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TEXTILE TECHNOLOGY

Fiber Sample Presentation System for Spectrophotometer Cotton Fiber Color Measurements

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ABSTRACT

The Uster® High Volume Instrument (HVI) is used to class U.S. cotton for fiber color, yielding the cotton-specific color parameters Rd and +b. The HVI examines a nine-square-inch fiber sample, such as the large AMS standard cotton "biscuits" or rectangles. Much interest has been shown in measuring cotton color on modern color spectrophotometers and on relating the HVI Rd and +b color parameters to more globally recognized, three-dimensional color space systems obtained from spectrophotometers, such as L*a*b*. Recent research established the relationships of Rd and +b to L* and b*. However, concerns have been expressed on the consistency of fiber measurements on large area cotton fibers with spectrophotometers. When fiber is measured on color spectrophotometers, hand pressure by an operator is often used to hold the fiber against the spectrophotometer sampling port for the measurement, but the pressure applied varies from operator to operator and from sample to sample. The need exists for a spectrophotometer fiber sampling system for large area fiber samples that allows for the application of uniform pressure to large cotton fiber samples. A program was implemented to develop a pressurized fiber sampling system for color measurements with large cotton fiber samples (e.g., AMS standard cotton biscuits). A sampling system for large cotton fiber samples was developed for spectrophotometers in which a uniform pressure is applied across the entire sample surface area. The color parameter most impacted by fiber pressure was L*. Protocols were developed for pressurized cotton fiber color measurements on spectrophotometers.

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The color assessments of cotton fiber and their textile end-products are critical quality properties. In the U.S., domestically produced cotton fiber is classed, and its key quality properties assessed, by the Uster® High Volume Instrument (HVI). Two quality properties measured on the HVI colorimeter are the fiber's diffuse reflectance (Rd) and its yellowness (+b). Rd and +b are color parameters that are specific to cotton fiber (two-dimensional color system), and they are not directly related to color measurements performed on the widely used color spectrophotometers, whose color results are often based on National Institute of Standards and Technology-traceable standards (color results). Unlike the colorimeter unit in the HVI, which measures Rd and +b at two visible wavelengths/wavelength regions, spectrophotometers cover the entire visible spectral region from 400 nm to 700 nm. Thus, color results from spectrophotometers have the potential to provide color information not available with the HVI. In addition, spectrophotometers are internationally used with well-known three-dimensional color systems, such as L*a*b* or CIELAB. In L*a*b* color space, L* represents the sample's lightness or darkness, a* represents the sample's redness or greenness, and b* represents the sample's yellowness or blueness. The higher L*, the lighter the sample; the more positive a*, the redder/less green the sample; and the more positive b*, the yellower/less blue the sample (Berns, 2000; Hunter, 1975; Judd and Wyszecki, 1975). When one compares two samples for color differences, a key term utilized is DE^*_{ab} (equation 1). DE^*_{ab} is defined as the square root of the sum of the square of the differences in L*, a*, and b* [(DL*), (Da*), and (Db*)], in which one of the two compared samples serves as the reference sample. As a general rule, a significant, readily discernible color difference between two samples occurs when DE^*_{ab} is greater than 1.0 (Berger-Schunn, 1994).

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

Strong linear relations have been established and validated for L*↔Rd and b*↔+b between spectrophotometers and the HVI using the standard ceramic tiles and reference cotton biscuits or rectangles commonly used by the USDA Agricultural Marketing Service (AMS) (Rodgers et al., 2008, 2009a; Thibodeaux et al., 2008). The major impact on color agreement between spectrophotometers and between the HVI and spectrophotometers was the use of glass at the spectrophotometer sampling port, and L* was the color parameter in L*a*b* color space that was most impacted by glass use. Glass use is normally required for cotton fiber color measurements to prevent potential spectrophotometer contamination by the fiber and to present a flat, uniform surface for color measurement.

Previous evaluations determined the impact of pressure on cotton fiber measurements and color measurements with small, "fluff" cotton samples and established protocols and procedures for minimizing the glass impact on spectrophotometer color measurements (Rodgers et al., 2009b, 2010). For small, loose cotton fiber samples, commercial fiber compression cells yielded acceptable color result consistency (color plateau at 30 psi cell pressure), but they were not physically able to perform spectrophotometer cotton color measurements on large, bulk fiber samples such as the AMS standard cotton biscuits (Fig. 1). Large fiber samples are often measured on color spectrophotometers by placing the fiber up to the instrument measurement port, using glass in front of the port and applying pressure by hand on the sample to hold the fiber in place. Consistency of applied pressure across the entire fiber surface was not possible with the use of hand-applied pressure. The pneumatic compression cells described above can be used only for small samples (normally less than 2.5 g of fiber), and they require excessive sample handling to remove, reorient, and reload the sample into the cell for repeat measurements. In addition, because the small pneumatic compression cells contain a glass plate at the bottom of the cell to hold the cotton, the glass leads to a glass impact that cannot be eliminated for all measurement conditions. Here we present the development of a new fiber sample presentation/sampling system for large, bulk fiber samples that provides improved spectrophotometer color measurement consistency over the hand-applied pressure method for large bulk samples.

Figure 1. Examples of AMS standard cotton fiber biscuits.

MATERIALS AND METHODS

All fiber spectrophotometer color measurements consisted of five replicates per sample (fiber surface changed with each measurement) and were made on the Gretag Macbeth CE7000A color spectrophotometer (presently X-Rite Incorporated, Grand Rapids, MI) "with glass" (with both a 6 mm thick HVI glass and with a 1 mm thick microscope slide or "thin glass" placed between the cotton sample and the spectrophotometer port). Typically, hand-applied pressure from the operator was used to maintain the large area samples against the sample port during the measurement (Fig. 2). The CE7000A settings were illuminant D65, 10° observer, large area of view (LAV, 25 mm), and with specular component included (SCI) and excluded (SCE).

Figure 2. Example of color measurements with hand-applied pressure.

The large area samples used in this evaluation consisted of one box of AMS standard cotton biscuits (12 biscuits per box) and a set of 25 routine domestic and international samples (raw lint, no special sample preparation, loose fiber). The color ranges for the 12 standard cotton biscuits were as follow:

L* = 79.8-89.1; a* = 0.7-2.4; b* = 6.7-11.6

The color ranges for the 25 routine domestic and international samples were as follow:

L* = 82.9-89.7; a* = 0.4-2.7; b* = 7.7-13.8

For the large, bulk sample spectrophotometer color measurements, a pressurized large sample pressure system (LSPS) sample presentation/sampling system was developed at the Southern Regional Research Center of the Agricultural Research Service (USDA-ARS-SRRC, New Orleans, LA) (Figs. 3 and 4). Initial color measurements were made on the 12 AMS standard cotton biscuits (well-prepared sample surface) using the conventional hand-applied pressure and the LSPS (10 to 40 psi, in 10 psi increments) methods, with both 6 mm thick HVI glass and 1 mm thick thin glass. To determine the applicability of the LSPS to all cotton samples (not just AMS standard biscuits), the color measurements were expanded to include 25 routine domestic and international cottons. For the routine cotton measurements, the fiber (75.0 ± 1.0 g) was placed into the same size box as used for the AMS biscuits, and the same procedures used for the AMS biscuits color measurements were followed. Based on the results with the large sampling system on the AMS biscuits and from previous studies (Rodgers et al., 2010), only SCI and the 1 mm thick thin glass were used in the routine sample measurements.

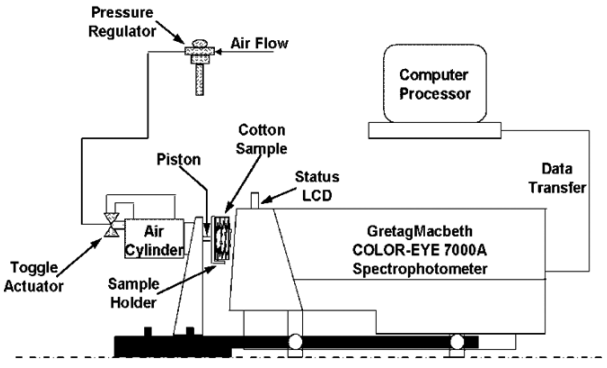

Figure 3. Schematic of the LSPS.

Comparative evaluations were performed at each applied pressure (hand-applied and LSPS measurements of 10-40 psi in 10 psi increments) to obtain the spectrophotometer fiber color results (L*, a*, b*, and DE^*_{ab}) of each sample. Average color results and average within standard deviation (SD_w, n = 5) for each color parameter were compared for the hand-applied pressure and at each pressure for the large fiber sampling system. The SD between pressure systems/pressure levels is used to indicate the relative range and variability between pressure systems/pressure levels for L*, a*, and b*. For this evaluation, a color change or difference was considered to be discernible and significant for DE^*_{ab} greater than 1.0 (Berger-Schunn, 1994). In addition, the color results for a specific color parameter (L*, a*, b*) were considered to have reached a plateau (pressure impact on fiber samples are considered minimal and not significant) at the pressure where no significant increase in color result was observed for the specific color parameter with increasing applied pressure.

Large Fiber Sampling System. An LSPS meant to equalize pressure during fiber measurement not only for the AMS cotton biscuits but also for routine, raw, loose cotton fiber samples, was fabricated and installed, with applied pressure of up to 50 psi available. The system was designed to attach to the color spectrophotometer to prevent movement of (and possible damage to) the spectrophotometer during prolonged use of the LSPS. In addition, the sample holder in the system can be adjusted to facilitate cotton color measurements at different locations.

Figure 4. LSPS connected to the Gretag-Macbeth CE7000A color spectrophotometer.

The LSPS consisted of a color spectrophotometer controlled and monitored by a computer as illustrated in Figs. 3 and 4. The load on the sample was applied from the loading mechanism located on the left side of the system. With an external air supply, an actual pressure on the sample of up to 50 psi can be maintained. The applied pressure to the cotton fiber sample was achieved by means of a 5 in bore, 3 in-stroke air cylinder activated by a four-way two-position function toggle actuator.

The sample was placed on a 6 in wide X 5.5 in high rectangular sample platform (33 in^2). A 1 in segment/edge to hold the sample box (1 in wide X 6 in long) was connected to the sample platform on one edge.

Color measurements were performed with a sample box, into which the fiber was placed. The sample box type used by AMS for their cotton biscuits were used for all LSPS color measurements. The box was 6.5 in long X 5 in wide X 1.5 in deep. The fiber was placed into the box, the box placed on the 1 in segment of the LSPS sample platform, and the toggle actuated. The sample was then smoothly moved into contact with the spectrophotometer sampling port by the air pressure, stopping at the designated pressure for the measurement. When the measurement was completed, the toggle switch was actuated to remove the box from the spectrophotometer, the box was manually relocated to a new sample position on the platform, and the process repeated to bring the sample into contact with the spectrophotometer. Five fiber measurements were made per sample.

RESULTS AND DISCUSSION

A program was implemented to improve pressure consistency across the entire fiber sample, with emphasis on the development and fabrication of a fiber sample presentation/sampling system that would yield improved spectrophotometer color result consistency for large bulk samples. An LSPS meant to equalize pressure during fiber measurement not only for the AMS cotton biscuits but also for raw cotton fiber samples, was fabricated and installed, with applied pressure of up to 50 psi available.

AMS Cotton Biscuits. AMS cotton biscuits, using the boxes in which they were placed by AMS, were measured with the 6 mm thick HVI glass and 1 mm thick thin glass under both SCI and SCE conditions on the CE7000A color spectrophotometer. For both HVI glass and thin glass for the AMS cotton biscuits, the color parameter most impacted by increasing applied pressure was L* for SCI. In general, only minor differences (< 0.10 color units) were observed for a* and b* with increasing pressure for the LSPS. The LSPS measurements yielded a higher average L* value compared to the hand-applied pressure method (Tables 1 and 2). Overall, the L*, a*, and b* results were much higher (> 0.5 color units) for the thin 1 mm glass compared to those results for the 6 mm thick HVI glass, with the largest glass differences (glass impact) observed for L*. The high consistency of the LSPS color results at all applied pressures was readily observed, even for L*, the color parameter most impacted by the applied pressure. Only small changes in L* were observed with the LSPS (< 0.50 L* range), even from 10 psi to 20 psi. For both the HVI glass and the thin glass, the DE^*_{ab} results for the LSPS indicated that the color plateau with increasing pressure was attained at 30 psi (Fig. 5). LSPS DE^*_{ab} results, though less than 1.0 for both the HVI glass and thin glass measurements, were much lower for the thin glass measurements.

Table 1. Pressure effects on color results, hand-applied vs. Large Sample Pressure System, Macbeth CE7000A, 6 mm thick glass, SCI, AMS biscuits (average of 12 biscuits)[z].

PRESSURE (psi)	AVERAGE L*	a*	b*
HAND	80.78	0.54	8.47
LSPS-10[y]	81.46	0.66	8.19
LSPS-20[y]	81.94	0.66	8.12
LSPS-30[y]	81.69	0.59	8.11
LSPS-40[y]	81.69	0.59	8.13
ALL			
AVG[x]	81.51	0.61	8.20
SD[x]	0.44	0.05	0.15
LSPS[y]			
AVG[x]	81.69	0.63	8.14
SD[x]	0.19	0.04	0.04

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, five readings per sample, specular component included (SCI), 6 mm thick glass placed in front of CE7000A sample port.

[y] LSPS = Large Sample Pressure System.

[x] AVG = average; SD = standard deviation.

Table 2. Pressure effects on color results, hand-applied vs. Large Sample Pressure System, Macbeth CE7000A, 1 mm thin glass, SCI, AMS biscuits (average of 12 biscuits)[z].

PRESSURE (psi)	AVERAGE L*	a*	b*
HAND	84.08	1.18	8.68
LSPS-10[y]	84.74	1.32	8.85
LSPS-20[y]	84.63	1.31	8.90
LSPS-30[y]	84.58	1.27	8.85
LSPS-40[y]	84.71	1.26	8.86
ALL			
AVG[x]	84.55	1.27	8.83
SD[x]	0.27	0.06	0.08
LSPS[y]			
AVG[x]	84.66	1.29	8.86
SD[x]	0.07	0.03	0.02

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, five readings per sample, specular component included (SCI), 1 mm thin glass placed in front of CE7000A sample port.

[y] LSPS = Large Sample Pressure System.

[x] AVG = average; SD=standard deviation.

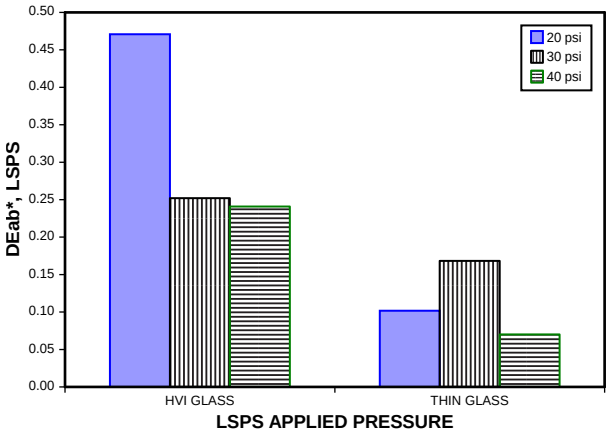

Figure 5. Pressure effects, LSPS, DE*ab, LSPS at 10 psi as reference, Macbeth CE7000A, 6 mm HVI glass and 1 mm thin glass, SCI, AMS biscuits (average of 12 biscuits).

In addition to the average color results for L*, a*, and b* with hand-applied pressure and at each LSPS pressure, the average within standard deviation (SD_w, n = 5) was obtained for the AMS cotton biscuits. The SD_w results were compared versus applied pressure for both the 6 mm HVI glass and 1 mm thin glass measurements. The highest SD_w results were obtained with L* (Figs. 6 and 7 for L*). Overall, the lowest SD_ws were obtained with the LSPS measurements. For the LSPS, similar color results were observed for both glass measurements. In both glass measurements, the L* SD_w was the highest, followed by b*. A distinct plateau was observed at 30 psi for both systems, although the differences with increasing pressure in SD_w for L*, a*, and b* were normally slight (< 0.20 color units at applied pressure ≥ 10 psi).

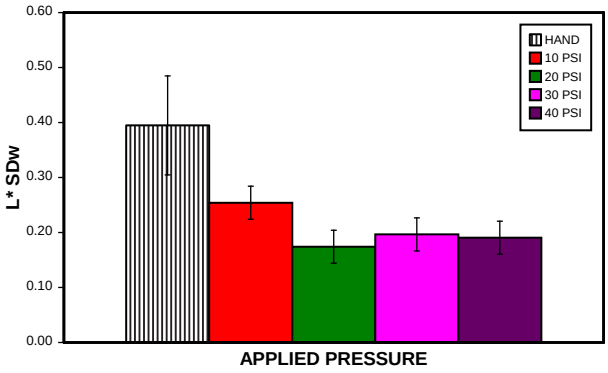

Figure 6. Average L* SDw, hand-applied pressure and LSPS (10-40 psi), 6 mm HVI glass. AMS cotton biscuits.

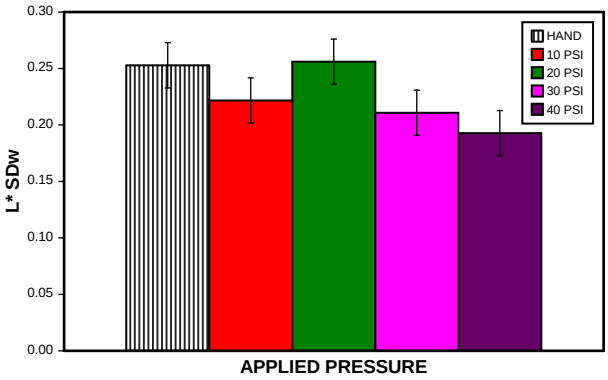

Figure 7. Average L* SDw, hand-applied pressure and LSPS (10-40 psi), 1 mm thin glass. AMS cotton biscuits.

Similar results for the AMS cotton biscuits were observed for SCE, as shown in Table 3. As observed for SCI, the overall L*, a*, and b* color results were much higher (normally > 0.5 color units) for the thin 1 mm

Table 3. Pressure effects on color results, hand-applied vs. Large Sample Pressure System, Macbeth CE7000A, 6 mm thick glass and 1 mm thin glass, SCE, AMS biscuits (average of 12 biscuits)[z].

PRESSURE (psi)	6-mm GLASS AVERAGE			1-mm GLASS AVERAGE		
	L*	a*	b*	L*	a*	b*
HAND	76.24	0.66	9.65	80.04	1.27	9.45
LSPS-10[y]	76.90	0.75	9.27	80.73	1.39	9.69
LSPS-20[y]	76.86	0.72	9.22	80.82	1.38	9.70
LSPS-30[y]	76.74	0.71	9.18	80.78	1.40	9.73
LSPS-40[y]	76.88	0.74	9.19	80.77	1.39	9.72
ALL						
AVG[x]	76.72	0.72	9.30	80.63	1.36	9.66
SD[x]	0.28	0.04	0.20	0.33	0.05	0.11
LSPS[y]						
AVG[x]	76.85	0.73	9.21	80.77	1.39	9.71
SD[x]	0.07	0.02	0.04	0.04	0.01	0.02

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, five readings per sample, specular component excluded (SCE), glass placed in front of CE7000A sample port.

[y] LSPS = Large Sample Pressure System.

[x] AVG = average; SD = standard deviation.

glass compared to those results for the 6 mm thick HVI glass, with the largest glass differences observed for L*. With the exception of the HVI glass b* results, the LSPS color measurements yielded higher average L*, a*, and b* values compared to the hand-applied pressure method. Small changes in L* were observed with the LSPS (< 0.50 L* range) from 10 psi to 40 psi for both HVI glass and thin glass measurements. The differences in SD_ws between the HVI glass and thin glass at each applied pressure were small and, for LSPS, in good agreement to the corresponding SCI SD_ws (< 0.05 color unit).

Routine Cotton Samples. In addition to the AMS cotton biscuits, the conventional hand-applied and SRRC LSPS pressure systems were compared on routine, raw, loose cottons. As noted previously, only SCI and the 1 mm thick thin glass were used in the comparative evaluations of 25 domestic and international routine cottons. L* was once again the color parameter most impacted by increasing applied pressure and by the pressure method used, with only minor differences observed for a* and b* (range of less than 0.60 color units). The routine cottons exhibited a much higher average L* value with the LSPS compared to the conventional hand-applied pressure method (Table 4). The DE^*_{ab} differences (hand-applied vs. LSPS) for the routine cottons were much larger compared to the AMS cotton biscuits (Fig. 8). The large increase in DE^*_{ab} for the routine cottons were due primarily to the larger differences in L* between the hand-applied pressure and LSPS color measurements (L* differences between hand-applied pressure and LSPS was > 1.5 color units for the routine cottons versus ~0.9 for the AMS cotton biscuits). The average L* and DE^*_{ab} values with the LSPS were overall very consistent, even at 10 psi (Fig. 9). The pressure impact was much greater for the routine cottons compared to the AMS cotton biscuits, most likely due to sample preparation variables (prepared state of the sample surface, uniform loading of the routine cottons fiber into the sample box, surface uniformity, etc.). The AMS standard cotton biscuits were well prepared, with a consistent loading of the fiber into the sample box and uniform fiber surface. For the routine samples, no extended efforts were made to make the sample preparation be equivalent to that of the AMS cotton biscuits. Thus, the sample preparation and surface presentation for the routine cottons were more random and more like "real life" laboratory sample preparation compared to that of the AMS cotton biscuits, and greater differences between the hand-applied pressure and LSPS color results were expected and observed. Compared to the hand-applied pressure method and the small pneumatic compression cells, the use of the LSPS minimized fiber sample handling and re-loading of the fiber sample for measurement.

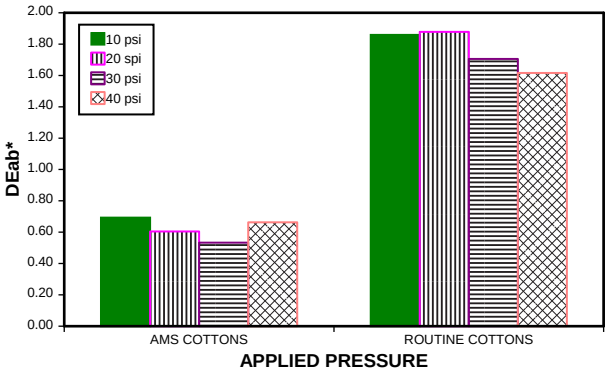

Figure 8. Pressure effects, hand-applied vs. LSPS, DE*ab, hand-applied pressure as reference, Macbeth CE7000A, 1 mm thin glass, SCI, AMS cotton biscuits (n = 12) and routine cottons (n = 25).

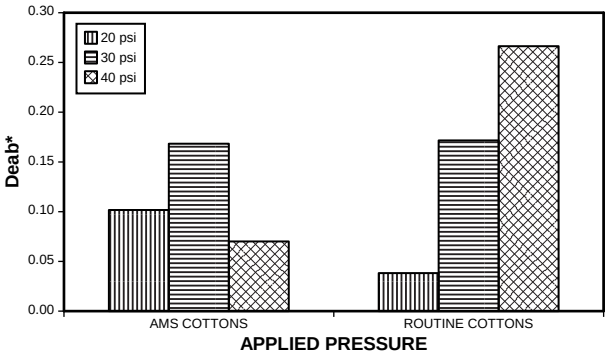

Figure 9. Pressure effects, hand-applied vs. LSPS, DE*ab, LSPS at 10 psi as reference, Macbeth CE7000A, 1 mm thin glass, SCI, AMS cotton biscuits (n = 12) and routine cottons (n = 25).

Table 4. Pressure effects on color results, hand-applied vs. Large Sample Pressure System, Macbeth CE7000A, 1 mm thin glass, SCI, routine cottons (n = 25)[z].

PRESSURE (psi)	AVERAGE L*	a*	b*
HAND	84.78	1.01	9.45
LSPS-10[y]	86.56	1.17	9.96
LSPS-20[y]	86.57	1.19	9.98
LSPS-30[y]	86.42	1.11	9.90
LSPS-40[y]	86.34	1.14	9.85
ALL			
AVG[x]	86.13	1.13	9.83
SD[x]	0.76	0.07	0.22
LSPS[y]			
AVG[x]	86.47	1.15	9.92
SD[x]	0.11	0.04	0.06

[z] MacBeth CE7000A, SRRC, illuminant D65, 10° observer, large area of view, five readings per sample, specular component included (SCI), 1 mm thin glass placed in front of CE7000A sample port.

[y] LSPS = Large Sample Pressure System.

[x] AVG = average; SD = standard deviation.

The average within standard deviation (SD_w, n = 5) results for the routine cottons were compared to each other and to the SD_w results for the AMS cotton biscuits (Fig. 10 for L* SD_w). For the routine cottons, the SD_ws for L* were much lower for the LSPS measurements compared to the hand-applied measurements (0.60 for hand-applied vs. approximately 0.3 for LSPS). The L* SD_ws for the routine cottons were higher than those for the AMS cotton biscuits, primarily for the hand-applied pressure measurements (0.60 for routine cottons and 0.25 for AMS cotton biscuits). Once again, the probable rationale for the increased L* SD_ws with the routine cotton measurements was the sample preparation variables (e.g., well-prepared AMS standard cotton biscuits versus "as is" routine cottons). In addition, the cotton bales selected for AMS standards are generally more uniform in fiber properties compared to routine cottons. However, even though the SD_ws for the routine cottons were markedly higher than the SD_ws for the AMS cotton biscuits for hand-applied pressure, the use of the LSPS resulted in SD_ws for the routine cottons that were consistent and approached the SD_ws for the AMS cotton biscuits. A distinct plateau for the LSPS was observed at 30 psi for both the AMS cotton biscuits and routine cottons, although the differences with increasing pressure in SD_w for L*, a*, and b* were normally slight (< 0.25 color units at applied pressures ≥ 10 psi).

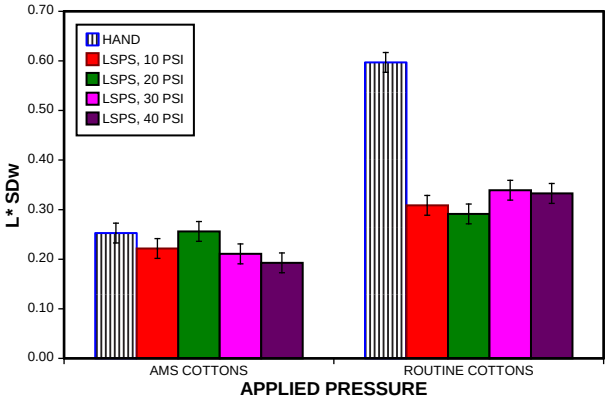

Figure 10. Average L* SDw, hand-applied pressure and LSPS, SCI, 1 mm thin glass. AMS cotton biscuits (n = 12) and routine cottons (n = 25).

In a previous evaluation, 30 psi was shown to be the optimal pressure for spectrophotometer cotton fiber color measurements on small fluffs, using commercial pressure compression systems (Rodgers et al., 2010). To be consistent with the previous evaluation, 30 psi was selected as the operational pressure for large bulk samples and the LSPS.

CONCLUSIONS

A program was implemented to develop a pressurized fiber sample presentation/sampling system for spectrophotometer color measurements with large cotton fiber samples (e.g., AMS standard cotton biscuits). An LSPS was developed for color spectrophotometer color measurements of cotton fibers. The LSPS's design resulted in an equalization of applied pressure to the entire cotton surface during fiber color measurements. Compared to the conventional hand-applied pressure color measurements, the LSPS system normally yielded higher L*, a*, and b* color results. The color parameter most impacted by fiber pressure was L*. High color result consistency and low DE^*_{ab}s were observed for the LSPS with both 6 mm thick HVI glass and 1 mm thick thin glass. The best overall color result consistency was obtained for the 1 mm thin glass measurements (lowest DE^*_{ab}s and SD_ws with increasing applied pressure for LSPS). Preliminary measurement protocols were developed for the LSPS system (spectrophotometer specular component included, 1 mm thin glass, 30 psi applied pressure).

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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.

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