EVALUATION OF THE USE OF ISOTESTER IN MEASURING COTTON FIBER PROPERTIES

by

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(Under the Direction of Helen H. Epps)

ABSTRACT

Cotton remains one of the most important natural fibers. Color of the cotton fibers and trash associated with it, are primarily of interest in this research. The IsoTester, a gin based classing instrument, was used for measuring cotton color and trash particles. Schaffner Technologies developed the IsoTester based on the long term vision that Gin-based classing will be implemented by 2020. In addition to Rd and + b, cotton color is also defined in terms of CIE L* a* b* and in this research cotton color measured from IsoTester is compared with the measurements obtained from two spectrophotometers - Hunter Lab LabScan XE and Macbeth Optiview. In addition to this, repeatability and reproducibility of IsoTester is measured.

INDEX WORDS: Cotton, IsoTester, Gin based classing, CIE L* a* b*, Hunter Lab LabScan XE, Macbeth Optiview, Repeatability and Reproducibility

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PROPERTIES

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CHAPTER 1

INTRODUCTION

Cotton is the most used textile fiber in the world. Its current market share is 56 percent for all fibers used for apparel and home furnishings and sold in the U.S (1). The Cotton industry is truly one of America's cornerstone industries with the growing popularity of cotton in nonwoven textiles and personal care items. It is generally recognized that most consumers prefer cotton personal care items to those containing synthetic fibers. Cotton color plays an important role in price – quality relationship in the market. Textile processing is influenced by the trash components found in cotton bales, which are inhomogeneous in color and contaminated with troublesome trash.

Traditionally, cotton grade has been based on four physical properties: color, trash, preparation, and extraneous material (2). In the USDA system, the reflectance (Rd) and the degree of yellowness (+b) describe cotton color. Degree of reflectance shows the brightness of the sample and yellowness depicts the degree of cotton pigmentation. Each color code is represented by a defined area located in a Nickerson-Hunter cotton colorimeter diagram. The color of the fibers is affected by climatic conditions, impact of insects and fungi, type of soil, storage conditions etc. There are five recognized groups of color: white, gray, spotted, tinged, and yellow stained. As the color of cotton deteriorates, the processability of the fibers decreases. Work at the University of Tennessee has led to color measurement using both a spectrometer CIE-based average color measurement and a color uniformity measurement using image analysis to improve the accuracy and provide additional measurement for color grading (3).

Trash is a measure of the amount of non-lint material, such as leaf and bark, in cotton. Trash content is assessed from scanning the cotton sample surface with a video- camera and calculating the percentage of the surface area occupied by trash particles. The values of trash content should be within the range from 0 to 1.6%. Trash content is highly correlated to leaf grade of the sample. Leaf grade is provided visually as the amount of cotton plant particles within the sample. There are seven leaf grades from one to seven and one below grade, eight. The term preparation describes the smoothness of the sample, i.e., lack of lumps and twists. The United States Department of Agriculture (USDA) and Agricultural Marketing Service (AMS), classes and grades cotton. These cotton fiber measurements have progressed from a subjective human classer to the objective High Volume Instrument (HVI).

The purpose of this study can be seen in the proposed context that by 2020 cotton classing will be done at the gin and warehouses under the AMS supervision and the classing will be based entirely on instrumental measurements (2, 11, 12, 13). Frederick Michael Shofner and Christopher Kyle Shofner (2, 13) envisioned that the Commission Internationale de l'Eclairage (CIE) color measurement will replace current USDA method of defining cotton color. CIE (Commission Internationale de l'Eclairage) is the primary international organization concerned with color and color measurement. Therefore it becomes important to study the color of cotton fibers in terms of CIE L* a* b* as measured by IsoTester and other color measuring instruments, for example spectrophotometers. IsoTester, a gin based classing machine introduced by Schaffner Technologies, Inc., was used in this study. The IsoTester® is a stand-alone instrument capable of measuring color, trash, and moisture of each sample produced at the gin. (Other available measurement modules are length, micronaire, neps, stickiness, and GinWizard.)

OBJECTIVES

The objectives of this study were:

1. To investigate the effect of trash removal (non-lint materials) on the color of raw cotton fibers taking redness – greenness attribute (a) into consideration, in addition to currently used lightness and yellowness.
2. To examine differences in cotton color measurements from the IsoTester and two color spectrophotometers- Hunter Lab LabScan XE and Macbeth Optiview.
3. To develop a model relating the cotton color measurements from IsoTester and two spectrophotometers- Hunter Lab LabScan XE and Macbeth Optiview.
4. To determine the degree of repeatability and reproducibility of the Iso Tester.

HYPOTHESES

The following hypotheses were tested:

1. There is no significant difference in CIE L* among the three instruments
2. There is no significant difference in CIE a* among the three instruments.
3. There is no significance difference in CIE b* among the three instruments.
4. A mathematical model does not predict the relation between cotton color measurements from IsoTester and two spectrophotometers.

ASSUMPTIONS

The following assumptions were associated with this study:

1. Trash on the surface of cotton sample is the representative of the trash in the complete sample because the machine "IsoTester" that was be used, measures trash on the surface of the cotton samples.
2. The Sample is the representative of the bulk.

LIMITATIONS

There were two main limitations to this study:

1. Because trash was removed manually, complete trash removal was not possible.
2. Moisture affects the measurements, and moisture was not controlled in this study.
3. From the pretest conducted on the IsoTester, it was found that the instrument showed zero percentage area for trash particles but the samples still contains trash particles. This observation can be explained by the fact that the area of trash particles is so small that the instrument cannot detect the trash particles. So these infinitely small trash particles still influence the color measurements.

CHAPTER 2

LITERATURE RIVIEW

COTTON FIBER

Mankind has been using the white hairs of cotton seeds for several thousand years to produce many different kinds of textiles, sometimes elaborately decorated. With increasing demand and improved fiber quality, a global textile industry based on cotton developed rapidly. Cotton fiber consists of cellulose, a natural polymer composed of many molecules of the sugar glucose. Its unique structure is ideally suited for textile production. Each fiber is basically a hollow tube a few centimeters in length that, when spun and woven, provides the very special characteristic "feel" of cotton.

Each cotton fiber is composed of concentric layers and a hollow central core is known as the lumen. The outermost layer, known as the cuticle, is thin layer of fats, proteins and waxes. Beneath the cuticle is the primary wall, composed mainly of cellulose in which fibrils are arranged in a criss – cross pattern. Further towards the center is the secondary wall composed of cellulose, which consists the bulk of the fiber. Table 1 (3) lists the percentage composition of the cellulosic and noncellulosic components present in a typical cotton fiber. Cellulose is present as fibrils organized in different layers whereas the noncellulosic substances such as pectin, fats and waxes are largely confined to the outer layers of the fiber.

Table – 1: Raw Cotton Composition (3)

80-90%	Cellulose
6-8%	Water
0.5 - 1%	Waxes and fats
0 - 1.5%	Proteins
4 - 6%	Hemicelluloses and pectin's
1 - 1.8%	Ash

QUALITY MEASUREMENT SYSTEMS

There is a continuous demand for improved cotton fiber quality. Cotton fiber quality is determined by various parameters such as the tearing strength of the cotton fiber, by the overall length and length uniformity of the cotton fibers, color, and trash and by the circumference, maturation and moisture content of the harvested cotton fiber. All these characteristics influence the spinning of the cotton fiber into yarn. Practically all cotton grown in the United States is classed by USDA (7). All instrument measurements currently utilized in USDA cotton classification are from Uster High Volume Instrument (HVI) systems (High Volume Instrument (HVI) is patented by Uster Technologies). Cotton fiber properties primarily of interest in this research were cotton color and trash content.

The USTER® HVI classing is the standard classification system in the United States and also for the international cotton trade. USTER® HVI is used for measurement of the most important cotton fiber properties of micronaire, fiber length (UHML), uniformity, short fiber index, strength, elongation, color, trash content and degree of maturity. HVI classing has been available to all growers since 1981. The fiber properties primarily of interest in this research are cotton color and trash content. The color of cotton is measured by the degree of reflectance (Rd) and yellowness (+b). Reflectance indicates how bright or dull a sample is, and yellowness indicates the degree of color pigment. A three-digit color code is used to indicate the color grade. This color grade is determined by locating the quadrant of the color chart in which the Rd and +b values intersect (4). For example, a sample with an Rd value of 72 and +b value of 9.0 would have a color code of 41-3 (Figure 1). In cotton classification, the color grade of American upland cotton is determined using the HVI Color Chart (instrument measurement), and referenced to color grade standards that are a part of USDA cotton standards. Leaf grade describes the leaf or trash content in the cotton. There are seven official leaf grades for American upland cotton designated as "Leaf Grade 1" through "Leaf Grade 7". They are all represented by official physical standards in the custody of the USDA. In addition, there is a descriptive "Below Leaf Grade Cotton" designation for American upland cotton that is lower in leaf grade than Leaf Grade 7 (4). Other foreign matter such as seed coat fragments, as well as the degree of smoothness or roughness with which cotton is ginned, may all affect the purity of the cotton lint. An HVI trash measurement is also available, although the traditional method of classer determination for leaf grade and extraneous matter continues to be included as part of USDA's official cotton classification.

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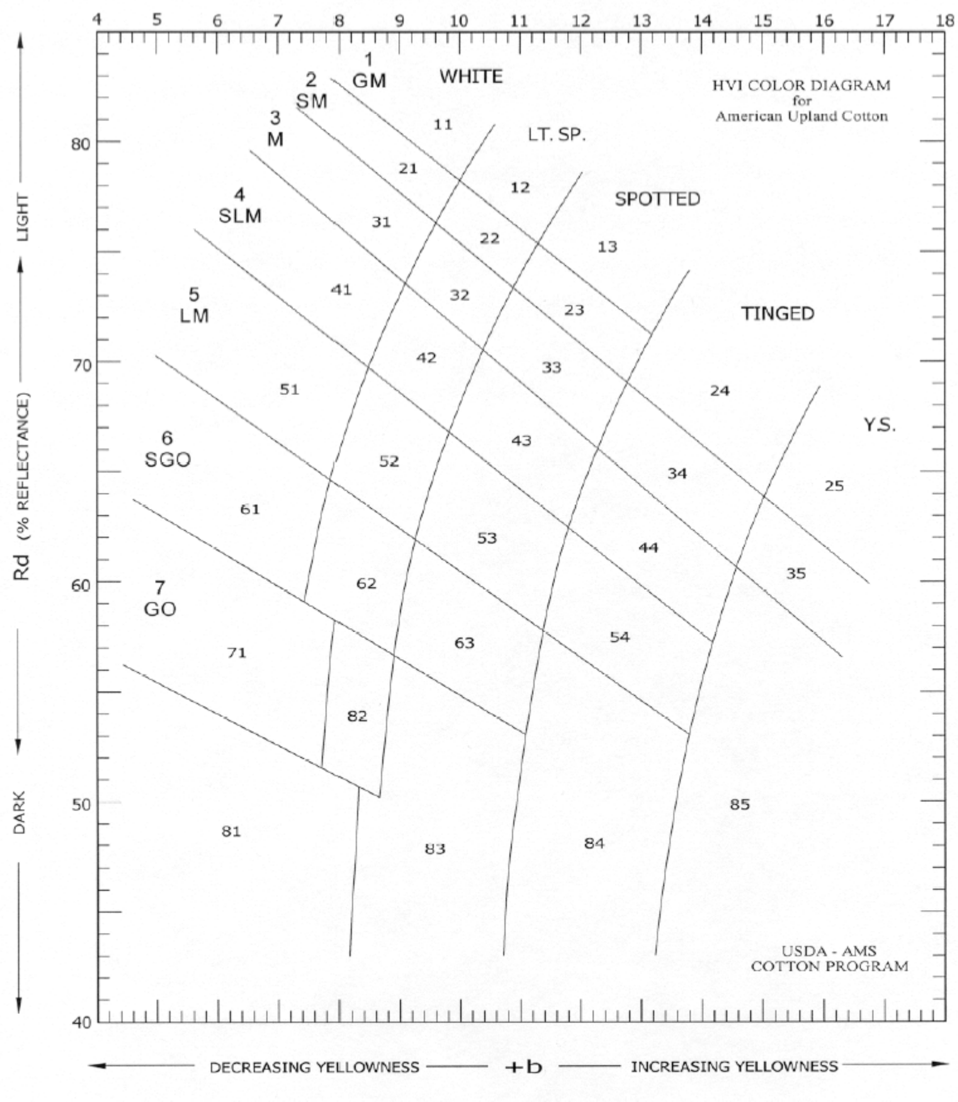

Figure 1: Official color grades for American upland cotton (4)

In this research two cotton fiber properties were investigated, namely – trash content and color. Color of the cotton fibers is also defined in terms of CIE L * a * b*, measured by spectrophotometers. Two spectrophotometers were used – Macbeth Color-Eye 7000A and Hunter Lab Scan. Spectrophotometers measure the reflectance from, or the transmittance through, materials as a function of wavelength. Color Eye 7000A is a bench top spectrophotometer with d/8^{O} sphere illumination geometry, and has the capability to measure both specular and total transmission. It measures reflection at 10nm intervals from 360nm to 750 nm. Four measurement aperture sizes are available to provide versatility in dealing with various sample sizes. Illuminant D65 simulates north sky daylight and is used for general evaluation of color, metamersim testing, providing visual correlation with spectrophotometric instrumental reading, and conformance with European and Japanese standard. Color temperature for D65 is 6500K. Illuminant C simulates the CIE average daylight with color temperature of 6770K (5).

Each color has its own distinct appearance, based on three elements: hue, chroma and value (lightness). By describing a color using these three attributes, it is possible to accurately identify a particular color and distinguish it from any other. In 1905, artist Albert H. Munsell originated a color ordering system - or color scale based on human perception. The Munsell System assigns numerical values to the three properties of color: hue, value and chroma. Adjacent color samples represent equal intervals of visual perception (5).

The CIE, or Commission Internationale de l'Eclairage (translated as the International Commission on Illumination), is the body responsible for international recommendations for photometry and colorimetry. The CIE Color Systems use three coordinates to locate a color in a color space. These color spaces include CIE XYZ, CIE L*a*b* and CIE L*C*h. The CIE Tristimulus Values (XYZ) are calculated from these CIE Standard Observer functions, taking into account the type of illumination and reflectance of the sample. At each wavelength x, y, and z are multiplied by the spectral energy emitted by the light source. Then that value is multiplied by the reflectance of the sample at each wavelength. The values for all the wavelengths are then summed (Figure 2). There are two problems with the specification of colors in terms of tristimulus values and chromaticity space. Firstly, this specification is not easily interpreted in terms of the psychophysical dimensions of color perception namely, brightness, hue, and chroma (5). While Y relates to value (lightness), X and Z do not correlate to hue and chroma. Secondly, the XYZ system and the associated chromaticity diagrams are not perceptually uniform. To overcome these limitations, the CIE recommended two alternate, uniform color scales: CIE 1976 (L*a*b*) and CIE LCH (L*C*h). The latter was intended for use with self-luminous colors while the former was intended for use with opaque surface colors.

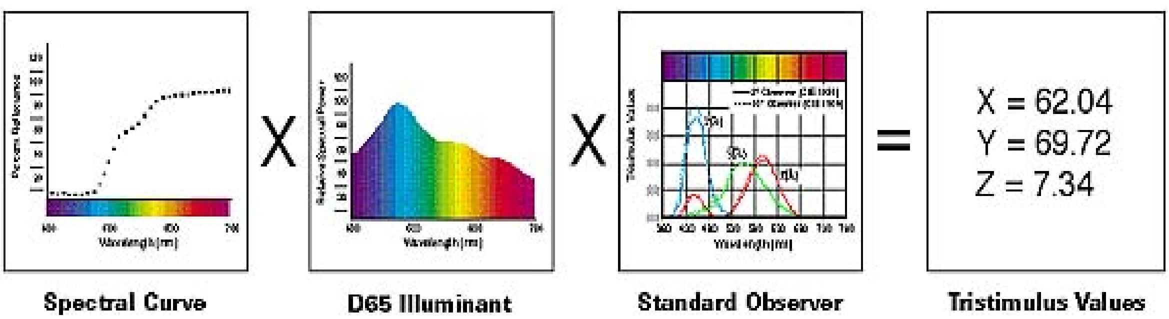

Figure 2: Calculation of Tristimulus values (7)

These color scales are based on the opponent-color theory of color vision (Figure 3). Opponent color theory developed by Ewald Hering (1920/1964) states that there are three opposing color pairs: blue/yellow, red/green, and black/white. Consistent with this theory, no two members of a pair can be seen at the same location, which explains why it is not possible to experience such colors as "bluish yellow" or "reddish green". This theory also helps to explain the after-image effect (if the eye is adapted to a yellow stimulus the removal of the stimulus leaves a blue sensation or after-effect) and the non-intuitive fact that an additive mixture of red and green light gives yellow and not a reddish-green.

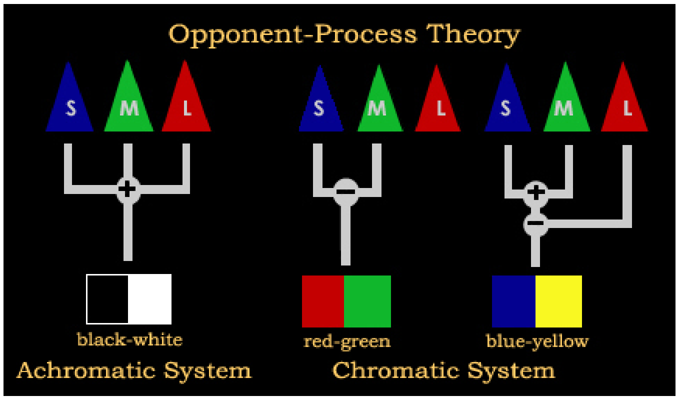

Figure 3: Opponent color theory (9)

CIELAB describes the specification of color perceptions in terms of a three-dimensional space (Figure 4). The L*-axis is known as the lightness and extends from 0 (black) to 100 (white). The other two coordinates a* and b* represents redness-greenness and yellowness-blueness respectively. Samples for which a* = b* = 0 are achromatic and thus the L*-axis represents the achromatic scale of grey from black to white. The quantities L*, a*, and b* are obtained from the tristimulus values according to the following transformations (5):

$L^* = 116(Y/Y_n)^{1/3} - 16,$

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

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

where X_n, Y_n, and Z_n are the values of X, Y, and Z for the illuminant that was used for the calculation of X, Y, and Z of the sample, and the quotients X/X_n,Y/Y_n, and Z/Z_n are all greater than 0.008856. When any of the quotients are less than or equal to 0.008856 a slightly different set of equations is used.

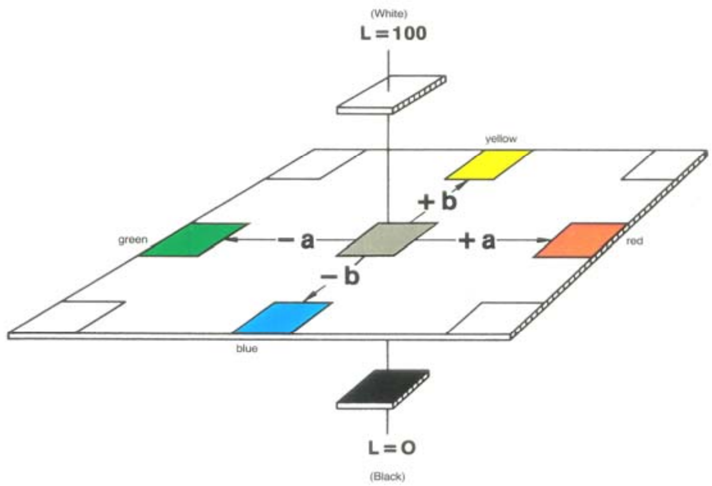

Figure 4: CIE L* a* b* Color space (12)

ISOTESTER: GIN BASED CLASSING INSTRUMENT

Gin-Based Classing, by definition, means classing cotton locally (in gins, warehouses, or mills) and transfer of the fiber quality measurements, including images, over the internet to the government-implemented classing office. The objective of the grading and classing program for cotton is to facilitate interstate and foreign commerce in cotton by providing official quality determinations that aid in marketing. A great progress has been occurring in cotton quality assessment for the last 20 years, during which a transition from human classing to instrumental classing began with the introduction of high volume instrument (HVI) lines being installed in the USDA/ AMS classing office. In 1991 USDA/ AMS added HVI instrumental measurement of fiber quality, in combination with the human classer measurements. The cotton is being classified by instruments, for micronaire, length and strength, and by human classers, for color grade, trash, extraneous matter, and preparation (13). The system, operated by USDA, is one that produces data that are accepted by all segments of the industry for both marketing and utilizing the cotton in the spinning mills. In the current process of classing cotton, bale samples are taken at the gin and sent to USDA classing office (CO), where samples are properly conditioned and tested. The data form that area classing office are sent to the gin and to Memphis to be complied into a national bank of HVI data. With the introduction of many fully automated measurement systems like HVI Spectrum, AFIS, Fiber Lab, IsoTester, Premier Automated Rapid Tester (ART), the concept of classing cotton at the gin is envisioned. Approximately 7 % of the US gins have invested in process monitoring and process control technology, so the first step towards Gin-based classing have already been made (14). These gins maximize the added value for their Producers, yielding them on average 1.5 cents/pound and they provide better fiber and added value for their Merchant and Spinner Customers (14). Technological advances in computers, networks, Internet, and image-based measurement technology are in place to support Gin-based Classing (GBC). Since trash is one of the fiber qualities most influenced by the gin, GBC can move forward rapidly when the Human Classer is replaced with the instrument.

Schaffner Technologies developed the IsoTester and GinWizard System based on the long term vision that Gin-based classing will be implemented by 2020 (Table 2). IsoTester, the new name for the predecessor RapidTester, is a stand-alone instrument capable of measuring color, trash, final bale moisture and length of cotton samples. Gin Wizard is a process monitoring system and software program that can acquire and present fiber quality data from IsoTester and as many gin processing parameters as desired. IsoTester robust design and its ability to operate in any environment, particularly gins, in combination with GinWizard enables gins to perform better job by controlling the amount of leaf, moisture, and length to avoid the discounts for the producers and to provide higher quality and more useable fiber to the mill.

Iso Tester utilizes advanced digital image scanning algorithm for color, trash bark and grass, and length measurements. Due to the size of the sample area, $64in^2$, the IsoTester utilizes larger area than any other device for testing color and trash. Another advantage of the Iso Tester color and trash module is the utilization of the physical USDA color grades samples (18). By utilizing the USDA samples the machine requires no calibration. The trash module software evaluates the same representative digital image for trash, as color, using segmentation and pattern recognition. This image based system will certainly improve the measurement of important fiber qualities over current methods and will accelerate replacement of the human classer measurements with instrumental measurements. This instrument have smaller footprint than HVI (high volume instrument) as shown in figure 5.

Figure 5: IsoTester

Table 2: Fiber quality data for classing purposes (13)

1980 Pre HVI	2000 Current USDA - AMS	2020
Human Measurements		
Grade Extraneous Matter Preparation Stable	Color grade Leaf grade Extraneous Matter Preparation	
Instrumental measurements		
Micronaire	Micronaire Length UHM LU Strength Tenacity Color Rd, +b HVI color grade Trash % area HVI leaf grade)	Micronaire Length UHM LU SFC Strength Tenacity Elongation Color CIE l* a* b* Color grade Trash % area Size, shape, color Type (extraneous matter) Moisture content Stickiness Maturity (fineness)

REPEATABILITY AND REPRODUCIBILITY (R&R)

Whether in a laboratory or a production line, taking measurements is a necessary part of any process or system. An adequate level of precision of the system is critical as it determines the capacity of the system to detect differences between the parts, samples, etc. It is therefore necessary to quantify the detection capability of the measurement process which is achieved by quantifying the variability therein. The total variation can be further decomposed into variation due to the instrument, variation due to the operators and variation due to the parts or samples**.** Although variations in the system can be caused by many different phenomena such as calibration error, stability and linearity of the instrument, typical R&R studies focus on the evaluation of repeatability and reproducibility of the process.

The main objectives in performing an R&R study are to identify and quantify the absolute and relative contribution of each source of variation, to decide if the measurement process is adequate or not and, if not, to correct the errors by recalibrating the instrument, training the operators, other mathematical corrections, etc. Repeatability and Reproducibility (R&R) studies analyses operator variation (repeatability) and Gage variation (reproducibility). Repeatability is the variation when an operator measures the same sample with same gage several times. Reproducibility is the additional variation observed when several operators use the same gage to measure the same sample (16). The combination of both sources of variation is referred as R&R. The term gage refers to any device used to make measurements and it refers to IsoTester in this work.

CHAPTER 3

METHODS AND PROCEDURE

MATERIALS

Cotton samples used in this research were a part of the OVT (Official Variety Trial) conducted at the UGA Department of Crop and Soil Sciences in Tifton, Georgia. Spectrophotometers used in this research were Macbeth Color-Eye 7000A and Hunter Lab Scan. The IsoTester, a gin based classing instrument, was used for all cotton measurements.

PROCEDURE

To investigate the effect of trash removal on the color of cotton fibers, samples from five different varieties of cotton were analyzed and for each sample three replications were performed. The varieties that were studied include FM 991RR, ST5599BR, DP424BII/R, ST4793RR, T5599B/R, DP555B/RR, FM966LL, SG521RR and DELTAPEARL. For each sample, cotton color was measured before and after trash removal and the change in CIE L* a* b* was studied. To study the cotton color data from three different color measuring instruments and to develop a model, samples from 15 different varieties of cotton were analyzed and for each sample five replications were performed. For all the color measurements, illuminants D65 and C were used at 10^{o} observer.

Repeatability and Reproducibility of IsoTester was analyzed by ANOVA method as described by Engineered Software Inc., Belleville, MI (16). Different fields often have different incentives for performing R&R studies and there are different methods for performing R&R

study depending on the depth of understanding of the measurement performance required. The R&R can be measured by using the following methods.

1. The Range Method
2. The Range Average Method
3. The ANOVA method

The range method provides a quick approximation of measurement variability, whereas the average and range method will determine both repeatability and reproducibility for a measurement system. The ANOVA method is preferred to the average range method. The ANOVA method quantifies the interaction between repeatability and reproducibility, and is considered to be more accurate than the average and range method. In this R&R study of IsoTester, ANOVA method as described by Engineered Software Inc., Belleville, MI, was used. When conducting a study, the recommended procedure is to use 10 parts, 3 appraisers and 2 trials, for a total of 60 measurements (16). The ANOVA design used is a two-way, fixed effects model with replications. From the table 3,

Repeatability = $5.15 \sqrt{MSE}$

Reproducibility = $5.15 \sqrt{(MSA - MSAB)/bn}$

The interaction between the appraisers and the parts is

$I = 5.15 \sqrt{(MSAB - MSE)/n}$

The measurement system repeatability and repeatability is

$R \& R = \sqrt{(Repeatability^2 + Reproducibility^2 + I^2)}$

The guidelines for acceptance of Gauge Repeatability and Reproducibility (% R & R) are (17):

1. Less than 10% error - The measurement system is acceptable.

2. 10% - 30% error - May be acceptable depending on factors like the importance of the application, the cost of the gauge, the cost of repair to the measurement system etc.
3. Over 30% error - The measurement system needs improvement

Table 3: ANOVA table (16)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F Statistic
Appraiser	SSA	a-1	$MSA = \frac{SSA}{a-1}$	$F = \frac{MSA}{MSE}$
Parts	SSB	b-1	$MSB = \frac{SSB}{b-1}$	$F = \frac{MSB}{MSE}$
Interaction (Appraiser, Parts)	SSAB	(a-1)(b-1)	$MSAB = \frac{SSAB}{(a-1)(b-1)}$	$F = \frac{MSAB}{MSE}$
Gage (Error)	SSE	ab(n-1)	$MSE = \frac{SSE}{ab(n-1)}$	
Total	TSS	N-1		

a = number of appraisers,
b = number parts,
n = the number of trials, and
N = total number of readings (abn)

CHAPTER 4

RESULTS AND DISCUSSION

The data obtained from three different color measurement systems, IsoTester, Macbeth Color eye 7000A and LabScan XE, were analyzed by regression analysis. The regression analysis shows that the CIE L*, a* and b* values of cotton fiber were affected by the type of color measurement system used. This can easily be explained on the basis of the different techniques employed in these instruments for measuring color of the sample. MacBeth 7000A and LabScan XE have different optical geometry. The term "geometry" refers to the placement of a sample relative to the light source and measuring lens in a spectrophotometer. MacBeth 7000A has Diffuse/8° geometry while labscan has $0/45^0$ geometry. For the tested samples, the value of CIE L* from isotester ranged from 89.78 to 93.26, for macbeth this range was from 83.79 to 87.66 and for labscan CIE L* was from 81.25 to 84.82. CIE a* reading from isotester ranged from 0.50 to 0.86, for macbeth this value was from 0.48 to 1.20 and for labscan, CIE a* was from 0.70 to 1.41. CIE b* value from isotester was from 9.68 to 13.22, for macbeth this value was from 6.76 - 9.31 and for labscan the value was from 8.30 to 10.66. For the complete CIE L* a* b* data values from the three machines, refer to appendix A.

Regression analysis with color measuring system as independent variable and CIE L*, a* and b* as dependent variables, were done to find out whether color measuring instrument significantly affects CIE L*, a* and b* value of the cotton fiber. A model was developed to predict the color value from IsoTester given the values from the two spectrophotometers. The models were in the form as shown below:

$L^*_{Iso} = \alpha + \beta_1 L^*_{Mac} + \beta_2 L^*_{Lab}$

$a^*_{Iso} = \alpha + \beta_1 a^*_{Mac} + \beta_2 a^*_{Lab}$

$b^*_{Iso} = \alpha + \beta_1 b^*_{Mac} + \beta_2 b^*_{Lab}$

Regression analysis between the CIE L* and color measuring system was done to analyze the effect of color measuring system used on CIE L*. Regression analysis shows that CIE L* of cotton fiber was affected by the type of color measuring system used (Table 4). R square of the linear model is .92, indicating that 92 % of the variation in the CIE L* value could be attributed to the type of color measuring system used.

Table 4: Regression Analysis of CIE L*

Source	DF	Sum of Squares	Mean Square	F value	Pr> F
Model	2	19.74049	9.87024	77.23	<.0001
Error	12	1.53355	0.12780		
Corrected Total	14	21.83653			

Root MSE	0.35749	R Square	0.9279
Dependent Mean	91.85800	Adj. R Square	0.9159
Coeff of Variation	0.38917		

Variable	DF	Parameter Estimate	Standard Error	t - value	Pr > |t|
Intercept	1	-0.98793	8.10340	-0.12	0.9050
L2	1	0.13469	0.12125	1.11	0.2884
L3	1	0.97524	0.11674	8.35	<.0001

L2 = CIE L* from MacBeth

L3 = CIE L* from LabScan

The model to predict the value of CIE L* from IsoTester, given the corresponding values from spectrophotometers, is

$L^*_{Iso} = - 0.98793 + 0.13469\ L^*_{Mac} + 0.97524\ L^*_{Lab}$

A second regression analysis, with color measuring system as independent variable and CIE b* as a dependent variable, was done to find out whether color measuring instrument affects CIE b* value of the cotton fiber. The results are shown in table 5. Since the p value is 0.0001 and R – square value is 0.91, the CIE b* value of the cotton fiber was found to be significantly affected by color measuring system.

Table 5: Regression Analysis of CIE b*

Source	DF	Sum of Squares	Mean Square	F value	Pr> F
Model	2	19.92763	9.96381	62.64	<.0001
Error	12	1.90891	0.15908		
Corrected Total	14	21.83653			

Root MSE	0.39884	R Square	0.9126
Dependent Mean	11.71333	Adj. R Square	0.8980
Coeff of Variation	3.40503		

Variable	DF	Parameter Estimate	Standard Error	t - value	Pr > |t|
Intercept	1	-0.00979	1.11743	-0.01	0.9932
b2	1	1.40256	0.26042	5.39	0.0002
b3	1	0.02423	0.23484	0.10	0.9195

b2 = CIE b* from Macbeth

b3 = CIE b* from LabScan

The model to predict the IsoTester CIE b* value from the corresponding values from spectrophotometers, is

$b^*_{Iso} = -0.00979 + 1.40256\ b^*_{Mac} + 0.02423\ b^*_{Lab}$

The results of the regression analysis, with color measuring instrument as independent variable and CIE a* of the cotton fiber, are shown in table 6

Table 6: Regression Analysis of CIE a*

Source	DF	Sum of Squares	Mean Square	F value	Pr> F
Model	6	0.07470	0.01245	3.14	0.0690
Error	8	0.03174	0.00397		
Corrected Total	14	0.10644			

Root MSE	0.06299	R Square	0.7018
Dependent Mean	0.68200	Adj. R Square	0.4782
Coeff of Variation	9.23574		

Variable	DF	Parameter Estimate	Standard Error	t - value	Pr > |t|
Intercept	1	143.87118	138.94187	1.04	0.3307
a2	1	74.15626	178.23073	0.98	0.3571
Ra2	1	-13.81762	11.31843	-1.22	0.2569
Sa2	1	-21.59107	24.68977	-0.87	0.4073
Qa2	1	-289.93583	279.91557	-1.04	0.3306
Qa3	1	5.64558	3.15349	1.79	0.1112
Ra3	1	2.13645	1.73532	1.23	0.2532

a1 = CIE a* from IsoTester

a2 = CIE a* from Macbeth

a3 = CIE a* from LabScan

Ra2 = 1/a2, Sa2 = a2*a2, Qa2 = √a2, Ra3 = 1/a3, Qa3 = √a3

The model to predict the IsoTester CIE b* value from the corresponding values from spectrophotometers, is

$$a_{Iso} = 143.87118 + 74.15626\, a_{Mac} - 13.81762\, (1/a_{Mac}) - 21.59107\, (a_{Mac} \times a_{Mac})$$

$$- 289.93583(\sqrt{a_{Mac}}) + 5.64558\, (\sqrt{a_{Lab}}) + 2.13645\, (1/a_{Lab})$$

From the tables 4, 5 and 6 and corresponding models, it can be concluded that the CIE L* and b* values can be predicted easily as compared with CIE a* values. The predicted values of CIE L*, a* and b* from these models and the original values of the analyzed samples, are given in appendix B.

Repeatability and Reproducibility (R&R) of IsoTester was analyzed by ANOVA method as described by Engineered Software Inc. R&R of IsoTester was measured for CIE L* and CIE a* of cotton fiber. ANOVA for R&R analysis of CIE L* is shown in table 7.

Table 7: The measurement system repeatability and repeatability of Isotester for CIE L*

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F Statistic
Appraiser	2	0.58533333	0.29266667	4.25
Part	9	84.83150000	9.42572222	136.94
Interaction	18	1.8080000	0.10044444	1.46
Gage (error)	30	2.06500000	0.06883333	
Total	59	89.28983333		

From the above table,

Repeatability = $5.15 \sqrt{.06883} = 1.35$

Reproducibility = $5.15 \sqrt{\{(.2926 - 0.1004)/ 10(2)\}} = 0.504$

Interaction = $5.15 \sqrt{\{(0.1004-.06883)/2\}} = 0.6470$

R & R = $\sqrt{(\text{Repeatability}^2 + \text{Reproducibility}^2 + I^2)} = \sqrt{(1.8225+ 0.254+0.4186)}$

$R \& R_{CIE\ L*} = 1.58$

The measurement system repeatability and repeatability for CIE a* is shown in table 8

Table 8: Measurement system repeatability and repeatability of IsoTester for CIE a*

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F Statistic
Appraiser	2	0.01633333	0.00816667	4.08
Part	9	0.60600000	0.06733333	33.67
Interaction	18	0.0470000	0.00261111	1.31
Gage (error)	30	0.06000000	0.00200000	
Total	59	0.72933333		

Repeatability = $5.15 \sqrt{0.002} = 0.23$

Reproducibility = $5.15 \sqrt{\{(.0081 - 0.0026)/ 10(2)\}} = 0.085$

Interaction = $5.15 \sqrt{\{(0.0026-0.002)/2\}} = 0.001545$

The measurement system repeatability and repeatability for CIE a* is

$R \& R = \sqrt{(0.0529+ 0.007225+0.0000023)}$

$R \& R_{CIE\ a*} = 0.353$

Table 9 shows the effect of trash removal on CIE L* a* b*. After trash removal, the samples becomes lighter as indicated by change in CIE L* values. Samples 1, 2 and 4 became more yellow as CIE b* is increased after trash is removed but more samples need to be analyzed before making any conclusions.

Table 9: Affect of trash particles on CIE L* a*b*

	Original				After Trash removal			
	% Trash	L*	a*	b*	% Trash	L*	a*	b*
1	0.41	94.5	-0.1	13.1	0.02	95.1	-0.4	13.6
2	0.56	92	-0.3	14.3	0.06	92	0.2	15
3	0.38	93.5	-0.2	14.1	0.22	93.7	-0.5	13.2
4	0.51	92.1	-0.2	13.1	0.27	92.1	-0.2	14.2

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study showed that there were prominent differences among the CIE L* a* b* values measured from the three color measuring instruments.

Based on the original hypotheses, the conclusions are:

1. Hypothesis one, that there is no significance difference in CIE L* among the three instruments, is rejected.
2. Hypothesis two, that there is no significance difference in CIE a* among the three instruments, is rejected.
3. Hypothesis three, that there is no significance difference in CIE b* among the three instruments, is rejected.
4. Hypothesis four, that a mathematical model does not predict the relation between cotton color measurements from IsoTester and two spectrophotometers, is rejected.

After trash removal, CIE L* increased, as anticipated. More samples need to be analyzed for statistical inference.

The results of this project have indicated the need for further research. This research can be extended to compare HVI color data with IsoTester data. It will be of interest because all instruments currently utilized in USDA cotton classification are from Uster High Volume Instrument (HVI) systems (High Volume Instrument (HVI) is patented by Uster Technologies).

Also, for future work, this research could be made more specific by comparing Tristimulus values (X, Y, Z) of cotton color from the different color measurement systems. A further recommendation would be to conduct a research project designed to analyze and compare the cotton fiber properties from HVI and newly fully automated measurement systems like HVI Spectrum, AFIS, Fiber Lab, IsoTester, Premier Automated Rapid Tester (ART). This project can give some significant results that will help the cotton industry in the proposed change from current HVI measurements to newly introduced gin based classing machines like IsoTester, HVI spectrum, Premier Automated Rapid Tester.

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Appendix A: CIE L* a* b* data of cotton fiber from three color measurement systems

S. No.	CIE L*		
	IsoTester	MacBeth	LabScan XE
1	92.44	85.97	84.03
2	92.68	85.54	84.10
3	93.26	85.14	84.47
4	92.22	85.62	83.18
5	92.86	86.50	84.20
6	92.76	86.69	84.82
7	92.72	87.13	84.33
8	93.02	86.29	83.96
9	93.16	87.66	84.41
10	90.84	84.26	82.90
11	90.29	83.97	82.33
12	89.78	85.05	81.25
13	90.86	84.28	82.48
14	90.54	85.12	82.04
15	90.44	85.62	82.10

S. No.	CIE a*		
	IsoTester	MacBeth	LabScan XE
1	0.86	1.20	1.41
2	0.66	0.80	1.21
3	0.8	0.91	1.28
4	0.74	0.93	1.25
5	0.68	0.85	1.16
6	0.72	0.75	1.05
7	0.74	0.96	1.23
8	0.50	0.92	1.14
9	0.58	0.89	1.11
10	0.62	0.48	0.70
11	0.71	0.55	0.76
12	0.64	0.79	1.05
13	0.66	0.51	0.76
14	0.68	0.63	0.80
15	0.64	0.659	0.88

S. No.	CIE b*		
	IsoTester	MacBeth	LabScan XE
1	12.86	9.31	10.66
2	13.06	8.77	10.67
3	12.6	8.48	10.28
4	13.22	9.01	10.46
5	12.72	8.55	8.48
6	11.58	8.11	9.78
7	12.4	8.92	10.18
8	12.66	8.74	10.28
9	12.34	8.85	10.27
10	9.68	6.76	8.34
11	10.12	6.91	8.30
12	11.54	8.31	9.77
13	10.00	6.90	8.48
14	10.26	7.48	8.56
15	10.66	7.78	8.95

Appendix B: Experimental data for measuring Repeatability and Reproducibility of IsoTester for CIE L* of cotton fibers

	Operator					
	A		B		C	
Part	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	90.9	90.7	90.1	90.3	90.5	90.1
2	91.3	91.4	91.6	91.3	91.2	90.8
3	90.1	90.6	90.3	90.1	90.1	90.1
4	91.8	91.5	91.7	91.5	91.7	91.7
5	93.6	93.5	93.3	92.4	92.7	93.5
6	92.9	92.9	93.4	93.2	92.7	92.8
7	92.8	93.3	93	93.2	92.2	92.9
8	93.9	93.6	93.6	93.6	93.6	93.7
9	93.2	93.4	93.7	93.5	93.4	92.6
10	92.7	92.8	92.9	93.2	92.0	93.0

Appendix C: The effect of trash removal on CIE L* a* b* value of cotton fiber

	Original sample				Sample after trash removal			
	% Trash	L*	a*	b*	% Trash	L*	a*	b*
PM2200B-TX	0.41	94.5	-0.1	13.1	0.02	95.1	-0.4	13.6
PM 819BRS	0.56	92	-0.3	14.3	0.06	92	0.2	15
CFM966BTX	0.38	93.5	-0.2	14.1	0.22	93.7	-0.5	13.2
FM958RS	0.51	92.1	-0.2	13.1	0.27	92.1	-0.2	14.2