37, which probably does not have a significant impact from a biological standpoint.

F_1s responded the same in both years, so the corresponding Z means were combined across years (Table 11). A 7215 (South Africa)/Tamcot CAMD-E resulted in the numerically highest Z mean as compared to all other hybrid combinations during the two years of this experiment. PAN575 (West Africa)/TAM B182-33 ELS also had a higher Z color value compared to most of the other hybrid combinations. For the most part, the Tamcot CAMD-E hybrids resulted in improved Z color values than the hybrids produced with TAM B182-33 ELS.

Combining Ability Estimates for XYZ Color System

For X, most of the SCA estimates were not significantly different from zero, indicating that most of the lines in combination with the two testers did not sufficiently enhance or diminish the X color value in the progeny (Table 12). However, the specific combination of PAN 575 (West Africa) with TAM B182-33 ELS exhibited a significant and positive SCA of 0.861. This result suggests that specific combinations of parents could be found that produce progeny with enhanced X color values and tentatively whiter fibers. Conversely, PAN 575 (West Africa) with Tamcot CAMD-E resulted in a significant and negative SCA of -0.861.

Table 12. Tristimulus X color value estimates of specific combining ability (SCA) effects of 36 upland lines and 2 testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Line	Geographic Area	TAM B182-33 ELS	Tamcot CAMD-E
China 632	China	-0.040	0.040
Chung Mein-Jue #7	China	-0.378	0.378
Duck Shelter	China	-0.779	0.779
Jiangsu #3	China	0.054	-0.054
Kang Bin Chang Mienne	China	-0.047	0.047
Lintsing Sze Tze 4B	China	0.291	-0.291
Lishan Big Boll	China	-0.416	0.416
Nanging #12	China	-0.545	0.545
Pengze	China	0.320	-0.320
Shan 5245	China	0.214	-0.214
Small Leaf	China	-0.076	0.076
Zhong Mian Suo 9 Hao	China	-0.091	0.091
Allen 333	West Africa	-0.150	0.150
Allen 333-61 CB 4027	West Africa	-0.198	0.198
BJA 592	West Africa	0.421	-0.421
F 280	West Africa	-0.361	0.361
Funtua FT-5	West Africa	0.468	-0.468
PAN 575	West Africa	0.861*	-0.861*
Reba W 296	West Africa	-0.068	0.068
A 7215	South Africa	-0.355	0.355
A-637-33	South Africa	0.426	-0.426
ALA 70-11	South Africa	-0.433	0.433
Albacala 7	South Africa	-0.380	0.380
BPA 68 CB 4030	South Africa	0.146	-0.146
Komati	South Africa	-0.097	0.097
Limpopo	South Africa	0.283	-0.283
Marico (Smooth)	South Africa	-0.268	0.268
Sabie	South Africa	0.290	-0.290
UK 64	South Africa	0.053	-0.053
Acala 1517-99	US	0.284	-0.284
Del Cerro	US	0.365	-0.365
Deltapine 491	US	0.324	-0.324
Phytogen 72	US	0.033	-0.033
ST 474	US	-0.136	0.136
Tamcot 22	US	-0.274	0.274
Tejas	US	0.260	-0.260
	Std. error	0.393	0.393

* Significant at 95% confidence interval (2xStd. error).

As with X, most of the SCA estimates for Y were not significantly different from zero (Table 13). Two lines, Duck Shelter (China) and PAN 575 (West Africa) resulted in significant SCA values. Duck Shelter combined positively with Tamcot CAMD-E and negatively with TAM B182-33 ELS with SCA values for Y of 0.852 and -0.852, respectively. The specific combinations of PAN 575/ TAM B182-33 ELS exhibited a positive and significant SCA of 0.931, suggesting that this combination would produce progeny from which selections could be made for improved Y color values. Conversely, PAN 575 /Tamcot CAMD-E exhibited a negative and significant SCA of -0.931, and this hybrid combination would potentially produce progeny with fibers that have inferior Y values.

A similar trend was observed for the combining ability estimates of the Z color value (Table 14). Most of the SCA estimates were not significantly different from zero, with the exceptions of Duck Shelter and PAN 575. Duck Shelter combined positively with Tamcot CAMD-E and negatively with TAM B182-33 ELS with SCA values of 0.957 and -0.957, respectively. PAN 575 combined positively with TAM B182-33 ELS and combined negatively with Tamcot CAMD-E with SCA values of 1.074 and -1.074, respectively. These SCA values suggest that Duck Shelter combined with Tamcot CAMD-E could enhance the tristimulus Y and Z color values in their F_1 progenies. On the other hand, these results indicate that PAN 575 when combined with TAM B182-33 ELS will improve all the tristimulus values (X, Y and Z) in their F_1 progenies.

Table 13. Tristimulus Y color value estimates of specific combining ability (SCA) effects of 36 upland lines and 2 testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Line	Geographic Area	TAM B182-33 ELS	Tamcot CAMD-E
China 632	China	-0.039	0.039
Chung Mein-Jue #7	China	-0.391	0.391
Duck Shelter	China	-0.852*	0.852*
Jiangsu #3	China	0.058	-0.058
Kang Bin Chang Mienne	China	-0.044	0.044
Lintsing Sze Tze 4B	China	0.326	-0.326
Lishan Big Boll	China	-0.449	0.449
Nanging #12	China	-0.607	0.607
Pengze	China	0.342	-0.342
Shan 5245	China	0.240	-0.240
Small Leaf	China	-0.090	0.090
Zhong Mian Suo 9 Hao	China	-0.098	0.098
Allen 333	West Africa	-0.171	0.171
Allen 333-61 CB 4027	West Africa	-0.248	0.248
BJA 592	West Africa	0.455	-0.455
F 280	West Africa	-0.405	0.405
Funtua FT-5	West Africa	0.506	-0.506
PAN 575	West Africa	0.931*	-0.931*
Reba W 296	West Africa	-0.066	0.066
A 7215	South Africa	-0.388	0.388
A-637-33	South Africa	0.467	-0.467
ALA 70-11	South Africa	-0.452	0.452
Albacala 7	South Africa	-0.391	0.391
BPA 68 CB 4030	South Africa	0.142	-0.142
Komati	South Africa	-0.116	0.116
Limpopo	South Africa	0.345	-0.345
Marico (Smooth)	South Africa	-0.289	0.289
Sabie	South Africa	0.313	-0.313
UK 64	South Africa	0.059	-0.059
Acala 1517-99	US	0.310	-0.310
Del Cerro	US	0.387	-0.387
Deltapine 491	US	0.352	-0.352
Phytogen 72	US	0.031	-0.031
ST 474	US	-0.152	0.152
Tamcot 22	US	-0.302	0.302
Tejas	US	0.283	-0.283
	Std. error	0.424	0.424

* Significant at 95% confidence interval (2xStd. error).

Table 14. Tristimulus Z color value estimates of specific combining ability (SCA) effects of 36 upland lines and 2 testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Line	Geographic Area	TAM B182-33 ELS	Tamcot CAMD-E
China 632	China	-0.157	0.157
Chung Mein-Jue #7	China	-0.393	0.393
Duck Shelter	China	-0.957*	0.957*
Jiangsu #3	China	-0.014	0.014
Kang Bin Chang Mienne	China	-0.218	0.218
Lintsing Sze Tze 4B	China	0.345	-0.345
Lishan Big Boll	China	-0.464	0.464
Nanging #12	China	-0.630	0.630
Pengze	China	0.374	-0.374
Shan 5245	China	0.295	-0.295
Small Leaf	China	-0.094	0.094
Zhong Mian Suo 9 Hao	China	-0.064	0.064
Allen 333	West Africa	-0.232	0.232
Allen 333-61 CB 4027	West Africa	-0.334	0.334
BJA 592	West Africa	0.383	-0.383
F 280	West Africa	-0.501	0.501
Funtua FT-5	West Africa	0.550	-0.550
PAN 575	West Africa	1.074*	-1.074*
Reba W 296	West Africa	0.013	-0.013
A 7215	South Africa	-0.378	0.378
A-637-33	South Africa	0.547	-0.547
ALA 70-11	South Africa	-0.348	0.348
Albacala 7	South Africa	-0.249	0.249
BPA 68 CB 4030	South Africa	0.165	-0.165
Komati	South Africa	-0.108	0.108
Limpopo	South Africa	0.433	-0.432
Marico (Smooth)	South Africa	-0.276	0.276
Sabie	South Africa	0.271	-0.271
UK 64	South Africa	0.003	-0.003
Acala 1517-99	US	0.306	-0.306
Del Cerro	US	0.309	-0.309
Deltapine 491	US	0.397	-0.396
Phytogen 72	US	-0.037	0.037
ST 474	US	-0.133	0.133
Tamcot 22	US	-0.327	0.327
Tejas	US	0.450	-0.450
	Std. error	0.461	0.461

* Significant at 95% confidence interval (2xStd. error).

L*a*b* Color System

The L* and b* data sets failed to meet the underlying assumptions of homogeneity and normality for ANOVA. A data transformation (arc sine for L* and inverse for b*) was applied to both data sets. Arc sine is the most appropriate data transformation for L*, since reflectance is measured as a percentage. While these transformations did not result in significant p-values for both the Bartlett and Shapiro-Wilks tests for homogeneity and normality, they resulted in higher p-values than any other transformations attempted (square root, 2^{nd} power, and logarithmic transformations). The a* data set met the underlying assumptions of homogeneity and normality for ANOVA, resulting in non-significant p-values for both the Bartlett and Shapiro-Wilks tests.

All genotypes differed significantly ($p < 0.001$) for the L*, a* and b* values (Table 15). Specifically, the Parent, F_1, and Parents vs. F_1s sources of variation were all significant at $p < 0.001$ for the L*, a* and b* values (except Parents vs. F_1s for a* that differed by $p < 0.05$). The ANOVA table did not reveal any significant Genotype x Year interactions, except for Line x Year for L* and Parents vs F_1s x Year ($p < 0.05$) for b*. The results from both years were combined for further analysis, but separation of line means by year for L* was necessary because of the significant Line x Year interaction term. The Line x Tester interaction term was significant ($p < 0.05$) for L*, but was not significant for both a* and b*. Therefore, the SCAs of the F_1s will be discussed for L*, since the 36 lines combined differently with the 2 testers for both years of the field

experiment. The GCAs of the lines and testers for a* and b* will be discussed, since the lines combined similarly with both testers over both years of the field experiment.

Lines varied ($p < 0.05$) for L*, and lines also varied for a* and b* ($p < 0.001$) (Table 15). The two testers were significantly different for both L* and a*, $p < 0.01$ and $p < 0.001$, respectively, but not for b*. Due to the significance of Parents, Parents vs. F_1s and F_1s, it is logical to conclude that there is genetic variation for L*, a* and b* among the 36 lines and 2 testers used in this experiment. This genetic variation could be sufficient for breeders to select for whiter fibers using this color identification system. For L* most of the variation within this parental set was found in the testers, while for b* most of the variation was in the lines relative to the testers. For the a* value both the lines and testers seem to demonstrate equal amounts of variation based on significance levels revealed by the ANOVA.

Table 15. Mean squares for CIE (International Commission on Illumination) L*a*b* values for 38 world upland cultivars and their F_1 progeny grown under irrigated field culture near College Station, TX in 2010 and 2011.

Source	df	L*	a*	b*
Year	1	0.4747	1.6474 **	4.9529 ***
[Rep(Year)]†	4	0.3667	0.0528	0.0415
Genotype	109	0.3689 ***	0.0671 ***	0.0561 ***
Parents	37	0.5425 ***	0.1160 ***	0.0893 ***
Parents vs F_1s	1	2.7711 ***	0.0654 *	0.3838 ***
F_1s	71	0.2445 ***	0.0416 ***	0.0342 ***
Line	35	0.3026 *	0.0546 ***	0.0605 ***
Tester	1	1.2055 **	0.5047 ***	0.0130
[Line*Tester]	35	0.1590 *	0.0154	0.0085
Genotype*Year	109	0.1186	0.0130	0.0087
Parent*Year	37	0.0971	0.0156	0.0085
Parent vs F_1s*Year	1	0.0990	0.0001	0.0487 *
F_1s*Year	71	0.1301	0.0118	0.0083
Line*Year	35	0.1543 *	0.0132	0.0121
Tester*Year	1	0.0559	0.0031	0.0020
Line*Tester*Year	35	0.1080	0.0108	0.0046
Error	436	0.1002	0.0121	0.0090

*, **, *** significant at $P < 0.05$, 0.01, and 0.001, respectively.
† Brackets indicate an error term.

Table 16. Average CIE† L*, reflectance, of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

		Year	
Lines	Region	2010	2011
A 7215	South Africa	85.33 a‡	85.27 a
Tejas	US	85.23 ab	84.87 a-f
PAN 575	West Africa	85.18 ab	85.17 ab
A-637-33	South Africa	84.99 a-c	85.12 a-c
Lintsing Sze Tze 4B	China	84.97 a-d	84.26 g-j
Del Cerro	US	84.95 a-d	84.95 a-e
Tamcot 22	US	84.92 a-d	84.55 d-j
F 280	West Africa	84.89 a-e	85.29 a
Acala 1517-99	US	84.84 a-f	84.89 a-f
China 632	China	84.83 a-f	84.77 a-g
Sabie	South Africa	84.78 a-g	84.73 b-g
Zhong Mian Suo 9 Hao	China	84.77 a-g	84.03 j
Chung Mein-Jue #7	China	84.74 a-g	84.87 a-f
Marico (Smooth)	South Africa	84.72 b-g	85.03 a-d
Reba W 296	West Africa	84.72 b-g	84.71 b-h
Phytogen 72	US	84.64 b-g	84.42 e-j
BPA 68 CB 4030	South Africa	84.64 b-g	84.77 a-g
Allen 333	West Africa	84.64 b-g	84.62 c-i
Jiangsu #3	China	84.63 b-g	84.13 i-j
Shan 5245	China	84.63 b-g	84.37 f-j
ST 474	US	84.55 c-h	84.58 d-j
UK 64	South Africa	84.50 c-h	84.36 f-j
Lishan Big Boll	China	84.45 c-h	84.91 a-e
Small Leaf	China	84.45 c-h	84.13 i-j
Albacala 7	South Africa	84.44 c-h	84.99 a-d
Deltapine 491	US	84.43 c-h	84.17 h-j
Funtua FT-5	West Africa	84.43 c-h	84.91 a-f
BJA 592	West Africa	84.42 c-h	84.91 a-e
Komati	South Africa	84.42 c-h	84.95 a-e
Nanging #12	China	84.42 c-h	85.18 ab
ALA 70-11	South Africa	84.37 d-h	84.11 i-j
Kang Bin Chang Mienne	China	84.31 e-h	84.30 g-j
Pengze	China	84.29 e-h	84.58 d-i
Limpopo	South Africa	84.29 f-h	84.88 a-f
Allen 333-61 CB 4027	West Africa	84.20 gh	84.90 a-f
Duck Shelter	China	83.99 h	84.49 d-j
Tester			
Tamcot CAMD-E	US		84.76 a
TAM B182-33 ELS	US		84.58 b

† CIE, International Commission on Illumination.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

There was a significant Line x Year interaction for L* in this experiment, so the means were reported separately by year (Table 16). A higher L* value indicates a brighter reflectance for the specific cultivar, but the L* value cannot exceed 100. In 2010, A 7215 (South Africa) had the highest mean value for L* among the cultivars from South African, and it differed significantly from seven of the ten South African cultivars included in this study. Tejas (US) had the numerically highest mean for L* of the US cultivars and differed significantly from two of the seven US cultivars. PAN 575 (West Africa) had the highest mean for L* in relation to the West African cultivars, and it was equal to or higher than three of the West African cultivars ($p < 0.05$). Lintsing Sze Tze 4B had the highest mean for L* of the Chinese cultivars, differing from three of the Chinese cultivars ($p < 0.05$). The cultivars that exhibited the highest L* value among the cultivars of their respective regions did not significantly differ from one another in 2010.

In 2011, A 7215, once again, had the numerically highest value for L* among the South African cultivars, higher ($p < 0.05$) than three of the remaining South African cultivars (Table 16). Del Cerro (US) had the highest mean for L* of the US cultivars, and it differed significantly from Deltapine 491. F 280 (West Africa) had the highest mean for L* of the West African cultivars, and it was equal to or higher than four of the other West African cultivars ($p < 0.05$). Nanging #12 (China) had the highest mean for L* of the Chinese cultivars in 2011, differing from eight of the Chinese cultivars ($p < 0.05$). Similar to the trend in 2010, in 2011 none of the cultivars that exhibited the

highest L* values from their respective regions were significantly different from each other.

The two testers significantly differed from each other for L* although the difference appears to be small, less than 0.2 (Table 16). This difference may not be biologically meaningful.

There was no significant F_1 x Year interaction for L*, so the means were combined across both years of the experiment (Table 17). A 7215 (South Africa)/Tamcot CAMD-E and PAN 575 (West Africa)/TAM B182-33 ELS demonstrated the two highest hybrid combination means for L* as compared to all the other hybrid combinations. These results indicate that progeny with improved L* (reflectance) may be selected from these two hybrid combinations.

Table 17. Average CIE† L*, reflectance, of F_1s of 36 upland lines and 2 upland testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	TAM B182-33 ELS	Tamcot CAMDE
PAN 575	West Africa	85.56 ab‡	84.79 d-q
A-637-33	South Africa	85.21 a-d	84.91 c-o
Tejas	US	85.11 a-f	85.00 c-k
Del Cerro	US	85.06 a-h	84.84 c-p
A 7215	South Africa	85.01 b-i	85.58 a
Acala 1517-99	US	84.94 c-m	84.79 d-q
Funtua FT-5	West Africa	84.84 c-p	84.50 h-t
Sabie	South Africa	84.83 c-q	84.68 d-t
BJA 592	West Africa	84.81 d-q	84.52 g-t
F 280	West Africa	84.79 d-q	85.38 a-c
China 632	China	84.69 d-t	84.91 c-n
Lintsing Sze Tze 4B	China	84.69 d-t	84.53 g-t
BPA 68 CB 4030	South Africa	84.69 d-t	84.72 d-t
Limpopo	South Africa	84.67 d-t	84.50 h-t
Marico (Smooth)	South Africa	84.64 d-t	85.11 a-e
Reba W 296	West Africa	84.59 e-t	84.84 c-q
Shan 5245	China	84.54 g-t	84.47 i-u
Komati	South Africa	84.54 f-t	84.84 c-p
Pengze	China	84.53 g-t	84.35 n-u
Chung Mein-Jue #7	China	84.52 h-t	85.09 a-g
Tamcot 22	US	84.49 i-u	84.98 c-l
Phytogen 72	US	84.45 i-u	84.60 e-t
Allen 333	West Africa	84.45 i-u	84.80 d-q
Albacala 7	South Africa	84.42 k-u	85.01 b-j
ST 474	US	84.40 m-u	84.73 d-s
Nanging #12	China	84.40 m-u	85.20 a-d
Deltapine 491	US	84.39 m-u	84.21 r-v
UK 64	South Africa	84.37 m-u	84.49 i-u
Lishan Big Boll	China	84.36 n-u	85.00 b-k
Allen 333-61 CB 4027	West Africa	84.33 o-u	84.76 d-r
Jiangsu #3	China	84.32 p-u	84.44 j-u
Zhong Mian Suo 9 Hao	China	84.26 q-v	84.54 e-t
Kang Bin Chang Mienne	China	84.19 s-v	84.42 l-u
Small Leaf	China	84.15 t-v	84.42 l-u
ALA 70-11	South Africa	83.92 uv	84.57 e-t
Duck Shelter	China	83.71 v	84.77 d-r

† CIE, International Commission on Illumination.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

Table 18. Average CIE† a*, redness/greenness, of 38 upland parental genotypes and their F_1s grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	Parent Mean	TAM B182-33 ELS	Tamcot CAMDE
Lintsing Sze Tze 4B	China	-0.48 a‡	-0.49 a-d	-0.48 a-c
Jiangsu #3	China	-0.49 ab	-0.46 ab	-0.52 a-g
Kang Bin Chang Mienne	China	-0.51 a-c	-0.49 a-e	-0.53 a-i
Small Leaf	China	-0.52 a-d	-0.46 ab	-0.57 b-q
Shan 5245	China	-0.52 a-e	-0.52 a-g	-0.53 d-h
China 632	China	-0.57 a-f	-0.54 a-i	-0.60 c-s
Zhong Mian Suo 9 Hao	China	-0.57 b-f	-0.53 a-i	-0.61 e-u
Allen 333-61 CB 4027	West Africa	-0.57 b-f	-0.45 a	-0.69 q-z
UK 64	South Africa	-0.58 c-f	-0.55 a-l	-0.61 d-u
Deltapine 491	US	-0.58 c-f	-0.57 a-p	-0.59 c-r
Pengze	China	-0.58 c-f	-0.56 a-n	-0.61 d-u
Phytogen 72	US	-0.59 c-f	-0.54 a-j	-0.63 g-u
ALA 70-11	South Africa	-0.59 c-f	-0.57 a-p	-0.62 g-u
Lishan Big Boll	China	-0.59 c-f	-0.54 a-i	-0.65 h-x
Nanging #12	China	-0.60 d-g	-0.50 a-f	-0.70 r-z
Chung Mein-Jue #7	China	-0.60 d-h	-0.59 c-r	-0.62 g-u
Funtua FT-5	West Africa	-0.61 e-i	-0.60 d-t	-0.61 f-u
Reba W 296	West Africa	-0.61 f-j	-0.59 c-r	-0.63 g-v
Limpopo	South Africa	-0.61 f-k	-0.68 n-z	-0.55 a-k
Sabie	South Africa	-0.61 f-k	-0.59 c-r	-0.63 g-v
ST 474	US	-0.61 f-k	-0.56 a-o	-0.66 k-z
Tamcot 22	US	-0.61 f-k	-0.55 a-m	-0.68 n-z
BPA 68 CB 4030	South Africa	-0.62 f-k	-0.56 a-n	-0.68 n-z
Duck Shelter	China	-0.62 f-k	-0.52 a-g	-0.72 t-z
Allen 333	West Africa	-0.63 f-k	-0.57 a-p	-0.69 q-z
Albacala 7	South Africa	-0.65 f-l	-0.64 g-w	-0.66 j-z
Del Cerro	US	-0.68 g-m	-0.65 i-y	-0.71 s-z
F 280	West Africa	-0.68 h-m	-0.60 d-s	-0.77 z
Tejas	US	-0.68 h-m	-0.67 l-z	-0.70 r-z
Acala 1517-99	US	-0.69 i-m	-0.68 o-z	-0.70 r-z
Komati	South Africa	-0.69 j-m	-0.63 g-v	-0.75 w-z
A 7215	South Africa	-0.69 j-m	-0.63 g-v	-0.76 w-z
BJA 592	West Africa	-0.69 k-m	-0.68 p-z	-0.71 r-z
Marico (Smooth)	South Africa	-0.72 lm	-0.67 m-z	-0.76 x-z
PAN 575	West Africa	-0.74 m	-0.75 v-z	-0.73 u-z
A-637-33	South Africa	-0.76 m	-0.77 yz	-0.76 w-z
Tester				
TAM B182-33 ELS	US	-0.58 a		
Tamcot CAMD-E	US	-0.65 b		

† CIE, International Commission on Illumination.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

No significant year interaction terms for a* existed, so all of the means for the lines, testers and F_1s were combined over the two years of the experiment (Table 18). All of the means for lines, testers and F_1s were negative, indicating that the cottons had a distinctive greenness. UK 64 (South Africa) had the mean for a* closest to zero of the South African cultivars, and it was equal to or higher than five other South African cultivars ($p < 0.05$). Deltapine 491 (US) had the mean for a* closest to zero of the US cultivars, and it differed significantly from three of the US cultivars. Allen 333-61 CB 4027 (West Africa) had the mean closest to zero for a* in relation to the other West African cultivars, differing significantly than three other West African cultivars. Lintsing Sze Tze 4B (China) had the mean closest to zero for a* as compared to the other Chinese cultivars, and it differed significantly from six of the other Chinese cultivars. Lintsing Sze Tze 4B was significantly different than the other three cultivars that had the a* means closest to zero for their respective geographic regions.

Some cultivars such as A 7215 (South Africa), Tejas (US), PAN 575 (West Africa) and A-637-33 (South Africa) demonstrate higher means for L* and b*, but exhibit lower means for a*. So these lines have improved reflectance and whiteness as related to yellowness/blueness, but have decreased whiteness as related to redness/greenness. Most of the Chinese cultivars had a* means closer to zero, while several African cultivars had more negative a* values, indicating greener cottons. Perhaps it would be beneficial to use some of these Chinese cultivars to breed for enhanced a*. In particular, Lintsing Sze Tze 4B (China) is always found within the top third of the means for L*, a* and b*.

The two testers differed for a*, but that difference is only 0.07, which is probably not biologically important. The superior hybrid combinations for a* are Allen 333-61 CB 4027 (West Africa)/TAM B182-33 ELS, Jiangsu #3 (China)/TAM B182-33 ELS and Small Leaf (China)/TAM B182-33 ELS because they were closest to a white color. It may be possible to select progeny with enhanced whiteness on the redness/greenness scale from some of these specific combinations although it would be difficult to maximize a* without adversely affecting L* and b*.

There were no significant year interaction terms for b*, so all of the means were reported herein as combined across two years of the experiment (Table 19). A lower b* value is preferred because it is closer to a value of zero, which is completely white in relation to yellowness/blueness. A-637-33 (South Africa) had the lowest mean for b* of the South African cultivars, and it differed significantly from five of the other South African cultivars. Tejas (US) had the lowest mean for b* as compared to the other US cultivars and, it was equal to or lower than one other US cultivar ($p < 0.05$). PAN 575 (West Africa) had the lowest mean for b* of the West African cultivars, differing significantly than three other West African cultivars. Chung Mein-Jue #7 (China) had the lowest mean for b* from the Chinese cultivars, and it differed from seven of the other Chinese cultivars ($p < 0.05$). A-637-33 (South Africa) differed significantly as compared to the other three cultivars that had the lowest b* means for their respective geographic regions. The two testers did not significantly differ from each other for b*.

Table 19. Average CIE† b*, yellowness/blueness, of 38 upland parental genotypes and their F_1s grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	Parent Mean	TAM B182-33 ELS	Tamcot CAMDE
A-637-33	South Africa	8.93 a‡	8.86 a	8.99 a-e
BPA 68 CB 4030	South Africa	8.96 ab	8.95 ab	8.97 ab
A 7215	South Africa	8.98 ab	8.99 a-d	8.97 a-c
Marico (Smooth)	South Africa	9.04 a-c	9.05 a-h	9.03 a-g
Albacala 7	South Africa	9.11 a-d	9.01 a-f	9.22 b-l
PAN 575	West Africa	9.16 b-e	9.02 a-g	9.29 f-p
Chung Mein-Jue #7	China	9.22 c-f	9.24 b-m	9.19 b-j
Tejas	US	9.24 c-g	9.10 a-i	9.38 i-r
Tamcot 22	US	9.24 c-h	9.28 e-o	9.19 b-k
Lintsing Sze Tze 4B	China	9.24 d-i	9.23 b-m	9.25 c-m
BJA 592	West Africa	9.24 d-i	9.31 g-o	9.17 b-j
F 280	West Africa	9.28 d-j	9.39 i-s	9.17 b-j
Limpopo	South Africa	9.30 d-k	9.23 b-l	9.37 i-r
Del Cerro	US	9.34 e-l	9.41 j-s	9.26 c-m
Reba W 296	West Africa	9.34 e-l	9.29 d-n	9.39 j-s
UK 64	South Africa	9.36 e-m	9.42 j-t	9.29 f-p
Lishan Big Boll	China	9.37 f-m	9.41 j-t	9.33 h-o
Shan 5245	China	9.38 f-m	9.34 h-q	9.42 j-t
Sabie	South Africa	9.39 f-m	9.43 j-t	9.34 i-q
Deltapine 491	US	9.40 f-m	9.37 i-r	9.43 j-t
Pengze	China	9.42 f-m	9.40 j-s	9.44 j-t
Allen 333	West Africa	9.42 g-m	9.50 l-u	9.35 i-r
Duck Shelter	China	9.45 i-n	9.59 o-u	9.32 h-o
Funtua FT-5	West Africa	9.46 h-n	9.42 j-t	9.49 k-u
Phytogen 72	US	9.49 j-n	9.57 n-u	9.42 j-s
Acala 1517-99	US	9.50 k-n	9.51 l-u	9.49 k-u
ST 474	US	9.50 k-n	9.51 l-u	9.50 l-u
Komati	South Africa	9.52 k-n	9.53 m-u	9.51 k-u
ALA 70-11	South Africa	9.52 k-n	9.46 j-u	9.59 q-u
Nanging #12	China	9.53 l-n	9.58 n-u	9.47 j-u
China 632	China	9.54 l-n	9.66 r-u	9.41 j-s
Kang Bin Chang Mienne	China	9.56 l-n	9.73 ut	9.38 i-r
Zhong Mian Suo 9 Hao	China	9.58 mn	9.56 n-u	9.59 n-u
Jiangsu #3	China	9.66 n	9.74 ut	9.58 n-u
Allen 333-61 CB 4027	West Africa	9.66 n	9.77 u	9.56 n-u
Small Leaf	China	9.67 n	9.69 s-u	9.64 q-u
Tester				
Tamcot CAMD-E	US	9.34 a		
TAM B182-33 ELS	US	9.38 a		

† CIE, International Commission on Illumination.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

A-637-33 (South Africa)/TAM B182-33 ELS and BPA 68 CB 4030 crossed with both testers resulted in the lowest mean values for b* as compared to the other hybrid combinations. Following with the trend revealed in a*, several of the African cultivars demonstrated superior means for b*, while many of the Chinese cultivars demonstrated inferior means for b*. It seems that it is difficult to maintain superior means for L* and b*, while enhancing a* in progeny. Perhaps hybrid combinations between the Chinese cultivars superior for a* and the African cultivars superior for L* and b* would result in progeny that could be selected for enhanced L*, a* and b* to maximize fiber whiteness.

From these data, it would seem that the use of the CIE L*a*b* color system would be more helpful for cotton breeding purposes as opposed to the tristimulus XYZ color system. The CIE L*a*b* system revealed the trend that as L* and b* improve, a* worsens, which is important information when trying to breed cultivars that maximize these three aspects of cotton whiteness. The tristimulus XYZ color system did not reveal such a trend. Despite the clear genetic variation that exists between the lines and testers for all the values associated with cotton whiteness, there does not seem to be enough variation to warrant the economic burdens of a cotton breeding program devoted entirely to fiber whiteness. If a less time-consuming method of phenotyping the cultivars according to one of these color systems could be found, then perhaps, a breeding program for fiber whiteness would be economically viable.

Table 20. CIE† L*, reflectance, estimates of specific combining ability (SCA) effects of 36 upland lines and 2 testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Line	Geographic Area	TAM B182-33 ELS	Tamcot CAMD-E
China 632	China	-0.021	0.021
Chung Mein-Jue #7	China	-0.200	0.200
Duck Shelter	China	-0.442*	0.442*
Jiangsu #3	China	0.032	-0.032
Kang Bin Chang Mienne	China	-0.024	0.024
Lintsing Sze Tze 4B	China	0.167	-0.167
Lishan Big Boll	China	-0.230	0.230
Nanging #12	China	-0.310	0.310
Pengze	China	0.178	-0.178
Shan 5245	China	0.124	-0.124
Small Leaf	China	-0.046	0.046
Zhong Mian Suo 9 Hao	China	-0.051	0.051
Allen 333	West Africa	-0.086	0.086
Allen 333-61 CB 4027	West Africa	-0.126	0.126
BJA 592	West Africa	0.235	-0.235
F 280	West Africa	-0.206	0.206
Funtua FT-5	West Africa	0.261	-0.261
PAN 575	West Africa	0.474*	-0.474*
Reba W 296	West Africa	-0.032	0.032
A 7215	South Africa	-0.196	0.196
A-637-33	South Africa	0.239	-0.239
ALA 70-11	South Africa	-0.236	0.236
Albacala 7	South Africa	-0.205	0.205
BPA 68 CB 4030	South Africa	0.074	-0.074
Komati	South Africa	-0.060	0.060
Limpopo	South Africa	0.178	-0.177
Marico (Smooth)	South Africa	-0.147	0.147
Sabie	South Africa	0.162	-0.162
UK 64	South Africa	0.029	-0.029
Acala 1517-99	US	0.162	-0.162
Del Cerro	US	0.196	-0.196
Deltapine 491	US	0.182	-0.182
Phytogen 72	US	0.014	-0.014
ST 474	US	-0.078	0.078
Tamcot 22	US	-0.156	0.156
Tejas	US	0.145	-0.145
	Std. error	0.219	0.219

* Significant at 95% confidence interval (2xStd. error).

† CIE, International Commission on Illumination.

Table 21. CIE† a*, redness/greenness, estimates of general combining ability (GCA) effects of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Geographic area	GCA
China 632	China	0.049
Chung Mein-Jue #7	China	0.014
Duck Shelter	China	-0.003
Jiangsu #3	China	0.124**
Kang Bin Chang Mienne	China	0.104**
Lintsing Sze Tze 4B	China	0.133**
Lishan Big Boll	China	0.023
Nanging #12	China	0.018
Pengze	China	0.033
Shan 5245	China	0.092*
Small Leaf	China	0.096**
Zhong Mian Suo 9 Hao	China	0.044
Allen 333	West Africa	-0.013
Allen 333-61 CB 4027	West Africa	0.044
BJA 592	West Africa	-0.079*
F 280	West Africa	-0.068*
Funtua FT-5	West Africa	0.010
PAN 575	West Africa	-0.122**
Reba W 296	West Africa	0.006
A 7215	South Africa	-0.078*
A-637-33	South Africa	-0.146**
ALA 70-11	South Africa	0.023
Albacala 7	South Africa	-0.032
BPA 68 CB 4030	South Africa	-0.001
Komati	South Africa	-0.076*
Limpopo	South Africa	0.004
Marico (Smooth)	South Africa	-0.103**
Sabie	South Africa	0.004
UK 64	South Africa	0.036
Acala 1517-99	US	-0.074*
Del Cerro	US	-0.064*
Deltapine 491	US	0.036
Phytogen 72	US	0.030
ST 474	US	0.004
Tamcot 22	US	0.002
Tejas	US	-0.069*
	Std. error	0.032
Tester		
TAM B182-33 ELS	US	0.034**
Tamcot CAMD-E	US	-0.034**
	Std. error	0.007

* Significant at 95% confidence interval (2xStd. error).

** Significant at 99% confidence interval (3xStd. error).

† CIE, International Commission on Illumination.

Table 22. CIE† b*, yellowness/blueness, estimates of general combining ability (GCA) effects of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Geographic area	GCA
China 632	China	0.177*
Chung Mein-Jue #7	China	-0.145
Duck Shelter	China	0.093
Jiangsu #3	China	0.297**
Kang Bin Chang Mienne	China	0.195*
Lintsing Sze Tze 4B	China	-0.119
Lishan Big Boll	China	0.011
Nanging #12	China	0.166*
Pengze	China	0.057
Shan 5245	China	0.017
Small Leaf	China	0.308**
Zhong Mian Suo 9 Hao	China	0.216*
Allen 333	West Africa	0.061
Allen 333-61 CB 4027	West Africa	0.302**
BJA 592	West Africa	-0.118
F 280	West Africa	-0.079
Funtua FT-5	West Africa	0.096
PAN 575	West Africa	-0.203*
Reba W 296	West Africa	-0.022
A 7215	South Africa	-0.380**
A-637-33	South Africa	-0.432**
ALA 70-11	South Africa	0.163*
Albacala 7	South Africa	-0.247**
BPA 68 CB 4030	South Africa	-0.399**
Komati	South Africa	0.157*
Limpopo	South Africa	-0.057
Marico (Smooth)	South Africa	-0.319**
Sabie	South Africa	0.028
UK 64	South Africa	-0.003
Acala 1517-99	US	0.138
Del Cerro	US	-0.025
Deltapine 491	US	0.038
Phytogen 72	US	0.133
ST 474	US	0.143
Tamcot 22	US	-0.124
Tejas	US	-0.123
	Std. error	0.078
Tester		
TAM B182-33 ELS	US	0.017
Tamcot CAMD-E	US	-0.017
	Std. error	0.018

* Significant at 95% confidence interval (2xStd. error).

** Significant at 99% confidence interval (3xStd. error).

† CIE, International Commission on Illumination.

Combining Ability Estimates for L*a*b* Color System

Most of the SCAs for L* were not significantly different from zero, indicating that lines and testers did not combine differently for this component of color L* (Table 20). However, Duck Shelter from China combined specifically with Tamcot CAMD-E, producing higher ($p < 0.05$) than average L* F_1 values at 0.442 units and with TAM B182-33 ELS to produce hybrids with lower than expected L* values. PAN 575 from West Africa also combined with the two testers to produce F_1 L* values different than the average of all F_1s. PAN 575 / TAM B182-33 ELS expressed a L* value 0.474 units higher than all F_1 combinations and 0.474 units lower when PAN 575 was crossed with Tamcot CAMD-E.

Unlike with the SCA values for L*, there were several GCA values for a* that were significantly different from zero (Table 21). Five of the Chinese cultivars exhibited significant positive GCAs for a*, which indicate that they on average improve the a*, and thus whiteness, in their respective F_1 progenies. Three of the West African cultivars, four of the South African cultivars and three of the US cultivars exhibited significant negative GCAs for a*, which indicate that they on average decreased whiteness, as indicated by a*, in their respective F_1 progenies.

While a positive GCA value is preferred for a*, a negative GCA value for b* would be preferred among this set of lines and testers because their b* values were above zero, a value that denotes a whiter color (Table 22). Six of the Chinese cultivars exhibited significant positive GCAs for b*, which demonstrate that, on average, they decreased whiteness, as indicated by the b* value in their respective F_1 progenies. Two

of the West African cultivars and seven of the South African cultivars exhibited significant negative GCAs for b*, which indicates that they, on average, increased whiteness as indicated by the b* values in their respective F_1 progenies. None of the US cultivars demonstrated a GCA value for b* that was different than zero, suggesting that none of the US lines when crossed with the two US testers would improve b*, thus whiteness, in a pedigree breeding program.

Maturity Measurements

The MR data set failed to meet the underlying assumptions of homogeneity and normality required for ANOVA. Therefore the data were transformed by arc sine because MR is a ratio. Even though this transformation did not result in non-significant p-values for the Bartlett and Shapiro-Wilks tests for homogeneity and normality, it resulted in a higher p-value than any other transformation attempted (square root, 2^{nd} power, inverse and logarithmic transformations).

The RbWth and Mic data sets also did not meet the underlying assumptions of homogeneity and normality for ANOVA. Despite various data transformations attempted (square root, 2^{nd} power, inverse, logarithmic and arc sine), non-significant p-values for Bartlett and Shapiro-Wilks tests of homogeneity and normality were not obtained. Therefore, the ANOVA was performed on the untransformed data sets for both RbWth and Mic.

Parents, F_1s, and parents vs. F_1s significantly differed ($p < 0.001$) for MR, RbWth and Mic, except for parents vs. F_1s for Mic which did not differ significantly (Table 23). The ANOVA table revealed significant Genotype x Year interactions for

MR ($p < 0.01$), RbWth ($p < 0.05$) and Mic ($p < 0.001$). Since these maturity measurements are so dependent upon the environmental growing conditions, it is unsurprising that there are significant Genotype x Year interactions. The Line x Tester interaction term was significant $p < 0.001$ for RbWth, but was not significant for both MR and Mic. Therefore, the SCAs of the F_1s will be discussed herein for RbWth, since the 36 lines combined differently with the two testers for both years of the field experiment and thus it is not appropriate to report GCAs of the lines and parents based upon the ANOVA. The GCAs of the lines and testers for MR and Mic will be discussed herein, since the 36 lines combined with the testers in relatively the same order for both years of testing.

Line and tester were both significant for MR, RbWth and Mic at $p < 0.001$ (Table 23). Due to the significance of Parents, Parents vs. F_1s and F_1s, it is logical to conclude that there is genetic variation for MR, RbWth and Mic among the 36 lines and two testers used in this experiment. It is also clear from the ANOVA and the numerous significant Genotype x Year interactions, that significant environmental variation was not successfully partitioned out for MR, RbWth, and Mic.

Table 23. Mean squares for Cottonscope® MR†, RbWth and Mic values for 38 world upland cultivars and their F_1 progeny grown under irrigated field culture near College Station, TX in 2010 and 2011.

Source	df	MR	RbWth	Mic
			---- μm ----	
Year	1	52.9244 **	4.2456*	118.7200***
[Rep(Year)]‡	4	1.9628	0.2106	1.1702
Genotype	109	2.3970 ***	1.8299***	0.6460***
Parents	37	3.3178 ***	2.6635***	1.1730***
Parents vs F_1s	1	20.5381 ***	19.8521***	0.3817
F_1s	71	1.6617 ***	1.1417***	0.3751***
Line	35	1.9570 ***	1.0734***	0.5925***
Tester	1	39.4613 ***	38.6613***	1.7334***
[Line*Tester]	35	0.2864	0.1380***	0.1188
Genotype*Year	109	0.2918 **	0.0899*	0.2123***
Parent*Year	37	0.2356	0.0934	0.2255***
Parent vs F_1s*Year	1	0.0003	0.0072	0.0168
F_1s*Year	71	0.3251 **	0.0893*	0.2081***
Line*Year	35	0.3622 **	0.0975*	0.2565***
Tester*Year	1	0.3637	0.4266*	0.0676
Line*Tester*Year	35	0.2869	0.0714	0.1637*
Error	436	0.2080	0.0661	0.1049

*, **, *** significant at $P < 0.05$, 0.01, and 0.001, respectively.
† MR, maturity ratio; RbWth, ribbon width; Mic, micronaire.
‡ Brackets indicate an error term.

Table 24. Average Cottonscope® MR† of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

		Year	
Lines	Region	2010	2011
Allen 333-61 CB 4027	West Africa	1.03 a‡	1.02 b-h
UK 64	South Africa	1.02 ab	1.06 ab
Phytogen 72	US	1.00 a-c	1.07 a
PAN 575	West Africa	0.99 a-d	1.05 a-c
Acala 1517-99	US	0.98 b-e	1.01 b-j
ALA 70-11	South Africa	0.98 b-f	1.03 a-f
Allen 333	West Africa	0.97 b-g	1.01 c-k
A-637-33	South Africa	0.97 b-g	1.00 c-l
Albacala 7	South Africa	0.97 b-g	1.04 a-d
BJA 592	West Africa	0.97 b-g	0.97 i-p
Del Cerro	US	0.97 b-h	1.04 a-d
BPA 68 CB 4030	South Africa	0.95 c-i	1.04 a-e
Reba W 296	West Africa	0.95 d-i	1.03 a-g
Tamcot 22	US	0.95 d-j	0.98 g-n
Limpopo	South Africa	0.94 d-j	0.98 g-o
A 7215	South Africa	0.94 d-k	1.04 a-e
Shan 5245	China	0.94 e-k	0.99 e-n
Duck Shelter	China	0.93 f-k	0.99 d-n
Deltapine 491	US	0.93 f-k	1.01 b-j
Funtua FT-5	West Africa	0.93 f-k	0.96 j-p
Nanging #12	China	0.93 f-k	0.93 o-r
Kang Bin Chang Mienne	China	0.93 g-l	0.97 i-p
Pengze	China	0.93 g-l	0.95 l-q
ST 474	US	0.93 g-l	0.95 m-r
F 280	West Africa	0.92 h-m	0.96 k-q
Marico (Smooth)	South Africa	0.91 i-m	0.98 h-p
Chung Mein-Jue #7	China	0.91 i-m	0.98 g-o
Tejas	US	0.91 i-m	0.99 d-n
Komati	South Africa	0.90 j-n	0.94 n-r
China 632	China	0.90 k-n	1.02 b-i
Jiangsu #3	China	0.89 k-n	0.96 j-p
Sabie	South Africa	0.89 k-n	0.91 q-r
Small Leaf	China	0.88 l-n	1.00 d-m
Lishan Big Boll	China	0.87 nm	0.90 r
Zhong Mian Suo 9 Hao	China	0.86 n	0.99 f-n
Lintsing Sze Tze 4B	China	0.80 o	0.93 p-r
Tester			
TAM B182-33 ELS	US	0.99 a	
Tamcot CAMD-E	US	0.93 b	

† MR, Maturity Ratio.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

Since the lines did not respond the same to years, for MR, line means must be reported separately by year (Table 24). In 2010, UK 64 (South Africa) had the highest mean MR of the South African cultivars, and it differed significantly than six of the other South African cultivars. Phytogen 72 (US) had the highest mean MR of the US cultivars in 2010, differing from four other US cultivars ($p < 0.05$). Allen 333-61 CB 4027 (West Africa) had the highest mean MR in relation to the West African cultivars in 2010, and it was equal to or higher than one of the seven West African cultivars ($p < 0.05$). Shan 5245 (China) had the highest mean MR as compared with the other Chinese cultivars in 2010, differing significantly than four other Chinese cultivars. In 2010, Shan 5245 differed significantly than the other three cultivars that had the highest MR for their respective geographic regions.

In 2011, Phytogen 72 and UK 64 (South Africa) were both superior in MR as to their respective geographic groupings as in the previous year (Table 24). PAN 575 (West Africa) and China 632 (China) demonstrated larger MR than Allen 333-61 CB 4027 and Shan 5245 in 2011. On average, the Chinese cultivars exhibited a lower MR, while the African cultivars had a higher MR. The two testers differed significantly for MR during the two years of the experiment.

Table 25. Average Cottonscope® MR† of F_1s of 36 upland lines and 2 upland testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	TAM B182-33 ELS		Tamcot CAMDE	
		Year		Year	
		2010	2011	2010	2011
Allen 333-61 CB 4027	West Africa	1.08 a‡	1.07 a-f	0.99 c-i	0.97 j-r
UK 64	South Africa	1.06 ab	1.10 a	0.97 d-l	1.01 c-p
Del Cerro	US	1.05 a-c	1.07 a-f	0.88 o-u	1.01 d-p
PAN 575	West Africa	1.05 a-c	1.08 a-d	0.92 i-r	1.02 b-n
Phytogen 72	US	1.03 a-d	1.10 a	0.97 d-l	1.05 a-i
Allen 333	West Africa	1.02 a-e	1.05 a-i	0.93 h-r	0.97 k-t
Albacala 7	South Africa	1.01 a-f	1.07 a-g	0.93 h-r	1.02 b-o
Acala 1517-99	US	1.00 b-g	1.02 b-n	0.97 d-l	1.00 e-p
A-637-33	South Africa	0.99 b-h	1.00 g-p	0.94 f-p	1.01 d-p
BPA 68 CB 4030	South Africa	0.99 c-i	1.08 a-c	0.92 i-r	0.99 h-q
BJA 592	West Africa	0.99 c-j	0.98 i-q	0.95 e-o	0.96 l-u
Nanging #12	China	0.98 c-j	0.96 k-t	0.87 q-v	0.90 s-w
ALA 70-11	South Africa	0.98d-k	1.06 a-h	0.98 d-k	1.01 d-p
Duck Shelter	China	0.98 d-k	1.03 a-k	0.89 o-u	0.95 n-v
Kang Bin Chang Mienne	China	0.97 d-k	0.98 i-q	0.88 p-u	0.95 m-v
Limpopo	South Africa	0.97 d-l	0.97 j-r	0.92 i-r	0.99 h-q
Shan 5245	China	0.96 e-m	1.03 a-k	0.91 k-s	0.94 p-v
F 280	West Africa	0.96 e-n	1.02 b-m	0.88 p-u	0.89 u-w
Reba W 296	West Africa	0.96 e-n	1.07 a-e	0.95 e-p	0.99 i-q
China 632	China	0.95 e-p	1.04 a-j	0.84 t-v	0.99 h-q
Deltapine 491	US	0.95 e-p	1.06 a-h	0.91 k-s	0.96 l-u
Tamcot 22	US	0.95 e-p	1.00 g-p	0.95 f-p	0.97 j-s
Pengze	China	0.95 f-p	0.95 n-v	0.91 k-t	0.96 l-v
Funtua FT-5	West Africa	0.94 f-p	0.98 i-q	0.91 k-s	0.95 o-v
ST 474	US	0.94 g-q	1.00 e-p	0.91 k-s	0.90 t-w
Lishan Big Boll	China	0.94 g-q	0.95 p-v	0.81 vw	0.86 w
Marico (Smooth)	South Africa	0.94 g-q	1.03 b-l	0.89 m-u	0.93 q-w
Jiangsu #3	China	0.93 g-r	1.00 e-p	0.85 s-v	0.92 q-w
Chung Mein-Jue #7	China	0.93 g-r	1.00 f-p	0.89 n-u	0.96 k-t
Tejas	US	0.93 h-r	1.04 a-j	0.89 o-u	0.95 p-v
Sabie	South Africa	0.92 j-s	0.97 k-t	0.87 r-v	0.86 w
A 7215	South Africa	0.91 k-t	1.09 ab	0.97 d-l	0.99 i-q
Small Leaf	China	0.91 k-t	1.04 a-i	0.85 s-v	0.95 o-v
Zhong Mian Suo 9 Hao	China	0.90 l-t	1.03 b-l	0.81 vw	0.95 p-v
Komati	South Africa	0.88 o-u	0.99 i-q	0.92 i-r	0.90 r-w
Lintsing Sze Tze 4B	China	0.77 w	0.97 j-r	0.83 u-w	0.89 wv

† MR, Maturity Ratio

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

A MR of 0.8 and below indicates that the fibers are immature. Only Lintsing Sze Tze 4B (China) in 2010 exhibited a MR of 0.80. Most of the lines and testers for both years have MR values between 0.8 and 1.0, which are considered to be mature fibers. A few lines, particularly ones from African, had MR values that were above 1.0, indicating that those fibers were very mature. In 2011, there were more lines with MR above 1.0, which is not surprising due to the extremely different weather conditions for both growing years.

There was a significant F_1 x Year interaction for MR, so the MR means for the F_1 progenies were reported separately by years (Table 25). Allen 333-61 CB 4027 (West Africa), UK 64 (South Africa), Del Cerro (US), PAN 575 (West Africa) and Phytogen 72 (US) all had superior hybrid combinations for MR with TAM B182-33 ELS for both 2010 and 2011. Typically the hybrid combinations with TAM B182-33 ELS had higher MR as compared to the hybrid combinations with Tamcot CAMD-E.

There were significant Line x Year and Tester x Year interaction terms for RbWth, so the means were all reported as separated by year (Table 26). Overall, the Chinese cultivars tended to have larger RbWth, indicating that their fibers were probably coarser or had larger fiber diameters. Conversely, the African cultivars tended to have smaller RbWth, indicating that their fibers were probably finer and had smaller fiber diameters. The genetic variability that exists for RbWth seems to be partitioned via different geographic regions in the various lines over the two years of the experiment. The two testers differed significantly for both years of the experiment.

Table 26. Average Cottonscope® RbWth† of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	Year	
		2010	2011
		---- µm ----	---- µm ----
Lintsing Sze Tze 4B	China	15.28 a‡	15.42 a-c
Zhong Mian Suo 9 Hao	China	15.24 ab	15.13 d-h
Small Leaf	China	15.21 ab	15.36 a-d
ST 474	US	15.21 ab	15.40 a-c
Sabie	South Africa	15.19 a-c	15.44 ab
Komati	South Africa	15.17 a-c	15.13 d-h
Tejas	US	15.15 a-d	15.26 a-e
Lishan Big Boll	China	15.06 a-e	15.46 a
Pengze	China	15.05 a-e	15.47 a
Jiangsu #3	China	15.05 a-e	15.33 a-d
Kang Bin Chang Mienne	China	15.01 a-f	15.26 a-e
F 280	West Africa	15.01 a-f	15.17 c-h
Reba W 296	West Africa	14.99 a-g	14.71 l-o
Chung Mein-Jue #7	China	14.97 b-h	15.06 e-j
Duck Shelter	China	14.95 b-h	15.16 c-h
China 632	China	14.95 b-h	14.79 j-n
Funtua FT-5	West Africa	14.91 c-i	15.16 c-h
Marico (Smooth)	South Africa	14.87 d-j	14.94 g-l
Tamcot 22	US	14.86 d-j	15.25 a-f
Nanging #12	China	14.85 e-j	15.12 d-i
Deltapine 491	US	14.82 e-j	14.90 h-l
Shan 5245	China	14.80 e-j	15.19 b-f
ALA 70-11	South Africa	14.72 f-k	14.86 i-m
BJA 592	West Africa	14.69 g-k	15.24 a-f
BPA 68 CB 4030	South Africa	14.68 g-l	14.70 l-o
Allen 333	West Africa	14.68 h-l	14.99 f-k
Limpopo	South Africa	14.63 i-m	14.78 k-n
A-637-33	South Africa	14.59 j-n	14.69 l-o
Albacala 7	South Africa	14.59 j-n	14.45 op
Phytogen 72	US	14.46 k-n	14.62 m-p
A 7215	South Africa	14.38 l-n	14.39 p
Allen 333-61 CB 4027	West Africa	14.38 mn	14.79 j-n
Del Cerro	US	14.38 mn	14.47 op
Acala 1517-99	US	14.38 mn	14.71 l-o
UK 64	South Africa	14.34 mn	14.54 n-p
PAN 575	West Africa	14.30 n	14.40 p
Tester			
Tamcot CAMD-E	US	15.10 a	15.32 a
TAM B182-33 ELS	US	14.56 b	14.66 b

† RbWth, Ribbon-Width.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

Table 27. Average Cottonscope® RbWth† of F_1s of 36 upland lines and 2 upland testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	TAM B182-33 ELS		Tamcot CAMDE	
		Year		Year	
		2010	2011	2010	2011
		---- µm ----	---- µm ----	---- µm ---	---- µm ----
Lintsing Sze Tze 4B	China	15.28 a-g ‡	14.94 n-w	15.27 a-g	15.91 a
Komati	South Africa	15.06 c-n	14.68 t-cc	15.28 a-g	15.57 a-g
Zhong Mian Suo 9 Hao	China	15.00 e-o	14.69 t-cc	15.48 a-c	15.57 a-g
Pengze	China	14.99 e-q	15.37 d-k	15.10 c-l	15.57 a-g
Sabie	South Africa	14.95 f-q	14.96 m-v	15.44 a-d	15.92 a
Tejas	US	14.91 f-r	14.76 q-bb	15.40 a-e	15.76 a-c
Reba W 296	West Africa	14.90 g-s	14.28 dd-ii	15.08 c-n	15.14 h-q
ST 474	US	14.89 g-s	15.12 i-r	15.53 ab	15.69 a-f
Tamcot 22	US	14.84 h-u	15.12 i-r	14.88 g-t	15.39 c-k
Small Leaf	China	14.83 h-u	14.89 p-y	15.60 a	15.82 ab
Jiangsu #3	China	14.76 j-v	14.95 m-w	15.33 a-f	15.72 a-d
Kang Bin Chang Mienne	China	14.76 j-v	15.02 k-t	15.27 a-g	15.51 b-h
Chung Mein-Jue #7	China	14.68 l-w	14.79 q-bb	15.27 a-g	15.33 e-m
Duck Shelter	China	14.68 l-w	14.84 p-aa	15.23 a-h	15.48 b-i
Marico (Smooth)	South Africa	14.66 n-w	14.57 w-ff	15.08 c-m	15.32 f-n
Lishan Big Boll	China	14.63 o-w	15.08 j-s	15.48 a-c	15.85 ab
F 280	West Africa	14.62 o-w	14.62 u-dd	15.39 a-e	15.71 a-e
China 632	China	14.61 o-w	14.60 v-ee	15.29 a-g	14.99 l-u
BJA 592	West Africa	14.61 p-w	15.06 j-t	14.77 j-v	15.42 c-j
Funtua FT-5	West Africa	14.60 p-w	14.94 m-w	15.21 a-i	15.38 c-k
Deltapine 491	US	14.57 q-w	14.44 bb-hh	15.08 c-n	15.35 d-l
Nanging #12	China	14.57 q-w	14.82 p-bb	15.13 b-k	15.42 c-j
ALA 70-11	South Africa	14.51 r-w	14.53 y-ff	14.92 f-r	15.18 h-p
Limpopo	South Africa	14.48 s-x	14.79 q-bb	14.79 i-u	14.78 q-bb
Shan 5245	China	14.46 t-y	14.80 q-bb	15.15 b-j	15.58 a-g
BPA 68 CB 4030	South Africa	14.44 u-y	14.28 dd-ii	14.93 f-r	15.13 h-q
A-637-33	South Africa	14.36 v-z	14.49 aa-gg	14.83 h-u	14.88 p-y
Allen 333	West Africa	14.33 w-z	14.69 s-cc	15.04 d-o	15.28 g-o
A 7215	South Africa	14.30 w-aa	14.23 ee-ii	14.47 s-x	14.54 x-ff
Albacala 7	South Africa	14.29 w-aa	14.19 ff-ii	14.88 g-t	14.70 s-bb
Phytogen 72	US	14.06 x-bb	14.31 cc-ii	14.87 g-t	14.93 o-w
Acala 1517-99	US	14.04 y-bb	14.50 z-gg	14.72 k-w	14.92 o-x
UK 64	South Africa	14.01 z-bb	14.12 gg-ii	14.67 m-w	14.97 m-v
Allen 333-61 CB 4027	West Africa	13.90 aa-bb	14.27 dd-ii	14.86 g-t	15.32 f-n
Del Cerro	US	13.83 bb	14.05 ii	14.93 f-r	14.88 p-z
PAN 575	West Africa	13.78 bb	14.06 hh-ii	14.81 h-u	14.74 r-bb

† RbWth, Ribbon-Width.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

There was a significant F_1 x Year interaction for RbWth, so the means reported were separated by year (Table 27). On average, the lines combined with Tamcot CAMD-E resulted in hybrid combinations that had increased RbWth, which indicates that the fibers were coarser (larger diameter) as compared to the hybrids formed with TAM B182-33 ELS. In 2010, the hybrid combination with the largest RbWth mean was Small Leaf (China)/Tamcot CAMD-E. In 2010, the hybrid combination with the smallest RbWth mean was PAN 575 (West Africa)/TAM B182-33 ELS. In 2011, the hybrid combination with the largest RbWth mean was Lintsing Sze Tze 4B (China)/Tamcot CAMD-E. In 2011, the hybrid combination with the smallest RbWth mean was Del Cerro (US)/TAM B182-33 ELS.

Until the advent of the Cottonscope®, it was impossible to accurately measure RbWth. Therefore, there is no definitive range associated with this important fiber quality measurement, such as there is for Mic. RbWth can neither be maximized nor minimized in cotton fibers because of the inherent physical properties of the fibers. A larger RbWth value is not preferable because it could indicate a larger fiber diameter. If fibers exhibit larger fiber diameters, then fewer fibers will be in a yarn cross-section and there will be less friction to hold the yarn together. Larger diameter fibers can also lead to more ends down in spinning. A smaller RbWth is preferred, but the RbWth should not be too small because that could indicate too small a fiber diameter. Smaller diameter fibers are individually weaker, which could increase SFC and fiber breakage during spinning. Evidently, more research involving the use of the Cottonscope® to investigate

the effects of RbWth on yarn quality is essential to developing an acceptable range of RbWth for cotton fibers.

There was a significant Line x Year interaction for Mic, so the line means were reported as separated by year (Table 28). In 2010, all of the line Mic values were within the acceptable Mic range of 3.5 to 4.9, with the exception of Lintsing Sze Tze 4B (China), which had a mean Mic of only 3.17. However, in 2011 only 17 of the 36 lines had Mic within the acceptable range, while the majority of lines had higher Mic values. During the growing season in 2011, there were drought conditions in the fields, so the cotton plants experienced both heat and water stress. It is possible that the Mic values were increased due the unfavorable environmental conditions during that growing season. The two testers differed significantly for the two years of the experiment and they both had Mic values within the acceptable range.

Table 28. Average Cottonscope® Mic† of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

		Year	
Lines	Region	2010	2011
Allen 333-61 CB 4027	West Africa	4.55 a‡	4.98 c-g
Reba W 296	West Africa	4.49 ab	4.96 c-g
ST 474	US	4.46 a-c	5.03 b-f
ALA 70-11	South Africa	4.40 a-d	5.24 a-c
Phytogen 72	US	4.33 a-e	5.34 ab
UK 64	South Africa	4.32 a-e	5.03 b-f
BJA 592	West Africa	4.30 a-f	5.06 b-f
Pengze	China	4.29 a-g	5.17 b-d
Allen 333	West Africa	4.28 a-g	5.10 b-e
Tamcot 22	US	4.25 a-h	5.22 a-d
Kang Bin Chang Mienne	China	4.25 a-h	5.04 b-f
Duck Shelter	China	4.20 a-h	5.18 b-d
Tejas	US	4.18 a-i	5.33 ab
A-637-33	South Africa	4.17 a-i	4.67 g-k
Komati	South Africa	4.15 b-i	4.59 i-k
Albacala 7	South Africa	4.13 b-j	4.76 f-k
F 280	West Africa	4.13 b-k	4.76 f-k
Funtua FT-5	West Africa	4.11 c-k	4.90 d-i
BPA 68 CB 4030	South Africa	4.10 c-k	5.06 b-f
Sabie	South Africa	4.09 c-k	4.60 h-k
Shan 5245	China	4.07 d-l	5.19 a-d
Acala 1517-99	US	4.04 d-l	4.78 e-k
Deltapine 491	US	4.04 d-l	5.01 b-f
Nanging #12	China	4.02 e-l	4.46 k
Chung Mein-Jue #7	China	3.99 e-l	4.93 c-h
Small Leaf	China	3.97 e-l	5.51 a
Limpopo	South Africa	3.94 f-m	4.55 jk
PAN 575	West Africa	3.93 f-m	4.75 f-k
Marico (Smooth)	South Africa	3.91 g-m	4.68 g-k
Jiangsu #3	China	3.90 h-m	5.08 b-f
Del Cerro	US	3.83 i-m	4.75 f-k
China 632	China	3.77 j-m	4.95 c-g
Zhong Mian Suo 9 Hao	China	3.76 k-m	5.07 b-f
Lishan Big Boll	China	3.69 l-m	4.49 jk
A 7215	South Africa	3.59 m	4.61 h-k
Lintsing Sze Tze 4B	China	3.17 n	4.80 e-j
Tester			
Tamcot CAMD-E	US	4.57 a	
TAM B182-33 ELS	US	4.44 b	

† Mic, Micronaire.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

There was a significant F_1 x Year interaction for Mic, so the F_1 Mic means were reported as separated by year (Table 29). In 2010, all the F_1 progenies had Mic values within the acceptable range except for the following hybrid combinations: A 7215 (South Africa)/TAM B182-33 ELS and Lintsing Sze Tze 4B (China)/TAM B182-33 ELS. In 2011, a similar trend was seen in the F_1s as in the lines because 18 of the hybrid combinations with TAM B182-33 ELS as a tester and 23 of the hybrid combinations with Tamcot CAMD-E as a tester resulted in Mic values that were outside of the acceptable Mic range for upland cotton. In general, the hybrid combinations with Tamcot CAMD-E resulted in higher Mic values than the hybrid combinations with TAM B182-33 ELS. From these data, it is easy to conclude that Mic is a trait that is highly variable and environmentally influenced.

Table 29. Average Cottonscope® Mic† of F_1s of 36 upland lines and 2 upland testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Region	TAM B182-33 ELS		Tamcot CAMDE	
		Year		Year	
		2010	2011	2010	2011
Reba W 296	West Africa	4.45 a-f‡	4.85 g-s	4.53 a-d	5.08 b-m
Kang Bin Chang Mienne	China	4.44 a-g	4.87 g-s	4.05 c-p	5.21 a-g
Pengze	China	4.40 a-h	4.99 d-o	4.17 b-o	5.35 a-f
BJA 592	West Africa	4.38 a-i	4.93 f-r	4.21 a-n	5.18 a-h
Allen 333-61 CB 4027	West Africa	4.36 a-j	4.79 g-t	4.74 a	5.16 a-i
Duck Shelter	China	4.34 a-k	5.22 a-g	4.07 c-p	5.14 a-j
UK 64	South Africa	4.32 a-l	4.93 f-r	4.31 a-l	5.13 a-j
Allen 333	West Africa	4.29 a-m	5.13 a-j	4.26 a-m	5.06 b-n
Nanging #12	China	4.28 a-m	4.43 s-u	3.77 m-r	4.48 q-u
Tamcot 22	US	4.23 a-n	5.20 a-g	4.26 a-m	5.24 a-g
Albacala 7	South Africa	4.20 b-o	4.66 k-u	4.07 c-p	4.85 g-s
ST 474	US	4.19 b-o	5.23 a-g	4.74 a	4.83 g-s
ALA 70-11	South Africa	4.14 c-p	5.08 b-m	4.67 ab	5.41 a-e
A-637-33	South Africa	4.13 c-p	4.33 tu	4.22 a-n	5.02 b-n
BPA 68 CB 4030	South Africa	4.13 c-p	4.93 f-r	4.07 c-p	5.19 a-g
Phytogen 72	US	4.12 c-p	5.18 a-h	4.54 a-c	5.49 ab
Sabie	South Africa	4.07 c-p	4.61 m-u	4.12 c-p	4.60 n-u
Tejas	US	4.07 c-p	5.19 a-g	4.28 a-m	5.47 a-c
F 280	West Africa	4.06 c-p	4.79 g-t	4.20 b-o	4.72 h-u
Jiangsu #3	China	4.03 c-q	5.00 c-o	3.77 m-r	5.15 a-i
Zhong Mian Suo 9 Hao	China	4.00 e-r	4.93 f-r	3.52 q-s	5.21 a-g
Del Cerro	US	3.98 e-r	4.51 p-u	3.67 o-s	4.99 d-o
Limpopo	South Africa	3.96 f-r	4.47 r-u	3.92 g-r	4.63 l-u
China 632	China	3.93 f-r	4.92 f-r	3.61 p-s	4.98 d-o
Deltapine 491	US	3.90 h-r	4.93 f-r	4.17 b-o	5.10 b-k
Lishan Big Boll	China	3.89 h-r	4.54 o-u	3.49 rs	4.44 s-u
PAN 575	West Africa	3.89 h-r	4.61 m-u	3.97 e-r	4.89 f-s
Funtua FT-5	West Africa	3.88 h-r	4.81 g-s	4.34 a-k	4.99 d-o
Marico (Smooth)	South Africa	3.86 i-r	4.72 h-u	3.97 e-r	4.64 k-u
Shan 5245	China	3.86 i-r	5.19 a-g	4.27 a-m	5.20 a-g
Chung Mein-Jue #7	China	3.83 j-r	4.77 g-t	4.15 b-o	5.08 b-l
Small Leaf	China	3.82 k-r	5.45 a-d	4.12 c-p	5.57 a
Komati	South Africa	3.81 l-r	4.49 q-u	4.49 a-e	4.70 i-u
Acala 1517-99	US	3.73 n-r	4.59 n-u	4.35 a-j	4.97 e-p
A 7215	South Africa	3.17 st	4.94 f-q	4.01 d-r	4.28 u
Lintsing Sze Tze 4B	China	2.83 t	4.68 j-u	3.51 q-s	4.92 f-r

† Mic, Micronaire.

‡ Means within a column followed by the same letter are not different at p = 0.05 according to Fisher's protected LSD.

Combining Ability Estimates for MR, RbWth and Mic

There were several GCA values among these lines for MR that were significantly different from zero (Table 30). Five of the Chinese cultivars exhibited negative GCA values that were significantly different from zero for MR, which indicate that they on average decreased the MR in their respective F_1 progenies. Three of the West African cultivars exhibited significant positive GCA values for MR. Four of the South African cultivars had positive GCA values that were significantly different from zero and two of the South African cultivars had negative GCA values different from zero. Three of the US cultivars exhibited significant positive GCAs for MR, which indicated that they on average improved the MR in their respective F_1 progenies.

Most of the SCAs for RbWth were not significantly different from zero, indicating that most of the lines in this study did not combine with either tester differently for RbWth (Table 31). Three lines, Pengze (China), Limpopo (South Africa) and Tamcot 22 (US) combined with TAM B182-33 ELS for RbWth significantly higher than the average of all lines and negative and significantly with Tamcot CAMD-E. These findings suggest that these specific combinations could possibly be used in a breeding program to improve RbWth, but it would be difficult since RbWth should not be maximized or minimized.

Five of the Chinese cultivars had GCA values for Mic significantly different from zero: three of them negative and two positive (Table 32). Two of the West African cultivars have positive GCAs that were significantly different than zero. Five of the South African cultivars had GCA estimates that differed significantly from zero: three of

them were negative and two of them were positive. Five of the US cultivars had GCA estimates that were significantly different from zero: one of these estimates was negative and the other four were positive. As compared to the combining ability estimates for degree of whiteness, there is more potential for genetic improvement from these genotypes in terms of MR, RbWth and Mic.

MR should be increased so that it is ideally over 1.0 because those fibers are very mature and will result in a higher quality yarn. In these germplasm from different geographic regions, there exists sufficient genetic variability to potentially increase MR. RbWth should neither be maximized nor minimized in order to maintain fibers of sufficient quality for textile manufacturing. However, Mic is never maximized or minimized, but should always held to be within a range identified as most desirable for most spinning and weaving operations. The environmental variation had such an impact on RbWth and Mic in this experiment that it would not be prudent to base a cotton breeding program solely on these two parameters.

Table 30. Cottonscope® MR† estimates of general combining ability (GCA) effects of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Geographic area	GCA
China 632	China	-0.008
Chung Mein-Jue #7	China	-0.018
Duck Shelter	China	-0.001
Jiangsu #3	China	-0.036**
Kang Bin Chang Mienne	China	-0.016
Lintsing Sze Tze 4B	China	-0.098**
Lishan Big Boll	China	-0.075**
Nanging #12	China	-0.033*
Pengze	China	-0.023
Shan 5245	China	0.000
Small Leaf	China	-0.025
Zhong Mian Suo 9 Hao	China	-0.042**
Allen 333	West Africa	0.025
Allen 333-61 CB 4027	West Africa	0.064**
BJA 592	West Africa	0.007
F 280	West Africa	-0.025
Funtua FT-5	West Africa	-0.016
PAN 575	West Africa	0.054**
Reba W 296	West Africa	0.027*
A 7215	South Africa	0.025
A-637-33	South Africa	0.023
ALA 70-11	South Africa	0.042**
Albacala 7	South Africa	0.042**
BPA 68 CB 4030	South Africa	0.033*
Komati	South Africa	-0.040**
Limpopo	South Africa	0.000 <
Marico (Smooth)	South Africa	-0.018
Sabie	South Africa	-0.061**
UK 64	South Africa	0.073**
Acala 1517-99	US	0.035*
Del Cerro	US	0.040**
Deltapine 491	US	0.007
Phytogen 72	US	0.074**
ST 474	US	-0.025
Tamcot 22	US	0.002
Tejas	US	-0.014
	Std. error	0.013
Tester		
TAM B182-33 ELS	US	0.030**
Tamcot CAMD-E	US	-0.030**
	Std. error	0.003

* Significant at 95% confidence interval (2xStd. error).

** Significant at 99% confidence interval (3xStd. error).

† MR, Maturity Ratio.

Table 31. Cottonscope® RbWth† estimates of specific combining ability (SCA) effects of 36 upland lines and 2 testers grown under irrigated field culture near College Station, TX in 2010 and 2011.

Line	Geographic Area	TAM B182-33 ELS	Tamcot CAMD-E
China 632	China	0.033	-0.033
Chung Mein-Jue #7	China	0.020	-0.020
Duck Shelter	China	0.002	-0.002
Jiangsu #3	China	-0.037	0.037
Kang Bin Chang Mienne	China	0.048	-0.048
Lintsing Sze Tze 4B	China	0.058	-0.058
Lishan Big Boll	China	-0.105	0.105
Nanging #12	China	0.011	-0.011
Pengze	China	0.223*	-0.223*
Shan 5245	China	-0.069	0.069
Small Leaf	China	-0.125	0.125
Zhong Mian Suo 9 Hao	China	-0.040	0.040
Allen 333	West Africa	-0.025	0.025
Allen 333-61 CB 4027	West Africa	-0.203	0.203
BJA 592	West Africa	0.170	-0.170
F 280	West Africa	-0.163	0.163
Funtua FT-5	West Africa	0.037	-0.037
PAN 575	West Africa	-0.129	0.129
Reba W 296	West Africa	0.037	-0.037
A 7215	South Africa	0.177	-0.177
A-637-33	South Africa	0.083	-0.083
ALA 70-11	South Africa	0.032	-0.032
Albacala 7	South Africa	0.025	-0.025
BPA 68 CB 4030	South Africa	-0.040	0.040
Komati	South Africa	0.021	-0.021
Limpopo	South Africa	0.220*	-0.220*
Marico (Smooth)	South Africa	0.005	-0.005
Sabie	South Africa	-0.061	0.061
UK 64	South Africa	-0.078	0.078
Acala 1517-99	US	0.023	-0.023
Del Cerro	US	-0.183	0.183
Deltapine 491	US	-0.053	0.053
Phytogen 72	US	-0.059	0.059
ST 474	US	-0.007	0.007
Tamcot 22	US	0.219*	-0.219*
Tejas	US	-0.072	0.072
	Std. error	0.105	0.105

* Significant at 95% confidence interval (2xStd. error).

† RbWth, Ribbon Width.

Table 32. Cottonscope® Mic† estimates of general combining ability (GCA) effects of 38 upland parental genotypes grown under irrigated field culture near College Station, TX in 2010 and 2011.

Lines	Geographic area	GCA
China 632	China	-0.15
Chung Mein-Jue #7	China	-0.05
Duck Shelter	China	0.18
Jiangsu #3	China	-0.02
Kang Bin Chang Mienne	China	0.14
Lintsing Sze Tze 4B	China	-0.52**
Lishan Big Boll	China	-0.41**
Nanging #12	China	-0.27*
Pengze	China	0.22*
Shan 5245	China	0.12
Small Leaf	China	0.23*
Zhong Mian Suo 9 Hao	China	-0.09
Allen 333	West Africa	0.18
Allen 333-61 CB 4027	West Africa	0.26*
BJA 592	West Africa	0.17
F 280	West Africa	-0.06
Funtua FT-5	West Africa	< 0.00
PAN 575	West Africa	-0.16
Reba W 296	West Africa	0.22*
A 7215	South Africa	-0.41**
A-637-33	South Africa	-0.08
ALA 70-11	South Africa	0.32**
Albacala 7	South Africa	-0.06
BPA 68 CB 4030	South Africa	0.07
Komati	South Africa	-0.13
Limpopo	South Africa	-0.26*
Marico (Smooth)	South Africa	-0.21*
Sabie	South Africa	-0.16
UK 64	South Africa	0.17
Acala 1517-99	US	-0.10
Del Cerro	US	-0.22*
Deltapine 491	US	0.02
Phytogen 72	US	0.33**
ST 474	US	0.24*
Tamcot 22	US	0.23*
Tejas	US	0.25*
	Std. error	0.09
Tester		
TAM B182-33 ELS	US	-0.06*
Tamcot CAMD-E	US	0.06*
	Std. error	0.02

* Significant at 95% confidence interval (2xStd. error).

** Significant at 99% confidence interval (3xStd. error).

† Mic, Micronaire.

CHAPTER IV

CONCLUSIONS

Data reported herein support that genetic variation for degree of fiber whiteness, MR, RbWth and Mic exist in the distinct pools of germplasm from the various geographic areas included in this study. While specific data from this study only applies to these lines and two testers, the significant combining ability estimates for cultivars from all geographic regions indicated that the genetic potential to enhance degree of fiber whiteness and maturity exists in a few cultivars from each geographic area and do not reside specifically in a given region.

A 7215 (South Africa), Tejas (US), PAN 575 (West Africa), Lintsing Sze Tze 4B (China) F 280 (West Africa) and Nanging #12 (China) and their F_1 progenies all demonstrated superior whiteness characteristics. PAN 575 is of particular interest because its combining ability estimates for the degree of whiteness variables (X, Y, Z, L*, a* and b*) were significantly different from zero.

Despite the evident genetic variation from this study for the degree of fiber whiteness, the difficulties in the phenotypic screening of this trait and its importance relative to other fiber traits are problematic. At this time, it is not advisable to begin a cotton breeding program based upon degree of fiber whiteness. It is not economically viable because more research is needed, so that adequate consideration is given to this particular fiber trait. However, it is advisable that the cotton color grading system should be switched to a more internationally recognized color grading system such as XYZ or CIE L*a*b* because of the increased ease of use.

Allen 333-61 CB 4027 (West Africa), Phytogen 72 (US), UK 64 (South Africa) and Lintsing Sze Tze 4B (China) and their F_1 progenies had enhanced maturity characteristics, particularly very high MR values, indicating that their fibers are more mature than some of the other cultivars. A cotton breeding program based upon MR measured by the Cottonscope® would be economically feasible due to rapid phenotyping and the clear genetic variation inherent in these germplasm pools. Despite the extensive variation that exists in the RbWth and Mic values from the germplasm in this study, it would be ill-advised to breed cotton germplasm for either RbWth or Mic. The environmental influence and fluctuation between environments of both RbWth and Mic, as well as confounding effects of both fiber fineness and maturity make them ill-suited to developing superior germplasm lines for maturity. Additionally, RbWth and Mic are traits that simply can not be minimized or maximized with any degree of accuracy.

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VITA

Name: Kendra Lyn Gregory

Address: Cotton Improvement Lab
2474 TAMU
Texas A&M University
College Station, TX 77843

Education:

BA in Spanish	Abilene Christian University	2010
BS in Environmental Sciences	Abilene Christian University	2010
MS in Plant Breeding	Texas A&M University	2012