COLOR MEASUREMENT

Application to Food Quality Grades

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The interpretation of reflectance colors in grading foods requires a knowledge of the principles underlying the physical measurements as well as an understanding of the methods of subjective grading. The tristimulus system of color notation is generally applicable to homogeneous, opaque foods, but in some cases a simpler approach is possible, such as reflectance measurement at one or two wave lengths. Reflectance measurements cannot be expressed in absolute units that are independent of the instrument used. The relative importance of the dimensions of brightness, saturation, and dominant wave length in determining color quality depends on the particular food being tested.

The measurement of reflectance colors in foods is attracting considerable interest (*2, 3, 9–14*). The interpretation of such measurements in grading foods for color quality requires a knowledge of the principles underlying both the physical measurements and the methods of subjective grading.

Reflectance measurements can be described according to their effect on the eye of a human "standard observer." There are two systems for assigning numerical values to reflected colors—the Munsell system, relating to color sensations, with dimensions of hue, chroma, and value (*6–8*), and the system of the Commission Internationale de l'Eclairage (C.I.E.) with corresponding dimensions of dominant wave length, purity, and photometric brightness (*7*). The color values defined by C.I.E. tristimulus colorimetry do not possess a purely physical significance but represent calculated psychophysical characteristics of light.

A modification of the C.I.E. system for the graphical portrayal of color measurements has been developed by Hunter for use with his color and color difference meter (*4, 5*). In the Hunter system the readings for a and b are plotted on rectangular coordinates. The angle formed by a line joining the color locus with the origin corresponds to the dimensions of hue or dominant wave length. In general, this angle can be represented by its cotangent, a/b. Saturation, a more general term for purity or chroma, is represented by the distance from the origin or $(a^2 + b^2)^{1/2}$. Brightness is read directly by the instrument either as L or R_d and is plotted perpendicularly to the plane of the diagram.

Reflectance Measurements at One or Two Wave Lengths

Tristimulus colorimetry involves either the determination of a complete reflectance spectrum, followed by a cumbersome calculation of color dimensions, or the use of an instrument equipped with special filters for determining the reflectance of three primary colors. Various efforts have been made to find a simpler method whereby reflectance measurements at one wave length or the ratio of measurements at two wave lengths could be related to the visual color grade of a given food product.

Based on general principles, there is considerable risk in the application of these simplified procedures. On the one hand, two colors may appear different to the eye, although they may have identical reflectances in the regions of the spectrum selected for measurement. On the other hand, two colors may be metameric and appear identical to the eye, even though their reflectance spectra are different. That colors are metameric cannot be determined by a simple inspection of their reflectance spectra but may be demonstrated by tristimulus calculations, by measurements with a tristimulus instrument, or by visual inspection under different illuminations.

An example of metameric colors is that of a Munsell paper designed to match tomato juice and the color of the corresponding juice. Munsell papers are designed to match tomato juice under one illumination (daylight), but because the reflectance spectra of the paper and the juice differ in that the juice has a small peak in reflectance at 550 mμ, they will not match in all other illuminations. This is shown in Figure 1 by a series of representative reflectance spectra for tomato juice measured on a Beckman spectrophotometer. The reflectance of the paper extends a little more to the orange side of red to compensate for the lack of a peak in the green region, as is shown in Figure 2 for the Munsell papers corresponding to the poorest colors acceptable as Grade A and as Grade C tomato juice. In the case of the Munsell tomato papers and well matched samples of tomato juice, neither a tristimulus instrument nor human observers can distinguish between the colors, although an examination of their reflectance spec-

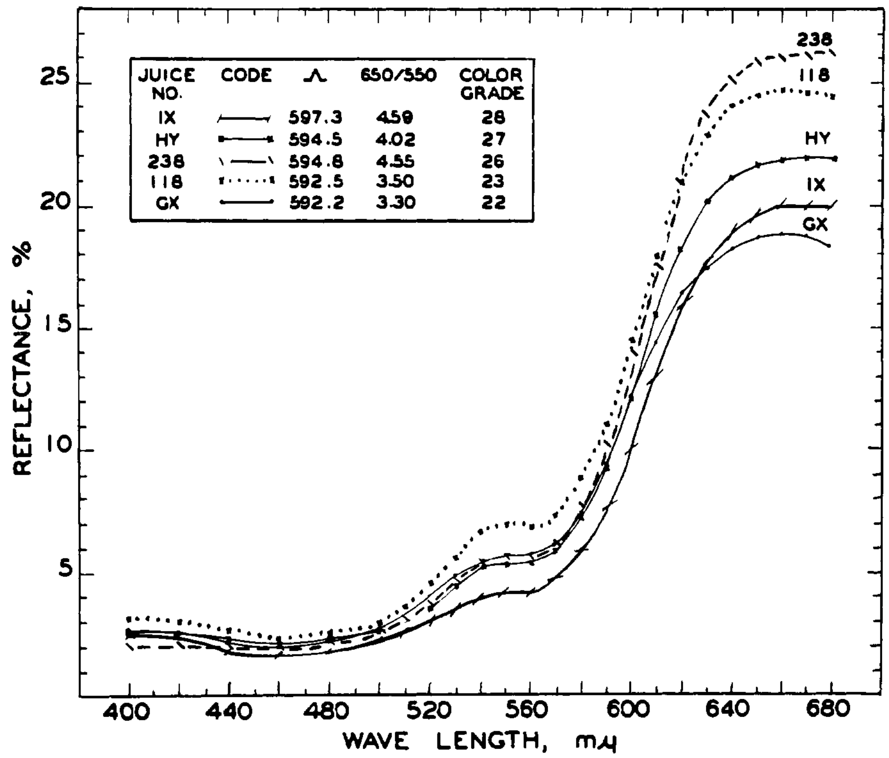


Figure 1. Reflectance spectra of tomato juices of different color grades

tra would quickly show that they are physically dissimilar.

Metameric colors are those that match under one illuminant, but not necessarily under a different illumination. This fact may help to explain the difficulty of obtaining reproducible visual color grading using metameric standards with natural daylight for illumination, as the quality of daylight is extremely variable.

In spite of these theoretical considerations, elaborate methods of tristimulus colorimetry are not always necessary in determining the color quality of a food by means of instrumental measurements. In the case of tomato juice, good color depends on the ripeness of the raw material and is associated with an increase in lycopene and a decrease in chlorophyll. Lycopene reflects in the red end of the spectrum and absorbs in the green, while chlorophyll reflects in the green and absorbs in the red. When present simultaneously, each pigment reduces the reflectance of the other. A single reading of reflectance at one wave length may depend on the relative amounts of the two pigments and thus serve as an indication of maturity.

Figure 1 shows the relation of the reflectance spectra to color quality for widely divergent juices. In the examples (selected for graphic presentation because of wide difference in color), the order of color quality is nearly the same as the order of the reflectance ratio at 650 and 550 mμ with the exception of two of the juices. The single reading at 550 mμ would identify the best juice, but not the worst.

In order to test this relationship it is necessary to examine a much larger number of samples. Table I gives the color measurements and color grades of 31 tomato juices consisting chiefly of commercial samples collected in New York State. The a_L/b_L ratio was found to be a reliable index of color quality in tomato juice. This ratio has been demonstrated (at a single grading of 700 samples) to correlate with color score with a correlation coefficient of 0.964 (*10*). For the samples listed in the table the reflectance ratio, 650/550, was a better index of quality than either the visual color score or the reflectance at 550 mμ. The use of an instrument measuring reflectance at only one wave length would not appear to be an improvement over visual inspection. Proof of this conclusion will require the examination of a much larger number of samples.

Limitation in Usefulness of Absolute Values of Color Dimensions

Table I illustrates that color quality can be expressed numerically in a variety of different ways, as, for example, *a/b* ratios for the Hunter meter and reflectance ratios for the Beckman. At first glance dominant wave length appears to be a general term that can be calculated from the readings of either instrument. This is misleading as the

Table I. Correlation of USDA Color Score and Beckman Reflectance Measurements with Measurements of Hunter Color Difference Meter

Sample	USDA Color Score	Beckman Spectrophotometer Data: Dominant wave length	550	650	650/550	Hunter Data: Dominant wave length	a_L/b_L
254	27	598.5	4.5	27.6	6.13	602.7	2.02
GZ	30	596.8	4.2	19.8	4.71	601.6	1.93
IX	28	597.0	4.3	19.9	4.63	600.7	1.85
IY	26	596.5	4.3	19.3	4.49	600.5	1.84
MC	27	595.9	4.4	20.5	4.66	599.8	1.78
FA	27	595.3	4.0	19.0	4.75	599.8	1.78
LX	28	596.5	4.8	21.9	4.56	599.7	1.77
FC	27	594.8	4.7	20.3	4.32	599.6	1.76
EA	27	595.4	4.2	19.0	4.52	599.4	1.75
MA	27	595.7	4.5	19.6	4.36	599.3	1.74
NX	27	595.2	4.2	18.7	4.45	599.3	1.74
CA	27	595.8	4.1	17.5	4.27	599.1	1.72
HX	28	595.5	4.8	19.9	4.14	599.0	1.71
BA	28	595.3	4.6	18.9	4.11	599.0	1.71
LY	26	595.5	4.8	23.8	4.96	599.0	1.71
JA	26	595.0	4.8	21.8	4.54	598.8	1.70
DD	27	595.6	5.1	22.5	4.41	598.7	1.69
CD	23	594.8	4.7	20.6	4.38	598.5	1.67
DA	27	595.0	4.9	20.1	4.10	598.0	1.63
CC	26	594.7	4.8	17.8	3.71	597.9	1.62
238	25	594.8	5.7	25.2	4.42	597.8	1.61
DC	27	594.2	5.2	20.9	4.02	597.7	1.61
HZ	27	594.9	5.3	21.3	4.02	597.5	1.59
HY	27	594.7	5.6	23.3	4.16	597.5	1.59
MD	25	593.8	5.3	20.2	3.81	597.3	1.57
BC	26	593.6	4.9	18.0	3.67	597.3	1.57
LZ	25	593.8	4.8	18.7	3.90	596.7	1.52
FD	24	593.3	5.2	20.2	3.88	596.1	1.47
JC	24	593.8	5.4	22.3	4.13	596.0	1.46
118	23	592.9	7.0	24.5	3.50	595.0	1.38
GX	22	591.8	5.7	18.6	3.26	593.7	1.27
Correlation with Hunter a_L/b_L	0.77	0.95	−0.76	0.09	0.85	1.00	...

actual values for dominant wave length depend on the particular instrument used, so that nothing is gained by making the additional calculations. In order to avoid confusion in the literature, the direct readings of a given color instrument should be reported as such.

The disagreement between dominant wave lengths obtained for tomato juice by the two instruments amounts to about 4 grade score units. This is surprising in view of the fact that the Hunter meter was calibrated with the aid of the Beckman spectrophotometer and was adjusted so that the two instruments gave identical dominant wave lengths for a standard porcelain tile in the range of tomato juice color.

Reflectance values are not comparable unless all experimental conditions are identical. Because different instruments differ in respect to the geometric arrangement of the light source, sample, and photocell (or eye in the case of the Maxwell spinning disk), there can be no "absolute" reflectance color measurements.

The observed divergence of dominant wave lengths obtained by two instruments in the case of tomato juice may have been partially due to the penetration of the juice by the light and its reflectance from particles beneath the surface. With this in mind, further tests were made on opaque surfaces to determine the extent of agreement among the Hunter meter, the Beckman spectrophotometer, and the Maxwell spinning disk. All three instruments are identical or equivalent with respect to the angles of reflected and incident light. Standard Munsell tomato papers were used for the test and the C.I.E. values and dominant wave lengths reported in Table II. As before, the Beckman was used to calibrate the other two instruments.

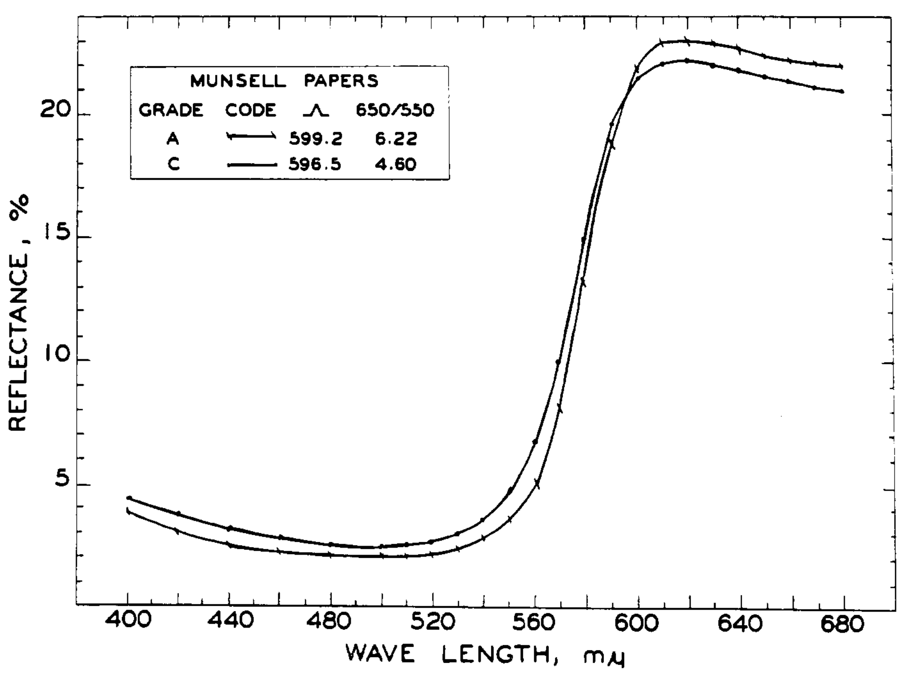
Table II. Measurement of Munsell Standard Tomato Paper Colors by Three Instruments

Tomato Paper	C.I.E. Coordinates	Method: Hunter color meter	Method: Beckman spectrophotometer	Method: Maxwell disk[a]
A_1	x	0.554	0.530	0.521
	y	0.364	0.351	0.351
	Y	0.082	0.0952	0.0998
	Λ[b]	599.0	601.2	600.7
A_2	x	0.524	0.543	0.521
	y	0.360	0.353	0.352
	Y	0.095	0.0888	0.1014
	Λ	598.4	601.2	600.5
A_3	x	0.512	0.568	0.565
	y	0.359	0.363	0.362
	Y	0.103	0.0775	0.0837
	Λ	598.3	599.8	599.9
C_1	x	0.551	0.501	0.504
	y	0.376	0.354	0.353
	Y	0.092	0.1061	0.1098
	Λ	596.4	598.8	599.3
C_2	x	0.522	0.541	0.535
	y	0.368	0.361	0.360
	Y	0.105	0.0955	0.1027
	Λ	596.4	599.0	599.3
C_3	x	0.486	0.567	0.560
	y	0.364	0.375	0.369
	Y	0.117	0.0852	0.0960
	Λ	595.2	597.2	598.0

[a] Munsell papers calibrated by Beckman spectrophotometer.
[b] Dominant wave length.

In the case of these opaque surfaces the agreement between the Hunter meter and the Beckman spectrophotometer was closer but still not complete. The values obtained by the Maxwell disk agreed with the Beckman within the probable error.

Figure 20. Reflectance spectra of Munsell papers representing minimum tomato juice grades



Application of Tristimulus Colorimetry To Color Grades in Foods

It has been demonstrated that dominant wave length (or related hue) is exclusively responsible for color grades of tomato juice (*10*). However, with other foods it is not always this property alone that determines color quality. Brightness, as well as hue, has been shown to be a factor in determining sauerkraut color grade (*9*).

Preliminary reflectance measurements have been made on apple slices from many varieties. With apple slices there is a wide variation in all three color dimensions. The hue may vary from green to yellow or the slices may be almost colorless. Measurements made on a few apple varieties are reported in Figure 3. Although no comprehensive study was made on subjective color grading, in the tests that were run, Cortland rated high for color and Yorking low. This might indicate that brightness is of major importance in determining color quality in apple slices.

In the case of peach puree, color measurements indicate a decided preference by manufacturers for a high color saturation. In this product desirable color was associated with high b readings on the Hunter scale. As the Hunter a values are low for peach puree,

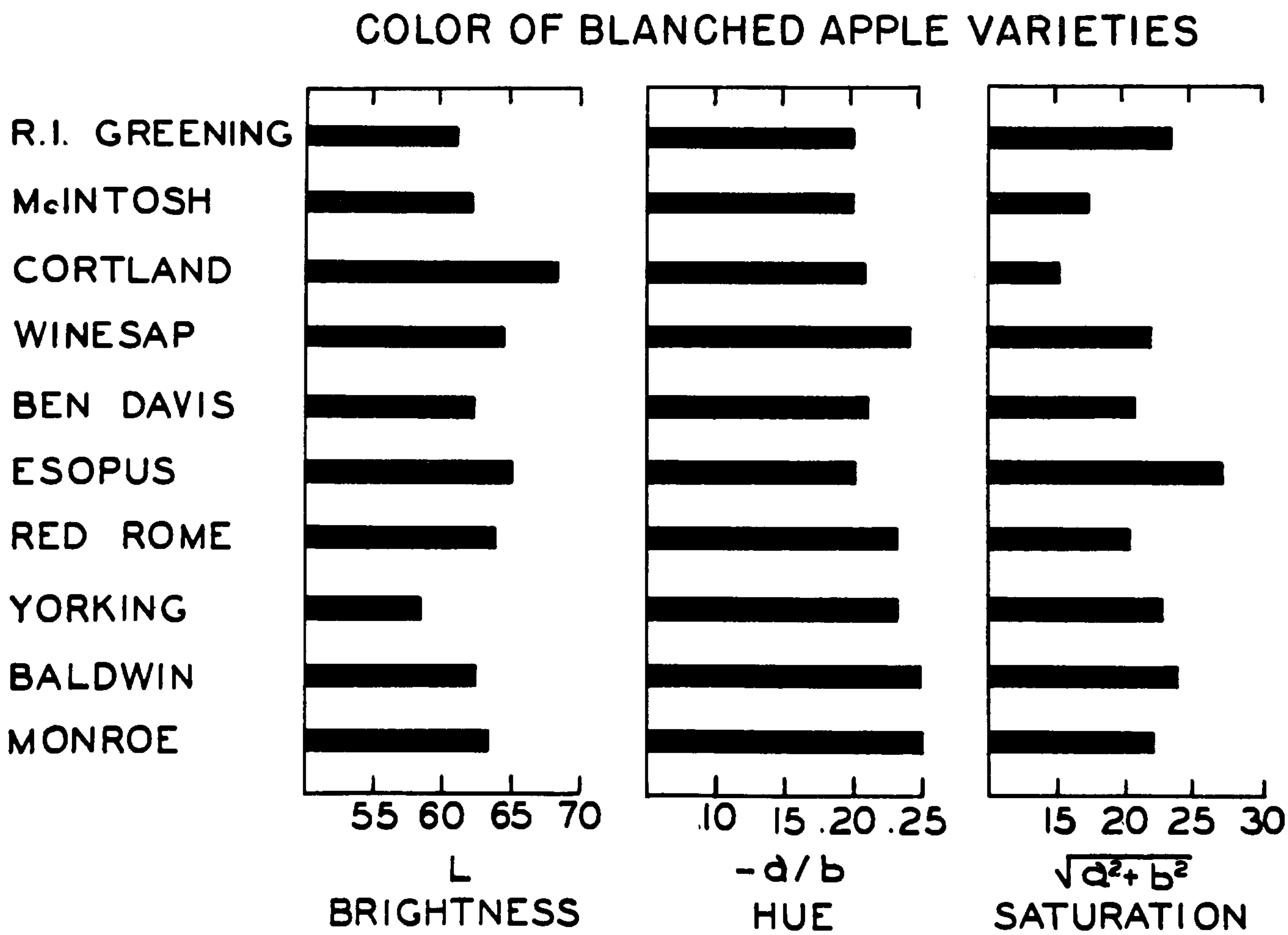
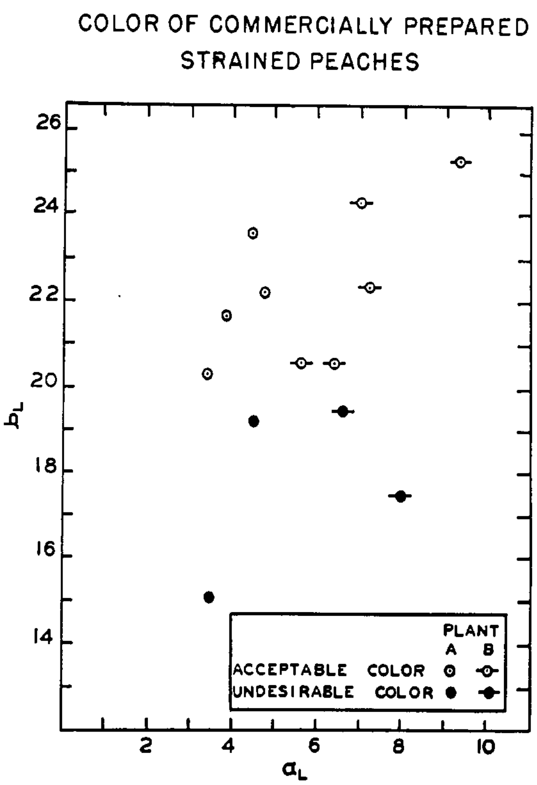


Figure 3. Color of blanched apple varieties

Figure 4. Color of commercially prepared strained peaches



saturation, $(a^2 + b^2)^{1/2}$, is determined largely by the b readings. A direct correlation between b readings and color acceptability results. In Figure 4 representative measurements on commercial samples of strained peaches are presented. A b reading above 20 was found to be necessary for acceptable color. More experimental work will be needed with many foods for which color is an important quality. The examples cited in this paper indicate that any one of the three color dimensions may, in certain cases, be important in determining color quality in foods.

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