Color Measurement of Roasted Coffee Using HunterLab Spectrophotometers

Introduction

This study was initiated to validate the use of color measurement spectrophotometers (visible spectrum spectrophotometers) for determining the roast color of coffee products. Although color measurement devices traditionally have been the method used to evaluate the degree of coffee roast, Near-infrared (NIR spectrum) instruments have recently become more prevalent in the market and have created some level of confusion with end-users. This study will demonstrate that visual spectrum spectrophotometers can be used to accurately determine the roast color of coffee products and provide additional advantages over NIR instruments.

Background

Color is one of the important variables used to predict the degree of coffee roasting and control the consistency and quality of roasted coffee products. Color is determined by measuring the reflectance from 400-700nm. For more than 60 years, HunterLab has been dedicated to the development and application of color measurement instruments to solve color related problems in industry and science. HunterLab instruments are compliant to CIE worldwide standards, offer traceability of instrument standards, and provide industry color scales for color documentation and communication.

For coffee products, NIR instruments typically measure reflectance in the 800-1000nm range. Measuring in the NIR is claimed to provide the degree of roast and a predictor of flavor as it relates to the chemistry of the roasting process and the caramelization of sucrose[1]. This last point is in some dispute and beyond the scope of this study. Color measurement is carefully defined by the CIE, Commission Internationale de L'Éclairage, the international organization for standardization of color measurement. It should also be noted that IR spectroscopy has the potential to provide information on weight loss and moisture content, chemical composition, and other related properties of coffee. However, the combination of these broad range of capabilities are rarely found in a single NIR instrument suitable for industrial quality and process control and are generally available only in laboratory analytical instruments.

Study

This study bases its experimental design in providing data that correlates with the visual coffee roast standards created by the SCAA – Specialty Coffee Association of America and used by industry to rate coffee color (often reported as Agtron number). Traditionally coffee roasters used a series of visual standards developed by the SCAA to rate the level of roast in their coffee products. This coarse visual scale works well in ranking coffee color but with only eight grades, does not provide great resolution in scoring coffee roast in process. Further, as with any visual grading system, human subjectivity introduces a level of error.

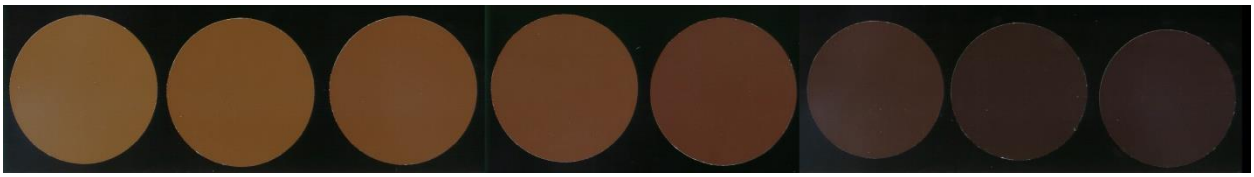


Figure 1 SCAA (specialty Coffee Association of America) Roast Coffee Kit showing color standard range from 95 (light) to 25 (dark)

This study compared visually graded coffee (using multiple human observers) with instrumental analysis using colorimetric and NIR methods described below.

The study focused on two particular methods for determining the degree of roast in coffee products. The first method used information collected from spectrophotometers measuring in of the visible spectrum from 400nm to 700nm. The second method used spectrophotometric data collected from the NIR, focusing on wavelengths in the 800nm to 1000nm range.

The results are further simplified by focusing on specific wavelengths that this study intends to show provides good correlation with visual evaluations and SCAA rankings. Reflectance in the visible region at 640 nm (10nm band pass) and in the NIR region at 880nm (10nm band pass) was used for reporting and comparison.

Measurement Devices

For this study HunterLab selected two of their color measurements spectrophotometers designed for the measurement of roast coffee, the ColorFlex EZ Coffee and D25 NC, along with a reference instrument the UltraScan PRO that can measure at both visible (400-700nm) and NIR (800-1000nm) wavelengths.

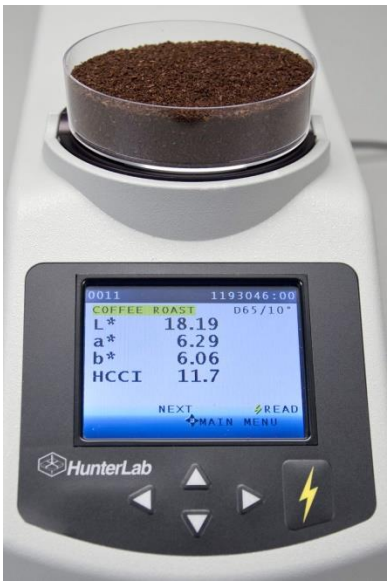


Figure 2: ColorFlex EZ Coffee measuring roast coffee color though the bottom of a clear plastic dish.

Figure 3: D25 NC (Non-Contact) measuring port down on both ground coffee and beans.

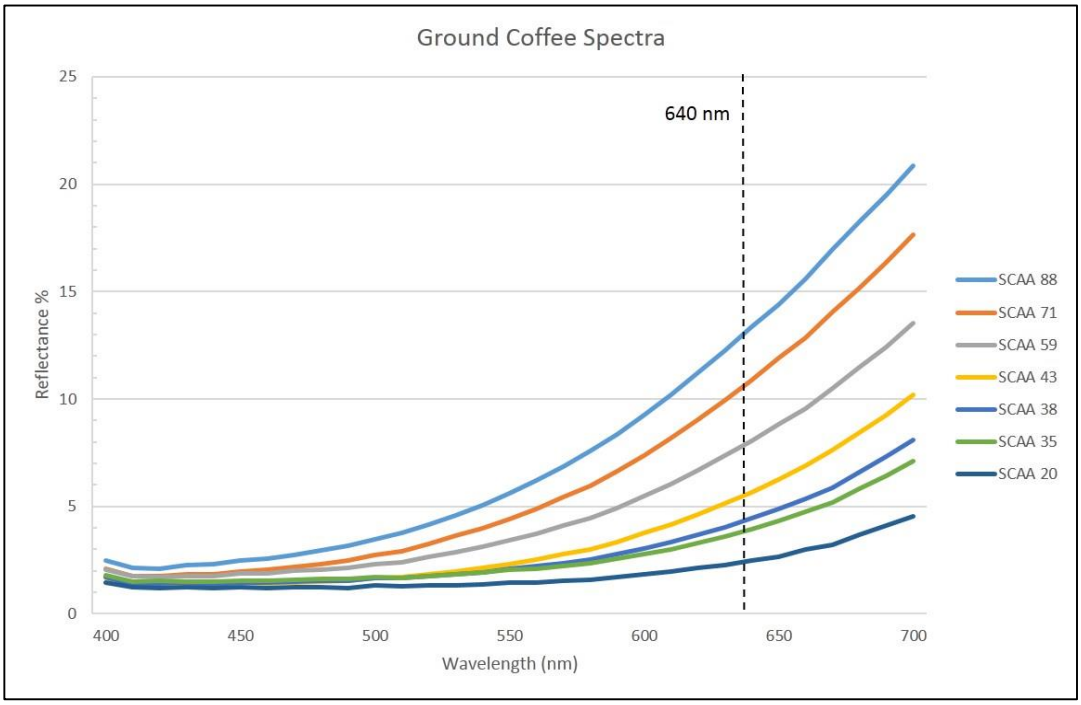
Sample Preparation and Test

1) Green coffee bean varieties were roasted for different durations to obtain a broad range of roast and color levels, ranging across 25 (dark) to 95 (light) range of SCAA Coffee Color. (SCAA Coffee Color is also referred to in industry as an Agtron number).
2) SCAA values (Agtron number) were independently obtained for each sample and used as reference values throughout the study.
3) After roasting, the coffee beans were ground, then placed in dishes for measurement.
4) As shown in Figure 2, the CFEZ Coffee measured the bottom surface of the sample through the clear bottom of a plastic dish. The D25 NC measured the sample in a non-contact manner, viewing sample directly as shown in Figure 3. The USPRO was utilized in reflectance mode (specular excluded) with ground coffee presented using a 50mm glass sample cell.
5) Measurements were taken for each sample in conformance with each instrument's operation manual.
6) Replicate samples from each sample set were independently measured and averaged to obtain a represent result of that roast level.
7) All color data was calculated using the CIE D65 illuminant and 1964 10 degree standard observer.
8) Spectral data was stored using each system's software for later retrieval and analysis.

Analysis of Results

Objective 1: Determine strength of correlation between instrumental measurement in the visible spectrum and results assigned through SCAA visual standards.

Measurements collected from the range of roast coffee samples produced spectral reflectance curves as shown in Graph 1.



Graph 1: Ground coffee spectra (visible spectrum)

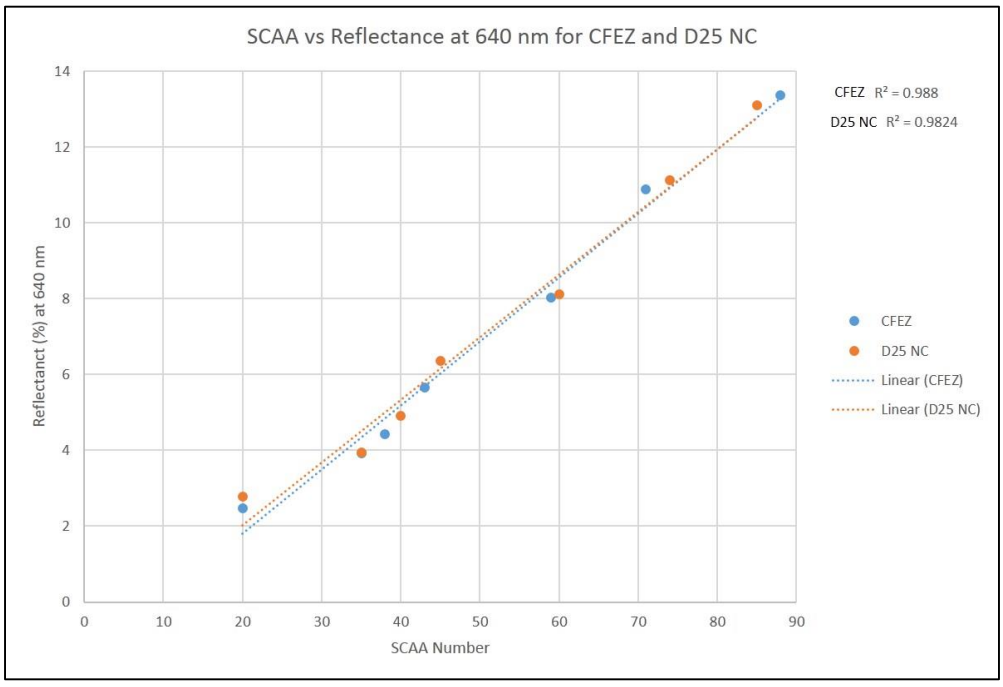
The curves show a clear differentiation related to the different degrees of roast. This supports the historical use of 640nm for roast classification.

From the reflectance spectra, reflectance values at 640nm were extracted and corresponding CIE L*a*b* colorimetric values calculated.

Table 1 below shows that the range of SCAA (Agtron) numbers from the roast coffee samples correlate well with the visual spectrum as shown in Graph 1, with greatest resolution in the red spectral range (640nm). Lower SCAA numbers are related to lower reflectance values at 640nm. With this understanding of spectral resolution HunterLab adopted the industry standard of 640nm as a target wavelength band for discerning the degree of coffee roast. The correlation of the 640nm reflectance and SCAA numbers for the roast samples is shown in Graph 2 below.

CFEZ Results					D25NC Results				
SCAA	R% 640nm	L*	a*	b*	SCAA	R% 640nm	L*	a*	b*
85	13.36	30.08	13.14	20.65	85	13.1	29.1	14.1	22.86
71	10.88	26.65	12.78	18.98	74	11.12	26.52	13.57	20.9
59	8.04	23.08	10.92	14.2	60	8.11	22.44	11.95	16.11
48	6.37	19.97	10.28	12.15	46	6.37	20.12	9.93	12.05
38	4.43	16.97	7.68	7.98	40	4.91	17.83	8.29	8.84
35	3.93	16.46	6.44	6.21	35	3.95	15.94	7.19	6.95
20	2.48	12.78	4.54	3.55	20	2.79	13.91	4.64	4.62

Table 1: Seven (7) ground coffee samples ordered from lightest to darkest and their measured SCAA, R% at 640 nm, and CIEL*, a*, b* values listed.



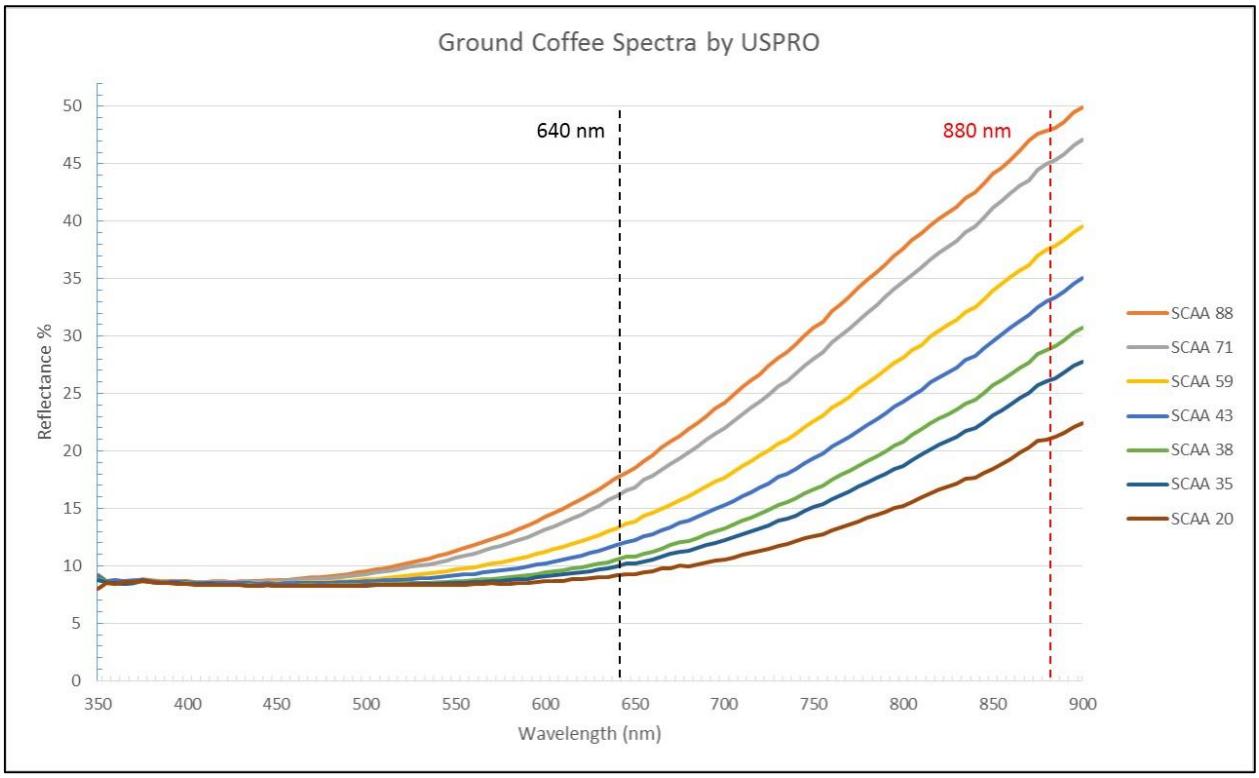
Graph 2: Correlation between SCAA number and 640nm reflectance

Objective 2: Comparison of visible spectrum measurements and NIR measurements.

Visible and NIR reflectance results were compared at the subject wavelengths of 640nm (visible) and 880nm (NIR) for the roast coffee sample set.

Although, the difference of reflectance at 880 nm between samples is greater than the reflectance difference at 640 nm for all seven (7) ground coffee samples, the discrimination at either wavelength was more than sufficient to properly evaluate roast levels.

All samples showed the same trend for the roast color changes in both the visible and NIR spectrums with excellent correlation. The resolution of reflectance at 640nm was capable of separating coffee roast samples with significant color differences. It is important to note that reflectance at 640 nm in the visible spectrum correlates to visual evaluation of the degree of coffee roast by humans.



Graph 3: Ground coffee spectra showing reference markings for the Visible and NIR wavelengths

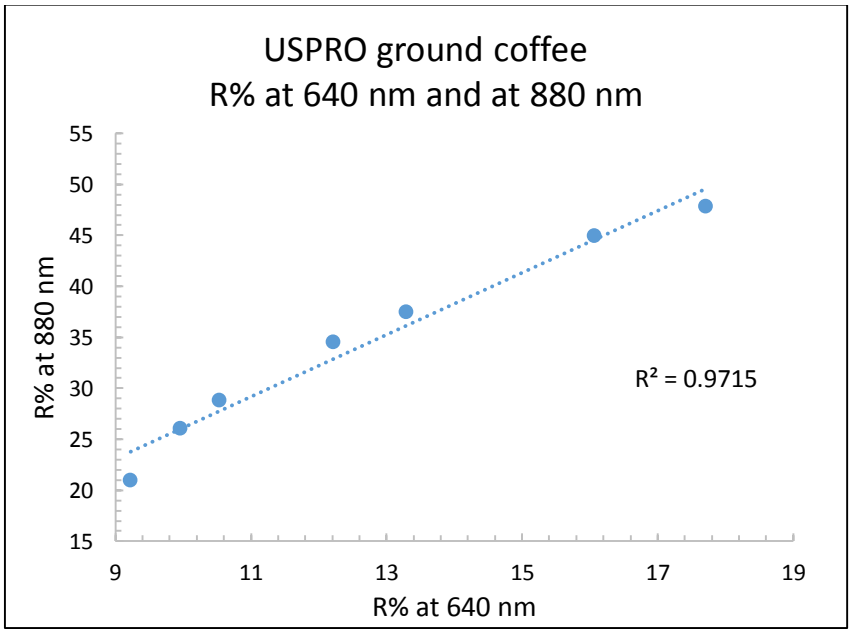
The results comparing reflectance values the visible and NIR measurements are shown in Table 2 below with the corresponding SCAA (Agtron) numbers.

SCAA (Agtron)	R% at 640 nm	R% at 880 nm
85	17.71	47.84
71	16.07	44.95
59	13.29	37.51
48	12.21	34.54

38	10.53	28.82
35	9.96	26.06
20	9.22	21.01

Table 2: 640 nm and 880 nm for the seven (7) ground coffee samples with different degrees of roast

The comparison of the two subject wavelengths of 640nm and 880nm are compared in Graph 4 below to show that a strong correlation between the measurements exists and support the premise that either wavelength will provide suitable results.



Graph 4: Correlation of R% at 640 nm and R% at 880 nm for 7 ground coffee samples

Practical Application of Results in HunterLab instruments.

Knowing that there is a strong correlation between the degree of roast color and the 640nm reflectance band, HunterLab has simplified measurement data with two quality metrics:

- SCAA Roast Classification (Agtron) reported in numbers and corresponding word classifications provides industry standard reporting of the final roast color.
- HunterLab Coffee Color Index (HCCI) measures the reflectance of ground coffee products at 640nm, which is best for measuring during the roasting process, taking the coffee product to a consistent end point.

Figure 4 HCCI and SCAA color indices are provided on HunterLab Coffee instruments.

Results and Recommendations

In this study we set out to understand:

1. How the reflectance % in the visible spectrum correlates to SCAA (Agtron) roast numbers,
2. How the reflectance % in the NIR compares to the visual range of roasted coffee samples,
3. How these principles can effectively be applied to HunterLab instruments.

HunterLab instruments were able to measure significant reflectance differences at 640nm to successfully differentiate the ground coffee samples for the full SCAA range. Compared to visual methods HunterLab instruments provide more objective and precise color measurement results for determining the degree of coffee roast

HunterLab instruments provide a complete color profile of coffee samples within the visual spectrum without the need of a dedicated NIR instrument. Other benefits of a HunterLab visible spectrophotometer include:

- Conformance to the global CIE system of color measurement for all products.
- Instrument calibration to match traceable standards.
- Independent diagnostic standards to verify HunterLab instrument performance.
- Application performance qualification (PQ) standards using the HunterLab Coffee Tile.
- Ability to measure the color of other products, in addition to coffee.

References

1. Specialty Coffee Association of America, 2010. Handbook series: Roast Color Classification system, www.scaa.org.
2. Weyer, L. G., 1985. Near-infrared Spectroscopy of Organic Substances. Applied Spectroscopy Reviews, 21, 1–43.

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