INVESTIGATING NEW FACTORS IN COTTON COLOR GRADING

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Abstract

The objective of this research is to further investigate factors that may have significant influences on cotton color measurement but are not considered in the current cotton color grading system. These factors include the redness content (*a*) in cotton chroma, and the presence of spots and trash particles in cotton. The study was based on the color data of the USDA physical standards for U.S. upland cotton and a number of selected samples measured by the imaging colorimeter (CTC) developed from the previous research and a Minolta CR-210 colorimeter. Three major results are found through this study: (1) the *a* content makes up 10% to 33% of the chroma, varying primarily with the major color category (white, light spotted, spotted, tinged and yellow stained). Within the same category, *a* is less variable than yellowness *b*. An approximate +*a* range for each major color category was determined. (2) CTC is less sensitive to the presence of spots and trash particles in the sample than CR-210 because CTC has a much larger viewing area. (3) The influence of spot and trash on the cotton color measurements depends on their sizes and colors in the sample. A change in cotton color data made by spots and trash may lead to a change in color grade. The computational removal of these regions from the sample image in CTC is effective in minimizing the effects of spot and trash. In addition, the paper introduces a new color diagram built on the measurements of reflectance-redness (R_d~a), which identifies the useful role of *a* in cotton color grading.

Cotton color notation consists of a double-digit number. The right digit indicates the five major categories (white, light spotted, spotted, tinged and yellow stained), and the left one indicates the seven subcategories (good middling, strict middling, …) [3]. In the current cotton classing system, cotton color is evaluated both instrumentally and visually. The colorimeter of the High Volume Instrument is used to measure the reflectance R_d and yellowness +*b* of cotton and to provide a color grade based on the Nickerson-Hunter color diagram [2,3], which illustrates the relationships between High-Volume-Instrument (HVI) color measurements and color grades. The color grade is then double-checked by the classer in reference to the universal standards. When the two grades conflict, the classer's grade is the final call for the sample. Cotton Incorporated conducted a survey on colorimeter-classer color grade disagreements for 1995's cotton at 14 USDA cotton classing offices (Figure 1), and found such disagreements exist commonly in all the classing offices. The disagreement was as high as 48% at office 12. According to this survey, a sample is more likely to be given a higher grade by the HVI (□ and ▨ in Figure 1) although the percentage of this disagreement varies among the offices. Another serious disagreement, perhaps the most disputable one, is the conflict between "white" and "light spotted" categories. It is more likely for an HVI colorimeter to assign a "white" grade to a sample labeled as a "light spotted" grade by a classer (□ in Figure 1). The highest WT-LS disagreement reaches 35.4% at office 8. The HVI-classer disagreement on color grade can result in a significant economic impact on both cotton producers and buyers.

The HVI-classer disagreement may arise mainly from differences in the process of color evaluation in these two methods. A classer can examine a much larger sample area than an HVI colorimeter, and is able to eliminate the influence of irregular regions (spots and trash particles). A classer classifies color grades by referencing a number of physical or descriptive standards, while a colorimeter computes color grades by locating color measurement points into corresponding blocks that divide the Nickerson-Hunter color diagram. The assigned color grade for a sample would be very sensitive when the color point is near to the boundary of two grade blocks. The third color attribute, redness, is not reflected in the HVI colorimeter, but is included in the classer's color perception. In order to find solutions for reducing colorimeter-classer disagreement on color evaluations, the new factors that influence the color measurements made by the colorimeter should be first investigated.

This research will further study the effects of redness, spots and trash particles on cotton color grades, and suggest ways to improve the reliability of instrumental color grading. Since an HVI colorimeter is unable to perceive these factors, we choose an imaging colorimeter developed in the previous research, the "Cotton Trash and Color Measurement system" (CTC) [4,5], and a Minolta CR-210 colorimeter [1] as the color measurement instruments. The USDA physical standards for upland cotton and 36 other samples selected from a cotton classing office are the experimental materials for the study.

Factor One: Redness

When cotton growth is terminated prematurely by frost or drought, the affected fibers usually appear yellow in various depths. Based on the amount of yellow fibers present in the samples, cotton is grouped into five major categories. The color of yellow fibers is often not purely yellow. Instead, it may fall in the yellow-orange range on the spectrum,

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containing more or less red colors. It can be readily noticed from the Nickerson-Hunter color diagram that a "white/good middling" sample can have the same yellowness as a "spotted/strict good ordinary" sample. This tells that the yellowness cannot exclusively reflect the chroma of the cotton color. The third color attribute, redness *a*, is a factor that should be taken into account in the instrumental grading of cotton color. In fact, the redness information is inevitably incorporated into the classer's evaluation.

In the USDA universal standards for the visual grading of cotton color, there are only seven physical standards for cotton in the white category, five in the spotted category, and three in the tinged category. The other two categories, light spotted and yellow stained, are presented by virtual (descriptive) standards. The physical standards provide ideal experimental materials for exploring the relevant range of *a* for each color category because of their wide selection of cotton color. The color values of the 15 physical standards were measured using the imaging colorimeter (CTC), and the distributions of R_d, *b* and *a* against color grades are displayed in Figure 2. Although R_d and *b* have clear trends to decrease with color grades both within and among color categories, *a* shows significant changes only among color categories. In the same color category, *a* appears to be almost invariant with sub-categories (good middling, strict middling, …) except the point at grade 34. Each color category has a certain level of *a*, which does not overlap with its neighboring categories (e.g., $a \cong 1$ for white, $a \cong 3$ for spotted, and $a \cong 4.5$ for tinged). This uniqueness of *a* among color categories would make it a useful role in the cotton color grading.

It is also interesting to examine the chromaticity of the universal standards from the chroma and hue perspectives. The chroma *C* and hue angle *h* have the following relationships with *a* and *b*:

$$C = \sqrt{a^2 + b^2}$$
$$h = \tan^{-1}(b/a)$$

The distributions *C* and *h* of the universal standards are presented in Figure 3. The standards in the three color categories (white, spotted and tinged) have non-overlapping levels of chroma and hue. Within the same category, the chroma of cotton decreases almost linearly with the sub-category (strict middling, good middling,…). Hues for all the standards are in the orange-yellow range (60º -90º). But, the hue angle steadily decreases when the color grade changes from grade 11 to grade 54, meaning that the lower the color grade (e.g., grade 54), the redder the cotton appears to be. Figure 4 displays the *b~a* measurements for the physical standards, and roughly shows the chroma and hue ranges for each color category. It is seen again that *a* varies mainly among the categories. In one category, *b* decreases when the sub-category changes from 1 to 7. Therefore, the changes in *C* and *h* in one category are mainly due to the change in *b*.

To quantify the contributions of *a* to cotton chroma *C*, the percentage of *a* in *C* for each physical standard was calculated and displayed in Figure 5. The *a*'s contributions take 10%~16% of *C* for cotton in the white color category; 21%~26% in the spotted category, and 28%~33% in the tinged category. Overall, the percentage of *a* increases as the color grade goes down. The redness content in *C* suggests that the *a*'s contribution to cotton color cannot be ignored, and should be included in the color grading system.

A precise R_d~*a* color grade diagram must be established based on the measurements of a great number of widely selected samples as done for the R_d~*b* color grade diagram. Due to the limited resources in this research, only a preliminary testing could be performed. The approximate range of *a* for each color category can be determined from Figure 2, and is shown in Table 1. Large scale testing to pursue more accurate distributions of *a* across the color categories has been arranged by the researchers in Cotton Inc., USDA and this group. An R_d~*a* color diagram was constructed by plotting the measured (R_d~*a*) data of one set of physical standards (○ in Figure 6). The diagram was roughly divided into small color blocks according to the *a* ranges of color categories. More accurate division of the color blocks can be made after a large quantity of samples has been measured. In this research, 36 more samples (22 white marked by ▼, 8 light spotted marked by △, 4 spotted marked by × and 2 yellow stained marked by ⧗ in Figure 5) were measured, and their R_d~*a* values were displayed in Figure 5. Most of the samples fall into their corresponding ranges.

The R_d~*a* color diagram can be used along with the current R_d~*b* color diagram (Figure 7). If the measurements of a cotton sample stays closely to one boundary of two color grades (e.g., white and light spotted) in the R_d~*b* diagram and the assignment of the color grade is uncertain, the location of the (R_d, *a*) measurements of the sample can be checked in the R_d~*a* diagram to see if the point is away from the boundary of the two color grades. A certain call for a color grade from the R_d~*a* diagram can help confirm an unsure grade in the R_d~*b* color diagram. For example, Figures 6 and 7 show the (R_d, *b*) and (R_d, *a*) points (marked 'o') of a sample. The (R_d, *b*) point is near the boundary of grades 31 and 32, but the (R_d, *a*) point is clearly in grade 31. Therefore, it may be more appropriate to rate this sample grade 31. The color grade from the R_d~*a* color diagram can be used as a secondary rating when the information in the R_d~*b* domain is not sufficient to make a solid call for the color grade.

Six more cotton samples that were graded "white" by an HVI colorimeter and "light spotted" by a classer were tested with this proposed method (see Table 2). From the (R_d, *b*) measurements of CTC, five samples fall in the white category and one (sample 4) in the light spotted category. But they are all close to the boundary of these two categories. For those whose (R_d, b) grades contradict with the classer's grades, the (R_d, a) grades can be used as one extra vote to make the final call. In these six samples, the (R_d, a) grades have changed the (R_d, b) grades twice (marked *), correcting the white category to the light spotted category. Therefore, the use of a information can reduce the chance of disagreement between colorimeter and classer. When both the (R_d, b) grade and the (R_d, a) grade of a sample disagree with the classer's grade, the sample may need to be inspected by another classer.

Factor Two: Spots

Locally yellowed areas in a cotton sample are regarded as spots. For a sample containing a few spots, both its overall color appearance and the existence of spots may prompt a classer to call the sample "light spotted". What is the influence of spots when the cotton's color is measured by a colorimeter? In general, this influence depends on the depth of the spot's color as well as the viewing area of the colorimeter. When the sizes of spots are not negligible relative to the viewing area of the colorimeter, the existence of the spots may cause appreciable change in color measurements and as a result alter the cotton color grade. An experiment was conducted to explore the sensitivity of cotton color change to the spots present in the sample. Four light-spotted cottons, their classer's grades 22, 32, 42, and 52 respectively, were selected in an effort to keep the amount of spots unchanged as the cotton brightness varies, and a Minolta colorimeter CR-210 was used to measure the colors of two selected areas on each sample, the areas with or without a spot. The viewing area of CR-210 is circular with a diameter of 5 cm. The change in one color attribute (R_d, a or b) caused by a spot is quantified by the relative difference ΔC defined as:

$$\Delta C = (C - C_0) / C_0 * 100\%$$

where C is one color attribute of the cotton sample without spots, and C_0 is the same color attribute of the sample with spots. A positive ΔC ($C > C_0$) indicates an increase in the color attribute without a spot being present. Table 3 summarizes the ΔC in R_d, a or b of the samples. It can be seen that all the color attributes of these four samples are affected by the presence of spots, with the change in a being the maximum. The $\Delta E(R_d)$ values show a positive change and $\Delta E(a)$ and $\Delta E(b)$ show negative changes, suggesting that the spots make the samples appear darker and more chromatic. As a result, the color grades of the samples are lowered when a spot is present inside the viewing area. Although the color change does not shift the color grade of sample 2, its sub-grade has changed from 31-4 to 31-3. Depending on the color and size of the spot, the influence on cotton color varies. Overall, the colorimeters with small viewing areas are sensitive to the existence of spots.

The same samples were measured with CTC system by taking two images for each sample. One image was captured with a spot present in the frame and the other without a spot in the frame. The viewing area of CTC is 8.47x6.35 cm^2, which is about 2.74 times larger than the viewing area of CR-210. The detailed spot information measured with CTC is presented in Table 4. In general, the spot areas account for less than 2% of the image area, and have lower values in reflectance R_d and higher values in the both chromatic attributes, a and b, as compared to the cotton lint. The color data of the four samples measured with CTC were provided in Table 5. The changes in all three-color attributes have dropped substantially. In fact, the color differences brought about by spots are smaller than the tolerance of variations for repeated measurements. A minor change in color is not sufficient to change the color grades of these four samples. Note also that the signs of ΔC of the three attributes are not consistent among the four samples, indicating that there are random errors contributing to the changes. In most cases, however, the influence of a single spot on the color measurements of CTC can be ignored because of the relatively large viewing area. To confirm this conclusion, the frequency distributions of the three-color attributes of sample 3 are presented (Figure 8). By adding a spot into the image, the R_d distribution shows a slight leftward shift, and the a and b distributions show a slight rightward shift. The patterns of the distributions remain almost unchanged. It should be noted that the analysis performed here applies only to a light spotted sample. When spots commonly exist in the sample, as seen in some spotted or tinged samples, the spot content in the image will increase, and therefore the influence of spots on cotton color will be more appreciable. This research was not designed to identify the critical level of the spot content that significantly changes CTC color measurements.

Factor Three: Trash Particles

Trash particles, such as leaf, bark and grass, are foreign matters in cotton that have substantially different colors from lint. They will affect the output of a colorimeter if they are not either physically or computationally removed from the scene as the colorimeter takes the measurement, as the color alteration depends on the type and amount of trash particles that the sample contains. An experiment was first conducted to test the sensitivity of the CR-210 colorimeter to a number of colored objects that simulate various trash particles. A number of colored papers were selected to cover a much wider range of color than cotton, and were alternatively inserted into the sample area that was being measured. The size of the papers is 25 mm^2, taking 1.27% of the measured area of CR-210. The boxes of grades 11 and 53 in the universal standards were chosen as two different backgrounds for their substantial difference in color. Their (R_d, a, b) values before placing any colored paper are (78.25, 1.30, 11.96) for grade 11 and (61.88, 3.09, 10.26) for grade 53 respectively. The colored paper was positioned at the center of the head of CR-210. Figure 9 shows how the color values of the two samples (R_{ds}, a_s, b_s) change with the color values of the planted colored papers

(R_{dp}, a_p, b_p). The two samples show the same amount of increase in R_{ds}, a_s and b_s as the papers' R_{dp}, a_p, and b_p increase. This indicates that the influence of colored matters in the sample on the cotton color is independent of the lint color. Some degree of linearity in the relationships of the two sets of (R_d, a, b) can be observed. When R_{dp} changes from 10 to 80, R_{ds} increases by about 9%.

Five cotton samples that have the same classer's color grade but different leaf grades were selected to test the influence of leaf on the color measurements made by the CR-210 colorimeter. A higher leaf grade means a higher leaf content. Table 6 shows the color values and grades of the samples before and after the leaves were manually removed from the samples. After the removal of leaves, the R_d of the samples increases, a decreases, and b shows only a slight increase. These tendencies are clearer when the leaf grade increases. The change in a is greater than in b. This reveals that leaves contribute more a components to the cotton chroma. For the samples whose leaf grades are not larger than 3, the color differences caused by leaves are not significant enough to alter the samples' color grades. For the samples whose leaf grades are larger than 3, the color differences bring about some changes in the color grades, especially for sample 5 whose leaf grade is 7. The leaf content of a high leaf grade sample becomes more noticeable in the viewing area of CR-210. Hence, CR-210, or any other colorimeter with a small viewing area, is not suitable for grading the color of a heavily contaminated sample. The CR-210 color grades without including leaves are closer to the classer's grades. This is because classers are trained to make color grades independent of trash particles.

The influence of trash on the color measurements of the same samples was also tested with CTC. One thing that is different from using CR-210 is that trash particles were removed not physically from the scene but computationally from the image where the color measurements were taken by CTC. The CTC software has specific functions to identify trash particles and to keep them from being counted as the color information is being collected pixel by pixel. Table 7 also shows the color data and grades of the samples when leaves are included or excluded in the color measurement. The color differences between the two cases are much smaller than those of the CR-210 data because CTC covers a larger area that evens out the contributions of leaf colors. Even if the leaves are included, CTC is able to make color grades that are similar to the classer's grades and to the grades without counting the leaves as well.

Figure 10 displays the percentage changes in R_d, a and b caused by excluding trash particles from the images in CTC. E% in R_d and b appear not to vary significantly with the leaf grades, but E% in a does, ranging from -4.2% at leaf grade 2 to –21.7% at leaf grade 7. Relatively, the a value measured by CTC is sensitive to the presence of leaves in the image. The high percentage changes in a with leaf grades are due to the small absolute values of a of the cotton samples and the large a components in leaf colors.

Summary

This study has found that the redness of cotton makes up from 10% of chroma in the white category to 33% in the tinged category, and can play an important role in cotton color grading. This paper has shown some preliminary results on establishing a new color diagram in the R_d~a domain, which can be used to provide a confirming color grade when the initial R_d~b grade disagrees with the classer's grade. The capability of measuring a is strongly recommended for any new colorimeter used to perform cotton color grading. Spots and trash particles can bring about various degrees of change in cotton color, depending on their size and color in the scene. The color change may yield a shift in color grade, especially when the color measurement is near the boundary between two grades. New colorimeters should include functions to eliminate spots and trash particles from color measurements.

Acknowledgement

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Reference

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Xu, B and Fang, C. and Huang, Y. and Watson, M.D., Chromatic Image Analysis for Cotton Trash and Color Measurements, in press, *Textile Research Journal*.

Xu, B and Fang, C. and Huang, Y. and Watson, M.D., Cotton Color Measurement by an Imaging Colorimeter, in press, *Textile Research Journal*.

Table 1. *a* Range for Each Color Category.

Color Category	*a*
White	<1.5
Light spotted	1.5~2.5
Spotted	2.5~4
Tinged	4~5.2
Yellow stained	>5.2

Table 2. Color Grades.

	Classer grade	HVI grade	CTC R_d	CTC b	CTC a	CTC R_d~b Grade	CTC R_d~a Grade	CTC Grade
1	32	31-4	73.7	8.5	0.8	31-4	31	31
2	32	31-3	75.6	9.5	1.9	31-3	32	32*
3	32	31-3	75.9	8.7	8.9	31-3	31	31
4	42	41-4	68.5	9.3	2.1	42-2	42	42
5	52	51-4	65.8	8.0	1.4	51-4	51	51
6	52	51-3	68.4	8.5	1.7	51-3	52	52*

* The third number in the HVI and CTC color grades is the quadrant number of a color grade block in Nickerson-Hunter color diagram.

Table 3. Influenmce of spot on color measurement with CR-210.

	Classer Grade	With Spots R_d	a	b	Grade	Without Spots R_d	a	b	Grade	$\Delta C(\%)$ R_d	a	b
1	22	71.9	1.8	12.1	23-3	75.6	1.5	11.2	22-1	5.2	-19.0	-7.2
2	32	73.9	1.4	9.4	31.4	75.9	1.2	9.1	31-3	2.8	-10.7	-3.1
3	42	61.0	3.2	10.6	53-4	69.9	2.2	9.9	42-1	14.5	-31.6	-7.0
4	52	62.4	1.9	8.7	52-2	64.7	1.7	8.0	51-4	3.7	-13.9	-8.4

Table 4. Characteristics of spots.

	Color R_d	Color a	Color b	Size (mm^2) Average	Size (mm^2) Maximum	Area %	Count
1	42.4	13.1	19.0	12.3	30.9	1.40	7
2	51.1	4.6	11.2	12.2	33.1	0.99	5
3	40.9	12.0	16.9	28.9	67.1	1.88	4
4	39.0	10.0	19.1	14.1	22.5	0.46	2

Table 5. Influence of spot on color measurement with CTC.

	Classer Grade	With Spots R_d	a	b	Grade	Without Spots R_d	a	b	Grade	$\Delta C(\%)$ R_d	a	b
1	22	75.5	1.7	11.4	22-1	75.6	1.6	11.2	22-1	0.2	-4.5	-1.9
2	32	75.9	0.7	8.9	31-3	76.0	0.8	9.0	31-3	0.2	9.2	0.6
3	42	70.9	1.7	10.1	42-1	72.0	1.6	9.6	42-1	1.5	-7.9	-4.8
4	52	65.5	1.4	8.6	52-1	65.1	1.4	8.6	52-1	-0.5	-0.4	0.1

Table 6. Influence of leaves on color measurements with CR-210.

Leaf Grade	Classer Grade	With Leaf R_d	a	b	Grade	Without Leaf R_d	a	b	Grade
2	41	71.7	0.84	7.5	41-2	72.6	0.72	7.7	41-2
3	41	71.6	1.48	7.9	41-4	71.8	1.44	8.0	41-4
5	41	74.5	1.04	8.5	31-3	74.9	0.88	8.6	31-4
6	41	72.2	1.13	7.6	41-2	73.5	1.03	8.0	41-1
7	41	69.6	1.24	7.4	51-1	71.4	0.95	7.5	42-1

Table 7. Influence of trash particles on color measurements with CTC.

Leaf Grade	Classer Grade	With Leaf R_d	a	b	Grade	Without Leaf R_d	a	b	Grade
2	41	72.3	0.49	7.1	41-2	72.8	0.47	7.1	41-2
3	41	72.4	1.09	8.2	41-4	73.0	1.01	8.1	41-3
5	41	74.7	0.70	8.6	31-4	75.5	0.62	8.6	31-4
6	41	73.6	0.75	7.8	41-1	74.2	0.60	7.8	41-1
7	41	71.6	0.80	7.9	41-4	72.5	0.62	7.8	41-2

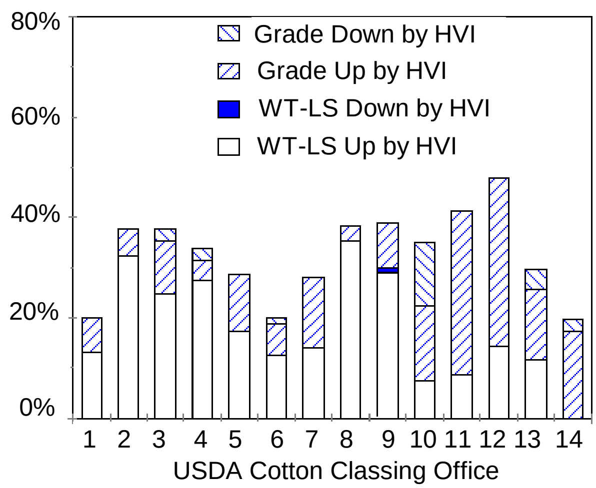

Figure 1 HVI-Classer Disagreement on Color Grades

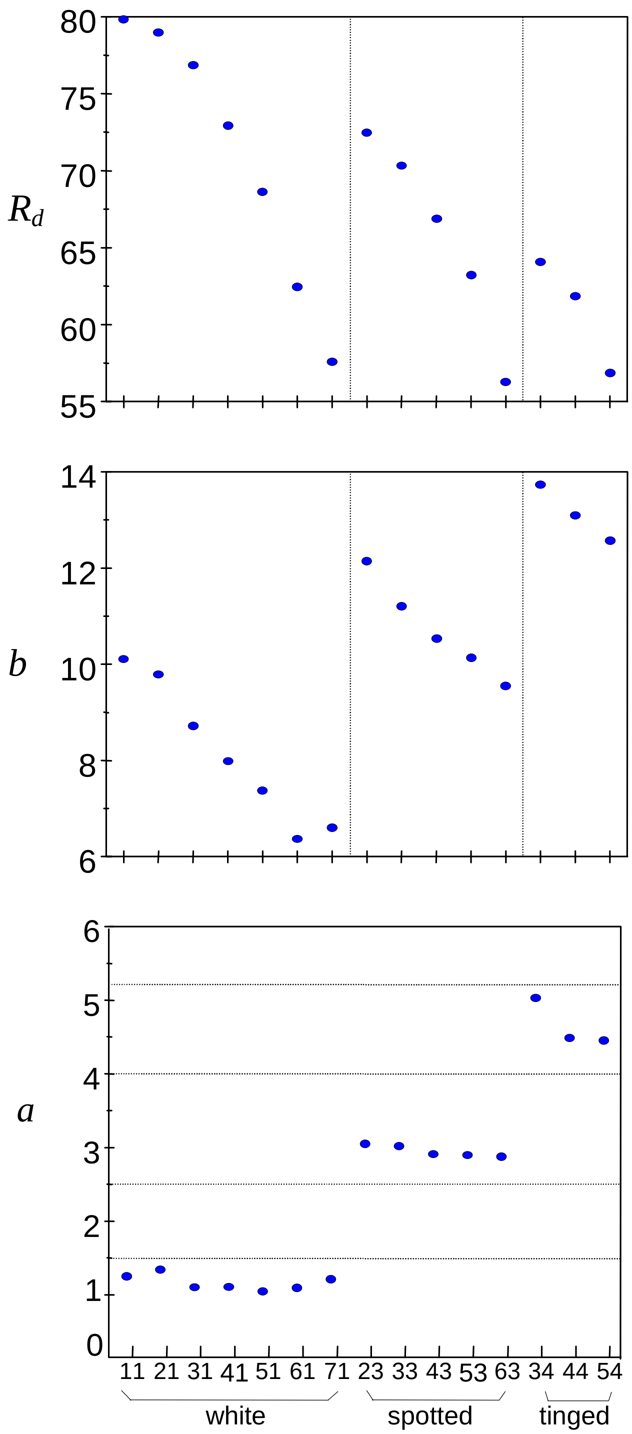

Figure 2 R_d, b and a of the USDA Physical standards

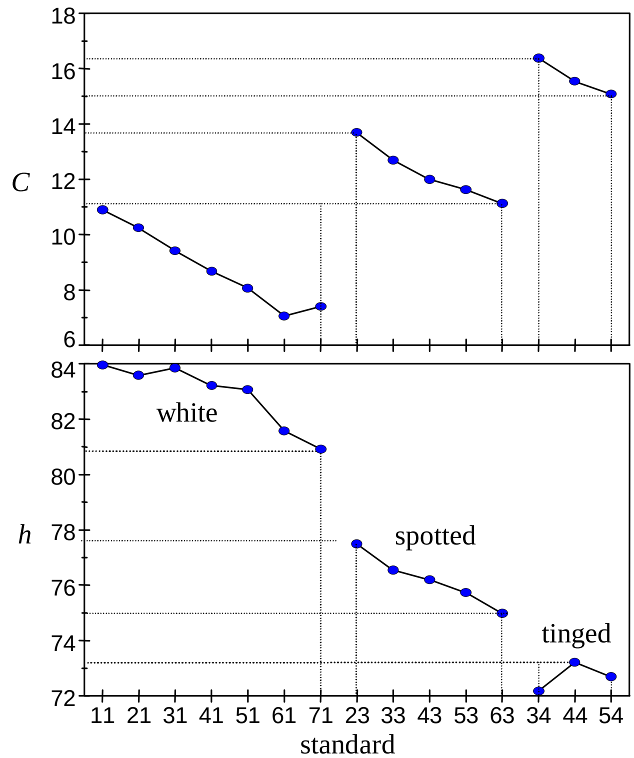

Figure 3 Chroma and Hue Angle of the Physical Standards.

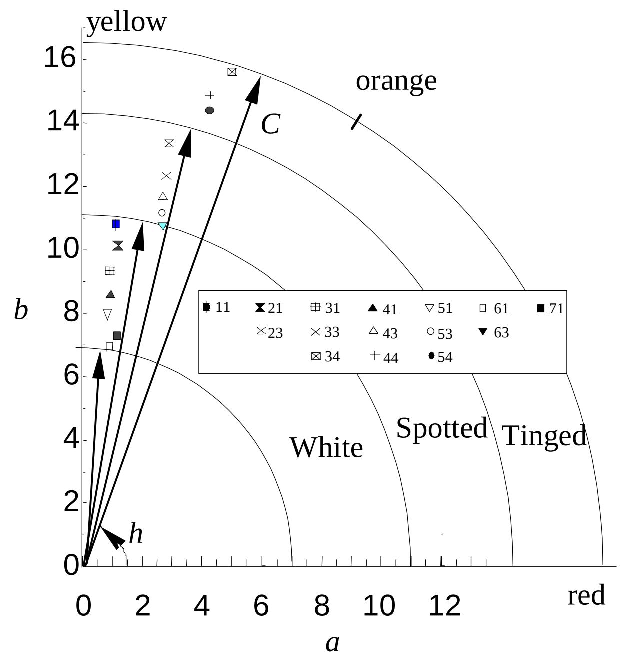

Figure 4 b~a Color Grade Diagram

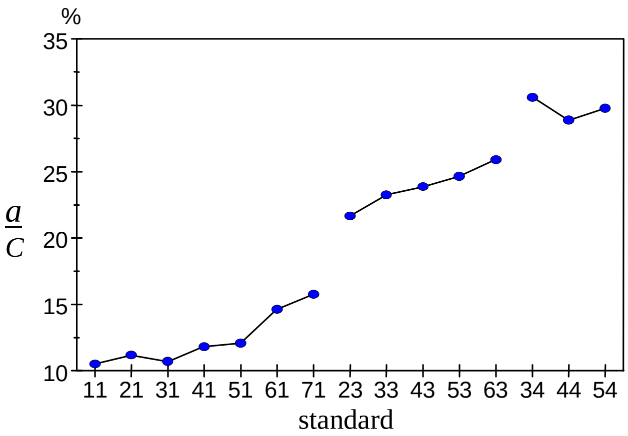

Figure 5 Contribution of *a* to Cotton Chroma *C*

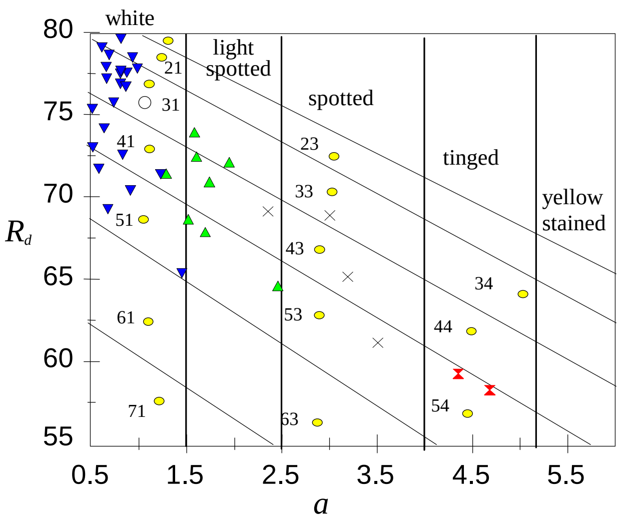

Figure 6 R_d~*a* Color Grade Diagram

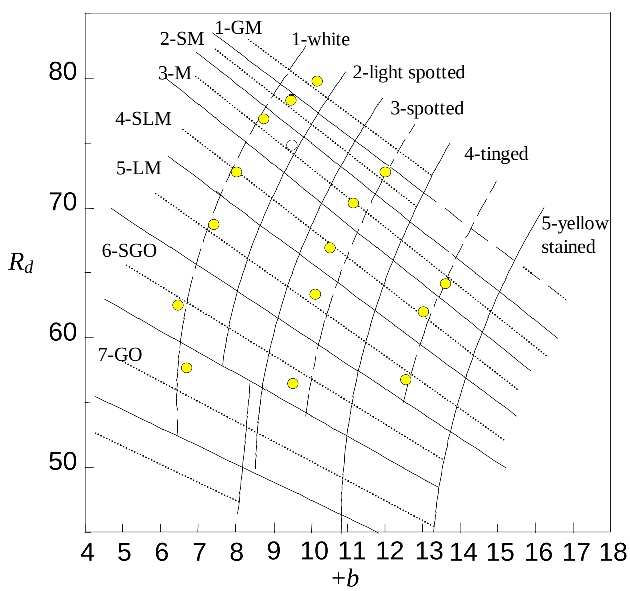

Figure 7 R_d~*b* Color Grade Diagram

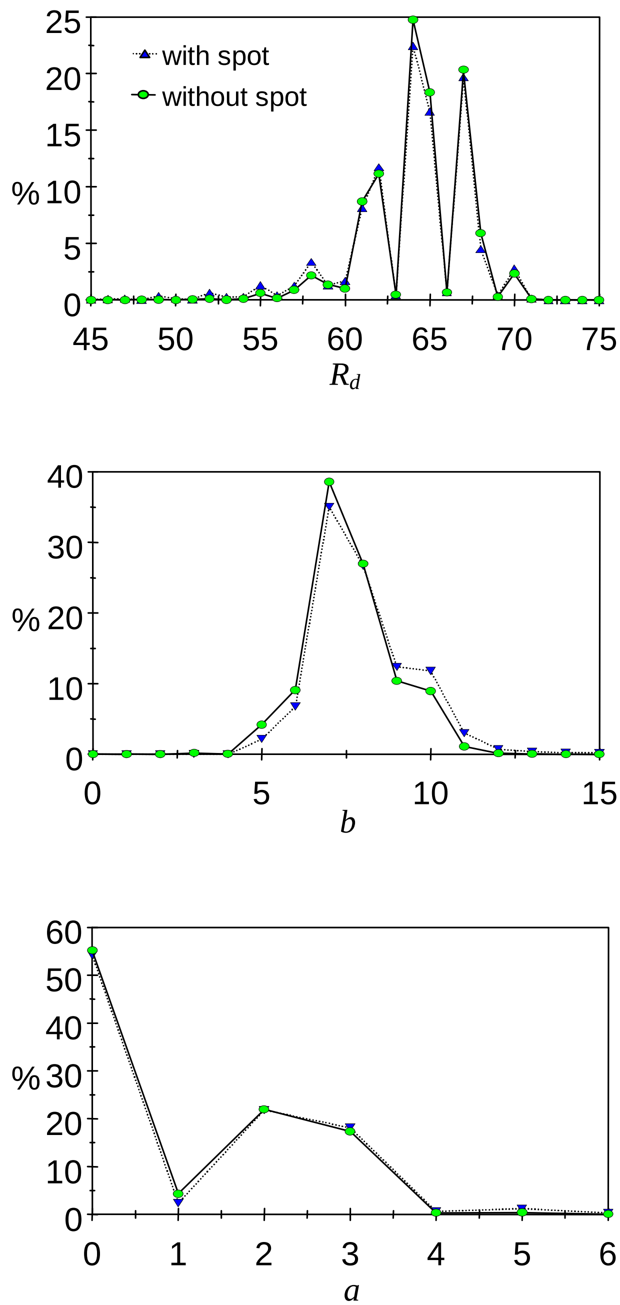

Figure 8 Changes of R_d, *b* and *a* Distributions with Spots

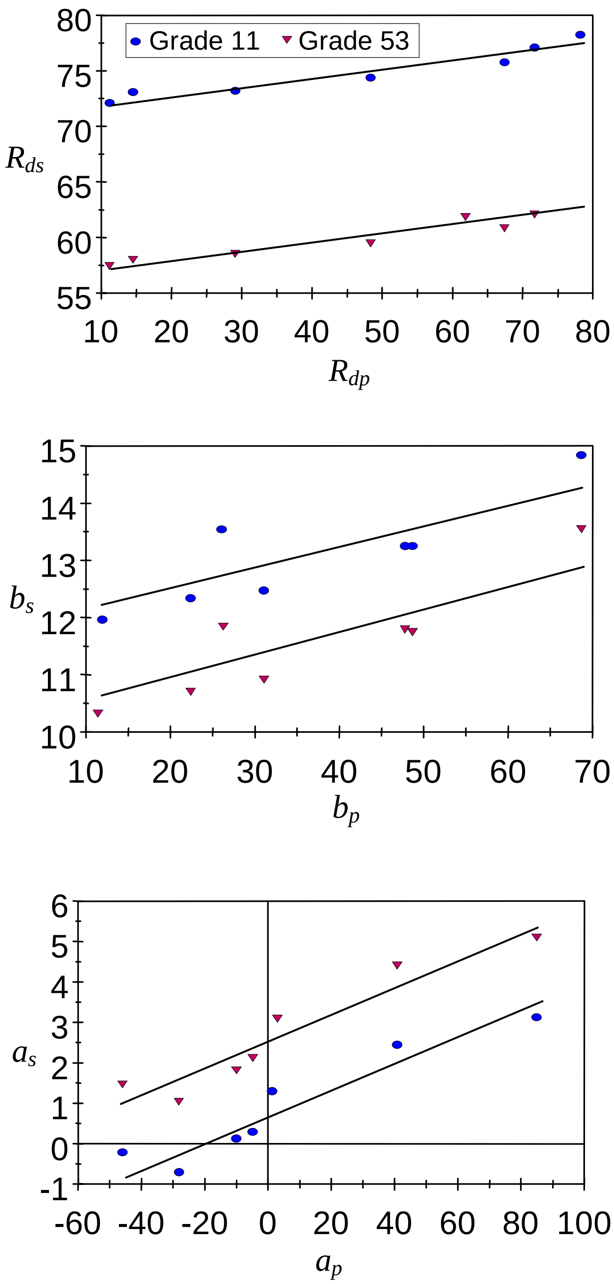

Figure 9 Cotton's Color Change with the Color of inserted Papers

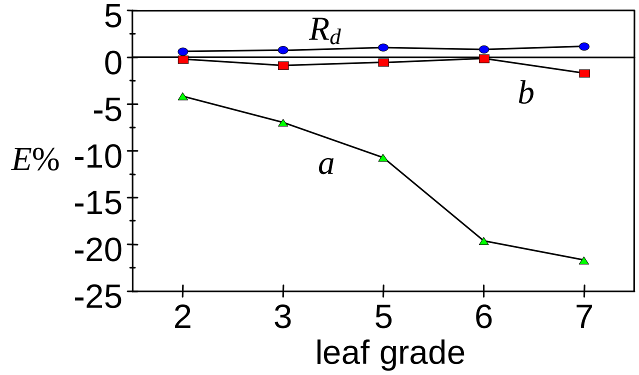

Figure 10 Percentage Changes of (R_d, a, b) with Leaf Grade