Geometrical Factors in Color Evaluation of Purees, Pastes, and Granular Food Specimens

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ABSTRACT

The standard measurement situation for color involves a specimen which is flat, uniform in color, and thin. For measurements of colors of many food products, instruments which give reliable and reproducible results when applied to the flat, uniform and thin traditional specimens are unreliable. This is because specimens of foodstuffs come in a variety of shapes, sizes and translucencies. The unreliability of instrument measurements can be shown to be related to instrument differences in geometry and to: (a) specimen nonflatness; (b) specimen variability in pattern, particle size, shape, compression, and/or humidity; and (c) specimen translucency.

IDEAL MEASUREMENT CONDITIONS

The standard model for color measurement by reflected light assumes that specimens are flat, uniform throughout, and opaque even in thin layers. The simple geometric models which are used to identify the two popular sets of geometric conditions of measurement are shown in Fig. 1. At the top, light is incident on the flat, opaque specimen at 45°; and the light reflected perpendicularly at 0° is then measured for color. Alternatively, at the bottom of Fig. 1 is shown the diffuse sphere technique by which all of the light reflected in all directions is collected for measurement. Here, the specimen is illuminated perpendicularly at 0° and light reflected in all directions is collected for measurement.

Thus the two popularly recognized conditions of illumination in view for color measurement by reflection are: (a) 45° illumination, 0° viewing; and (b) 0° illumination, diffuse viewing. There are so-called reciprocal conditions in which the angles for illumination and viewing are reversed, and, according to theory, usually identified by the name "Helmholtz Reciprocal Relation," the reciprocal conditions give results identical to the standard ones.

Actually, beams of light are not properly represented by vectors of single directions of projection, as is shown in Fig. 1. Instead, as is shown in Fig. 2, the directions of light in any given beam must always be identified by a cone of directions centering about the axial direction. In general, foodstuffs are relatively diffusing so angular
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magnitudes of the cones of directions within a measuring instrument is seldom a significant factor.

However, what is important are the light-beam diameters and the edge-of-window clearances between beam diameters and specimen windows, as is shown in Fig. 3. This clearance between the diameter of the beam of light incident upon the specimen and the window through which the specimen is exposed for measurement is, as will be shown below, a significant factor in the color measurement of both translucent foodstuffs and coarse, granular food materials. This viewing-window clearance is important wherever light penetrates the specimen.

FOOD INDUSTRY SPECIMENS
Where specimens are not flat, the light projected by reflection tends to decrease with surface roughness and with increasing granule size. Typical non-flat food-industry specimens are whole green peas, potato chips and French fries, and flakes of breakfast food.

Figure 4 is an impressive illustration of the part played by granule size in reflection and color. Here are four vials, all with the same green glass in them. The only variable is particle size and yet, as can be seen in the figure, the changes observed and the corresponding measured colors are very great. These differences are the result of contrasts between the optical phenomena of scattering and absorption. Light is reflected and diffused, making the powder look white, by repeated contacts of light with the particle surfaces. Light is colored green by the process of absorption while passing through the glass. The relative contributions of green absorption and white scattering differ greatly between the few large particles and the many small particles of the otherwise identical material.

The form of any given natural material will significantly affect its color, whether observed visually or measured by instrument. As an example, in Fig. 5 points are shown representing Hunter a,b color values of five forms of tomato product. There are whole fruit, cut fruit, tomato puree, concentrated solids, tomato paste, and freeze-dried tomato powder. Figure 5 is an a,b color diagram showing how greatly the colors of these different specimens differ from each other. Even within one of the specimens, a cut tomato, measurements within it show large variations. This is not surprising when one considers how white the interior of the tomato is near the stem end and how it varies in color from the central pulpy area to the edge.

However, with all such specimens as nonuniform as whole berries or meats, color appearance can be both measured and judged meaningfully. Success in measurement of these nonuniform specimens depends on adequate control and identification of the conditions of measurement.

THE TRANSLUCENCY ERROR
Attention was called above to the importance of window in a color-measuring instrument. Of primary importance is the clearance, shown in Fig. 3, between the diameter of the beam incident on the specimen and the edge of the window through which the specimen is
illuminated and viewed. This clearance is an important factor in color measurements of translucent foodstuffs.

Figure 6 illustrates the problem in a sample of grapefruit juice. This grapefruit juice is in a colorless glass where, at the top, the material is seen as it is normally encountered in everyday living. Light enters the grapefruit juice and, after absorption and scattering, emerges frequently at some distance from the point at which it enters to give the characteristic pale yellow color normally observed. At the bottom of the glass, there has been added an opaque cardboard shield with color quite similar to that of juice. This cardboard color, however, is readily seen as being slightly darker than the juice at the top. If however, a rectangular window is cut in the cardboard, the same juice seen through this window appears as dark or darker than the cardboard. This apparent darkening of the juice occurs because light going in through the window, is diffused by the translucent material to other areas of the sample. Relatively little of it comes back out the window through which it entered.

Figure 7 shows the change of color, as the viewing window diameters were changed, of three samples of orange juice. The dimensions are Hunter L, a and b. It is noteworthy that the shifts of OJ score correspond to almost four full points. This is more than is regularly

![Figure 5. Hunter a,b colors of five different forms of tomato product.](image)

Trapping of light in translucent specimens by edges of window is illustrated in Fig. 3 and 6. The light which suffers most is that which strikes the specimen near the edge of the window. The dimension which is crucial is the average distance which rays travel before they encounter a window edge when they seek to emerge toward the observer or toward the observing light receptor. It can be appreciated that wavelengths, not readily absorbed by the product, will travel further within the translucent material and will therefore be more likely to be trapped than the wavelengths of light which are strongly absorbed and therefore do not travel very far. In other words, the red end of the spectrum, which is where the grapefruit juice transmits most strongly, is least absorbed and therefore is most likely to be trapped by the edge-of-window effect. The result is that the light seen in the window is not only darker than the grapefruit juice seen above, but is also grayer and perhaps somewhat greener.

Measurements were made of a number of foodstuffs, using for all the measurements, an incident beam of light about 1 inch in diameter on the center of the specimen. Three different conditions of observing the specimen were then used, and the changes in observed color (when compared with colors of completely opaque standards) were recorded. The smallest window was 1 1/4 inches in diameter, barely large enough to contain the 1-inch diameter light beam. The second window was 2 1/4 inches in diameter, thus giving a little over 1/2 inch leeway between incident beam and edge of the window. Finally a 4-inch window was used, giving an almost 1 1/2 inch opportunity for lateral travel of light before trapping.

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![Figure 6. Photograph of grapefruit juice. Note that juice is lighter above cardboard where light enters from all sides, but is darker below where light has to enter and exit through a restricted window.](image)

![Figure 7. Changes of measured color in Hunter. L.a.b of two specimens of orange juice, as instrument windows are decreased from 4 inches (best) to 1 1/4 inches in diameter.](image)
encountered in samples of the product going to market from any given region.

Figure 8 shows the same sort of changes in color of three samples of tomato juice. Here there is an L vs. a diagram at the top and a b vs. a diagram at the bottom. Note how these samples measure darker and less saturated in color as the window sizes become smaller.

According to the tomato color formula developed by Yeatman and others, the smaller window improves the TC score, primarily because it makes the juice darker. Darkness rewards the scoring. By contrast, the orange juice color, shown in Fig. 7, improves in score as the windows became larger.

Figure 9 summarizes the measurements made of a number of different products, including peanut butter, steak, French dressing and others not mentioned above. The magnitude of change of measured color by adding 1 inch to the diameter of the window varies from less than 1 unit for peanut butter, which is quite opaque, to more than 8 units for orange juice, which is translucent. This translucency (or edge-of-window error) is potentially a significant problem in the measurement of the color of many different foodstuffs.

Figure 8. Changes of measured color in Hunter L,a,b of three specimens of tomato juice, as instrument windows are decreased from 4 inches (best) to 1 1/4 inches in diameter.

Figure 9. Changes in measured color of seven foodstuffs from adding one inch to diameter of instrument window.

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