Available online at www.sciencedirect.com
ScienceDirect
Innovative Food Science and Emerging Technologies 7 (2006) 302 – 308
Innovative Food Science & Emerging Technologies
www.elsevier.com/locate/ifset

Application of Kubelka–Munk analysis to the study of translucency in fresh-cut tomato

M.M. Lana [a,b,*], M. Hogenkamp [a], R.B.M. Koehorst [c]

[a] Horticultural Production Chains Group, Wageningen University, Marijkeweg 22, 6709 PG, Wageningen, NL, The Netherlands
[b] Embrapa Hortaliças, Caixa Postal 218, 70359970, Brasília-DF, Brazil
[c] Laboratory of Biophysics, P.O. Box 8128, 6700 ET, Wageningen, NL, The Netherlands

Received 4 November 2005; accepted 12 April 2006

Abstract

In order to assess the development of translucency in fresh-cut tomato (*Lycopersicum esculentum* cv. Belissimo) during refrigerated storage, two experiments were conducted. In the first one, tomato slices obtained from fruits at breaker and at red stage were stored at 5±0.5 °C and monitored at regular intervals for 9 days. In the second one, slices obtained from fruits at the light-red stage were stored at 5±0.5 °C, 9±0.7 °C and 13±0.7 °C for 4 days. Intact (control) fruits were stored at the same conditions and sliced immediately before the evaluations. In both experiments, translucency was assessed using Kubelka–Munk analysis and through visual evaluation using a scale from 0 to 4. The translucency of cut tomato slices increased during storage in both experiments. Fruits at red stage got translucent faster than fruits at breaker stage and the intensity of translucency was also higher for more ripe fruit. The storage temperature did not influence significantly the development of translucency, indicating that the water soaking of the pericarp tissue is not a result of chilling injury. The K/S (absorption coefficient/scattering coefficient) ratio increased during storage for cut fruits and remained practically constant for intact fruits, reflecting the effects of treatment observed visually. Additional experiments indicated that the removal of the locular gel combined or not with washing and drying the slice cut surface inhibited the development of translucency.

Keywords: *Lycopersicum esculentum*; Tomato fruit; Spectrophotometry; Kubelka–Munk analysis; Water soaking; Wound injury; Minimally processed

Industrial relevance: The development of translucency is a common alteration in the appearance of fresh-cut fleshy tissue after processing, which renders the product unappealing for consumption. It is of interest for the fresh-cut industry to be able to assess the development of translucency and then evaluate the effect of different procedures in its occurrence and intensity. This paper presents the use of Kubelka–Munk analysis, a technique of widespread use in other fields like printing and painting, to assess the development of translucency in sliced tomato and to study how this process is affected by storage temperature and maturity stage of the fruit.

1. Introduction

The operations necessary to prepare fresh-cut fruits and vegetables (peeling, cutting, shredding, etc.) can induce undesirable changes in colour and appearance of these products during storage and marketing. Degradation and oxidation of pigments like chlorophylls and carotenoids are likely to occur as a consequence of wounding (Heaton & Marangoni, 1996; Jamie & Saltveit, 2002). Browning of cut surfaces due to the production of wound-related compounds has been extensively studied and reported for many different products (Bolin & Huxsoll, 1989; Rocha & Morais, 2003), (Gonzalez-Aguilar, Wang, & Buta, 2000; Loaiza-Velarde, Mangrich, Campos-Vargas, & Saltveit, 2003). Loss of water causes loss of sheen and gloss at the cut surface of cut pears (Gorny, Cifuentes, Hess-Pierce, & Kader, 2000) and a whitening or dehydrated surface develops in carrots (Barry Ryan & O' Beirne, 1998), shredded green papaya (Techavuthiporn, Kyu, & Kanlayanarat, 2003) and sliced tomatoes (Artes, Conesa, Hernandez, & Gil, 1999). Equally important, but less studied, are changes in the refractive index and in the homogeneity of the tissue that result in the development of translucency or a water-soaked appearance after

* Corresponding author. Embrapa Hortaliças, Caixa Postal 218, 70359970, Brasília-DF, Brazil. Tel.: +55 613 3859000; fax: +55 613 5565744.
E-mail address: milza@cnph.embrapa.br (M.M. Lana).

1466-8564/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ifset.2006.04.001

processing and have a great impact in colour and appearance of the product. This seems to be particularly important for fleshy tissue as tomatoes (Artes et al., 1999; Gil, Conesa, & Artes, 2002; Lana, Tijskens, & van Kooten, 2005), melon (Aguayo, Escalona, & Artes Calero 2004; O'Connor-Shaw, Roberts, Ford, & Nottingham, 1994), papaya (O'Connor-Shaw et al., 1994) and pears (Soliva-Fortuny, Grigelmo-Miguel, Hernando, Lluch, & Martín-Belloso, 2002).

Translucency is the property by which light can penetrate and disperse into and/or through a material (Hutchings, 1994). A translucent material is one that both transmits and scatters light. How much translucent an object is depends on the extent to which the light entering a sample is reflected, scattered or absorbed. As a phenomenon, translucency occurs between the extremes of transparency and opaqueness (Hutchings, 1994).

The reflection of light from opaque and translucent materials depends on the ratio of absorption to scatter as affected by pigmentation, refractive index and the light-scattering properties of the material (MacDougall, 2002). The interaction of light scatter and absorption is particularly important in influencing the perceived appearance. Besides that, translucency is one of the most important sources of structural error in the measurement of colour, since it can lead to severe confusion in both visual assessment and instrumental measurement. Its confounding effect in the colour appearance of such products as fruit juice, dairy products and meat was extensively studied by MacDougall (2002). Because of that, the measurement of colour of translucent samples requires in addition to colour measurement the inclusion of some measure of light scatter, in order to obtain an adequate definition of colour appearance (Judd & Wyszecki, 1975; MacDougall, 2002).

The Kubelka–Munk analysis was originally derived in 1931 by P. Kubelka and F. Munk in order to predict the optical properties of any given material. It found an extensive use in the industry of paints, inks and others (Cortat, 2004). In food science and horticulture the Kubelka–Munk analysis has been used in the study of optical properties of a range of different products (Budiastra, Ikeda, & Nishizu, 1998; Knee, Tsantili, & Hatfield 1988; Law & Norris, 1973; MacDougall, 2002; Pauletti, Matta, Castelao, & Rozyckl, 2002; Rozycki, 2003; Talens, Martinez-Navarrete, Fito, & Chiralt, 2002).

The changes in optical properties of tomato fruit during maturation were assessed by Hetherington and MacDougall (1992) using the Kubelka–Munk analysis. They measured a decrease in scatter from green to red tomatoes and this was expressed into a change from opacity to increasing translucency as the fruits turned red. Because the Kukelka–Munk analysis assumes homogeneity of the sample being analysed, the fruit was dissected into different parts (skin, outer pericarp, inner pericarp and locular contents), since they all scatter and absorb light in a different way. For all stages of maturity the outer pericarp was the most translucent tissue (less opaque). The columela and locular content were opaque and densely packed, albeit in a jelly surrounding in the case of locular contents.

The assessment of translucency in fresh-cut products has been made by visual evaluation by many researchers (Bai, Saftner, & Watada, 2003; Bai, Saftner, Watada, & Lee, 2001; Gil et al., 2002; Jeong, Brecht, Huber, & Sargent., 2004; O'Connor-Shaw et al., 1994; Portela & Cantwell, 2001).

In the present study the changes in optical properties in the pericarp of fresh-cut tomato slices were assessed using the Kubelka–Munk analysis and visual evaluation. The effects of the stage of maturity of the fruit at harvest and the storage temperature on the development of translucency are discussed. Additionally, inferences about the development of translucency after cutting are made, based on additional experiments as described in the next sections.

2. Material and methods

2.1. Experiment 1. Effect of stage of maturity

Tomato fruit (*Lycopersicum esculentum* cv. Belissimo) were harvested in a commercial greenhouse in Made (The Netherlands) in September 2004, at stages of maturity 3 (breaker) and 9 (red) according to the tomato colour chart from The Greenery (Barendrecht, The Netherlands). The fruit were transported immediately after harvesting and selection to Wageningen (The Netherlands), washed in cold tap water in a sanitised room and stored overnight at room temperature.

The next day, fruits similar in colour, shape and size were paired and numbered. One fruit was stored intact while the other was sliced in 7-mm-thick transversal slices, using a professional meat/food slicer (model 250 VK, Berkel Prior B.V. Ridderkerk, The Netherlands). The first and last slices were thrown away and the central four were stacked in the same relative position they had in the fruit. Intact and sliced fruits were placed in a white polystyrene tray (138 mm × 138 mm × 25 mm) and covered with a permeable plastic film (used for microwave cooking) and stored at 5 ± 0.5 °C. Preliminary assays (described in detail in Lana & Tijskens, 2006) demonstrated that there was no significant change in the atmosphere inside the package for both cut and intact fruits. For each maturity × cutting (or intact) × storage time combination, 6 replicates, each one corresponding to a tray with 1 fruit, were analysed. Only the second slice from the bottom of the stack was used. The evaluations (spectrophotometric measurements and visual evaluation) were performed immediately after processing, before cooling, and after 1, 2, 3, 5, 7 and 9 days under storage. Intact fruits were sliced immediately before evaluation, in the same way the other fruits have been sliced previously.

2.2. Experiment 2. Effect of storage temperature

Tomato fruit (cv. Belissimo) at maturity stage 7 (light-red) were harvested in a commercial greenhouse in Berkel en Rodenrijs (The Netherlands) in October 2004. The fruit were handled, processed and packaged as described in the previous section. Sliced and intact fruits, used as controls, were stored at 5 ± 0.5 °C, 9 ± 0.7 °C or 13 ± 0.7 °C. For each temperature × cutting (or intact) × storage time combination, 6 replicates, each one corresponding to a tray with 1 fruit, were analysed immediately after processing, before cooling, and then everyday for up to 4 days.