# HVI COLOR AND UV/VISIBLE SPECTRAL RESPONSE OF COTTON FIBERS

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## Abstract

Classification of cotton color is assessed by both human classers and HVI measurements. However, there are demonstrated inconsistencies between them, partly due to the human classer's subjective perception and partly due to HVI's 2-filter limitation. To improve the agreement, a number of attempts have been made, including the consideration of +a (redness) factor, the scanning of a larger cotton surface, and the adoption of neural network classifiers. As a different approach, this work introduced relative yellowness (%+b) or relative lightness (%Rd) that were derived from HVI color Rd and +b readings, and explored the feasibility of one variable for the characterization of cotton color. In order to examine the effectiveness of %+b or %Rd and also its equivalency to that of +b or Rd, cotton physical properties and UV/visible spectra were utilized. The pair of %+b and +b had a more pronounced relationship than that of %Rd and Rd, and the first PC (PC1) scores revealed more remarkable correlation with %Rd than with Rd. Furthermore, the PLS model performance was significantly improved for cotton lightness prediction with the use of %Rd.

## Introduction

Cotton color has been recognized as one of key cotton quality indexes for fiber manufacturers. To ensure a fair trade and good-quality textile products to the consumers, the US Department of Agriculture (USDA)'s Agricultural Marketing Service (AMS) has established the official color standards for grading Upland cottons, known as universal standards, with five major categories and three to eight subcategories within one major category (USDA, 2005). Experienced human classers / inspectors visually compare the cotton fiber sample with the physical standards and assign a color grade to the sample if a color match is found. Classers also take into account of non-lint cotton contaminants (such as plant leaf and extraneous matter) in a sample for color grading. In general, the classification process is both labor intensive and prone to both human error and classer-to-classer variations.

Since the development of high volume instrumentation (HVI) in 1960s, USDA has updated the cotton classing method. At present, this HVI system has been evolved into an official color instrument and also yields additional cotton qualities as fiber length, length uniformity, strength, and micronaire (Gordon, 2007). To class a cotton color, the HVI measures the fiber sample at two specific wavelengths / filters, then calculates the two unique color parameters, Rd (diffuse reflectance, lightness or grayness) and +b (yellowness), and next locates the sample position in the cotton color diagram of Rd versus +b (USDA, 2005).

Although the HVI color module measures lightness (Rd) and yellowness (+b) with the use of only 2 color filters, it provides consistent Rd and +b readings on cotton fibers. However, the system ignores the contribution from the third color attribute, the redness (+a). It might be one of main reasons leading to substantial disagreements in cotton color classification between HVI method and the human classers, who are capable of obtaining more color and comprehensive information on a sample. To improve the agreement between the classers and HVI measurements, several attempts have been reported (Cheng et al., 1999; Duckett et al., 1999; Xu et al., 1997, 1998a, 1998b, 2000). They included the addition of +a factor, the optimal selection of three primary color filters, the spectral imaging collection of a larger cotton surface, and the introduction of innovative data analysis, for instance, neural network classifier.

On the other hand, recently Rodgers et al. (2008) have validated the relationship of HVI Rd and +b to the globally recognized color system (L* a* b*) and also revealed the effects of instrumental and operational variables on the color readings. Meanwhile, they have observed the distinct difference between the different spectrophotometers for L*↔ Rd correlation agreements and the linearity for b*↔+b correlations, and suggested the possible factors resulted in poor L*↔ Rd relationship as the use of HVI glass in front of sample, the use of only 2 color filters, and the algorithms of computing Rd, +b, L*, and b*.

An alternative approach to current HVI color module might be the consideration of ratio algorithm, since it could reduce the interference from HVI glass and +a factor in the measurement of one fiber sample and thus highlight the fraction of yellowness (+b) relative to that of lightness (Rd). The relative yellowness (%+b) could be calculated simply by the following equation:

$$\%{+b} = (+b / (+b + Rd)) * 100\%$$

Obviously, relative lightness (%Rd) can be easily obtained from the difference by subtracting %+b value from 100. Therefore, the specific objective of this study was to examine the efficiency of one HVI color variable (%+b or %Rd) in the characterization of cotton color, with the aid of cotton physical properties and also principal component analysis (PCA) and partial least square (PLS) regression of cotton spectra in the 226-750 nm UV/visible region.

## Materials and Methods

### Cotton Samples, HVI Measurements, and UV/Visible Spectral Collection

A total of 123 cotton samples from different portions of 21 commercial bales and 6 cotton standards were well conditioned at a constant relative humidity of 65% and temperature of 72 ± 2 ºF. Their color and physical properties were measured by an Uster HVI 900A system (Zellweger Uster, Inc., Knoxville, TN, USA). Reflectance spectra were recorded in the 220-2200 nm region at 1 nm interval and with a NIR cup loaded with ca. 0.5 g cotton fiber by using a JASCO V-670 UV/visible/NIR spectrometer (JASCO, Eastern Shore, MD, USA).

### PCA and PLS Models

The UV/visible/NIR spectra were imported into the PLSplus/IQ package in Grams/AI (Version 7.01, Galactic Industrious Corp., Salem, NH, USA, current part of Thermo Fisher Scientific) and were smoothed with a Savitzky-Golay function (polynomial = 2 and points =13), prior to developing PCA / PLS models. All 123 spectra were submitted for PCA operation in the 226-750 nm spectral region with mean centering (MC) spectral pretreatment and full (one-sample-out rotation) cross-validation. During the PLS regression, eighty-two of 123 spectra were used for calibration equation development, and the remaining 41 (every 3rd sample) spectra were used for model validation. To optimize the accuracy of PLS calibration models, the data were undergone different combinations of the spectral pretreatments. The full cross-validation method was also used, and the number of optimal factors selected for the PLS equation generally corresponded to the minimum of the predicted residual error sum of squares (PRESS). The saved regression equations were subsequently applied to the validation samples. Model accuracy and efficiency were assessed in the validation set on the basis of coefficient of determination ($R^2$) and root mean square error of validation (RMSEV). Usually, an optimal model should have lower RMSEV and higher $R^2$

## Results and Discussion

### Descriptive Statistics of Cotton Samples

Table 1 summarizes the univariate correlation coefficients between pairs of four color parameters and three key physical qualities. There existed several moderate correlations among them. Compared to positive and moderate correlations between Rd/%Rd and strength/mean length, +b/%+b correlated with them negatively and moderately. Meanwhile, all color characteristics had insignificant correlations with micronaire component. Existence of moderate correlations between color attributes and strength / mean length properties suggested that the development of cotton color is probably associated with at least one fiber physical property during the cotton growth and maturity. Moreover, the use of %Rd or %+b only improved the correlation between mean length and %Rd.

As anticipated, four color descriptions had stronger correlations with each other than with physical qualities. Notably, the pair of +b and %+b showed a much higher relationship than that of Rd and %Rd (0.98 vs. 0.74), probably suggesting HVI +b readings are more reliable and accurate than corresponding Rd values. Therefore, further improvement in lightness determination from HVI measurement is essential. The observation is in good agreement with previous report from different approach (Rodgers et al., 2008).

Table 1. Univariate correlation coefficients between color and physical qualities from HVI measurement.
(Absolute values >= 0.50, 0.50-0.20, and < 0.20 were to have significant, moderate, and insignificant correlations).

| | **Rd** | **%Rd** | **+b** | **%+b** | **strength** | **micronaire** | **mean length** |
|---|---|---|---|---|---|---|---|
| Rd | 1 | | | | 0.45 | 0.20 | 0.24 |
| %Rd | 0.74 | 1 | | | 0.44 | 0.14 | 0.39 |
| +b | -0.59 | -0.98 | 1 | | -0.39 | -0.10 | -0.40 |
| %+b | -0.74 | -1 | 0.98 | 1 | -0.44 | -0.14 | -0.39 |

**Cotton Color / Physical Indexes and PCA of UV/Visible Spectra**

Cotton fiber is a natural macromolecule and exhibits complex spectral feature in UV and visible region. To extract useful information, all spectra were subjected to PCA characterization in the 226-750 nm UV/visible spectral region. The first two principal components (PCs) accounted for 96.4% of the total variation, with the first PC (PC1) = 88.4% and the second PC (PC2) = 8.0%. The univariate correlation coefficients between two PCs (PC1 and PC2) and cotton color / physical qualities are given in Table 2. As expected, PC1 scores retained significant correlations with all color indexes and moderate correlations with strength / mean length property, while PC2 had a significant correlation only with micronaire index.

Table 2. Univariate correlation coefficients between PC scores and color / physical qualities.
(Absolute values >= 0.50, 0.50-0.20, and < 0.20 were to have significant, moderate, and insignificant correlations).

| | **Rd** | **%Rd** | **+b** | **%+b** | **strength** | **micronaire** | **mean length** |
|---|---|---|---|---|---|---|---|
| PC1 | -0.75 | -0.95 | 0.92 | 0.95 | -0.50 | -0.14 | -0.34 |
| PC2 | -0.14 | 0.10 | -0.15 | -0.10 | 0 | -0.63 | -0.06 |

Compared to a small increment in correlations between PC1 scores and cotton yellowness from +b to %+b, there was a remarkable increase (0.75 to 0.95) between PC1 scores and cotton lightness characteristics from Rd to %Rd. Such an enhancement of %Rd not only confirms the findings from above HVI values alone, but also suggests the linear response from UV/visible spectra, which could be the base for easy and accurate prediction of cotton relative lightness from spectral models. Examples of plotting PC1 scores against Rd/%Rd, shown in Fig. 1, indicated that cotton fibers had a tendency to distribute in a linear manner, with the use of %Rd. Meanwhile, at least five clusters could be more easily and subjectively distinguished from the %Rd plot than from the Rd one. The discrimination of five clusters corresponded well with that of color grade diagram between +b and Rd, in which cotton fibers located from Light Spotted to Tinged major categories and within the Good Middling subcategory (not shown).

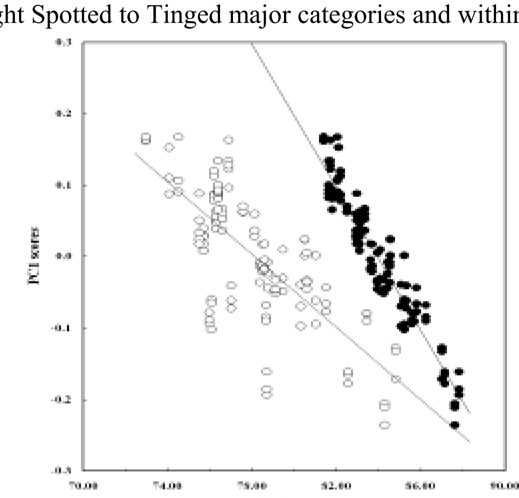


Fig.1. PC1 scores *versus* Rd (○) and %Rd (●).

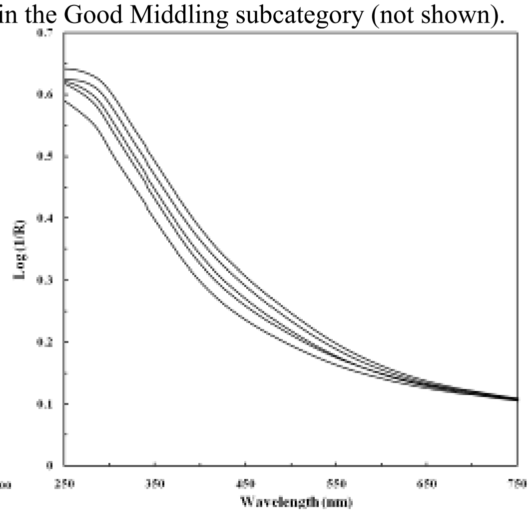


Fig.2. Spectra at various %+b from bottom to top.

By averaging the spectra from individual cluster with %+b values in the respective range of < 13.0, 13.0-15.0, 15.0-17.0, 17.0-18.0, and > 18.0, the representative spectra of cotton fibers are compared in Fig. 2. Characteristic and intense absorptions (< 650 nm) represent a mixture of contributions from the pigmentations in cotton fibers, for example, flavonoids (Hua et al., 2007). Apparent spectral intensities increase with the elevation of %+b and facilitate the spectral model development for the classification and grading of cotton color.

**Cotton Color and PLS Regression of UV/Visible Spectra**

Table 3 gives PLS regression model statistics on the calibration and validation sets. To find the best model, a number of spectral preprocessing algorithms were used. These included various combinations of mean centering (MC), multiplicative scatter correction (MSC), and the first ($1^{st}$) and second ($2^{nd}$) derivatives. For the individual color index, the best performance was determined by lower RMSEV and higher $R^2$ in the validation set.

Table 3. Comparison of PLS statistics in calibration and validation sets from UV/visible spectra.

| Color index | Spectral processing | Optimal factors | Calibration set (n=82) Range | $R^2$ | RMSEC | Validation set (n=41) Range | $R^2$ | RMSEV |
|---|---|---|---|---|---|---|---|---|
| +b | MC | 6 | 10.92-17.20 | 0.942 | 0.381 | 10.92-17.20 | 0.913 | 0.462 |
| %+b | MC | 4 | 12.18-18.60 | 0.957 | 0.359 | 12.18-18.60 | 0.927 | 0.459 |
| Rd | MC+$1^{st}$ deri. | 11 | 72.92-84.80 | 0.950 | 0.596 | 72.92-84.80 | 0.868 | 0.986 |
| %Rd | MC | 4 | 81.40-87.82 | 0.957 | 0.359 | 81.40-87.82 | 0.927 | 0.459 |

All optimal models were derived from such spectral pretreatments as MC and $1^{st}$ derivative. The RMSEV and $R^2$ in validation set for lightness models were much improved from 0.986 to 0.459 of RMSEV and 0.868 to 0.927 of $R^2$ with the use of %Rd, whereas those for yellowness were insignificantly raised from +b to %+b. This is in good consistent with the PCA characterization, in which only the spectral information was used and no reference values were involved. Also, the model for %+b or %Rd needed less optimal factors and could potentially reduce the interference from spectral noise.

Relationship between the HVI derived values (Rd and %Rd) and those predicted from the optimal spectral models is displayed in Fig. 3. It suggests how well the spectral prediction models responded with the reference values from HVI measurements for validation samples.

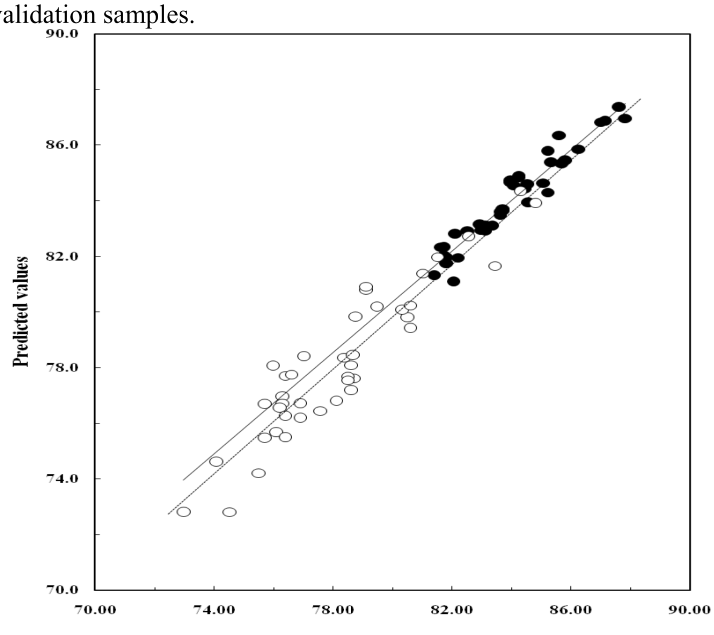


Fig.3. Comparison of spectral models to predict Rd (○) and %Rd (●).

From the predicted +b and %+b (or %Rd) values, we might estimate the corresponding Rd ones. It is not surprising that there were large discrepancies between HVI measured Rd values and those derived from the +b/%+b approach. However, this research has explored the feasibility of one color variable for cotton color characterization. In order to draw profound conclusion, more samples and more accurate Rd measurement should be examined.

## Summary

The study presents a characterization of HVI color index and suggests the feasibility of one variable, relative yellowness (%+b) or relative lightness (%Rd), for the classification and grading of cotton color. Although the use of %+b or %Rd only improved the correlation between mean length and %Rd, the pair of +b and %+b had a more enhanced linear correlation than that of Rd and %Rd. The first PC (PC1) score from PCA revealed more significant correlations with %+b or %Rd than with +b or Rd, especially a remarkable improvement for cotton lightness description. The plot of PC1 against Rd/%Rd indicated the obvious class separation with %Rd. Furthermore, PLS regression model performance was apparently high for cotton lightness with the use of %Rd. The results suggested the potential of utilizing one color variable for classification and grading of cotton color.

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