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ScienceDirect
Postharvest Biology and Technology 43 (2007) 115–120
Postharvest Biology and Technology
www.elsevier.com/locate/postharvbio

Ultrasonic study of the complete dehydration process of orange peel

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Received 31 January 2006; accepted 30 July 2006

Abstract

The use of ultrasonic measurements as an alternative technique to control the natural dehydration process of the orange peel is assessed by means of studying a sample of 140 fully hydrous "Navelina" oranges at ambient conditions. Velocity and absorption coefficients of ultrasound waves through the orange peel were measured together with physico-mechanical properties (weight loss, oil-gland break stress and thickness of the peel) for a period of 84 days, i.e. as far as the complete dehydration state of the fruit. In this study, the time dependence of the properties and the correlations between them are shown. Finally, an absolute scale of the hydration state of the orange has been established using ultrasonic properties that could be measured in a non-destructive way. These measurements can also be used to obtain information about the peel thickness.

Keywords: Oranges; Ultrasound; Postharvest; Time dependence; Quality testing

1. Introduction

Citrus fruit has a relatively long postharvest life in comparison with some other fruit and vegetables. Nevertheless, the peel ages during storage, although, the loss of moisture from the peel is continuously replenished by the movement of moisture from the pulp. If this loss, due to the combined effect of respiration and transpiration, goes on unchecked, the fruit shrivels up and becomes unmarketable (Chalutz et al., 1985; Agustí, 2000; Singh and Reddy, 2006). Therefore, the state of the citrus peel is very relevant in evaluating the quality of the fruit and needs to be controlled to guarantee the fresh properties of the fruit necessary for commercialisation.

Penetration tests (Magness–Taylor, force/deformation, Kramer multiblade shear) applied directly to the surface of fruit are the most acceptable methods for measuring firmness and turgidity of fruit and vegetables (Abbott, 1999; Barreiro and Ruiz-Altisent, 2000). In this sense, research has been carried out for many years to determine the resistance of fruit and vegetables to compression force. Kaufmann (1970) measured the effect of water potential and temperature on the extensibility of citrus peel. Sarig and Nahir (1973) reported the initial and permanent deformation of a creep test on citrus fruit to indicate firmness, and Gyasi et al. (1981) determined Poisson's ratio for citrus fruit peel and pulp. Singh and Reddy (2006) provided information on changes in postharvest physico-mechanical properties of orange peel and fruit under ambient and refrigerated storage conditions in order to help to determine the appropriate handling, packaging, storage and transportation systems. Although penetrometer measurements are widely used, since they are moderately well correlated with human perception of firmness and with storage life, there are some problems related to the use of probes of varied geometries (rounded, hemispherical or flat tips) under the generic term Magness–Taylor (Abbott, 1999). On the other hand, devices used for deformation test measurements are expensive, and these techniques are slow, destructive and not very adaptable for on-line sorting of horticultural products.

In recent decades, the possibility of substituting these methods by non-destructive ultrasonic methods has been documented in several papers (Finney, 1967; Garret and Furry, 1972; Sarkar and Wolfe, 1983; Mizrach et al., 1989, 1996; Verlinden et al., 2004; Bechar et al., 2005; Camarena and Martínez-Mora, 2006). Wave propagation velocity and absorption (Kuttruff, 1991) are basic acoustic properties of

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doi:10.1016/j.postharvbio.2006.07.012

fruit and vegetables that can be correlated with the indexes used for the quality evaluation (Abbott, 1999; Barreiro and Ruiz-Altisent, 2000).

To replace destructive and mechanical penetration methods by non-destructive ultrasonic measurements means a great advance in technology in order to carry out rapid studies on the state of the fruit at the time of harvest, during storage, and at distribution points. Moreover, there are other advantages since this technique can be fast, non-destructive, fully automated, and performed on-line.

Within this context, the objective of this study was to examine the relationship between physico-mechanical characteristics (oil-gland break stress, thickness, and dehydration) and ultrasonic characteristics in "Navelina" orange peel during complete dehydration of orange fruit under ambient conditions. After a description of the measurement system, the fruit selection procedure and the measurement protocol, we analyze the results of the changes in physico-mechanical and ultrasonic properties of the orange peel and their changes with storage time. Finally, we propose an absolute scale to predict the hydration state and the peel thickness of an orange, using ultrasonic measurements.

2. Experimental set-up

A transmitter–receiver experimental device was designed to allow normal transmission and reception of ultrasonic signals through the fruit peel (Fig. 1). An harmonic wave function generator (Agilent 33220) and a power amplifier (ENI 240L) were used to excite a 50 kHz ultrasonic transducer. An identical transducer was used for reception, and an oscilloscope for data acquisition and analysis. The transducers were mounted in a structure that allowed a good coupling with the orange peel. The peel was cut into 520 mm^2 slices enabling them to be inserted between the two transducers, whose surface was 550 mm^2, at a constant strain (15 N) in such a way that the ultrasonic waves were propagated from the flavedo to the albedo. Recorded data were used to determine the velocity of wave propagation and the absorption coefficient of the peel, using a procedure described elsewhere (Camarena and Martínez-Mora, 2006).

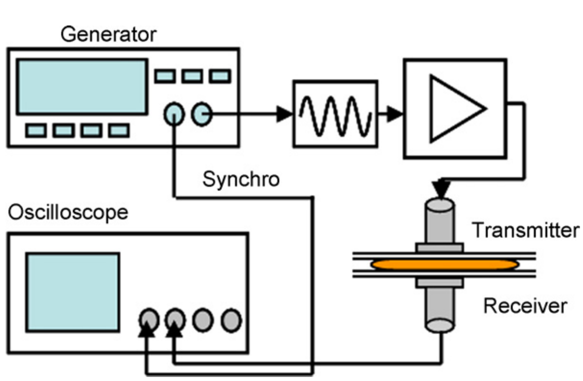

Fig. 1. Diagram of the ultrasonic measuring system.

Dehydration of the fruit was monitored in parallel by measuring the loss of weight of the fruit, which is strongly related to the moisture level, and using a penetrometer (fruit pressure tester with 0.8 mm of head diameter and 0.5 N precision) to evaluate the strain required to break the oil gland of the orange.

3. Fruit selection and test procedures

A set of 140 "Navelina" sweet oranges (*Citrus sinensis*, L. Osbeck) were harvested on December 13, 2004 from the same field (La Safor, Valencia, Spain), with similar size (mean diameter 7.3 cm and S.D. 0.4 cm), weight (mean weight 187 g and S.D. 25 g) and maturity (mean maturity index 10.4 and S.D. 0.6 for 20 oranges). It was raining heavily (450 l/m^2 in 157 h) for 2 weeks before the harvest, so the oranges were completely hydrated. No specific chemical processing was applied to the fruit and they were stored under ambient conditions (20–23 °C and 45–52% relative humidity). The oranges were subjected to both physico-mechanical and ultrasonic tests over 84 days. On each day of measurement, 10 oranges were selected from the batch. To evaluate dehydration, the oranges were weighed on the first day (P_{initial}) and on the date of the measurement (P_{final}) with a precision of 0.1 g. Dehydration (Dh) is related to the loss of weight and is defined as:

$$\text{Dh} = \frac{P_{\text{Initial}} - P_{\text{final}}}{S} \tag{1}$$

where S is the value of the surface area of the orange evaluated as a sphere from the diameter measurement.

The oil-gland break stress measurements were done with a penetrometer by applying an increasing pressure on rice paper in contact with the orange peel. The turgidity force, which is the value of the force just at the moment when the paper was dampened (Camarena and Martínez-Mora, 2006), was registered. Later, the oranges were peeled.

The ultrasonic parameters of the fruit, namely the velocity of the wave and the amplitude, were measured at the end, because of the destructive nature of this measurement (peel measurements). These properties were evaluated, using Eqs. (2) and (3), from the measurement of the thickness of the peel (d) (mean value of three measurements with a calliper), the time delay (Δt) in the received signal due to the ultrasound wave travelling through the peel, and the value of the amplitude (V) of the received signal (attenuated because of the passage through the peel). V_0 is the value of the amplitude registered when there was no peel between the transducers.

$$c = \frac{d}{\Delta t} \tag{2}$$

$$\alpha = -\frac{1}{d} 20 \log\left(\frac{V}{V_0}\right) \tag{3}$$

Three measurements were performed for V, V_0 and Δt in each orange: with flavedo area facing up, turning 120° each