OPTICAL PROPERTIES OF FOODS

Durán, L., and **Calvo, C.**
IATA-CSIC, Valencia, Spain

Keywords: Optical properties, color, gloss, translucency, foods

Contents

Summary

Optical properties are those material properties resulting from physical phenomena occurring when any form of light interacts with the material under consideration. Only optical properties detected by the human eye are discussed here. In the case of foods, the main optical property considered by consumers in evaluating quality is color, followed by gloss and translucency, or turbidity, and other properties of much lower interest.

Light can be defined as the visible part of the whole electromagnetic spectrum (wavelengths between 380 and 770 nm). When light strikes an object (food or other) several optical phenomena take place: absorption, refraction, transmission, scattering, and reflection. The change in intensity and/or quality undergone by light when

interacting with the material greatly depends on the composition and the structure of the said material. Foods contain chromophores that are capable of altering the nature of light, thus determining whether the food has color or not. The cones in the human retina are sensitive to different qualities of light and can therefore detect colors, primarily blue, green, and red. Optical nerves transmit these perceptions to the brain and the observer perceives a color sensation.

Color sensation is formed by three attributes: hue, saturation or purity, and lightness. Systems have been developed to name and classify colors. Color can also be measured with instruments. There are spectrophotometers that measure intensity of light through the whole visible spectrum, and colorimeters designed to measure some parameters related to sensory colors. The latter type does not define colors in physical terms, but is very useful in the quality control of foods, and gives results normally correlated with visual measurements.

Gloss is the name given to light specularly reflected from a plain smooth surface. It is important in some cases but very little attention has been dedicated to it. Translucency is also worth consideration in some liquid foods, for example, fruit juices. Its measurement can be determined by considering the contributions of both absorbed and scattered light when traversing these products.

1. Introduction

In general, optical properties are material properties that result from the physical phenomena occurring when any form of light (the visible portion of the electromagnetic radiation spectrum) interacts with the material under consideration. In this discussion, only the optical properties having some type of effect on visual appearance will be considered. The final result depends on the nature of light, the composition and structure of the material, and other external factors like geometrical disposition of the light source, eye, and object, as well as on the optical properties of surrounding surfaces. Vision capacity of the observer and psychological factors are also very important in defining the object’s visual appearance.

Color is no doubt the most important optical property of nearly all materials and, particularly, foods. Since ancient times, colorants were available to humans for ornamental purposes and very likely for use in foods, too. Artists have handled color concepts for centuries, but it was Newton who first introduced scientific knowledge by launching his Theory of Colors in 1666.

Visual appearance also includes other characteristics of foods, like shape, size, surface and flesh structure, gloss, translucency, and defects. Among these, only gloss and translucency are important optical properties. In addition, there are other optical properties, like fluorescence and phosphorescence, but of no relevance to foods.

In this discussion, the exposition is structured around the above mentioned aspects: nature of light, physical phenomena**,** optical properties of materials, the vision process, and visual appearance, comprising color, gloss, and translucency.

2. Nature of Light

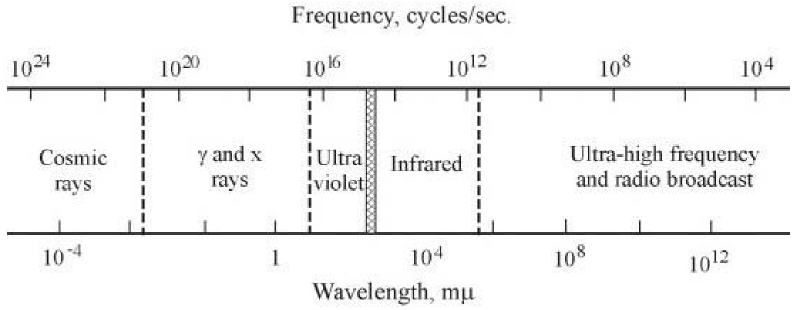

Figure 1. Electromagnetic radiation spectrum. Shaded zone = visible light.

Light can be defined as the visible part in the whole electromagnetic spectrum, comprising wavelengths between 380 and 770 nm. Below this range ultraviolet radiation occurs and above it, infrared radiation (Figure 1).

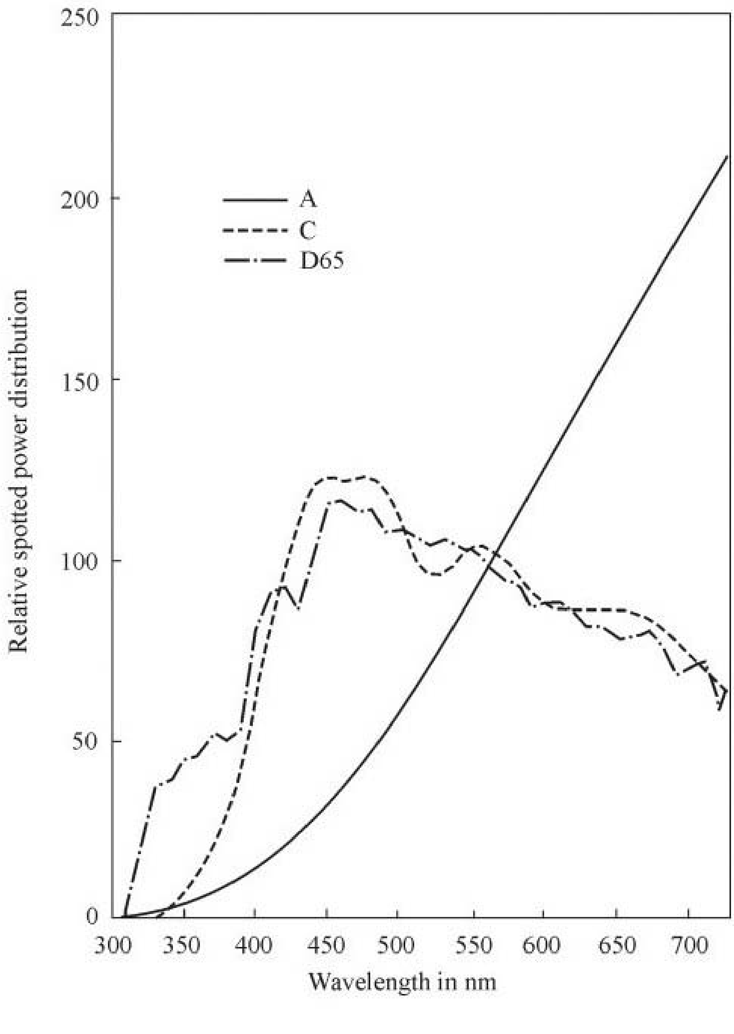

Figure 2. Relative energy distribution of most common illuminants.

Energy within this relatively small visible zone may appear distributed in many different ways; each particular distribution defines the "quality" of light. White light, for example, should theoretically have the same energy at all wavelengths along the spectrum. This has never been obtained; in practice, white light is substituted by what is called "natural daylight". This is defined as "diffuse daylight, preferably from a partially cloudy North sky in the northern hemisphere and a partially cloudy South sky in the southern hemisphere" (ISO 11037), and is considered the closest approximation to white light perceived by humans. To favor measurements, artificial standards have been defined, as in CIE Standard Illuminant *C* or *D65* (Figure 2), which can be approximately reproduced as a real source for use in appropriate cabins. Other types of illuminants, like Illuminant *A*, which represents light produced by tungsten filament lamps (Figure 2), can also be used, but should not be referred to as white light.

Any possible distribution of energy along the visible spectrum will produce a particular sensation in the human eye that is normally recognized as color, as will be discussed later (6.1).

3. Physical Phenomena

When light, whether white or not, strikes a solid or liquid object, several phenomena take place:

3.1. Refraction-absorption-transmission

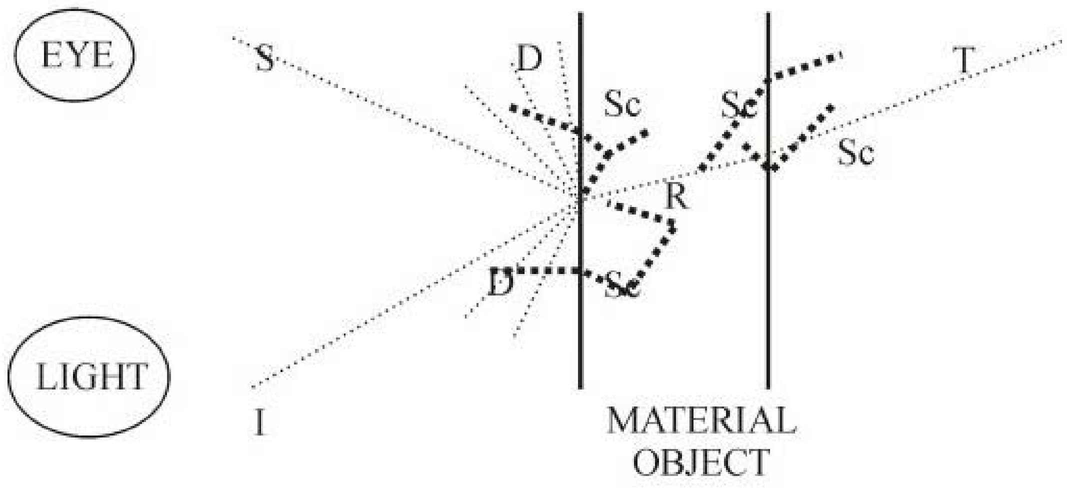

Figure 3. Schematic representation of interactions light-material. I = incident, T=transmitted, S=specularly reflected, R=refracted, Sc=scattered, D=diffusedly reflected.

The light ray may change in direction and/or in quality. The incident beam (I) (Figure 3) changes its direction, is then refracted (R) on entering the object due to the difference in optical densities of the media involved, usually air and food, and changes again in the opposite direction upon exiting the object. This change in direction is not important for most foods in terms of color quality. It will only affect the appearance of objects seen through transparent liquids. The light emerging or transmitted (T) may be different in quality from the incident beam as a result of the energy absorbed by the object, the magnitude of the absorption being unequally distributed throughout the visible spectrum. This phenomenon shows up when dealing with transparent and colored materials. If the object behaves as opaque, light will not get through and consequently no light will be seen from the other side.

3.2. Reflection

The light ray hitting an opaque material will be reflected in two different ways. A small part of the incident light bounces on the surface and comes out at the same angle as the incident beam and with the same quality or spectral distribution of energy. This is called specular reflection (S) and is normally identified as gloss in smooth surfaces. The main part of the incident light will undergo diffused reflection (D), i.e., it will travel somewhat through the outer layers of the material, where it is partly absorbed, more for some energy frequencies than others, and consequently, it is altered in its spectral quality. This diffused light will come out in practically all directions and is responsible for what is called the color of opaque objects.

3.3. Scattering

On dealing with translucent materials that are neither fully opaque nor fully transparent, a more or less significant portion of light going through the object is “obliged” to change direction randomly and repeatedly, as a result of interactions with parts of the internal structure, mostly with particles suspended in liquid. This scattered light (Sc) will eventually come out of the material traversing the surface and joining either the diffusely reflected light in more opaque objects or the transmitted light in more transparent ones.

4. Optical Properties of Materials

As stated above (1), when light and an object interact, characteristics of the physical phenomena taking place (i.e., changes in the light path and/or light quality) depend mainly on the nature of light and on the composition and structure of the material. The latter is responsible for the optical properties of said material. Some chemical and physical material properties modify light, as it goes through a transparent object or reflects off of an opaque object.

4.1. Chromophores

Some special dispositions of atoms have the faculty to absorb light energy in different amounts at different wavelengths. The emerging beam will then have a different spectral distribution: white light will be converted into a colored light, commonly identified as the color of that particular substance. Photons, the light energy units, promote electrons to higher energy orbitals. The difference in energy is absorbed at specific wavelengths bands, determining the spectral distribution of the non-absorbed (either transmitted or reflected) light beam and, hence, the color of the material (Table

1).

Wavelength (nm)	*Color*
400-450	Violet
450-500	Blue
500-570	Green
570-590	Yellow
590-610	Orange
610-700	Red

[From: Hardy A.C. (1936). *Handbook of colorimetry*. Massachusetts Institute of Technology. Cambridge, Massachusetts: The Technology Press.]

Table 1. Color names commonly assigned to the different regions of the visible spectrum.

Chromophores or color-changing chemical structures are present in many natural and artificial materials, like colorants or dyes. Chemically, there are several atomic groups capable of altering light quality. A series of conjugated double bonds, for example, are present in carotenoids (lycopene, β-carotene) and in the two most abundant colorants in nature, chlorophyll (vegetables) and hemoglobin (blood). In the latter two, a special atomic disposition consisting of a 16-member central ring and 4 pyrrol rings is thought to be responsible for color; in chlorophyll, a central metal atom, copper, provides green color, while in hemoglobin a central iron atom makes it appear red.

When observing or analyzing the optical properties of materials, chromophores are not the only responsible elements. Their location and distribution in the complex structure of a foodstuff are also relevant. Physical properties of the different structural elements, like turgid cells, fibers, vacuoles, air pockets, etc., play important roles in the optical behavior of the particular food under consideration. A clear example would be the big difference observed in visual appearance, including color, which can be detected between raw green peas before and after a short blanching treatment. The chlorophyll content is almost unchanged, but the translucency of the tissues is notably modified, the product being perceived as much greener and brighter after heating.

Altering particle size can drastically change the color of many materials. A common phenomenon familiar to many can be observed when large pieces of blue copper sulfate (used for sanitizing water in swimming pools) are ground. They will progressively lose color (become paler) until finally a white powder results, without any chemical reaction having occurred.

4.2. Colorants

It is well known that colorants are present in most foods and also constitute an important group of food additives. A considerable part of food attractiveness is color. Besides the pleasure felt upon looking at properly colored foods, consumers relate color with other quality and safety attributes, like degree of ripeness in fruits and vegetables, flavor and texture of meats, fish wholesomeness, etc (see *Sensory Evaluation*).

Natural colors, such as those mentioned above (**4.1**), may be used as color additives with certain limitations. A list permitted for food use in the US and EU is given in Table 2.

NATURAL FOOD COLORS		
	FDA list	EU list
Annatto extract	73.30	E160b
Anthocyanins	--	E163
β-Apo-8'-carotenal [a]	73.90	E160e
β-carotene [a]	73.95	--
Beet powder	73.40	E162
Canthaxanthin [a]	73.75	E161g
Caramel	73.85	E150a
Carrot oil	--	--
Chlorophylls and chlorophyllines	--	E140
Cochineal, carmine	73.100	E120
Copper complexes of chlorophylls and chlorophyllines	--	E141
Cottonseed flower, toasted	X	--
Curcumin	73.600 & 73.615	E100
Fruit and vegetable juices	X	--
Grape color extract	X	--
Grape skin extract	73.170	--
Lutein	--	E161b
Lycopene	--	E160d
Mixed carotenes and β-carotene		E160a
Paprika and paprika oleoresin	73.340 & 73.345	E160c
Riboflavin	73.450	E101
Saffron	X	--
Turmeric and turmeric oleoresin	X	--
Vegetable carbon	--	E153

[a] Only natural-identical forms are permitted by FDA

[From: Henry B.S. (1996). Natural food colors. In *Natural food colorants*, 43-44 pp. (eds. G.A.F. Hendry and J.D. Houghton). Glasgow, UK: Blackie Academic & Professional.]

Table 2. Natural food colorants permitted in United States (FDA list) and in the European Union

-
-
-

Bibliography

ASTM. (1987). *Standards on Color and Appearance Measurement.* Philadelphia: ASTM. [This document contains standardized conditions for measurement].

Calvo C. (1996). Optical Properties. In *Handbook of Food Analysis*. (ed. L.M.L. Nollet). New York: Marcel Dekker, Inc. [A comprehensive review of existing methods to measure optical properties of foods, mainly color].

Duran L., Rodrigo M., and Alcedo M.J. (1976). Measurement of colour and turbidity in orange juice. *Revista de Agroquimica y Tecnologia de Alimentos* **16**, 98-106. [A practical example for measuring color and degree of opacity in translucent foods].

Francis F.J. and Clydesdale F.M. (1975). *Food colorimetry: theory and applications.* Westport, CT: Avi Publishing Company, Inc. [A general textbook dealing with all aspects of food colorimetry].

Hardy A.C. (1936). *Handbook of colorimetry.* Massachusetts Institute of Technology, Cambridge: The Technology Press. [An old book containing very clear concepts related to definitions of colors and spectral characteristics].

Hendry G.A.F. and Houghton J.D. (1996). *Natural food colorants.* Glasgow: Blackie Academic & Professional. [A detailed description of colorants existing in nature that can be used in foods].

Hutchings J.B. (1994). *Food colour and appearance.* Glasgow: Blackie Academic & Professional. [In this book, color is considered as part of food appearance. Sensory aspects of color vision and instrumental measurement are discussed].

ISO Standard. (1999). *11037. General guidance and test method for the assessment of the colour of foods.* [This international standard contains standardized conditions for visual color measurement].

Judd D.B. and Wyszecki G. (1967). *Color in Business, Science and Industry.* John Wiley and Sons, Inc. [A classical book dealing with measurement of color and translucency, mainly in paints].
Lozano R.D. (1978). *El color y su medición.* Editorial América Lee. Buenos Aires (Argentina). [A general textbook, in Spanish, on colorimetry from a mathematical approach].

MacAdam D.L. (1985). *Color measurement. Theme and variations.* Springer-Verlag. [This book contains updated information on color specifications according to different color systems, as well as the fundamentals of measurement].

Manuel F. E. (1968). *A Portrait of Isaac Newton.* Belknap Press of Harvard, Cambridge: University Press. [Interesting biography of Newton].

McLaren K. (1986). *The colour science of dyes and pigments.* 2nd edition. Bristol and Boston: Adam Hilger Ltd. [A well documented book on the characteristics of colorants in broad use, not only in foods]

Peleg M. and Bagley E.B. (1983). *Physical properties of foods.* United States of America, Institute of Food Technologists; International Union of Food Science & Technology. [A general book on physical properties of foods with a very concise and comprehensive chapter on color and its measurement].

Biographical Sketches

Luis Durán received his Master of Science in Food Science and Technology at the University of California-Davis (US) and his Ph.D. in Chemistry at the University of Sevilla (Spain). He is a Research Professor at the Instituto de Agroquímica y Tecnología de Alimentos, a center of the Spanish Research Council, where he has developed his research and teaching activities, mainly in the fields of rheological and optical properties of foods. At present, he is Head of the Physical and Sensory Properties Laboratory and Editor-in-Chief of the journal, *Food Science and Technology International*.

Carlos Calvo received his Ph.D. in Chemistry from the University of Valencia (Spain) and Food Technologist by the Ministry of Education and Science (Spain). He is Researcher at the Instituto de Agroquímica y Tecnología de Alimentos (CSIC), a center of the Spanish Research Council (CSIC), and member of the Physical and Sensory Analysis of Foods Laboratory at the same institute, where he has developed his research and teaching activities, mainly in the field of optical properties of foods.