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An analytical method for determination of quality parameters in cotton plumes by digital image and chemometrics

Maria Ivanda S. Gonçalves [a], Welma T.S. Vilar [a], Everaldo Paulo Medeiros [b], Márcio José Coelho Pontes [a,*]

[a] Departamento de Química, Universidade Federal da Paraíba, João Pessoa, PB, Brazil
[b] Embrapa, Centro Nacional de Pesquisa de Algodão, Campina Grande, PB, Brazil

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ABSTRACT

This paper proposes an analytical method based on the use of digital images and multivariate calibration for the determination of degree of yellowness (+b), reflectance (Rd) and content of wax (WAX) in samples of white cotton plumes and naturally colored plumes. Digital images acquisition of cotton plumes was carried out through a webcam and histograms containing frequency distributions of color index in red-green-blue (RGB), hue (H), saturation (S), value (V), and grayscale channels were obtained. Models of multivariate calibration based on Regression by partial least squares (PLS) using the complete histogram, as well as multiple linear regression (MLR) with the selection of variables by successive projections algorithm (SPA) were developed, validated and compared. Satisfactory prediction results were obtained for both models with Root Mean Square Error of Prediction (RMSEP) values varying from 0.76–0.83, 2.49–2.53% and 0.30–0.33% for +b, Rd and wax, respectively. According to a paired *t*-test at a 95% confidence level, no statistically significant difference was found between the predicted and reference values. An *F*-test at 95% confidence level does not indicate significant differences between the RMSEP values obtained with the full-histogram PLS and MLR-SPA models. It is a simple and low-cost method that does not use reagent, does not destroy the sample and performs analysis with comparable results to the reference method.

1. Introduction

Cotton is a very important natural fiber for the world economy (Dutt et al., 2004). The business value of cotton is directly associated with its quality features, such as length, strength, fineness and color, which are essential for the quality of the yarn (Gordon, 2007). Some of these features are determined by a visual/manual inspection (USTER®, 2006; USDA, 2001). However, this type of analysis is subjective and can lead to unsatisfactory results. Another way to conduct the analysis of this material is HVI (High Volume Instrument) system, which was introduced by the USDA (United States Department of Agriculture) (USTER®, 2006) between the 1960s and 1970s and is still widely used for the quality control of cotton samples. Among the measurements performed by this system are: micronaire index, length, length uniformity, short fiber index, Count strength product, strength, elongation, impurities, reflectance and degree of yellowness (Gordon, 2007; USTER®, 2006; USDA, 2014). The HVI system has as a disadvantage: it is a high-cost system and it needs an adequate infrastructure, as well as a trained person to perform the analysis. The measurements performed with the manual/visual method and the HVI system use physical reference standards determined by the USDA and other organizations (USDA, 2014).

Among the physical parameters determined by the HVI system, we could mention the degree of yellowness (+b) and reflectance (Rd), relevant cotton features directly associated with its color. The classification of cotton plumes in relation to color is an important analysis with commercial interest, as this parameter can contribute to an indication of the quality of textile products (Cui et al., 2014). For this classification, the HVI system provides the +b and Rd values that intersect in a Nickerson-Hunter's diagram, generating a code for the cotton color index (USTER®, 2006; USDA, 2001). The literature on the subject has some research (Cui et al., 2014; Duckett et al., 1999; Matusiak and Walawska, 2010; Rodgers et al., 2013; Liu et al., 2010; Kang and Kim, 2002) focused on the determination of +b and Rd to measure the color degree.

Duckett et al. (1999), Matusiak and Walawska (2010), Rodgers et al. (2013) used Spectrophotometric methods and the CIE

* Corresponding author at: Universidade Federal da Paraíba, Departamento de Química – Laboratório de Automação e Instrumentação em Química Analítica/Quimiometria (LAQA), CEP 580051-970 João Pessoa, PB, Brazil. Tel./fax: +55 83 3216 7438.
E-mail address: marciocoelho@quimica.ufpb.br (M.J.C. Pontes).

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(Commission Internationale de l'Eclairage) color spaces to determine the parameters of cotton color. The results obtained were compared with those determined by the HVI system. Liu et al. (2010) used the UV/Visible/NIR spectroscopy associated with the PLS method to predict the attributes of color and other physical properties of cotton fibers. In addition to this study, the authors also assessed pattern recognition methods in order to classify three classes of cotton samples regarding the micronaire value. Kang and Kim (2002) used digital images to measure the color parameters of cotton and the residues present in the fiber, and they applied a system of artificial neural networks to classify the cotton color. Recently Cui et al. (2014) used images obtained by a scanner to assess the distribution and color variation within the cotton sample. The results obtained by the HVI system were employed for the comparison.

In relation to chemical parameters, the wax content of the cotton samples is one of the most important qualities. In fact, the wax cotton is essential for the efficiency of the spinning process, since it provides a lubricating layer that reduces the friction between the fiber and the machinery. However, high wax content can be a disadvantage, since this layer can also act as an impermeable barrier to the entry of water molecules and dyes in the fiber or yarn produced. Such barrier should be removed by washing and/or bleaching (Gordon, 2007) for a successful dyeing.

The reference method for determination of wax content in cotton was developed by Conrad (1944), which involves the use of organic solvents and gravimetric analysis. This procedure is time consuming, laborious, destructive and involves toxic chemicals.

Cui et al. (2002) and Price et al. (2002) determined the wax content by Conrad's method to analyze its relationship with different properties of the cotton fiber and its effect on the properties of the yarn. Pan et al. (2010) used the classical methodology of pulp and wax content to verify the quality of naturally colored cotton fiber based on those two properties. The authors concluded that, about quality, the presence of wax is not desirable, since it negatively correlated to important properties, such as fiber yield and cellulose content. Dutt et al. (2004) compared three types of colored fiber cottons, i.e., white, brown and green, for their fiber quality and yield. The comparison of fiber quality suggested that colored cotton fiber was inferior when compared with white cotton fiber.

Thus, it is necessary the development of rapid, low-cost and non-destructive analytical methodologies for the determination of the physical and chemical quality parameters of the cotton fiber with results comparable with those obtained by the reference methods (USTER®, 2006; Conrad, 1944).

Digital image-based methods combined with chemometric tools have become a good alternative to the development of new analytical methodologies focused on the determination of quality parameters in different matrices (Acevedo et al., 2009; Santos et al., 2012; Botelho et al., 2014; Dominguez and Centurión, 2015).

The color models employed by digital image techniques have as main objective to specify color in a standard way (Gonzalez and Woods, 2002). The models most commonly used to classification are the RGB (R – Red, G – Green and B – Blue), the HSV (H – Hue, S – Saturation and V – value) and the grayscale (Gonzalez and Woods, 2002). The RGB model is based on the mechanism of color formation in the human eye, where combinations, at different levels, of light radiation at red, green and blue wavelengths provide radiation of different colors (Gonzalez and Woods, 2002). In that mechanism are involved phenomena of absorption and reflection of light, since the colors perceived by human eyes in an object are related to the nature of the light reflected by it (Solomon and Breckon, 2011). The HSV system is more representative of the way humans perceive colors, and sometimes it is also more convenient for image processing. In this alternative color space, hue represents the type of color (e.g. red or yellow), saturation refers to the relative purity or the amount of gray in a color, and value indicates brightness (Solomon and Breckon, 2011; Plataniotis and Venetsanopoulos, 2000).

It is important to emphasize that in the scientific literature, we have not found research involving the use of digital images with multivariate calibration methods for determination of degree of yellowness, reflectance and wax content in cotton plume samples.

The present work investigates the use of digital image data and multivariate methods for simultaneous determination of degree of yellowness (+b), reflectance (Rd) and wax content in cotton plume samples (white and naturally colored). For this purpose, digital images of cotton plume samples were recorded from a webcam and the frequency distribution of color indexes in the red (R), green (G), blue (B), hue (H), saturation (S), value (V), and grayscale channels were obtained. Two regression techniques were evaluated, namely multiple linear regression with variable selection by successive projections algorithm and partial least square (PLS).

2. Materials and methods

2.1. Samples

In this study, white plumes (cultivars BRS 8H, BRS Aroeira) and naturally colored samples (BRS 200 Marrom, BRS Topázio, BRS Rubi, BRS Safira and BRS Verde) were used. Fig. 1 shows the images of the different cultivars studied. All samples were provided by the Brazilian Agricultural Research Corporation (Embrapa Cotton), located in Campina Grande-PB, Brazil. The samples were obtained from different plants, lots and periods of 2013. A total of 76 samples were used to determine the degree of yellowness and reflectance, and 63 samples for the wax content. A mass of 10.0 g was applied to all analyses (digital images and determination of quality parameters).

Before all the analysis, the samples were stored with a temperature controlled at 20 ± 2 °C and relative humidity of 65 ± 2% during 24 h, according to the recommended by the ASTM D1776 (2004) – (Standard Practice for Conditioning and Testing Textiles).

2.2. Reference methods

The HVI equipment, Uster® HVI 1000 model was used for the determination of quality physical parameters (+b and Rd) in cotton plume samples. Each property was measured three times and the average was used for the data treatment.

For the determination of wax content, the methodology is in accordance with Conrad (1944). The procedure involves the use of Randall extractors properly identified; about 2.5 g (w_s) of cotton plumes from cartridges made of qualitative filter paper folded and

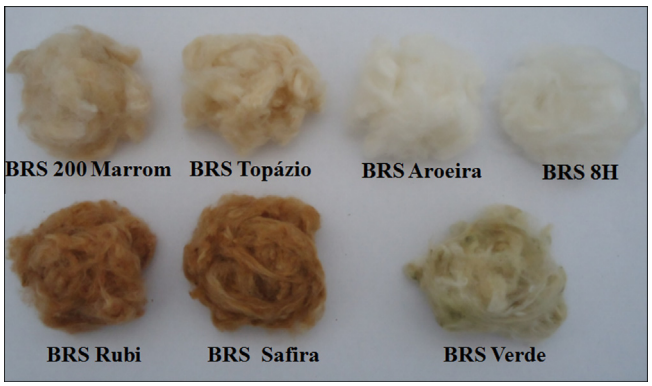

Fig. 1. White and naturally colored plumes used in this study.