

Instrumental measurement of texture and color of meat and meat products

Alena Saláková

Department of Meat Hygiene and Technology
Faculty of Veterinary Hygiene and Ecology
University of Veterinary and Pharmaceutical Sciences Brno
Brno, Czech Republic

Abstract

The paper provides an overview of selected instrumental methods for the evaluation of textural properties and color of meat and meat products. Among the most commonly used methods that evaluate these qualities are the Warner-Bratzler test, the puncture test, and the texture profile analysis. The color evaluation of meat and meat products is performed on spectrophotometers that operate in the CIELAB system.

Hardness, TPA, Warner-Bratzler test, CIELAB

1. Texture

Texture is an important aspect of meat quality, sometimes even more important than color or flavour. Of the textural characteristics, the most frequently mentioned are hardness (toughness), cohesiveness and juiciness. The methods applied to evaluate texture can be divided into three groups: sensory methods, instrumental methods (also known as objective, physical or mechanical) and indirect methods (e.g. determination of collagen content in meat, amount of dry matter, etc.) (Kamdem and Hardy 1995, Combes et al. 2003).

Instrumental evaluation of texture

Most of the instrumental methods of texture evaluation are based on mechanical tests, which include the measurements of resistance the food presents to forces greater than gravity that are acting on it. The mechanical texture measurement is usually destructive, because the applied force exceeds the strength of the tested sample, thereby destroying it in the process (Krkošková 1986). Instrumental methods such as Allo-Kramer test, Warner-Bratzler test, and texture profile analysis are the most common ways of evaluating meat tenderness (toughness) (Cavitt et al. 2004).

Texture is objectively measured by the force or energy expended to cut or compress a sample of meat and meat products (Listrat et al. 1999). The instrumental methods require the samples to be larger and precisely defined. It is difficult or impossible to compare the results between laboratories with samples of different sizes or shapes (Xiong et al. 2006), or at different instrumental settings.

Texture profile analysis – TPA

Texture profile analysis (TPA) is one of the methods that simulate the conditions that the food is exposed to in the mouth (Xiong et al. 2006).

It is an objective method of instrumental analysis. The test consists of compressing a sample of food in two cycles (Figure 1). The most common method of loading is to keep the speed of one of the plates constant while measuring the compressive force. The resultant loading curve displays force as a function of sample deformation. The compressive plate (Plate III, Figure 2) should be larger than the tested sample, and the sample should have a smooth, flat surface, so that the area in contact with the plate is known and constant (Krkošková 1986). The force vs. deformation function permits to derive the individual

Address for correspondence:

Ing. Alena Saláková, Ph.D.
Department of Meat Hygiene and Technology
Faculty of Veterinary Hygiene and Ecology
University of Veterinary and Pharmaceutical Sciences Brno
Palackého tř. 1/3, 612 42 Brno, Czech Republic

Phone: +420 541 562 749
Fax: +420 541 321 230
E-mail: salakovaa@vfu.cz
www.maso-international.cz

textural parameters, namely hardness, tenderness, adhesion, springiness, chewiness, gumminess, and cohesiveness. The compression rate of 50 to 100 mm·min⁻¹ is chosen as a compromise between the estimated bite speed (around 300 to 500 mm·min⁻¹) (Houška et al. 1994), and the ability of the apparatus to record the forces with sufficient accuracy even in small samples. A total relative deformation of samples is 50 to 80%.

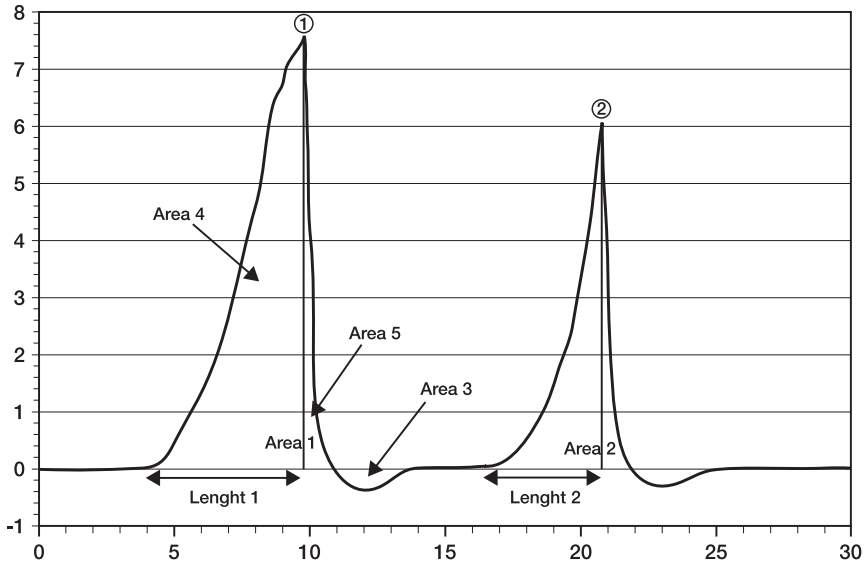


Fig. 1. Texture profile analysis (TPA) (Caine et al. 2003)

Explanation of the individual parameters in Figure 1 (Caine et al. 2003):

- Hardness (toughness) (Ha) is the maximum force reached during the first compressive cycle.
- Adhesion (Adh) is the force required to separate the sample surface from the compressive plate surface in contact with it (Area 3).
- Springiness (Spr) is an active deformation length in mm during the second compression divided by the sample height (Length 2/Length 1).
- Cohesiveness (Co) is the ratio of energies in the second cycle relative to the first one.
- Chewiness (Ch) is defined as $Ch = Gu \times Spr = Ha \times Co \times Spr$.
- Gumminess (Gu), defined as $Gu = Ha \times Co$, is characteristic for semi-solid foods with a low degree of hardness and a high degree of cohesion.

Warner-Bratzler Test

Warner-Bratzler evaluation of shear strength is very common, although the methodologies are not uniform (Leaflet 1997). This shear test makes it possible to measure the forces necessary to cut a sample of tissue. The shearing action permits to model the behavior of food during the first bite. A sample with muscle fibers parallel to the longer axis is cut with a Warner-Bratzler knife until completely severed, while recording the maximum strength and toughness, i.e. the energy required to cut the sample (Proceedings 1999).

The sample must be prepared and positioned so that the cut is perpendicular to the muscle fibers (Plate III, Figure 3). The knife speed can be varied as desired, even during the measurement, from the minimum of $0.5 \text{ mm}\cdot\text{min}^{-1}$ to the maximum of $1000 \text{ mm}\cdot\text{min}^{-1}$.

This method allows to measure the maximum force (N) as a function of knife displacement (mm) and the pressure needed to shear (cut off) a given sample of meat (MPa). The result of this measurement indicates the hardness (toughness) of the meat (Listrat et al. 1999). The repeatability of results in Warner-Bratzler testing increases quadratically with increasing number of sample measured. The highest repeatability is obtained by taking 10 measurements from one experimental sample (Wheeler et al. 1996).

Penetrometry (Puncture Tests)

This test is based on penetrating the sample with a probe. The method can be used in two ways (Proceedings 1999):

- measure the force required to penetrate to a certain depth, at a constant probe speed
- measure the puncture depth attained within a set time, or otherwise with constant force acting on the probe.

Penetrometers represent the oldest, and the longest-used, group of texture-measuring instruments. In principle, they measure the forces required to achieve a partial or total penetration of a probe into the tested material (Plate IV, Figure 4). The greater the requisite force, or the smaller the penetration depth, the more resistant the material is. Penetrometers can be particularly useful in testing the consistency of fats and gels (Krkošková 1986).

Other instrumental methods for texture evaluation

Other tools to measure texture instrumentally are cutting devices, masticometers that simulate chewing, texture meters, consistometers, viscosimeters, and extruders (Krkošková 1986).

The methods of texture evaluation are destructive, time-consuming and ill-suited for online applications. There is a need to develop a quick, non-destructive, accurate and on-line technology. These techniques could rely on NIR (Near Infrared Reflectance) spectroscopy for its speed, easy of deployment, and minimal sample moisture interference. Common applications include not only the quantitative forecast of the chemical, textural, and sensory characteristics of meat, but also, for example, a classification of beef by tenderness (Liu et al. 2003).

Comparison of instrumental methods for texture evaluation

Ruiz de Huidobro et al. (2005) compared the application of both methods discussed (Warner-Bratzler test and TPA) to determine the sensory characteristics associated with the texture of beef. The study indicates that the TPA test predicted the sensory hardness better than the Warner-Bratzler test. In general, the authors are leaning toward the TPA test in beef texture evaluations. Warner-Bratzler shear force (WBS) and the sensory rating of chewiness decline in the course of aging. However, the sensorial rated juiciness varies very little (Liu et al. 2003). The Warner-Bratzler shear force has the highest coefficient of variability (27.5%). The sensorial texture evaluation exhibits the coefficients of variability ranging from 7% to 19%. The Warner-Bratzler shear force showed negative correlations with the initial toughness (-0.61), amount of connective tissue (-0.49), the total toughness (-0.60), and with the sample's overall tastiness (-0.56). The results show positive correlations between the Warner-Bratzler shear force and the TPA toughness (0.35). Both methods probably measure similar textural properties (Caine et al. 2003).

Differences in heat processing make the comparison of results between the individual studies difficult, because the final temperature of the sample core is not always precisely defined (Combes et al. 2003).

2. Color

To a consumer, color is a very important criterion. Color depends on the concentration of myoglobin and the degree of its oxidation, as well as the meat structure (Ruiz de Huidobro et al. 2003). The visual appearance of meat products triggers a reaction in the consumer that leads to a decision to buy or not to buy, to consume or not to consume, a particular item. The color is probably one of the most important visual factors in purchasing decisions concerning meat and meat products (Hunt et al. 1991; Wulf and Wise 1999). Color, as seen by the consumer, is a physical interaction of light with the meat registered by the human eye and interpreted by the brain. Colors are therefore perceived subjectively.

Color description

Physically, color is radiation containing a mixture of different wavelengths, a segment of the visible spectrum reflected by the object whose color is being assessed in the observer's eye. Color, or more precisely what a person perceives as color, depends on a number of local conditions. The most prominent among them are spectral composition and the angle of the incident light, the observer's viewing direction, the surface properties involved, and the properties of the observer, such as his vision acuity, his adaptation to the ambient light, or his age (Třešňák 1999a).

With respect to the observer's properties, an objective color assessment is further complicated (aside from color sensitivity disorders that affect about 10% of the population) by the fact that our senses are susceptible to being deceived by expectation and memory: a casual glance does not register color variations of familiar objects caused by changes in ambient lighting. That's because a person automatically adjusts for both the intensity of lighting and the white color reference. Research also reveals that the color perception of an object is influenced by the colors in its proximity. Consequently, when sharing information and communicating about colors, it is essential to follow an objective and exact protocol to describe, measure, and verify colors.

Color can be characterized by three basic properties:

- Hue – the property that normally serves to differentiate one color from another. The red color differs from blue, green from yellow. Mixing of the neighboring spectral colors is possible to obtain a smooth transition – for example, red and yellow create a spectrum of colors from red to orange to yellow. The beginning and the end of this series are connected.
- Brightness – describes the colors on a scale of “dark – light”. Black and white, together with the shades of gray between them, is referred to as neutral colors, and in that sense they have no hue.
- Saturation – describes the color property in the sense of transition from a neutral gray to a pure hue with the brightness being constant. This is sometimes described as a transition from a faint to a vivid shade. This property can be visualized by imagining that a chosen color (say yellow) is being gradually added to gray, resulting in pure yellow (Třešňák 1999a; MacDougall 2002).

Objective measurement of meat color

The color of meat can be evaluated by using color standards, by reflectance spectrometry measurement, or by video analysis (VIA) (Purchas 2004). An alternate method is NIR (Near Infrared Reflectance) Spectroscopy, which is characterized by

speed, ease of use and a minimal interference due to moisture and/or color of the samples (Liu et al. 2003).

Color Systems

The foundation of CIE (Commission Internationale de l'Éclairage) in 1931, responsible for formulating and promoting international standards, was a response to calls for color standardization. CIE generates, among other things, definitions of color spaces, standards applicable to measurement methodologies, observer's characteristics, and illumination parameters (Třešňák 1999b).

a) Munsell System

This system was the first one to identify the color of an unknown sample in a three-dimensional space (already in 1905). The color is described by three attributes as hue (H), value (V) or lightness and chroma (C) or color purity. Munsell also identified five basic colors (Red, Yellow, Green, Blue, and Purple), which he placed evenly around the circumference of a circle, with five composite colors (YR, GY, BG, PB, RP) interposed between them (Plate IV, Figure 5). The Munsell circle has a total of 10 color sectors with assigned numerical values – the basic version has 100 steps around the perimeter, but fractional numbers can be used if needed. Color saturation increases from the center of the circle to its edge. The vertical axis represents brightness that assumes the values from 0 to 10, where 0 is absolute black and 10 is absolute white (Hunt et al. 1991; Třešňák 1999a; Warriss 2000).

b) CIEXYZ System

The CIE system (1931) for color measurement transforms the spectrum of an object's reflectance or transmittance into a three-dimensional color space (Plate IV, Figure 6). In doing so, it relies on the spectral distribution energy of the light source and the chromatically corresponding function of a standard observer. Instead of the "real" primary colors of red, green and blue, it uses an X, Y, Z space, where Y is the light reflectance or transmittance, including the initial light stimulus. Using the Y values and chromatic coordinates x and y, each color can be uniquely positioned in such a color space under standard illumination and with a standard observer (MacDougall 2002).

Brightness is thus expressed by the value Y and colors with this brightness are arranged in a chromatic diagram (x, y). Hues are distributed along the circumference of this diagram, and the saturation changes as it moves towards the central, neutral area. The downside is that the separation of colors in the diagram does not always match the difference perceived by the observer (Hunt et al. 1991; Třešňák 1999b).

c) CIELAB System

The CIELAB color system is one of the most commonly used color spaces to measure the color of an object. CIELAB was created in 1976 in an effort to deal with one of the great problems of the original XYZ space, where equal distances on the x and y axes in the chromatic diagram did not correspond to chromatic coordinates (Konica Minolta 2006). CIELAB is the counterpart of a color system based on a previous (1942) system devised by Richard Hunter, called "Lab" (Plate V, Figure 7).

Color is defined as a point in a three-dimensional space in relation to coordinates L^* , a^* , and b^* . L^* signifies the lightness of the color. It is located on a vertical axis in space, and its value ranges from 0 (black) to 100 (white). The coordinates a^* and b^* represent the values from which saturation and hue of a color can be calculated. They exist in a horizontal plane. An a^* is part of a spectrum of wavelengths corresponding to colors from green ($-a^*$) to red ($+a^*$), b^* from blue ($-b^*$) to yellow ($+b^*$) (Warriss 2000).

Color cannot be simultaneously green and red, or blue and yellow, so it is possible to introduce values describing the location of a hue between green and red, or blue and yellow. If a color is defined by the CIE $L^*a^*b^*$, then L^* indicates the brightness (luminosity), a^* indicates the position between primary colors R/G (red/green), and b^* indicates the position between primary colors Y/B (yellow/blue). The circular chart has a neutral area in the center, whereas in the 3-dimensional shape forming the $L^*a^*b^*$ space, the neutral colors (black, degrees of gray, and white) pass through the centre of this body (Třešňák 1999b).

Coordinates L^* , a^* , b^* define the position of a color in a uniform color space. In practice, the most frequently desired information is how the sample differs from a standard. CIE $L^*a^*b^*$ is based on the perception of identifiable color differences in a coordinate system. However, it does not determine the degree of color difference acceptability. The degree of acceptability varies depending on the type of sample (MacDougall 2002).

The position of a color in coordinates a^* , b^* may be marked in the circular chart, but the true color position is obtained only after including the L^* value and position of color in space.

d) LCh Color Space

This space works with cylindrical coordinates (Plate V, Figure 8). L^* represents the value of brightness (lightness). The C^* value stands for saturation (chroma), and it has a zero value in the center and increases with the distance from the center, h° is a hue angle expressed in degrees and has its origin on the $+a^*$ axis. The value of 0° for $+a^*$ represents red, 90° for $+b^*$ yellow, 180° for $-a^*$ green, and 270° for $-b^*$ blue (Konica Minolta 2006).

The CIE $L^*C^*h^\circ$ model is very intuitive in color evaluations, because it follows the natural human concept of colors. It also relates easily to other color systems, such as the Munsell color notation (Třešňák 1999b).

Color variations

Color space CIE $L^*a^*b^*$ allows to identify, count, and measure objective variances between the different colors with relative ease. This difference, consisting of deviations ΔL^* , Δa^* , Δb^* , is best expressed by term ΔE^* , which is a square root of the sum of the individual deviations squared.

A scale indicating the degree of disagreement between two colors was devised to facilitate the communication (Table 1) (Třešňák 1999a).

Table 1. Color differentiation scale (Třešňák 1999a)

ΔE^*	Description
0.0 – 0.2	Imperceptible
0.2 – 0.5	Minute
0.2 – 1.0	Perceptible
0.5 – 1.5	Slight
1.0 – 2.0	Recognizable
1.5 – 3.0	Clearly perceptible
2.0 – 4.0	Not yet discordant
3.0 – 6.0	Medium
4.0 – 8.0	Moderately discordant
Over 6.0	Prominent or moderately disturbing
12.0	Very prominent
16.0	Disturbing

Standardization of measuring conditions

The definition of a “standard” observer is one of the fundamental requirements in color evaluations. The observer’s characteristics derive from the research of the effect that color has on an “average” man. There are two types of observers, according to the angle under which the rays enter the eye, specifically the color-seeing retina. A 10° observer perceives the color with the entire retina (visible

area at a distance of 50 cm is 8.8 cm), whereas a 2° observer perceives color with the most sensitive parts of the eye, the so-called yellow spot (visible area at a distance of 50 cm is 1.7 cm). It is also important to consider the influence of ambient lighting for correct color assessment.

Currently, the basic standard conditions are as follows:

- illuminant D50 or D65 (daylight);
- position 0/45° or 45/0° (target-viewing angle for the observer and the angle of external light incidence – both geometries yield equivalent results);
- a 10° observer or a 2° observer.

Standard light D65: normal daylight (with some UV), color temperature 6504 °K. Used in testing samples supposed to be illuminated by daylight, with a portion of UV radiation.

Standard daylight D50: daylight containing a UV component having the color temperature of 5003 °K.

Standard light C: normal daylight without a UV component, color temperature 6774 °K. Used for samples illuminated by daylight without additional UV radiation.

Standard light A: incandescent light with the color temperature of 2856 °K. Used for samples illuminated by this type of light (Třešňák 1999a; Warriss 2000).

Impact of sample thickness, light source, and type of background on color determination

As far as the role of background in sample evaluation is concerned, Bianchi and Fletcher (2002) proved experimentally that the color of samples 2 and 3 cm thick is not affected by their background. In 1 cm thick samples, background color influences the sample color in chicken meat, specifically the a* value, while having no effect on values L* and b*. In turkey meat, influenced are the values of a* and b* whereas the L* value remains unaffected by the background. Sandusky and Heath (1996) found that the background color has a significant effect in 0.5 cm thick samples, whereas the sample thickness of 1.0 and 1.5 cm showed little difference.

Sample thickness affects the color of chicken and turkey meat more than background color. Background color becomes important only when working with thinner samples (Bianchi and Fletcher 2002).

When the product is packaged and displayed, its appearance depends largely on the lighting system, which creates special conditions for color measurement (Hunt et al. 1991).

Barbut (2004) evaluated the influence of light source on the acceptability of color in Hungarian sausages. He used three different sources: the classic light bulb, fluorescent light and a halide lamp. The respondents gave the highest rating to the color under the light bulb, because it had more red than the other two sources, which made the color look brown.

References

- Anon 1 [on-line]. CIE 1931 color space; available at [27. 11. 2007] http://en.wikipedia.org/wiki/CIE_1931_colour_space
- Anon 2 [on-line]; available at [30. 8. 2012] www.boscarol.com/media/images/cms/cie4.gif
- Barbut S 2004: Effect of retail lights on acceptability of salami. *Meat Sci* **66**: 219-233
- Bianchi M, Fletcher DL 2002: Effects of broiler breast meat thickness and background on color measurement. *Poultry Sci* **81**: 1766-1769
- Bourne M 2002: Food texture and viscosity. Concept and measurement. 2nd edition, New York: Academic press, 427p
- Caine WR, Aalhus JL, Best DR, Dugan MER, Jeremiah LE 2003: Relationship of texture profile analysis and Warner-Bratzler shear force with sensory characteristics of beef rib steaks. *Meat Sci* **64**: 333-339
- Cavitt LC, Youm GW, Meullenet JF, Owens CM, Xiong R 2004: Prediction of poultry meat tenderness using Razor blade shear, Allo-Kramer shear, and sarcomere length. *J Food Sci* **69**: 11-15
- Combes S, Lepetit J, Darche B, Lebas F 2003: Effect of cooking temperature and cooking time on Warner-Bratzler tenderness measurement and collagen content in rabbit meat. *Meat Sci* **66**: 91-96

- Houška M, Paulíčková I, Pokorný J 1994: Korelace hodnocení senzoričké a přístrojové tvrdosti. *Potravinářské vědy* **12**: 475-488
- Hunt MC, Acton JC, Benedict RC, Calkins CR, Cornforth DP, Jeremiah LE, Olson DG, Salm CP, Savell JW, Shivas DS 1991: Guidelines for Meat Color Evaluation. AMSA USA 1991, 17 p
- Instron, Co. [on-line] 2007: available at [15. 10. 2007] <http://www.instron.co.uk/wa/applications/food/testing.aspx>
- Kamdem AT, Hardy J 1995: Grinding as a method of meat texture evaluation. *Meat Sci* **39**: 225-236
- KonicaMinolta 2006: Přesná komunikace o barvě. Konica Minolta - firemní literatura, 2006: 57p
- Krkošková B 1986: Textúra potravin. 1. vyd., Bratislava : Alfa, 200p
- Leaflet AS 1997: [on-line] Comparison of round and square cores in the determination of beef tenderness by Warner-Bratzler and Instron www.extension.iastate.edu/Pages/ansci/beefreports/asl-1463.pdf
- Listrat A, Rakadjiyski N, Jurie C, Picard B, Touraille C, Geay Y 1999: Effect of the type of diet on muscle characteristics and meat palatability of growing Salers bulls. *Meat Sci* **53**: 115-124
- Liu Y, Lyon BG, Windham WR, Realini CE, Pringle TDD, Duckett S 2003: Prediction of color, texture, and sensory characteristics of beef steaks by visible and near infrared reflectance spectroscopy. A facility study. *Meat Sci* **65**: 1107-1115
- MacDoughall DB 2002: Colour in food, improving quality. England: Woodhead publishing: Limited, 378 p
- Ruiz de Huidobro F, Miguel E, Blázquez B, Onega E 2005: A comparison between two methods (Warner-Bratzler and texture profile analysis) for testing either raw meat or cooked meat. *Meat Sci* **69**: 527-536
- Sandusky CL, Heath JL 1996: Effect of background color, sample thickness, and illuminant on the measurement of broiler meat color. *Poultry Sci* **75**: 1437-1442
- Proceedings 1999: Kurz reometrie potravin. Praha : VÚPP, 20p
- Třešňák K 1999A: Barvy a barevné modely. *Svět tisku* **6**: 58-60
- Třešňák K 1999B: Barvy a barevné prostory. *Svět tisku* **10**: 90
- Warriss PD 2000: Meat Science. An Introductory Text 1st edition, Wallingford : CABI 2000, 312p
- Wheeler TL, Shackelford SD, Koohmaraie M 1996 Sampling, Cooking and Coring effects on Warner-Bratzler Shear force Values in Beef. *J Anim Sci* **74**: 1553-1562
- Wulf DM, Wise JW 1999: Measuring Muscle Color on Beef Carcasses Using the L*a*b* Color space. *J Anim Sci* **77**: 2418-2427
- Xiong R, Cavitt LC, Meullenet JF, Owens CM 2006: Comparison of Allo-Kramer, Warner-Bratzler and razor blade shears for predicting sensory tenderness of broiler breast meat. *J Tex Stud* **37**: 179-199

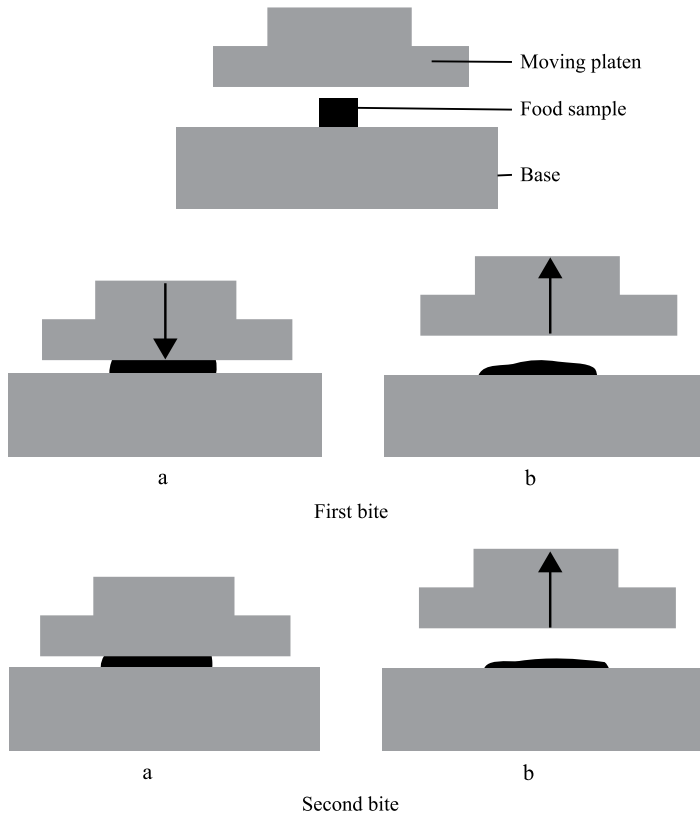


Fig. 2. Two compression cycles during a TPA analysis (Bourne 2002)

a – downstroke actions during the first and second bites, b – upstroke actions during the first and second bites

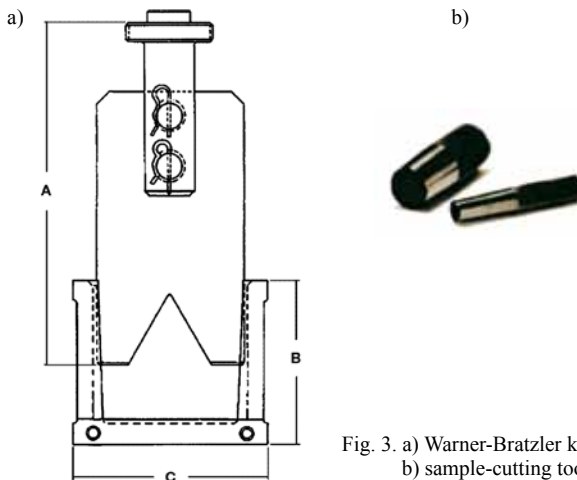


Fig. 3. a) Warner-Bratzler knife

b) sample-cutting tools (Instron Co. 2012)



Fig. 4. Probes for penetrometric evaluation of texture (puncture tests) (Photo: Saláková)

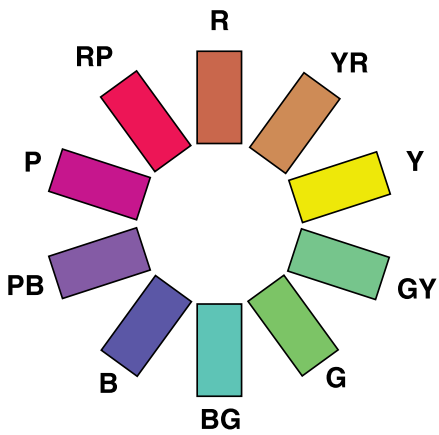


Fig. 5. Munsell System (Třešňák 1999a)

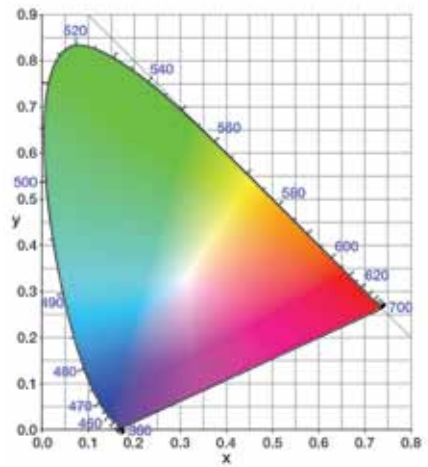


Fig. 6. CIE XYZ (Anon 1 2012)

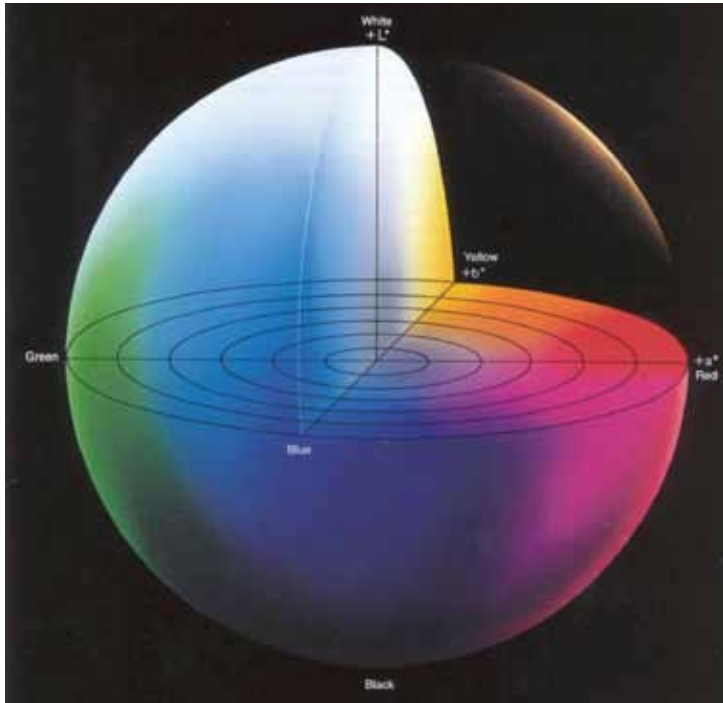


Fig. 7. CIELAB ($L^*a^*b^*$) diagram (KonicaMinolta 2012)

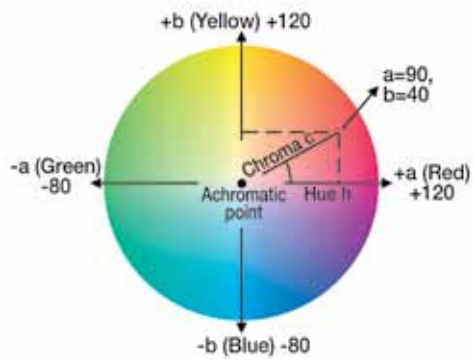


Fig. 8. Color Space LCh ($L^*C^*h^\circ$) (Anon 2 2012)