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Viscoelasticity, texture and ultrastructure of cut apple as affected by sequential anti-browning and ultraviolet-C light treatments

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ABSTRACT

The aim of this work was to analyze the effect of UV-C radiation (fluence: 11.2 kJ/m^2), with or without an anti-browning pretreatment containing 1% (w/v) ascorbic acid plus 0.1% (w/v) calcium chloride, on the linear viscoelastic properties (oscillatory shear and creep/recovery), instrumental texture (TPA), sensory texture and ultrastructure (ESEM, TEM) of cut apple. Changes in structural features and viscoelastic parameters were mainly evidenced after refrigerated storage. All samples showed a viscoelastic solid behavior with the storage modulus (G') dominating the viscoelastic response. Overall, both dynamic moduli decreased, and instantaneous compliance (J_0), decay compliances (J_1 and J_2) and fluidity significantly increased after treatments and storage at 5 °C, while retardation times were in general constant. Fracture properties proved to be the most highly correlated with sensory texture. The test panel only significantly differentiated stored untreated apple from the other samples regarding fracturability and juiciness. Mechanical spectra and creep parameters showed ability to evidence ultrastructural differences (rupture of membranes, swelling of cells, alteration of cell walls) in the surface of cut apples subjected to the different treatments.

1. Introduction

Physical methods for removing microorganisms from produce surfaces include ultrasound, short-wave ultraviolet radiation (UV-C), high pressure, high-intensity electric field pulses, radiofrequency and ionizing radiation (Gil et al., 2009). UV-C is a radiation in the range of 200–280 nm which cross DNA pyrimidine bases of cytosine and thymine to form crosslinks, impairing formation of hydrogen bonds with the purine base pair on the complimentary strand of DNA and thus reproduction of microorganisms (Bintsis et al., 2000; Guerrero-Beltrán and Barbosa-Cánovas, 2004; Shama, 2006). It has also been proved to cause significant damage in the cytoplasmic membrane integrity and in the cellular enzyme activity (Schenk et al., 2011). Few studies regarding the influence of UV-C disinfection on fruit quality (color, texture, taste, and aroma) during storage have been made (Shama and Alderson, 2005; Erkan et al., 2001). The reported effects are quite diverse depending on the type of produce and the dosages applied (Shama, 2006) and in most of cases the effects are restricted to whole produce. Recently, Gómez et al. (2010) examined the effect of UV-C irradiation at different doses on structure, surface color, compression properties and native flora and inoculated microorganism behavior of cut apple stored in refrigeration for 7 days. They also explored the use of some pretreatments (hot water blanching, dipping into a solution containing ascorbic acid, calcium chloride) to minimize apple browning caused by UV-C light. Color and compression parameters were found to be dependent on UV-C dose, storage time and type of pretreatment. At the end of storage, samples exposed to only UV-C light turned darker (lower L^* values) and less green (higher a^* value) when compared to fresh-cut apple slices or to samples on day 0 and this effect was more pronounced at the greatest UV-C dose. Both pretreatments helped in maintaining the original color of apple slices after UV-C light exposure. Light microscopy observations clearly indicated that the modifications in color of only UV-C irradiated apples could be at least partially ascribed to the breakage of cellular membranes, which would cause a loss of functional cell compartmentalization, increasing enzyme–substrate contact with the consequent increase in tissue browning. Results indicated that UV-C light must be combined with a suitable anti-browning pretreatment to be used as a tool by the minimally processed produce industry to reduce surface microbial load avoiding color deterioration of cut apple. Regarding compression behavior, this preliminary study showed that UV-C treatment applied at different doses on raw apple had not a significant effect on true rupture stress (σ_R^R) and deformability modulus (E_d) values on day 0. But at day 7, σ_R^R and E_d of raw apple were significantly higher than those of UV-C treated samples. Also, the decrease in E_d values

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Nomenclature

ESEM	environmental scanning electron microscopy
G'	storage modulus (Pa)
G''	loss modulus (Pa)
J	creep compliance (Pa^{-1})
J_0	instantaneous compliance (Pa^{-1}), Eq. (1)
J_i	retarded compliance associated with the *i*th-Kelvin–Voigt element, Eq. (2), (Pa^{-1})
LM	light microscopy
LVR	linear viscoelastic range
n, k	empirical constants, Eq. (1)
PP	percentage of weight loss, Eq. (3), dimensionless
p	weight of apple sample at time t (g)
t	time (s)
tan (δ)	($=G''/G'$) loss tangent, dimensionless
TEM	transmission electron microscopy

Greek symbols

γ	strain at time t, dimensionless
δ	phase angle (rad)
η	coefficient of viscosity of the dashpot, Eq. (2) (Pa s)
λ	retardation time, Eq. (2), (s)
τ	constant shear stress, Eq. (2), (Pa)
ω	angular frequency (s^{-1})

Subscripts

i	*i*th Kelvin–Voigt element, Eq. (2), $i = 1, 2$
N	associated to Newtonian flow
t	at time t
0	initial value

of UV-C irradiated apples previously immersed into the anti-browning solution was in general significant (although small) after the treatment as well after 7 days of storage.

Producing high quality fruit products requires understanding the factors controlling texture. One component of sensory texture is rheological properties. They are an overall manifestation of structure (micro-, ultra-, nano) features and the inter-atomic and intermolecular interactions (Peleg, 2006). The relationship between rheological properties and microscopic features of plant tissues is well known. Dynamic oscillatory shear and creep/recovery tests performed in the linear viscoelastic regimen are usually used to determine material properties, allowing characterizing microstructures in a non-destructive manner (Khan et al., 1997). This is not the case in the mouth and in the TPA analyzer, where irreversible deformation takes place. At the cellular and tissue levels, the three major structural factors that contribute to mechanical behavior of plant-based foods are turgor (i.e. the force exerted on the cell membrane by intracellular fluid), cell wall rigidity, and cell–cell adhesion, determined by the integrity of the middle lamella and the plasmodesmata (Jackman and Stanley, 1995; Waldron et al., 1997; Alzamora et al., 2000, 2008).

Because of the need to gain more information about the effect of UV-C radiation combined with an anti-browning pretreatment and refrigerated storage on apple tissues, the specific aims of this study were:

(a) To analyze the linear viscoelastic behavior as derived by from dynamic oscillatory and creep tests.
(b) To explore the texture profile analysis (TPA) attributes and their correlation with sensory texture evaluation.
(c) To evaluate the ultrastructure by transmission and environmental scanning electronic microscopy and to explore how differences in tissue structure were expressed by viscoelastic, TPA and sensory parameters.

2. Materials and methods

2.1. Sample preparation

Raw apples (*Malus pumila*, Granny Smith var.; a_w 0.98; 10.4–12.2 °Brix, pH 3.3–3.4) were purchased at a local market and maintained at 4–5 °C until use. Before processing, whole fruit was washed in water, dipped in sodium hypochlorite solution (100 ppm free chlorine, 3 min) and rinsed in water. All cutting boards, tools and holding vessels were sanitized in the same way before use.

Apples were hand peeled and slices of parenchymatic tissue with tangential orientation were cut parallel to the axis through the calyx and the stem. The slices were cut out vertically with a cork borer to obtain 0.03 m in diameter and 0.006 m in thickness discs. All slices were taken from the middle part between the center and the surface of the fruit, where there were few vascular bundles. Apple discs were dipped in distilled water (4–5 °C) for 1 min to eliminate cellular fluids, dried with tissue paper and immediately subjected to the different treatments to avoid the loss of moisture.

2.2. UV-C equipment and dosimetry

The UV-C irradiation device consisted of one bank of two reflectors with unfiltered germicidal emitting lamps (maximal emission at 253.7 nm, TUV-15W G 13 T8 55 V, Philips, Holland) located 0.1 m above the produce tray. The UV-C lamps and the treatment area were enclosed in a wooden box covered with aluminum foil with a cover protection for the operators. A ventilation device was installed in a corner of the box to avoid temperature increase due to UV-C radiation. The mean air temperature during the treatments was 27 ± 1 °C. Prior to use, the UV-C lamps were allowed to stabilize by turning them on at least 15 min.

The UV-C intensity emitted from the lamps was determined by using the iodure/iodate chemical actinometer (Rahn, 1997). All reactive employed in UV-C dosimetry were analytical grade from Merck Química Argentina S.A. (Argentina). The test was made by cuadruplicate and the mean value was reported. Variations in radiation dose absorption were minimized by placing the samples within a uniform area of the radiation field (between the lamps and equidistant with respect to lamp extremes).

2.3. Treatments

Prior to irradiation, some apple discs were immersed into an anti-browning solution (anti-browning dipping, AD) containing 1% (w/v) ascorbic acid (food grade, Química Oeste S.A., Argentina) plus 0.1% (w/v) calcium chloride (food grade, Saporiti S.A., Argentina), pH 3.5, for 5 min at 4 °C (Gómez et al., 2010; Ponting et al., 1972).

Apple discs with and without previous immersion into the anti-browning solution were exposed to irradiation for 20 min (fluence: 11.2 kJ/m^2) on one side. The selected dose was suitable to achieve microorganism's inactivation on apple slices. The log reductions for different microorganisms inoculated and native flora varied between 1.0 and 1.9 log cycles for apple discs without previous