

## Technical paper

# Application of Non-Destructive Portable Firmness Tester to Pears

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Received September 28, 2000; Accepted March 16, 2001

**The firmness tester originally developed for melons was improved to measure the ripeness of pears. Sampling frequency was increased to measure pears and user interface on a data acquisition program was also improved. In addition, two microphones and a stabilizer rod were arranged to form a tripod for stable measurement on the curved surface of the fruit. The transmission velocity, destructive firmness measurement and sensory evaluation were carried out for 96 La France pears and 85 Le Lectier pears. The transmission velocity calculated from the cross correlation of two acoustic signals showed a high level of correlation ( $R=0.94$ ) with apparent elasticity measured in destructive tests. Measurements with the firmness tester could be used to monitor physiological changes in ripening pears.**

Keywords: pears, firmness, acoustics, non-destructive testing, monitoring

Acoustic techniques are attractive as methods for the non-destructive measurement of fruit quality. Many studies have been done using acoustic techniques on various kinds of produce (Armstrong *et al.*, 1990; Chen *et al.*, 1992; Miyamoto *et al.*, 1996; Yamamoto *et al.*, 1980, 1984a, 1984b). Most of the researchers applied frequency analysis techniques to analyze sound signals, and observed that resonant frequencies decreased with ripening. Resonant frequencies, however, were affected by the size and shape of the sample. In addition, the mechanism of producing multiple resonant frequencies in some produce was not clarified by experimental evidence.

Sugiyama *et al.* (1994) found that the impact waveforms of acoustic signals induced by the impact of a pendulum with a melon were transmitted along the equator of the melon at a uniform velocity, and yielded an index of firmness. This transmission velocity decreases as the melon ripens. Furthermore, the lower transmission velocity in the time domain agreed with the lower peak frequency in the frequency domain, both theoretically and practically.

There are two advantages to using the transmission velocity instead of the resonant frequency to evaluate ripeness. First, the transmission velocity method compensates for variations in the size of the samples, because the circumference of the sample, which can be replaced with the distance between two microphones, is included in the calculation. Second, it is easy to detect a maximum peak in the impact waveform for calculation of the transmission velocity. On the other hand, many resonant frequencies were observed using the resonant method, and it is difficult to determine which one is the optimal firmness index.

Based on this technique, a portable instrument for measuring melons was developed (Sugiyama *et al.*, 1998). It was possible to monitor firmness throughout the relevant stages of the life cycle of the melon, i.e., during growth and after harvesting. In this study, the firmness tester was modified to measure the firmness of pears and its performance examined.

## Instrumentation

*Design specifications* Figure 1 shows the portable pear firmness tester we improved. It consists of an impulse generator, an amplifier, a PC card-type A/D converter and a computer (PC). The amplifier, with a size of 115×80×20 mm, was fixed on the back of the PC by a Velcro grip tie. Any PC can be used if it has a PC card slot (Type II) and has Microsoft Windows installed. Pulling the trigger of the firmness tester starts the measurement and the result appears on the PC screen in less than a second. As shown in Fig. 1, the entire system is sufficiently small and lightweight to be carried easily into the field. Details of the instrument were described in a previous paper (Sugiyama *et al.*, 1998).

*Modification* Pears are relatively firmer than melons. This means the firmness tester must be able to measure high transmission velocity. To achieve this, the sampling frequency for data acquisition was increased from 70 kHz to 125 kHz by equipping it with a new A/D converter (DAQCard-AI-16E-4, National Instruments). Higher time resolution can be obtained with this improvement.

Two microphones and a stabilizer rod were arranged to form a tripod for stable measurement on the curved surface of pears (Fig. 1).

The user interface on the data acquisition program was also improved. It was written in Visual Basic. Figure 2 shows a typical screen of the measurement. The two sound signals, their time difference calculated from correlation coefficient and transmission velocity as a firmness index are displayed on the screen.

## Materials and Method

*Samples* A total of 96 La France pears and 85 Le Lectier pears were examined to evaluate applicability of the firmness tester. Sample specifications are shown in Fig. 3. A combination of 3 different temperatures (25°C, 10°C and 2°C) and various storage periods were programmed to create a wide range of firmness. Different periods of storage also help to assure firmness diversity. The transmission velocity was measured for each pear and compression tests and a sensory evaluation were carried out.

Ripeness was also monitored in the storage at 3 different temperatures.

**Transmission velocity** The transmission velocity was measured near the equator of the pears by the firmness tester. Four measurements were taken from different locations on each fruit. The average of these was calculated and used as the nondestructive firmness index.

**Destructive firmness measurement** A conventional compression test was carried out using a universal testing machine (Texture Analyzer®, Stable Micro Systems). A sample was extracted by a stainless steel cylinder, 12 mm in diameter with a knife edge at one end. Four samples were extracted from around the equator of each pear. The skin segment, which is 2 mm in depth, was discarded and the next 13 mm segment was compressed along its length at 0.5 mm/s. The resulting compression force/deformation curves were converted to stress/strain curves.

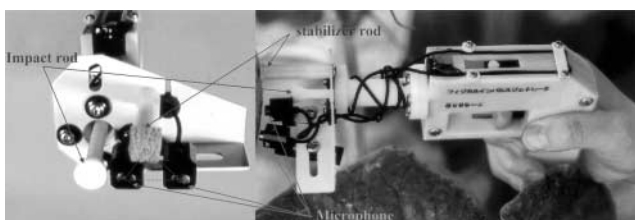


Fig. 1. Portable firmness tester for pears.

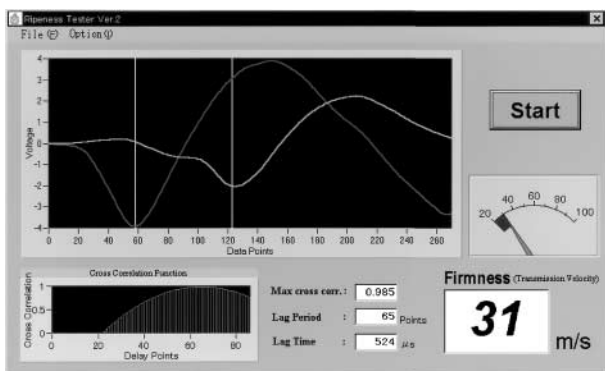


Fig. 2. Data acquisition screen on PC.

	La France	Le Lectier
Number:	96	85
Mass :	256 ± 9.71g	374 ± 54.7g
Sugar Content(Brix%)	13.6 ± 0.71	15.6 ± 1.3

\*Harvested in Fukushima, Japan  
 \*\* ± indicates standard deviation

Fig. 3. Sample specification.

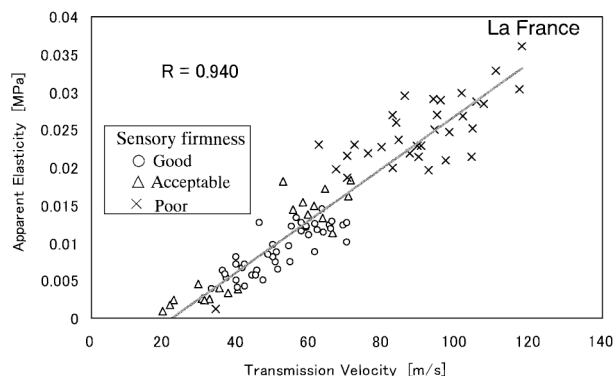


Fig. 4. Apparent elasticity and transmission velocity (La France).

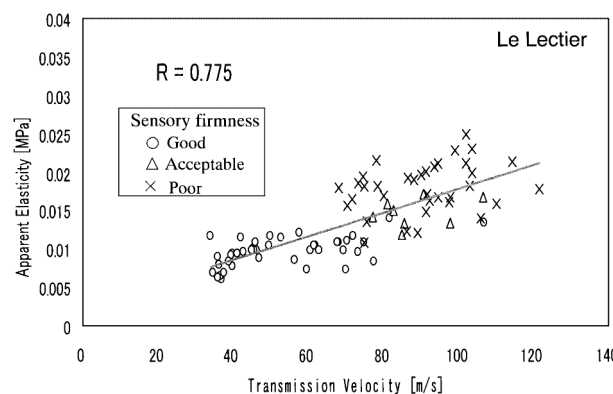


Fig. 5. Apparent elasticity and transmission velocity (Le Lectier).

Apparent elasticity in this study was then calculated from the slope at 4% strain, which was found from stresses between 3.7 and 4.3% strain, by dividing  $\Delta$ stress by  $\Delta$ strain. A similar analysis was performed by Abbott *et al.* (1995) on apples and by Sugiyama *et al.* (1994, 1996, 1998) on melons. The values reported for apparent elasticity were the averages of the four samples.

**Sensory evaluation** The range of appropriate firmness for eating was determined by sensory evaluation tests. The balance of the sample left after the destructive firmness measurement was taken was divided into 12 equal parts and evaluated by 12 panelists. Panelists were required to rate only the sample's firmness as 'fair' (moderate firmness) or 'poor' (too soft or too hard) after tasting it. In our preliminary test, we found that a rating system of more than 2 choices, such as 'good', 'fair', and 'poor', did not have good repeatability nor achieve consistent results. Because of this, we decreased the number of choices and increased the number of panelists. The score for each pear was determined by the ratio of 'fair' responses it received out of a possible 12. 'Good firmness' means that more than 8 of the panelists evaluated the sample as 'fair'. 'Acceptable firmness' means 4 to 7 panelists evaluated it as 'fair'. 'Poor firmness' means that fewer than 4 panelists evaluated it as 'fair'.

**Results and Discussion**

**Ability of measuring firmness** The relationship between apparent elasticity, as measured by the compression test, and transmission velocity for La France is shown in Fig. 4. There was

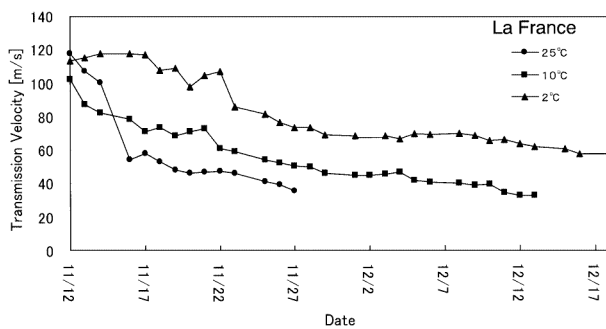


Fig. 6. Ripeness monitoring with the firmness tester on La France.

a high level of correlation ( $R=0.940$ ) between the test results. Each symbol in the figure indicates the result of sensory evaluation. The transmission velocity of pears evaluated as having good firmness ranged from 40 to 70 m/s for La France.

The similar relationship for Le Lectier is shown in Fig. 5; its correlation coefficient ( $R=0.775$ ) is worse than that of La France. The reason for this was initially thought to be unequal distribution of firmness. Le Lectier is large enough to have greater firmness deviation than La France during the ripening stages. In fact, this physiological feature was observed by several panelists, who said that the firmness of Le Lectier was different even within one sample. However, the coefficient of variation for both transmission velocity and apparent elasticity did not show much difference between Le Lectier and La France. Further investigation is necessary to explain this lower correlation for Le Lectier.

**Ripeness monitoring** Firmness changes for La France in the storage at 3 different temperatures were monitored by the firmness tester and representative data is shown in Fig. 6. Measurements were carried out on samples daily. Samples at 25°C and 10°C began to deteriorate after the transmission velocity decreased to less than 40 m/s. This velocity coincides with the bottom range of the 'Good' score in sensory evaluation. The firmness tester was able to monitor the firmness precisely enough for pears.

## Summary and Conclusions

There was a good correlation between destructive firmness indices and transmission velocity, if uniform firmness within a sample was guaranteed. The range of 'good' firmness for La France was between 40 m/s and 70 m/s. The firmness tester followed physiological changes in storage at different temperatures.

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