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Research Note

Nondestructive ultrasonic monitoring of tomato quality during shelf-life storage

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Abstract

A nondestructive ultrasonic method was used to monitor the firmness and sugar content of greenhouse tomatoes (cv. 870) during their shelf-life. This method is based on measurement of acoustic wave attenuation in the fruit tissue, by means of ultrasonic probes in contact with the fruit peel. The fruit for measurement were transferred from the greenhouse to a controlled-temperature room, and were subjected to nondestructive ultrasonic tests and also to destructive penetration measurements of firmness. The results were analyzed statistically to determine the changing relationships between the ultrasonic attenuation measurements and the destructive measurements, during the shelf-life. The differences in the acoustic signals transmitted through the tissue of fruit of various degrees of firmness were measured and analyzed as well. The measured attenuation and the firmness were found to decrease significantly during shelf-life. A linear relationship between the attenuation and the firmness was observed until the end of the softening process. This suggests that this ultrasonic method might be used as a nondestructive means of monitoring the firmness of tomatoes during various stages of storage.

Keywords: Ultrasonics; Tomato; *Lycopersicon esculentum*; Firmness; Sugar content; Ripeness; Nondestructive; Quality

1. Introduction

Ripening indicators in greenhouse tomatoes (*Lycopersicon esculentum* Mill) are softening of the flesh, decreasing acidity, and change in color. The change in sugar content during maturation is not considerable, but is important to consumers. Tissue firmness is the property most relevant to consumer perceptions of ripening, and it is the factor most closely related to the stage of maturity in tomatoes (Keidar and Geisenberg, 1989). A trained person can assess this parameter, but at present a destructive measurement method is required. Consumer demand for high-quality products raises the need for a reliable, rapid, nondestructive, non-invasive technique for maturity determination, especially during harvest and at the packing site. There are several techniques for nondestructive measurement of quality parameters in various fruit and vegetables, e.g., acoustic impulse response (Schotte et al., 1999), and ultrasound (Mizrach et al., 1997; Verlinden et al., 2004). The ultrasonic technique was suggested previously to determine some quality parameters of fruit and vegetables (e.g., Mizrach et al., 1994) but not for fresh greenhouse tomatoes. Verlinden et al. (2004) used a similar ultrasonic technique to evaluate chilling injury in tomatoes, but found difficulties with contact pressure between the probes and the tomato flesh. They applied destructive penetration of the probes to record their results and suggested the development of a nondestructive ultrasonic technique to make this method applicable.

A nondestructive, ultrasonic method, developed by Mizrach et al. (1994) is a potential solution; it is based on a patented system that enables the fruit quality attributes to be determined by measuring the changes in ultrasonic waves passing through the peel and flesh (Mizrach et al., 1995) with no damage to the fruit. Several models of devices based on this technique have been developed and successfully used for nondestructive determination of quality attributes of mangoes (Mizrach et al., 1997), of avocados during their shelf-life (Mizrach and Flitsanov, 1999), and of the maturity of avocados while on the tree (Mizrach et al., 1999). This technique has also been successfully used to monitor the softening of avocados in low-temperature storage (Mizrach et al., 2000). A progress report summarized the research on the use of the ultrasonic technique to determine avocado and mango fruit properties (Mizrach, 2000).

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The objective of the present study was to apply the nondestructive ultrasonic technique to tomatoes (cv. 870) during shelf-life, and to analyze the ultrasonic attenuation measurements in conjunction with measurements of the firmness and sugar content of the fruit, in order to test the possible use of the ultrasonic method as a technique for nondestructive determination of the tomato ripening stage.

2. Material and methods

Eighty tomatoes (*Lycopersicon esculentum* Mill. cv. 870) were taken from a greenhouse in the Lachish Experimental Station of the Israeli Ministry of Agriculture and Rural Development. The tomatoes were picked at stage 7 (light red), according to the 12-stage (1: green to 12: full red) Agrexco Q4-VG-22 color card (Carmel Produce, Israel), and placed in an air-conditioned laboratory at 20 °C and about 85% relative humidity (RH). A preliminary study showed that under these conditions the initial turning-red color changed to full red in the course of 7–8 days, in parallel with the softening process. Therefore, the fruit were arbitrarily divided into two groups. The tomatoes of the first group comprised 10 fruit, marked from N1 to N10 and named the "N1–N10" group, were designated for nondestructive tests only. Those of the second group, named the "1–70 group", were divided into seven batches of 10 fruit each and marked from 1 to 70; these tomatoes were designated for both nondestructive and destructive tests. The peel of each fruit was marked at two opposite locations on the "equator", i.e., the circumference of the largest cross-section perpendicular to the blossom end-stem end axis, in preparation for the tests described below.

The mechanical structure of fruit tissue, its physicochemical quality indices, and each change in quality attributes of the fruit, affect the amplitude of the ultrasound signal passing through the fruit tissue, and the attenuation of the ultrasonic wave can be evaluated. Previous studies with avocado and mango fruit suggested that there is a good correlation between the attenuation of the ultrasonic signal and the mechanical and physiological properties of the fruit tissue (Mizrach et al., 1994, 1997) and this correlation was examined for tomatoes in the present study.

The ultrasonic measurement system comprised a Model USL33 low-frequency ultrasonic pulser-receiver with high penetration power (Krautkramer GMBH, Pstfach, Germany), a pair of 50-kHz ultrasonic transducers and a microcomputer system for data acquisition and analysis (Mizrach et al., 1997). The transducers were mounted with an angle of about 120° between their axes and were held in contact with the fruit by application of a fixed load, so that an ultrasonic signal could be transmitted and received over a variable short distance between their tips, across the peel of the fruit. In the through-transmission mode, in which one transducer acted as a transmitter and the other as a receiver, a known ultrasonic signal was emitted into the fruit flesh and the signal emerging from the fruit tissue was measured. The attenuation of the ultrasonic signal as it passed through the tissue of the fruit was measured, and the attenuation coefficient was calculated according to an exponential expression (Krautkramer and Krautkramer, 1990).

The penetration tests were applied to unpeeled fruit, with a Chatillon Durometer (John Chatillon and Sons, New York) fitted with a 6.35 mm diameter conical head with a 60° cone angle. Each fruit was subjected to a penetration test at each of the two marked points, which were near the location of the ultrasonic transducer contact points, and the tests were applied in the radial direction. The measurement results were then summarized. The maximum penetration force (firmness) was recorded at a penetration rate of 3 mm/s, and the maximum penetration depth was about 7 mm.

A slice weighing about 15 g was cut from each fruit separately; it included the area close to the region in which the acoustic readings had been taken and extended from the skin and through the core. The slices were macerated with a commercial juice extractor, filtered and centrifuged at 10,000 × g for 10 min. The sugar content of the supernatant juice was determined with a Model PR-1 digital refractometer (Atago Co., Tokyo, Japan), and expressed as percentage Brix in the juice.

Two kinds of experiments were carried out that involved observations over the course of time (shelf-life): the first kind, applied to fruit N1–N10, used the nondestructive ultrasonic test only; the second kind, applied to fruit 1–70, used both nondestructive and destructive tests. Each of the fruit N1–N10 was subjected to ultrasonic excitation at a fixed, marked location, at daily intervals during shelf-life, and the changes in the acoustic pulse amplitude were recorded until a very low penetration (<2.23 N) force was measured. In the second experiment, 7 batches of 10 fruit from the 1 to 70 group were subjected to a sequence of acoustic, mechanical and physiological tests; the nondestructive ultrasonic tests were conducted first, followed by the destructive tests, which comprised the firmness penetration and the sugar content tests, as described above.

3. Results and discussion

The attenuation of the ultrasonic waves passing through the tissue of the fruit was calculated during the course of storage for the fruit in groups N1–N10 and 1–70. The calculated attenuation was plotted against storage time for the N1–N10 group (Fig. 1).

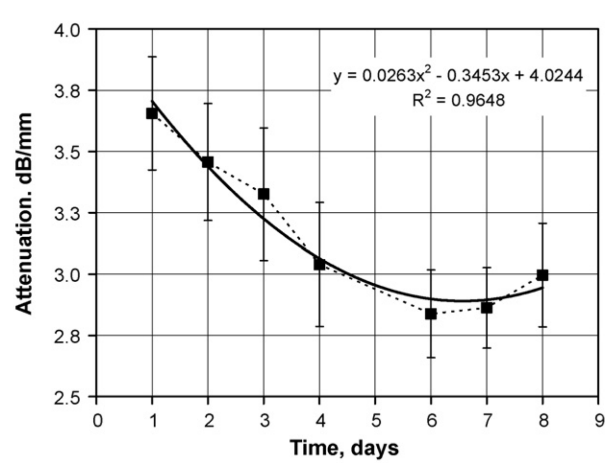

Fig. 1. Variation of the mean values of wave attenuation with storage time in fruit group N1–N10. Vertical lines represent confidence limits of the mean ($\alpha = 0.05$).