Color Measurement of Cereal and Cereal Products

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Color is an important attribute to the food industry. Consumers frequently look at a product and make a judgement decision largely based on overall appearance including color. Often color and flavor are directly related. As an example, for many breakfast cereals, if the product looks dark it will probably taste burnt, if it looks light it will probably taste underdone. In this example color variation and moisture content are also related. Manufacturing processes such as extrusion and baking can effect final product color. Ingredient color can also effect the color of cereal products. Thus to obtain and maintain the desired color, it is important to monitor and control ingredient color as well as monitoring the product through the manufacturing process.

Color assessment is done for several reasons. These include:

- To determine and document ingredient effect on product color
- Determination of color change as a result of storage, processing and other factors
- QC test to ensure consistency of ingredient color
- Quality tests to determine conformance to final product specification

Visual color assessment can be done, however it has several shortcomings. First to make reliable visual evaluations multiple variables must be controlled. These include the spectral quality of the light source, the intensity of the light source, the angular size of the light source, the direction from which the light strikes the sample, the direction in which the sample is viewed, the distance between specimen and color standard, and the observer's spectral response. Colors that fall between visual color standards are often difficult to communicate to other individuals. Visual color assessment is subjective, tiring and frequently tedious.

Instrumentation

Instrumental color measurement is more straightforward than visual methods, eliminates subjectivity, is more precise, takes less time and overall is much simpler to perform. There are basically three types of color measurement instruments used for cereal and cereal product color measurement. These are the monochromatic colorimeter, the tristimulus colorimeter and the colorimetric spectrophotometer.

The **monochromatic colorimeter** does not measure color per se. It only measures the amount of light reflected in relative units in a narrow area of the red, green, blue or yellow region of color. Because of this, a monochromatic colorimeter is basically colorblind and sees only all red, or all green, or all blue, or all yellow. Thus it can easily give erroneous results. For example, to measure the "browness" of breakfast cereal flakes the green filter may be used to measure lightness to darkness. If there were two different batches of cereal where one was a light brown and the other was a darker brown but with a green cast, the instrument could indicate that they were the same color even though visually they would look different. A benefit of the monochromatic colorimeter is that it can view a large area (6" diameter) and obtain a good optical average of relatively large coarse samples such as corn or wheat flakes.

The **tristimulus colorimeter** can also view large areas of sample but has the added benefit that it measures true color and correlates to what the eye sees. It actually simulates the eye/brain sensitivity to color by simultaneously using specialized glass color filters and light detectors. The human eye can detect up to 10 million different shades of color and the tristimulus colorimeter can quantify all of them. Because of its large area of view, it is excellent for measuring coarse samples like coarse breakfast cereals, extruded snack products, pasta, noodles and tortilla chips.

Like the tristimulus colorimeter, the **colorimetric spectrophotometer** measures true color. However it uses a somewhat different measurement principal. It measures the entire visible spectrum of light (rainbow) being reflected from a sample and then using mathematical tables representing the human eye color sensitivity and mathematical tables representing the color output of different light sources, calculates the result. This type of instrument is even more precise than the tristimulus colorimeter and at the same time is normally lower in cost than either the monochromatic colorimeter or the tristimulus colorimeter. It does not measure as large an area as the tristimulus colorimeter and thus is best for measuring samples like rice, flour, wheat, corn, barley, starch, and less coarse breakfast cereals. Some colorimetric spectrophotometers also have the ability to measure transmitted color so they are suitable for measuring samples like corn syrup and grain alcohol.

Color Scales

To be useful a color scale should relate to how we see color, be simple to understand, be linear throughout color space and be able to quantify color differences.

The color scales that are most widely used by the food industry are the Hunter L,a,b and the CIE L*,a*,b* scales. These are 3-dimensional scales. Both are based on the opponent-colors theory that states that the red, green and blue human eye cone responses are re-mixed into black-white, red-green, and yellow-blue, opponent coders as they move up the optic nerve to the brain.

The L,a,b type of scales simulate this as:

- **L** (lightness) axis – 0 is black, 100 is white
- **a** (red-green) axis – positive values are red; negative values are green and 0 is neutral
- **b** (yellow-blue) axis – positive values are yellow; negative values are blue and 0 is neutral

All colors that can visually be perceived can be measured in either L,a,b scale. These scales can also measure the color difference between a sample and a standard. **Color difference is always calculated as SAMPLE minus STANDARD and is frequently stated with a Δ symbol.**

- If **ΔL** is positive, then the sample is lighter than the standard. If negative, it would be darker than the standard
- If **Δa** is positive, then the sample is more red (or less green) than the standard. If negative, it would be more green (or less red)
- If **Δb** is positive, then the sample is more yellow (or less blue) than the standard. If negative, it would be more blue (or less yellow)

L,a,b color difference can also be expressed as a single value, **ΔE**. This value defines the size of the total color difference, but does not give information about how the colors differ.

The larger the ΔE value, the larger the color difference. It is defined by the following equation:

$$\Delta E = v(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2$$

Whiteness is a color index by which a sample is judged to approach the preferred white. It is important because in many cases observer ratings of whiteness correspond to consumer preferences for products such as rice and flour. Our visual judgement of whiteness is primarily dependent on how light a sample is and the presence or absence of blue or yellow tint. If two white samples had the same lightness, the one that was bluer (or less yellow) would be judged to be whiter. A single number **whiteness index (WIE)** is used as a measurement of whiteness. It mathematically combines lightness and yellow-blue into a single term. The higher the whiteness index the whiter the sample.

Sample Preparation and Presentation

The ideal sample for color measurement would be flat, smooth, uniform, non-directional and either totally opaque or totally transparent. Of course in the real world this is rarely the case. Thus compromises must be made.

Some guidelines to achieve the greatest measurement precision are:

- Choose samples that are representative of the product
- Prepare the sample in a way to best approximate the ideal sample characteristics
- Prepare samples in the same way each time
- Present the samples to the instrument in a repeatable manner
- Make multiple preparations of the sample and average measurements

It is common practice to take at least three readings (with replacement) for a non-uniform sample and then to average the readings. A method to establish the correct number of readings to average is to create one set of averaged readings by reading the same sample three times (with replacement) and average the readings. Next, measure the same sample again three times and average. You will now have two averages to compare. If the ΔE between the two averages is less than or equal to 0.11, then three readings are sufficient to provide repeatable results. If the ΔE is greater than 0.11, then try the same procedure again with a greater number of averaged readings until the repeatability is sufficient. The goal of this procedure is to find the lowest possible number of readings that will provide repeatable results.

The following example of a measurement procedure will use rice as the product being measured. Rice has several non-uniform characteristics that require compensating preparation and presentation techniques in order to ensure a repeatable sample measurement. Rice is granular - not a solid sample – and must be measured through the bottom of a clear cup or dish (with a flat bottom) to be effectively made into a solid. It is also translucent – not opaque – and will be sensitive to ambient light and small differences in the optical configuration of the instrument. Using sufficient sample thickness will minimize these effects.

The measurement method is as follows:

- Configure the instrument software to read in the desired scale or index. For rice one might select a whiteness index. Also configure the software to automatically average the number of readings to be made for each measurement set
- Orient the instrument with the measurement port facing up
- Standardize the instrument with the calibrated tiles that came with the system
- Scoop up rice from the sample batch and fill the sample cup to the top. A 2-inch sample thickness should make the translucent, irregularly shaped rice effectively opaque for reflectance measurement
- Place the sample cup on the instrument measurement port so that the rice will be read through the flat bottom of the cup
- Take a single reading of the rice. Dump and refill the cup and take another reading. Repeat this until the desired number of readings to average has been made. Averaging multiple readings minimizes measurement variation associated with non-uniform samples
- Record the average values for the sample batch

There are many benefits to the quantitative measurement of cereal and cereal product color including consistent product color, reduced waste, consistent package content and improved customer satisfaction to name a few. Use of proper instrumentation and measurement protocol will ensure high precision and correlation to visual perception.