The *Journal of Cotton Science 14:240–250 (2010)*
http://journal.cotton.org, © The Cotton Foundation 2010

TEXTILE TECHNOLOGY

Minimization of Operational Impacts on Spectrophotometer Color Measurements for Cotton

James Rodgers*, Sho Yeung Kang, Chanel Fortier, Xiaoliang Cui, Christopher Delhom and James Knowlton

ABSTRACT

Cotton fiber in the U.S. is classified for color with the Uster® HVI, using the parameters Rd and +b. Rd and +b are specific to cotton fiber and are not typical globally recognized color systems. An earlier program established and validated the feasibility of correlating HVI Rd and +b to the globally recognized color system L*a*b*, available on most commercial spectrophotometers. For cotton fiber measurements, glass placed between the sample and the spectrophotometer measurement port is recommended. A program was implemented to 1) investigate in detail the impacts of key operational and instrumental parameters on spectrophotometer color measurements applicable to cotton fiber, with emphasis on instrument specular component, glass use, and pressure on the fiber; 2) determine the feasibility of minimizing the major impacts; and 3) develop uniform protocols for measuring cotton fiber on spectrophotometers. Evaluations were made on AMS standard tiles, AMS cotton biscuits, and loose cotton samples. The major impact on spectrophotometer color results was glass use, with the glass impact increasing with increasing glass thickness. L* was the color parameter most impacted by glass use, specular component, and applied fiber pressure. The optimum applied pressure for color measurements on small portions of loose cotton fibers was 30 pounds per square inch gauge. Protocols for minimizing glass impacts on spectrophotometer color measurements and for pressurized fiber measurements were determined, with the best overall results obtained with the use of specular component included, glass with glass calibration, and constant applied pressure for fiber measurements.

J. Rodgers*, S.Y. Kang, C. Fortier, X. Cui, and C. Delhom, USDA-ARS-Southern Regional Research Center, 1100 Robert E. Lee Blvd., New Orleans, LA 70124; J. Knowlton, USDA-AMS-Cotton and Tobacco Program, 3275 Appling Road, Memphis, TN 38133.
*Corresponding author: james.rodgers@ars.usda.gov

Color is often viewed as the interaction and combination of three components—a light source, an illuminated object, and the eye/observer or some form of visual system (Berns, 2000; Hunter, 1975). For humans, the observed or perceived color of an object is the reflected light from the sample's surface that is observed by the eye in the visible color spectral region of electromagnetic radiation. This visible region for the human eye is normally considered to be between 400 nm (violet) and 700 nm (red).

The three components of the visual system are converted from visual color to instrument color through the mathematical combination of the spectra of an illuminant (light source), the object, and a spectral matching function (Anonymous, 2000; Berns, 2000). There are two broad classes of instrumentation that provide instrumental color for fibers and other materials—colorimeters and spectrophotometers. Colorimeters are instruments in which the object's color is determined with two, three, or more broad-band filters located between the 400 nm to 700 nm spectral region; spectrophotometers are instruments in which the object's color is determined by measuring the entire spectral region in small increments (10 nm or smaller).

Instrumental color measurements yield a set of numbers that are representative of the total reflectance spectrum from the object's surface and are an indication of the object's "color." In most cases, the instrumental color of an object is represented as a 3-dimensional or tristimulus color space system (xyz axes) (Anonymous, 2000; Berns, 2000; Judd and Wyszecki, 1975; Ohno, 2000). Using algorithms from the Commission on Illumination (CIE), the color results from color instruments can be converted into the CIE XYZ tristimulus values (often called the XYZ color space system) for an object. It was found that nonlinear transformations of CIE

XYZ resulted in improved perception of color and agreement between instrumental color results and human observers. One global color system derived from CIE XYZ is CIELab or L*a*b*. L*a*b* is often used for fibers and textiles. L* denotes the lightness or darkness of a sample and is valued from 0 to 100 (the higher the L*value, the "whiter" or "lighter" the sample); a* denotes the redness or greenness of a sample (the higher the a* value, the "redder" the sample; the lower the a* value, the "greener" the sample); and b* denotes the blueness or yellowness of a sample (the higher the b* value, the "yellower" the sample; the lower the b* value, the "bluer" the sample) (Berns, 2000; Hunter, 1975; Judd and Wyszecki, 1975; Ohno, 2000). Color difference between L*a*b* results are expressed by DE^*_{ab} (equation 1), which is the square root of the square of the differences in L* (DL*), in a*(Da*), and in b*(Db*) between a reference unit or system and the unit or system being compared.

$$DE^*_{ab} = \sqrt{(DL^*)^2 + (Da^*)^2 + (Db^*)^2} \qquad (1)$$

When DE^*_{ab} is greater than 1.0, a color difference is considered to be significant (Berger-Schunn, 1994).

The Uster® High Volume Instrumentation (HVI, Uster Technologies AG, Uster, Switzerland) is used to class cotton produced in the U.S. The HVI utilizes a cotton colorimeter, in which two broad-band filters are used to obtain the cotton color parameters Rd and +b (2-dimensional color system). Rd is the diffuse reflectance from the fiber sample's surface, and +b is the yellowness of the sample. The higher the Rd value, the greater the reflectance of light from the sample's surface; the higher the +b value, the more yellow the sample. The two broad-band filters used in the HVI cover only two specific regions of the visible spectrum—not the entire visible spectral region. The Agricultural Marketing Service (AMS) of the United States Department of Agriculture (USDA) supplies two sets of color standards for color measurements, each sample has been measured on the AMS master colorimeter for its standard Rd and +b value—a set of five ceramic tiles and a set of 12 uniform cotton "biscuits".

Rd and +b are cotton-specific color terms, resulting from research that began in the 1930s by Nickerson and colleagues (Nickerson, 1931; Nickerson et al., 1950). An instrument using Rd and +b to grade cotton was developed in 1948, and the transition to Rd and +b for instrument measurement of cotton fiber color began. Rd and +b have performed well as an instrument measurement of cotton color, but several areas for improvements exist. For example, Rd and +b do not readily relate to other well known and globally recognized color systems that are based on 3-dimensional tristimulus color (e.g., L*a*b*); their measurement does not cover the entire spectral region (e.g., does not represent the entire region from 400-700 nm); and there is no National Institute of Standards and Technology (NIST)-like traceability or means to certify/verify the color results for the AMS standard tiles or standard cotton biscuits measured on the two-filter HVI with Rd and +b. Modern color spectrophotometers use the full visible spectral region (400-700 nm, minimum), use globally recognized color spaces, and have NIST-traceable standards. Therefore, the use of modern spectrophotometers on cotton in research could lead to improved overall color analysis systems and protocols for cotton fibers that could be used to complement and strengthen the present HVI cotton color system.

Previous evaluations were performed with numerous bench-top and portable color spectrophotometers in which the relationships between HVI Rd and +b color results and spectrophotometer L*a*b* color results were determined for color tiles, AMS standard tiles, and AMS cotton biscuits. These evaluations established and validated strong L*↔Rd and b*↔+b correlations between the spectrophotometers and the HVI for tiles and cottons (Rodgers et al., 2008, 2009; Thibodeaux et al., 2008). The Rodgers evaluations also investigated the impact of glass use. The use of glass, in which a glass plate of specified thickness is placed between the sample and the spectrophotometer port, is required for cotton fiber measurements to obtain a consistent sample surface and to prevent contamination of the spectrophotometer with loose cotton fiber. Evaluations were performed with and without glass on the tile samples to determine the impact of glass use, using a 6-mm thick HVI glass. Color unit agreement was good ($DE^*_{ab} < 1.0$ normally) between the bench-top units and fair-to-good for the portable units for AMS tiles when an HVI glass was not placed in front of the tile sample at the measurement port. Glass use resulted in significant decreases in between-instrument color agreement ($DE^*_{ab} > 1.0$ for most samples) for both bench-top and portable color instruments, with between-instrument agreement for cotton being worse than the agreement for tiles. L* was the spectrophotometer color parameter most impacted by HVI glass use. However, whether glass was or was not used, the linear relationships for L*↔Rd and b*↔+b on the different bench-top spectrophotometers were similar. Similar glass impacts and L*↔Rd slope results were observed by Shofner and colleagues (2006) between the IsoTester digital color system, automatic color and trash station (ACTS), and a bench-top spectrophotometer.

The previous evaluations demonstrated the need for a more detailed study of major operational and instrumental parameters that could impact spectrophotometer L*a*b* results and the need to develop protocols to minimize these impacts. A program was implemented to 1) investigate in detail the impacts of key operational and instrumental parameters on spectrophotometer color measurements applicable to cotton fiber, with emphasis on instrument specular component, glass use, and pressure on the fiber; 2) determine the feasibility of minimizing the major impacts; and 3) develop uniform protocols for measuring cotton fiber on spectrophotometers. The program was a joint project of the AMS Cotton Program, Cotton Incorporated, and the Cotton Structure & Quality (CSQ) research unit with the Southern Regional Research Center of the Agricultural Research Service-USDA (CSQ/SRRC-ARS-USDA).

MATERIALS AND METHODS

The instrumental and operational variables evaluated for their impact on color spectrophotometer results for tiles and cottons were instrument specular component, glass use and glass type, and applied pressure on the fiber. All tile and cotton samples were measured on the bench-top Gretag MacBeth CE7000A (X-Rite, Inc., Grand Rapids, MI, USA) color spectrophotometer at the Materials Testing Laboratory of the CSQ/SRRC-ARS-USDA. Each sample was measured five times with the spectrophotometer settings of illuminant D65, 10° observer, and large area of view (LAV, 25 mm sample port).

For the specular component portion of this study, the samples used consisted of two sets of AMS standard ceramic tiles (five tiles per set). Each tile sample was measured without glass (tile samples placed directly against the spectrophotometer port) with the specular component excluded (SCE) and included (SCI) settings.

For the glass use and glass type components of this study, the samples used consisted of two sets of AMS standard ceramic tiles (five tiles per set) and two boxes of AMS standard cotton biscuits (approximately 5” × 6.5” rectangle of cotton, 12 biscuits per box). Each tile sample was measured with glass (a glass plate was placed between the sample and the spectrophotometer port) and without glass, and the cotton samples were measured with glass only. Two types of glass plate were used in these evaluations—an ~6-mm thick HVI glass and a 1-mm thick microscope slide. Four conditions of glass use were employed to evaluate the impact of glass on the color results—no glass use, standard glass use, glass use with a glass correction factor (X-Rite), and glass use with a glass calibration (instrument calibrated with the glass). In normal operation, the spectrophotometer is calibrated with its standard tile, and no glass is used in the calibration (sample placed directly against the sampling/measurement port). This was the calibration method used for the no glass use/without glass and standard glass use/with glass conditions. The same basic calibration method was used for the glass correction factor/with glass condition, except that the glass correction algorithm in the X-Rite software is activated after the standard calibration is complete. The algorithm provides an overall glass correction to SCI color measurements [the same for all thin glasses; no correction for different glass parameters (quality, thickness, etc.)] to minimize the effects of the internal reflection of light and its impacts on color results (Laidlaw, 2001; Stearns, 1969). For the glass use with a glass calibration condition, the instrument is calibrated with the glass between the standard tile and the measurement port.

Pressure impacts on the color measurements were made for cottons only and for small portions of loose cotton fibers randomly oriented (loose cotton fiber) using the HunterLab fiber compression cell (HunterLab Associates, Reston, VA). At this time, a hydraulic sampling system to uniformly apply pressure to large cotton fiber samples (e.g., AMS standard cotton biscuits) is not commercially available, so all applied pressure evaluations on fibers were performed with the HunterLab pressure cell on small portions of well-defined loose cotton fibers. The samples used consisted of a set of five domestic and five international cotton samples. Each sample was measured five times with SCE and SCI. For each sample, a sample of 3.0 ± 0.5 g of fiber was placed into the HunterLab compression cell, the color measurement performed, and the sample reloaded four more times (n = 5 for each sample). Color measurements were made from 10 to 40 psig (pounds per square inch, gauge) in increments of 10 psig.

The spectrophotometer color results for each operational and instrumental variable of interest were compared by L*, a*, b*, and DE^*_{ab} for each sample. As noted earlier, DE^*_{ab} evaluates the total color change or difference between samples or instrumental/operational parameters of interest for all three color coordinates (3-dimensional color space). In general, a significant color change was considered to have occurred when DE^*_{ab} is >1.0 (Berger-Schunn, 1994). Statistical analyses were based primarily on DE^*_{ab}, and significant differences in DE^*_{ab} were denoted at $DE^*_{ab} > 1.0$.

For the applied pressure evaluation, the L*a*b* color results for each sample were compared as the pressure applied to the fiber increased from 10 to 40 psig. The pressure at which the specific color parameter reached a plateau (minimal increase or cycling in color result with increasing applied pressure) was considered the pressure at which the pressure impact (change in color parameters L*, a*, and b* with each 10 psig pressure increment) on fiber samples was considered minimal and not significant (less than one DE* increase with increasing 10 psig pressure intervals for L*, a*, b*).

RESULTS AND DISCUSSION

Specular Component Evaluations. In color measurements, one can measure the color of an object with the specular component (gloss component of reflected light) either excluded (sample's color) or included (sample's appearance). The impact of spectrophotometer specular component on tile color results was evaluated, without the use of glass. In general, the SCI and SCE results were in overall good agreement and tracked each other. The SCI color measurements normally yielded higher L*, slightly lower a*, and lower b* results compared to the SCE color results. L* was the color parameter most impacted by specular component (Fig. 1 and Table 1).

Glass Impacts Evaluations: Impact on SCE and SCI Measurements. In this study, the impacts of glass use on the overall spectrophotometer color results, to include the impacts on SCI and SCE measurements, were evaluated using the AMS standard tiles and HVI glass (6-mm thick). The largest differences between the SCE and SCI results occurred when glass was used in the measurement, with the largest impact for L* (Table 2). The results indicated that the glass impact is much higher for the SCE measurements compared to the SCI measurements for the AMS tiles. The use of SCI tended to minimize the glass impact by approximately 50% (based on DE^*_{ab}) for the AMS tiles evaluated. (Fig. 2, Table 2). It is reasonable to assume that the improvements in glass impact minimization observed for SCI measurements on tiles would extend to cotton fiber spectrophotometer color measurements. Based on the above SCE-SCI results and the results from the glass impact study on SCI-SCE, SCI is recommended for use for cotton fiber spectrophotometer color measurements. The impact of glass use on spectrophotometer color results was significantly greater than the impact of specular component on color results (Figs. 1 and 2, Tables 1 and 2). For example, the impact of specular component (SCE-SCI) on DE^*_{ab} was, at most, 2.55 for the AMS tiles (Table 1), whereas the impact of glass use was often above 3.00 (and for SCE more than 8.00 on occasion) (Table 2).

Glass Impacts Evaluations: Impact of Glass Type. As noted above, preliminary spectrophotometer color results indicated that the use of SCI tended to minimize the glass impact by approximately 50% for tiles. The program was expanded to investigate the impact on color results from different types of glass and ways to minimize the glass impact. Two glass types were used—the standard 6-mm thick HVI glass and a 1-mm thick microscope slide. Measurements were performed for both SCE and SCI on AMS tiles (glass and no glass) and AMS cotton biscuits (glass only). The samples were measured with no glass (tiles only), glass (6-mm thick HVI glass or 1-mm thick microscope slide), glass correction factor (X-Rite program), and glass with glass calibration (glass used in the instrument calibration). The glass correction factor is based on the mathematical algorithms of Stearns (1969), and the use of these algorithms to minimize glass impacts on the SCI color results of nonfiber samples was demonstrated by Laidlaw (2001). As noted by Laidlaw, the "…glass correction is not perfect, but permits the accurate measurement of samples that otherwise could not be measured at all…" (e.g., fibers). The glass correction factor is normally used for SCI measurements only, but it was also evaluated for SCE in this investigation as a point of comparison.

Table 1. Comparison of SCE and SCI, AMS standard tiles, no glass use[z].

SAMPLE	SCE-NG[y]			SCI-NG[y]			DELTA			
	L*	a*	b*	L*	a*	b*	DL*	Da*	Db*	DE^*_{ab}
101	90.18	0.52	5.94	90.65	0.51	5.76	0.47	-0.01	-0.18	0.51
102	79.87	1.41	13.07	80.37	1.39	12.86	0.50	-0.02	-0.21	0.54
103	86.02	2.00	15.35	86.78	1.95	14.98	0.76	-0.05	-0.37	0.85
104	79.15	-0.60	2.76	81.68	-0.60	2.45	2.53	0.00	-0.32	2.55
105	87.17	1.06	9.22	89.33	1.00	8.64	2.16	-0.06	-0.58	2.24
201	91.90	-0.02	6.73	92.38	-0.03	6.54	0.48	-0.01	-0.19	0.52
202	78.22	1.05	13.16	78.85	1.03	12.90	0.63	-0.02	-0.26	0.69
203	86.42	1.46	16.26	87.37	1.41	15.84	0.95	-0.05	-0.42	1.04
204	78.05	-0.64	5.31	80.49	-0.62	4.88	2.45	0.01	-0.43	2.49
205	87.36	1.04	9.20	89.51	0.98	8.62	2.15	-0.06	-0.58	2.22
AVERAGE	84.43	0.73	9.70	85.74	0.70	9.35	1.31	-0.03	-0.36	1.36

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, 5 reading per sample, DELTA-DL*/Da*/Db* and DE^*_{ab} for each tile, 2 sets of AMS standard tiles

[y] SCE = specular component excluded; SCI = specular component included; NG = no glass placed in front of CE7000A sample port

Table 2. Impact of glass use on SCE and SCI[z].

SAMPLE	SCI-NG[y]			SCI-G[y]			DELTA			
	L*	a*	b*	L*	a*	b*	DL*	Da*	Db*	DE^*_{ab}
101	90.65	0.51	5.76	86.68	-0.28	5.09	-3.97	-0.79	-0.67	4.10
102	80.37	1.39	12.86	77.51	0.59	10.76	-2.86	-0.80	-2.10	3.64
103	86.78	1.95	14.98	83.25	1.11	12.96	-3.54	-0.84	-2.02	4.16
104	81.68	-0.60	2.45	78.24	-1.19	1.90	-3.44	-0.59	-0.54	3.53
105	89.33	1.00	8.64	85.32	0.18	7.55	-4.02	-0.81	-1.09	4.24
201	92.38	-0.03	6.54	88.52	-0.80	5.88	-3.86	-0.77	-0.66	3.99
202	78.85	1.03	12.90	76.43	0.28	10.67	-2.42	-0.75	-2.22	3.37
203	87.37	1.41	15.84	83.48	0.63	13.64	-3.88	-0.78	-2.20	4.53
204	80.49	-0.62	4.88	77.81	-1.20	4.02	-2.69	-0.58	-0.86	2.88
205	89.51	0.98	8.62	85.52	0.17	7.55	-3.98	-0.81	-1.07	4.20
AVERAGE	85.74	0.70	9.35	82.28	-0.05	8.00	-3.47	-0.75	-1.34	3.86

SAMPLE	SCE-NG[y]			SCE-G[y]			DELTA			
	L*	a*	b*	L*	a*	b*	DL*	Da*	Db*	DE^*_{ab}
101	90.18	0.52	5.94	82.27	-0.24	5.81	-7.91	-0.76	-0.14	7.95
102	79.87	1.41	13.07	71.93	0.75	12.46	-7.94	-0.66	-0.61	7.99
103	86.02	2.00	15.35	78.26	1.32	14.86	-7.76	-0.67	-0.49	7.80
104	79.15	-0.60	2.76	70.93	-1.26	2.52	-8.22	-0.66	-0.24	8.25
105	87.17	1.06	9.22	79.12	0.32	8.91	-8.06	-0.74	-0.31	8.10
201	91.90	-0.02	6.73	84.14	-0.80	6.63	-7.76	-0.78	-0.10	7.80
202	78.22	1.05	13.16	70.61	0.41	12.49	-7.61	-0.64	-0.67	7.66
203	86.42	1.46	16.26	78.29	0.79	15.65	-8.13	-0.67	-0.61	8.18
204	78.05	-0.64	5.31	70.57	-1.28	5.00	-7.48	-0.65	-0.30	7.51
205	87.36	1.04	9.20	79.53	0.30	8.95	-7.83	-0.74	-0.25	7.87
AVERAGE	84.43	0.73	9.70	76.57	0.03	9.33	-7.87	-0.70	-0.37	7.91

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, 5 reading per sample, DELTA-DL*/Da*/Db* and DE^*_{ab} for each tile, 2 sets of AMS standard tiles

[y] SCE = specular component excluded; SCI = specular component included; NG = no glass placed in front of CE7000A sample port; G = glass (HVI glass) used

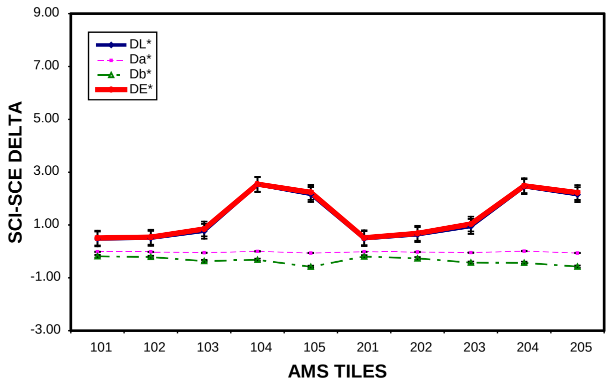

Figure 1. Specular component impact on L*a*b* (SCE and SCI), AMS standard tiles. No glass was used in the color measurements. Data bars are 1 standard error.

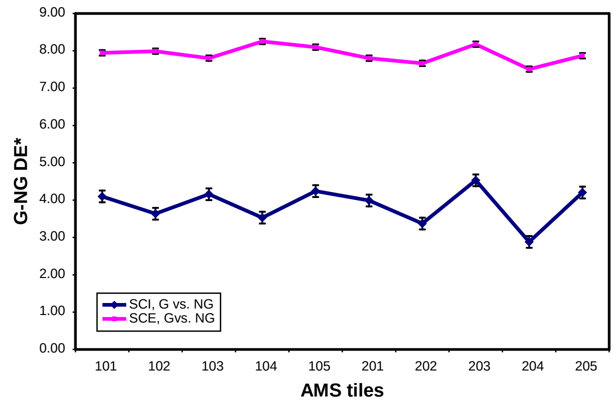

Figure 2. Glass impacts on SCE and SCI results, DE*ab, AMS standard tiles. G = HVI glass use; NG = no glass use. Data bars are 1 standard error.

As observed above, the use of glass significantly impacted the color results for both SCE and SCI. The major impact of the use of glass was to lower L* for both SCE and SCI measurements, which can result in large differences in DE^*_{ab} when glass is used. The use of a microscope slide (1-mm thick) in place of the standard HVI glass (6-mm thick) significantly minimizes the glass impact, especially for the SCI results (Tables 3, 4, 5, 6 for AMS tiles). Compared to no-glass results, the DE^*_{ab}s for microscope slide use was significantly less than the DE^*_{ab}s for HVI glass use for both SCE and SCI (normally ≥ 50% reduction in DE^*_{ab}s). Thus, the use of a thin glass of high quality (e.g., 1-mm microscope slide) significantly minimizes the glass impact on L* and DE^*_{ab}, compared to thick glass (e.g., 6-mm HVI glass).

Minimization of Glass Impacts. For microscope glass (Tables 4 and 6), the glass impact was minimized significantly for tiles when either the glass correction factor or the glass calibration was used with SCI, with significantly lower DE^*_{ab}, with L*a*b* results comparable to the no-glass results (Table 6). However, the glass correction factor with the microscope slide did not significantly diminish the DE* for SCE from the DE^*_{ab} observed for glass use (Table 4). This result is not unexpected, as the glass correction factor is designed for SCI measurements. The only condition for SCE that improved the no glass-glass use color agreement to acceptable levels was the use of glass calibration (DE^*_{ab}s often < 1.5).

Table 3. Glass impact, SCE, HVI glass, two AMS tile sets[z].

SAMPLE	SCE-NO GLASS (NG)[y]			SCE-HVI GL[y]				SCE-HVI GL/CAL WITH GL[y]			
	L*	a*	b*	L*	a*	b*	DE^*_{ab}	L*	a*	b*	DE^*_{ab}
101	90.18	0.52	5.94	82.27	-0.24	5.81	7.95	89.45	0.64	6.26	0.80
102	79.87	1.41	13.07	71.93	0.75	12.46	7.99	78.39	1.61	13.41	1.54
103	86.02	2.00	15.35	78.26	1.32	14.86	7.80	85.11	2.29	15.94	1.12
104	79.15	-0.60	2.76	70.93	-1.26	2.52	8.25	77.02	-0.57	2.66	2.13
105	87.17	1.06	9.22	79.12	0.32	8.91	8.10	86.28	1.22	9.63	0.99
201	91.90	-0.02	6.73	84.14	-0.80	6.63	7.80	91.38	0.07	7.14	0.66
202	78.22	1.05	13.16	70.61	0.41	12.49	7.66	77.04	1.23	13.39	1.21
203	86.42	1.46	16.26	78.29	0.79	15.65	8.18	85.12	1.74	16.79	1.43
204	78.05	-0.64	5.31	70.57	-1.28	5.00	7.51	76.89	-0.60	5.38	1.16
205	87.36	1.04	9.20	79.53	0.30	8.95	7.87	86.40	1.22	9.62	1.07
AVERAGE	84.43	0.73	9.70	76.57	0.03	9.33	7.91	83.31	0.89	10.02	1.21

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, 5 reading per sample, DELTA-DL*/Da*/Db* and DE^*_{ab} for each tile, 2 sets of AMS standard tiles

[y] SCE = specular component excluded; NG = no glass placed in front of CE7000A sample port; HVI GL = 6-mm HVI glass placed in front of CE7000A sample port; HVI GL/CAL WITH GL = unit calibrated with 6-mm HVI glass at sample port

Table 4. Glass impact, SCE, microscope slide glass, two AMS tile sets[z].

SAMPLE	SCE-NO GLASS (NG)[y]			SCE-MICRO SLIDE[y]				SCE-MICRO SLIDE/ GL CORRECTION[y]				SCE-MICRO SLIDE/ CAL WITH GL[y]			
	L*	a*	b*	L*	a*	b*	DE^*_{ab}	L*	a*	b*	DE^*_{ab}	L*	a*	b*	DE^*_{ab}
101	90.11	0.53	5.96	86.28	0.47	6.15	3.84	86.39	0.46	6.42	3.75	89.54	0.63	6.31	0.68
102	79.82	1.39	13.04	75.61	1.42	12.85	4.21	75.03	1.46	14.74	5.08	78.35	1.60	13.47	1.55
103	86.00	2.00	15.37	82.03	2.10	15.45	3.97	81.94	2.05	16.93	4.35	85.07	2.30	16.11	1.23
104	79.16	-0.61	2.78	75.20	-0.71	2.63	3.96	74.57	-0.80	2.95	4.60	78.01	-0.60	2.73	1.15
105	87.17	1.06	9.25	83.45	1.06	9.34	3.72	83.44	1.03	10.01	3.81	86.52	1.22	9.66	0.78
201	91.87	-0.01	6.77	88.13	-0.08	7.03	3.75	88.29	-0.13	7.26	3.62	91.35	0.04	7.20	0.68
202	78.15	1.05	13.15	73.96	1.07	12.88	4.20	73.19	1.09	14.93	5.27	76.72	1.23	13.52	1.49
203	86.40	1.46	16.27	82.47	1.56	16.37	3.93	82.39	1.44	17.89	4.32	85.59	1.73	17.09	1.18
204	78.03	-0.65	5.30	74.14	-0.72	5.14	3.89	73.38	-0.83	5.85	4.69	76.83	-0.61	5.36	1.20
205	87.37	1.03	9.22	83.54	1.02	9.32	3.83	83.58	1.02	9.98	3.87	86.72	1.21	9.67	0.81
AVERAGE	84.41	0.73	9.71	80.48	0.72	9.72	3.93	80.22	0.68	10.70	4.34	83.47	0.88	10.11	1.08

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, 5 reading per sample, DELTA-DL*/Da*/Db* and DE^*_{ab} for each tile, 2 sets of AMS standard tiles

[y] SCE = specular component excluded; NG = no glass placed in front of CE7000A sample port; MICRO SLIDE = 1-mm microscope slide placed in front of CE7000A sample port; MICRO SLIDE/GL CORRECTION = glass correction algorithm with 1-mm microscope slide at sample port; MICRO SLIDE/CAL WITH GL = unit calibrated with 1-mm microscope slide at sample port

Table 5. Glass impact, SCI, HVI glass, two AMS tile sets[z].

SAMPLE	SCI-NO GLASS (NG)[y]			SCI-HVI GL[y]				SCI-HVI GL/CAL WITH GL[y]			
	L*	a*	b*	L*	a*	b*	DE^*_{ab}	L*	a*	b*	DE^*_{ab}
101	90.65	0.51	5.76	86.68	-0.28	5.09	4.10	90.58	0.53	5.50	0.27
102	80.37	1.39	12.86	77.51	0.59	10.76	3.64	80.85	1.38	11.33	1.61
103	86.78	1.95	14.98	83.25	1.11	12.96	4.16	86.96	1.98	13.67	1.33
104	81.68	-0.60	2.45	78.24	-1.19	1.90	3.53	81.74	-0.49	2.16	0.31
105	89.33	1.00	8.64	85.32	0.18	7.55	4.24	89.30	1.01	8.07	0.57
201	92.38	-0.03	6.54	88.52	-0.80	5.88	3.99	92.32	0.01	6.29	0.26
202	78.85	1.03	12.90	76.43	0.28	10.67	3.37	79.70	1.04	11.25	1.85
203	87.37	1.41	15.84	83.48	0.63	13.64	4.53	87.21	1.48	14.39	1.46
204	80.49	-0.62	4.88	77.81	-1.20	4.02	2.88	81.33	-0.51	4.35	0.99
205	89.51	0.98	8.62	85.52	0.17	7.55	4.20	89.44	1.01	8.07	0.56
AVERAGE	85.74	0.70	9.35	82.28	-0.05	8.00	3.86	85.94	0.74	8.51	0.92

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, 5 reading per sample, DELTA-DL*/Da*/Db* and DE^*_{ab} for each tile, 2 sets of AMS standard tiles

[y] SCI = specular component included; NG = no glass placed in front of CE7000A sample port; HVI GL = 6-mm HVI glass llaced in front of CE7000A sample port; HVI GL/CAL WITH GL = unit calibrated with 6-mm HVI glass at sample port

For HVI glass (Tables 3 and 5), the glass impact was minimized significantly for tiles when the glass calibration is used with SCI and SCE (significantly lower DE^*_{ab} results, with L*a*b* results comparable to the no-glass results for SCI). The glass impact of HVI glass is normally less for SCI (often significantly so) than for SCE, as shown by the lower SCI DE^*_{ab}s for the AMS tiles both with HVI glass (standard) and with glass calibration (Tables 3 and 5). Due to the thickness of the HVI glass, the use of a glass correction factor was not applicable for thick glass (e.g., HVI glass), and the use of a glass correction factor was dropped for HVI glass. For HVI glass, the glass impact was minimized significantly for tiles only when the glass calibration was used with SCI and SCE. The minimization of glass impact DE^*_{ab} results are summarized in Fig. 3.

Table 6. Glass impact, SCI, microscope slide glass, two AMS tile sets[z].

SAMPLE	SCI-NO GLASS (NG)[y]			SCI-MICRO SLIDE[y]				SCI-MICRO SLIDE/ GL CORRECTION[y]				SCI-MICRO SLIDE/ CAL WITH GL[y]			
	L*	a*	b*	L*	a*	b*	DE^*_{ab}	L*	a*	b*	DE^*_{ab}	L*	a*	b*	DE^*_{ab}
101	90.63	0.52	5.78	89.89	0.46	5.76	0.74	90.08	0.43	5.87	0.56	90.51	0.53	5.62	0.20
102	80.34	1.38	12.82	80.00	1.31	11.74	1.13	79.85	1.32	12.98	0.52	80.56	1.39	11.66	1.18
103	86.77	1.95	15.00	86.18	1.95	14.17	1.02	86.28	1.85	15.02	0.50	86.80	2.02	14.11	0.89
104	81.67	-0.59	2.45	81.38	-0.62	2.39	0.30	81.26	-0.66	2.56	0.43	81.93	-0.54	2.25	0.33
105	89.33	1.02	8.65	88.67	0.96	8.43	0.70	88.89	0.91	8.70	0.46	89.31	1.03	8.32	0.33
201	92.36	-0.02	6.56	91.60	-0.06	6.60	0.76	91.82	-0.10	6.65	0.55	92.27	0.01	6.45	0.15
202	78.79	1.04	12.90	78.67	0.98	11.68	1.23	78.42	0.97	13.03	0.40	79.21	1.05	11.58	1.39
203	87.37	1.42	15.85	86.77	1.45	14.99	1.05	86.91	1.31	15.86	0.47	87.42	1.51	14.93	0.93
204	80.49	-0.62	4.87	80.23	-0.62	4.59	0.38	80.08	-0.68	4.99	0.43	80.80	-0.55	4.45	0.53
205	89.53	0.99	8.63	88.82	0.95	8.42	0.74	89.02	0.89	8.68	0.52	89.49	1.02	8.30	0.33
AVERAGE	85.73	0.71	9.35	85.22	0.68	8.88	0.81	85.26	0.62	9.43	0.48	85.83	0.75	8.77	0.63

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, 5 reading per sample, DELTA-DL*/Da*/Db* and DE^*_{ab} for each tile, 2 sets of AMS standard tiles

[y] SCI = specular component included; NG = no glass placed in front of CE7000A sample port; MICRO SLIDE = 1-mm microscope slide placed in front of CE7000A sample port; MICRO SLIDE/GL CORRECTION = glass correction algorithm with 1-mm microscope slide at sample port; MICRO SLIDE/CAL WITH GL = unit calibrated with 1-mm microscope slide at sample port

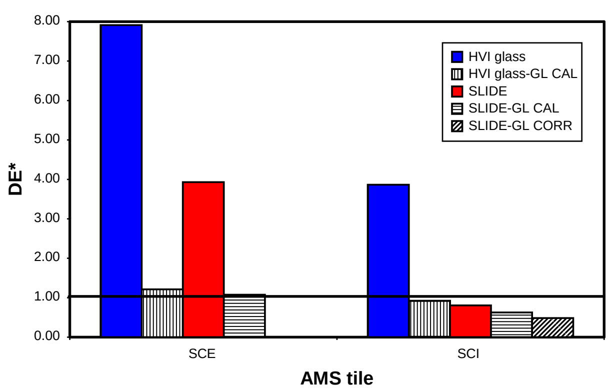

Figure 3. Impact of glass use and glass minimization methods, DE*ab, HVI glass, and microscope slide. GL = glass, GL CORR = glass correction factor, GL CAL = glass calibration.

For cottons, glass is normally recommended to present a smooth/compressed surface against the measurement port and to prevent fibers from falling into the spectrophotometer (prevent sphere contamination). Thus, no glass-glass comparisons are not feasible for cottons with typical sphere spectrophotometers. In addition, the HVI unit uses glass for its color measurements, so no glass is not a realistic option for cotton color comparisons. However, the impact of HVI glass use on cotton fiber, and means to minimize the HVI glass impact, can be inferred from a comparison of AMS tiles and AMS cotton biscuit samples that have similar L* color results. A program was implemented to infer the capabilities of glass–calibrate-with-glass condition as a means to minimize glass impacts on cottons measured on color spectrophotometers. Similar results were observed for both HVI glass use and microscope slide glass use. A typical example of the results is presented for L* in Table 7 for two cottons and two tiles with similar L* when HVI glass is used (worst case scenario is HVI glass use). For the tiles, the decrease in L* when glass was used was similar to the increase in L* when the glass–calibrate-with-glass condition was used (absolute DL*, 2-1 ~ absolute DL*, 3-2). Further, the L* for the glass–calibrate-with-glass was similar to the L* for no glass (absolute DL*, 3-1 < 1.5). The best results were obtained for SCI. For the AMS cottons biscuits, it was interesting to note that the increases in L* in going from the glass to the glass–calibrate-with-glass conditions (6.66-7.05 for SCE and 3.21-3.26 for SCI) were similar to the increases in L* for the tiles under the same conditions (6.43-7.17 for SCE and 3.27-3.71 for SCI). Thus, excellent agreement was observed under the same conditions (glass compared to glass–calibrate with glass) for the tiles and cottons. Because the color results for the tiles indicate that the glass–calibrate-with-glass condition yielded similar results to the no-glass condition, it can be inferred that the glass–calibrate-with-glass condition would also yield similar results to no-glass measurements for cottons. Thus, the use of the glass calibration factor and SCI would minimize the impact of glass on fiber color measurements significantly and could reduce the glass impact to a minor component of color uncertainty between the HVI and color spectrophotometers, with DE^*_{ab} between no glass and glass calibration conditions normally expected to be less than 1.0. In addition, because the cotton and AMS tiles are pressed against the glass in the HVI color measurements, one could state that the HVI is actually using a glass–calibrate-with-glass condition itself.

These results, for both the HVI and microscope glass, once again demonstrate that SCI is less impacted by glass, and thus more easily adjusted to minimize glass impacts, compared to SCE. The use of glass calibration, which can be used with both HVI glass and microscope slide and with SCE and SCI, is the most versatile means to minimize the glass impact on tile color measurements, with the best results obtained with SCI (DE* < 1.0 normally). It is implied from the cotton biscuit evaluations that the glass calibration factor can significantly minimize the glass effect on the color results for cotton measurements.

Impact of Pressure on Color Results. In addition to specular component and glass use impacts, the impact of pressure on fiber color results is of importance in spectrophotometer (and HVI) color measurements. When cotton fiber is measured behind glass, be it on the HVI colorimeter or color spectrophotometer, pressure must be applied to the fiber to present a more uniform sampling surface. With spectrophotometer fiber measurements, the pressure applied to the fiber is often the standard slight pressure of the pressure arm/sample arm on the spectrophotometer or the use of hand pressure by the operator. A HunterLab fiber pressure cell was used to study the influence of pressure on cotton fiber color measurements, and the optimal pressure for consistent fiber measurement when a fiber cell is used to measure cotton fiber (with glass, constant pressure). Ten fiber samples (five domestic, five international) were measured in the fiber cell at pressures from 10 to 40 psig, in 10 psig increments. The color parameter most impacted by fiber cell pressure was L* (Table 8, Fig. 4). Large increases in L* results were observed as the pressure was increased, but minimum impacts on a* and b* results were observed. L* color results increased to a plateau as the pressure was increased, and the within-sample standard deviation normally decreased to a small plateau as the pressure was increased (Fig. 5). For most samples, changes in color values and within-measurement standard deviations with increasing cell pressure, began to level off at 20 psig. The major changes with cell pressure reached

Table 7. Minimization of glass impact on L*, AMS tiles and cotton biscuits, no Glass, Glass, Glass–Calibrate with Glass, SCE, and SCI[z].

SAMPLE	NO GLASS (1)	HVI GLASS (2)[y]		HVI GLASS/CAL WITH GL (3)[y]		
	L*	L*	DL* (2-1)	L*	DL*(3-2)	DL*(3-1)
AMS TILES						
SCE						
202	78.22	70.61	-7.61	77.04	6.43	-1.17
105	87.17	79.12	-8.06	86.28	7.17	-0.89
SCI						
202	78.85	76.43	-2.42	79.70	3.27	0.84
103	86.78	83.25	-3.54	86.96	3.71	0.18
AMS COTTON BISCUITS						
SCE						
307	NA	70.80	NA	77.85	7.05	NA
301	NA	79.93	NA	86.59	6.66	NA
SCI						
312	NA	76.66	NA	79.87	3.21	NA
304	NA	82.96	NA	86.22	3.26	NA

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, 5 reading per sample, DELTA-DL*/Da*/Db* and DE^*_{ab} for each tile, 2 sets of AMS standard tiles

[y] SCE = specular component excluded; SCI = specular component included; HVI GL = 6-mm HVI glass placed in front of CE7000A sample port; HVI GL/CAL WITH GL = unit calibrated with 6-mm HVI glass at sample port

a definitive plateau at 30 psig (DE^*_{ab} with 10 psig pressure increase was less than 1.0 at 30 psig). The SCI and SCE results tracked each other (Fig. 6), but the impact of increasing pressure on L*a*b* color results and within-measurement standard deviation was often more dramatic for SCE. Based on these results, 30 psig is the recommend cell pressure for fiber measurements under constant pressure (both SCI and SCE). Although the pressure effects can be significant at low applied pressures, their impact was less than the impact observed with the use of HVI glass when the applied pressure is maintained at a minimum of 30 psig.

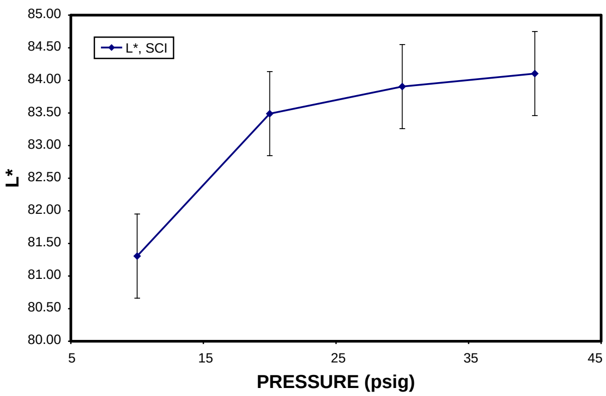

Figure 4. Pressure impacts on cotton, L*, HunterLab cell, SCI, all cottons. Data bars are 1 standard error .

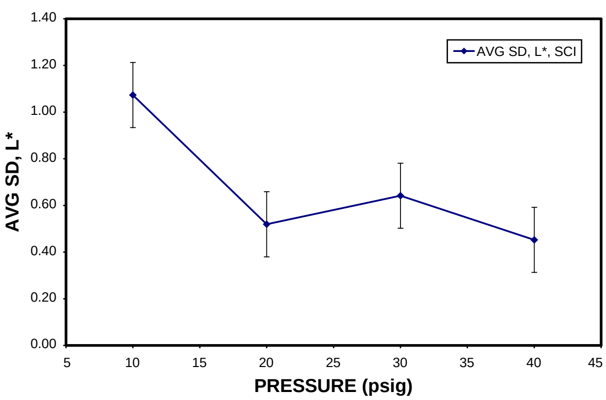

Figure 5. Pressure impacts on cotton, standard deviation, L*, HunterLab cell, SCI. Data bars are 1 standard error.

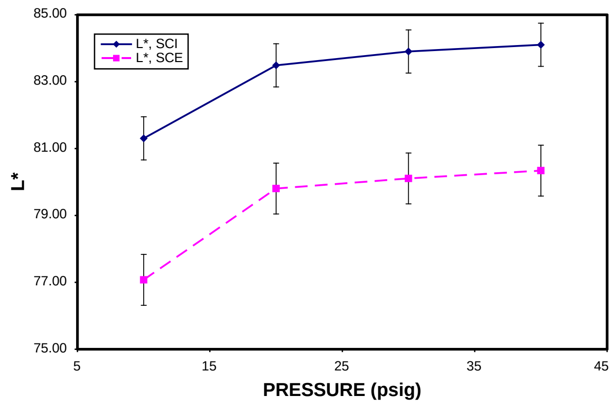

Figure 6. Pressure impacts on cotton, SCI vs. SCE, L*, HunterLab cell. Data bars are 1 standard error.

CONCLUSIONS

A program was implemented to 1) investigate in detail the impacts of key operational and instrumental parameters on spectrophotometer color measurements applicable to cotton fiber, 2) determine the feasibility of minimizing the major impacts, and 3) develop uniform protocols for measuring cotton fiber on spectrophotometers. The operational and instrumental parameters investigated were specular component, glass use and type of glass used, and pressure applied to the fiber. For all operational and instrumental parameters, L* was the color parameter most impacted in all cases. The glass impact on spectrophotometer color results was much greater than the impact of specular component type and applied pressure on the fiber. The use of SCI decreased the glass impact on DE^*_{ab} color results by approximately 50% compared to the DE^*_{ab} color results obtained with SCE. The thickness of the glass used did significantly impact the color results: the glass impact of the 6-mm thick HVI glass on color results was significantly greater than that of the 1-mm thick microscope slide. The 1-mm microscope slide significantly minimized the glass impact for all color results. For both domestic and international

Table 8. Change in L*a*b* and DE^*_{ab} with increasing pressure applied to small fiber fluffs[z].

PRESSURE (psig)	AVERAGE (10 samples)						
	L*	a*	b*	DL*	Da*	Db*	DE^*_{ab}
10	81.31	1.01	9.64	NA	NA	NA	NA
20	83.49	1.26	10.30	2.18	0.25	0.66	2.20
30	83.90	1.22	10.30	0.41	-0.04	0.00	0.42
40	84.10	1.27	10.34	0.20	0.05	0.04	0.21

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, 5 reading per sample, DELTA-DL*/Da*/Db* and DE^*_{ab} for each tile, 2 sets of AMS standard tiles Hunterlab fiber compression cell

cottons, as the applied pressure is increased, a color plateau is reached for L* at 20 to 30 psig, and 30 psig was selected as the optimum applied pressure for spectrophotometer color measurements on small portions of loose cotton fiber. Protocols for minimizing glass impacts on spectrophotometer color measurements were determined for AMS standard tiles and loose cotton fiber samples, with the best overall results obtained with SCI, glass with glass calibration, and 30 psig for applied pressure to the fiber.

ACKNOWLEDGMENTS

The authors wish to express their appreciation for the funding support of Cotton Incorporated for this project. The authors wish to acknowledge Jeanine Moriatis, Clare Kappel, and Sarah Lillis for their outstanding work in preparing and running all samples.

DISCLAIMER

The use of a company or product name is solely for the purpose of providing specific information and does not imply approval or recommendation by the USDA to the exclusion of others.

REFERENCES

Anonymous. 2000., What is color and how is it measured? HunterLab Application Note 12 (5): May, 2000.

Berger-Schunn, A. 1994. Practical Color Measurement. John Wiley & Sons, NY.

Berns, R.S. 2000. Billmeyer and Saltzman's Principles of Color Technology, 3rd ed. John Wiley & Sons, NY.

Hunter, R. 1975. The Measurement of Appearance. John Wiley & Sons, NY.

Judd, D., and G. Wyszecki. 1975. Color in Business, Science, and Industry, 3rd ed. John Wiley & Sons, NY.

Laidlaw, A. 2001. To glass or not to glass? AATCC Rev. 1(4):30–33.

Ohno, Y. 2000. CIE fundamentals for cotton color measurements. p. 540–545. *In* NIP16: International Conference on Digital Printing Technologies, Vancouver, BC, Canada, 16-20 Oct. 2000. Soc. Imaging Sci. Tech., Springfield, VA.

Nickerson, D. 1931. A colorimeter for use with disk mixture. J. Optical Soc. Am. 21:640-642.

Nickerson, D., R. Hunter, and M. Powell. 1950. New automatic colorimeter for cotton. J. Optical Soc. Am. 40-446-449.

Rodgers, J., D. Thibodeaux, X. Cui, V. Martin, M. Watson, and J. Knowlton. 2008. Instrumental and operational impacts on spectrophotometer color measurements. J. Cotton Sci. 12:287–297.

Rodgers, J., J. Campbell, X. Cui, and D. Thibodeaux. 2009. Feasibility of "traceable" color standards for cotton color. AATCC Rev. 9(1): 42–47.

Shofner, F., M. Watson, Y. Zhang, S. Lee, and K. Shofner. 2006. Moving to CIE color, traceably. p. 1921–1925. *In* Proc. Beltwide Cotton Conference, San Antonio, TX. 3-6 Jan. 2006. Natl. Cotton Counc. Am., Memphis, TN.

Stearns, E. 1969. The Practice of Absorption Spectrophotometry. John Wiley & Sons, NY.

Thibodeaux, D., J. Rodgers, J. Campbell, and J. Knowlton. 2008. The feasibility of relating HVI color standards to CIELAB coordinates. AATCC Rev. 8(11): 44–48.