RELATING SPECTROPHOTOMETER READINGS TO VISUAL GRADING OF MAPLE SYRUP

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Color grading of maple syrup is based on placing syrup samples within four or more categories based either on visual comparison to color references or measurement of light transmission with a spectrophotometer. With a spectrophotometer, specific transmission values are used as break points to divide syrup samples into color grades. The purpose of this report is to describe the lack of agreement between existing light transmission break points and visual grading and how this problem can be addressed.

BACKGROUND

Visual color grading of maple syrup began in 1910 using a series of 20 caramel solutions based on a specific recipe (Balch 1930, Brice and Turner 1956). In 1950, colored glass references were introduced to overcome the problem that caramel solutions were difficult to standardize and changed color density with time. Colored glass references are more stable and appear not to change over long periods of time. Consequently, the USDA visual reference kit is the standard, and is written into grading regulations in the US and in several states. Glass standards were discontinued in US-manufactured kits and recently were replaced with plastic standards. The Lovibond Comparator, produced in England, uses permanent glass references that are approved by the USDA and by Canadian authorities.

Caramel solutions made with a recipe are very difficult to standardize because caramel color is sensitive to the sugar source and cooking method. In order to standardize the caramel solutions, Balch (1930) used light transmission at 560 nm as the break points between light (75%T), medium (60.5%T), and dark amber (44%T) solutions. This approach uses light transmission determined spectrophotometricly as the primary standard for preparing caramel solutions as secondary standards. At some point before 1982, Canada adopted spectrophotometric grading as the primary standard using the light transmittance break points established by Balch and added a break point of 27% to separate Canada No. 3 from No. 2.

Spectrophotometers have potential advantages. No human judgment about color is involved. Measurements are reproducible for a specific instrument and, potentially, between different instruments. The measurements quantify color density so that reasonably exact comparisons between syrups can be made and color intensity changes with manufacturing, storage, container type, etc. can be more easily documented. The spectrophotometric method is the standard in Canada. Visual grading remains the standard in the US.

In 2000 Hanna Instruments introduced a simple, low-cost analyzer for measuring transmission of maple syrup samples. Several producers in the US who used the meter felt that they were not getting accurate results. We undertook a study of this problem and to compare a variety of grading techniques and equipment.

METHOD

This study involved collecting 84 syrup samples and grading them using three different Hanna analyzers, two laboratory spectrophotometers (Hewlett-Packard 8452A Diode Array and Beckman DU640), two USDA glass kits, and a Vermont Temporary Grading Kit. We also tested the visual kits under a variety of lighting conditions eventually using specific colored lights and filters. Most of the tests were made in a laboratory with controlled

temperature conditions. Some of the visual tests were made in a sugar house where we explored background color.

DETERMINING TRANSMITTANCE BREAK POINTS

When we compared the visual and spectrophotometric grading, we found significant differences (Table 1). A significant number (45%) of Grade A and B samples were placed in darker grades when the spectrophotometric transmission standards were used. One sample was placed in a lighter grade using the transmission standards. Also, six samples graded as Commercial using the Vermont Temporary kit were graded as B (extra dark) using the 27% transmission standard. Table 1 also illustrates that different visual graders and different spectrophotometric instruments produce slightly different results.

The differences are less within methods than between methods. Garrett et al. (1983) also found that the transmission standards produced darker grades and they recommended against using what they referred to as "Canadian standards." Based on this earlier study and our results, we conclude that the current spectrophotometric breakpoints and current US visual grading systems do not produce the same results, more so than is currently understood.

Table 1. Comparison of visual and spectrophotometric grading

Number of samples placed in grades using two USDA glass kits, a Vermont Temporary kit, two Hanna analyzers, Beckman and Hewlett-Packard (H-P) spectrophotometers using the Canadian transmission standards. The USDA kit and USDA regulations do not have a commercial grade.

Grade	USDA1	USDA2	Vermont	Hanna 1	Hanna 3	Beckman	H-P
A-Light	13	12	11	3	0	2	0
A-Med.	18	20	18	9	11	12	10
A-Dark	27	23	30	33	30	30	28
B-ExDark	26	29	9	25	31	28	33
Commercial			16	12	12	12	13

Spectrophotometers themselves are not at fault and it is possible to get better agreement with the USDA visual references if a different set of breakpoints is used. Though they preferred visual grading, Garrett et al. proposed a new set of break points. However, they were based on a laboratory spectrophotometer rather than the now available Hanna analyzer and they don't describe how the breakpoints were chosen.

Using the USDA glass standards, we grouped the samples by color grades and then ranked the samples within groups by transmittance as determined by the Hanna analyzers. We used two different approaches to selecting new breakpoints, though both gave similar results. In one case, we took the average transmittance of two samples at the low end of a visual grade and two samples at the high end of the next grade.

However, the transmission values overlapped the grade boundaries. For example, one or two light syrups had transmission values that were darker than some medium syrups and one or two medium syrups had higher transmission values than some light syrups. Additionally, because of the small consistent differences between Hanna analyzers noted above, for any break point chosen different meters would place samples on different sides of the break point. This situation always would produce a small number of mis-graded syrups (meaning that visual and Hanna grading would not agree).

As a second approach to choosing break points, we looked for values that minimized the number of mis-graded samples. In choosing these breakpoints, we also examined all the visual data to determine if the USDA visual grade was supported. The results of the second method are given on the next page:

U.S. Syrup Grade Classification	% Light transmittance (Cornell)
Light Amber	Not less than 62
Medium Amber	Not less than 50
Dark Amber	Not less than 36
Extra Dark	Less than 36

For comparison, the Balch-Canadian and Garrett et al. transmittance standards are:

Grade Classification	Balch %T	Garrett et al %T
Light Amber	75	64.5
Medium Amber	60.5	51.5
Dark Amber	44	29.0

If the proposed new break points are applied to the transmission values from the two Hanna analyzers in Table 1, the following sample classification results. These results are closer to the USDA classifications and reflect that Hanna 3 produced somewhat lower transmission values (graded darker) than Hanna 1.

Grade	Hanna 1	Hanna 3
A-Light	14	11
A-Medium	20	16
A-Dark	23	29
B-ExDark	15	16
Commercial	12	12

SOURCES OF VARIATION IN TRANSMITTANCE AND VISUAL MEASUREMENTS

As a group, the Hanna analyzers behaved consistently. At least two readings were taken on each sample with each meter; the sample was rotated 90 degrees between readings so the light beam had a different path through the sample. The average difference for repeated measurements was 0.28. 0.29, and 0.36 transmission units for each of the three meters. This is similar to differences found for laboratory spectrophotometers using a similar test. Large differences between repeat samples were infrequent (but occurred) andseemed to be due to imperfections in the cuvettes, to imperfections in the syrup that were not visible to the eye, or to something about how a particular meter was used as these differences did not always occur with the same sample on different meters.

The three Hanna analyzers were consistently different from each other. The average differences in readings between the three meters were 1.1, 1.9, and 2.6 transmission units. This amount of variation is not unusual or unexpected. The laboratory spectrophotometers also produced different readings from each other and from the Hanna analyzers, though these differences were not in a consistent direction. Larger differences between three Hanna analyzers were found by Heiligmann (personal communication). The electronics within the Hanna analyzers are sufficiently complex that it is probably difficult to bring different meters into exact agreement with each other, even though each is adjusted and calibrated at the factory.

Different visual grading methods also produced different results. These differences appear with samples close to the standards in color. Different individuals will make different grade decisions with the same kit. The same person with the same kit may make different decisions when the background light changes. Different kits can produce different results. We will provide more details on visual kit comparisons in a subsequent report.

DISCUSSION

The lack of agreement between spectrophotometric grading using the break points established by Balch and visual grading methods is a puzzle. The process of manufacturing colored glass with the appropriate hue and color density is demanding. Despite

the extensive instrumental analysis of caramel solutions and glass, it is evident in Brice and Turner that the absorbance match was not exact, especially in the longer wavelengths above 560 nm. Our eyes are very sensitive in the part of the light spectrum transmitted by maple syrup. It appears that a good match between glass and caramel, and thus between visual and spectrophotometric methods was never achieved in the beginning. There is no indication that Brice and Turner conducted the comparison performed here and by Garrett et al. The current Vermont Temporary Kit uses caramel solutions that are standardized through visual comparison with a USDA glass kit. This would avoid a mismatch between these two methods.

One source of variation between spectrophotometers relates to the choice of 560 nm as the central wavelength for measurement and the light absorption/transmission properties of maple syrup. This measuring point was chosen to correspond with the peak color sensitivity of human vision as this was understood at the time. Maple syrup absorbs strongly (transmits little) at blue wavelengths and the transmission increases smoothly into the red region. At 560 nm the transmission is changing with change in wavelength. Transmission will be significantly different at 550 or 570 nm compared to 560.

Spectrophotometers measure light with different spectral bandwidth “windows.” The laboratory spectrophotometers, which used different measurement techniques, had bandwidths of 1.5 and 1.8 nm. The Hanna meters have bandwidths of 2.0 nm. Our eyes have bandwidths of about 350 nm. This means that different instruments will see different amounts of the light spectrum and might be expected to produce different transmission results, especially where close judgments are required.

Another important source of variation between spectrophotometers and visual graders is that the color properties (hue) of syrups can vary. The change from light to dark amber involves increasing redness. Within a grade some syrups may have orange or red hues; they are not simply different densities of amber. This can be seen on a spectrophotometer as different angles to the slope of change in transmission with wavelength and different ratios of absorbance at two wavelengths. These different color properties reflect differences in syrup chemistry.

Visual grading also has sources of variation that will produce different grading results. Our eyes sense colors principally with three pigments. Our brains combine what our eyes sense to produce our color perception. There is variation among individuals that will cause each of us to sense or interpret colors slightly differently. The color of the light passing through the sample and the color standard will affect the ability to make a color density comparison, especially when samples are close to the standard in color density. Differences in hue between samples described above will produce different visual impressions about color match.

Brice and Turner used considerable effort to produce colored glass that was a close match to the caramel solutions. Their data show that the color match was not perfect, which would produce somewhat different results between visual and spectrophotometric methods when syrup chromaticity varies.

The variation inherent in both visual grading and in spectrophotometric grading will make it impossible to perfectly match these two approaches for all maple samples.

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