3P1-8

Elasticity of water melon flesh evaluated by using surface-wave velocity

表面波速度を用いたスイカの硬さ評価

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1. Introduction

There is an increasing need for better quality evaluation of fluits. Firmness or crispness is one of the major quality indices. Acoustic techniques have been widely used to monitor firmness or matulity of watermelon [1]. In the acoustic impulse response method [2] for studying the natural frequency of watermelon with a pendulum hitting device, the sensory firmness or maturity is correlated with characteristic parameters composed of the resonant frequency of the detected sound waveform, and the mass and density of the watermelon sample. Sugiyama et al. [3] found that the velocity of an acoustic impulse decreased as melons ripened. A portable firmness tester, incorporating an impact plunger and two microphones, was also developed to measure the velocity, which correlates well with the apparent elasticity using surface waves.

Ikeda et al. [4] measured Rayleigh-wave velocity on watermelon flesh in the frequency range of 800-2400 Hz. The measured velocity was correlated well with a sensory firmness evaluation by 78 numbers of students. Although this study provides a useful method for measuring elasticity of watermelon flesh, the method can not be used for the screening of watermelon because this is a destructive method. The present study aims to develop a nondestructive method to evaluate the elasticity of watermelon flesh.

2. Experimental

1.1 Principle

Structure of watermelon is approximately twofold: a pericarp (fruit skin) and a flesh. The pericarp is hard and the flesh is soft. Propagation property of surface waves on the pericarp is affected by the underlying flesh. We utilize a property that surface-wave energy is confined to a region of about one-wavelength depth. The surface-wave velocity at different frequencies depends on elastic property at different depth. Thus the velocity dispersion on the pericarp may provide a measure of elasticity of flesh.

1.2 Experimental system

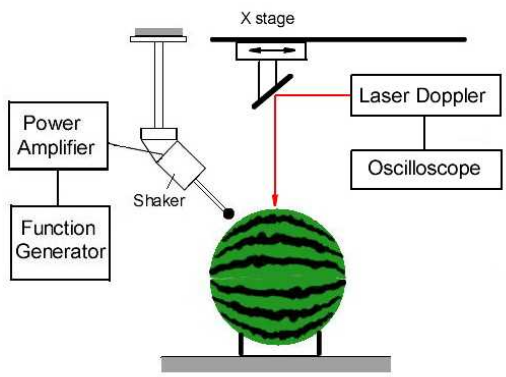

Fig. 1. Experimental system of measuring surface-wave velocity on watermelon.

Experimental system is shown in Fig.1. Surface waves are excited by an oscillator (a metal bar with a length of 25 mm and diameter of 4 mm) connected to a shaker (LDS V101, Bruel & Kjaer). The edge of the oscillator gently touched the surface of the watermelon pericarp. A pulsed-wave signal with a duration of 10 cycles at 400–7000 Hz was applied to the oscillator by using a function generator (WF1944A, NF Corporation) and a power amplifier (PM4400, Marantz). We detected the pulsed waves using a laser Doppler vibrometer (NLV-2500, Polytech) and was displayed on an oscilloscope (DSO7012B, Agilent). Signals were recorded with 2 mm increment of propagation distance by moving the sliding stage supporting a laser mirror. The time shifts of the detected peaks were plotted as a function of the propagation distance between the oscillator and the detecting laser, from which the surface wave velocities were obtained. The measured region was near equator of the sample. Small-sized watermelon with diameter of approximately 16 cm was obtained from a farmer (Ibaraki, Japan) with a variety of Kurokodama named as “Yuuwaku no hitomi”.

3. Results and discussion

Surface-wave velocity measured as functions of frequency for four samples of watermelon is shown in Fig.2. All the samples showed a similar tendency that the velocity gradually increases with frequency. The high-frequency limit of the surface-wave velocity may be the value in pericarp (a part of skin), since the wavelength at higher frequency is so small that the surface-wave energy is confined within the pericarp. The wavelength at 8 kHz is predicted to be 12 mm which is even larger than the thickness of 6 mm for pericarp. Conversely, the low-frequency limit is predicted to represent the value of the underlying flesh. The pericarp was cut and the surface-wave velocity in flesh was also measured, as shown in Fig.3. The measured region was just under the pericarp measured. The surface-wave velocity was in the range of 24 -40 m/s and the result suggested no frequency dependence. This frequency independence is in agreement with the results by Ikeda et. al. They obtained the value of 31.2 m/s for Matsuribayashi 777 variety and 25.0 m/s for Wasenissho variety. A 5-ranked sensory test of firmness by 78 students clearly exhibited that Matsuribayashi 777 is harder than Wasenissho.

It is interesting to note that the surface-wave velocity extrapolated to zero frequency in Fig.2 is similar to the velocity of flesh in Fig.3. The extrapolated values were 34.2, 30.4, 33.5 and 33.0 m/s, while the corresponding values of flesh were 35.9, 37.3, 33.7, and 27.6 m/s. This correspondence suggests that the surface-wave velocity on flesh can be obtained from the velocity dispersion curve measured on pericarp. Theoretical analysis [5] of the surface wave on layered media supports this interpretation. Detailed analysis is a future task.

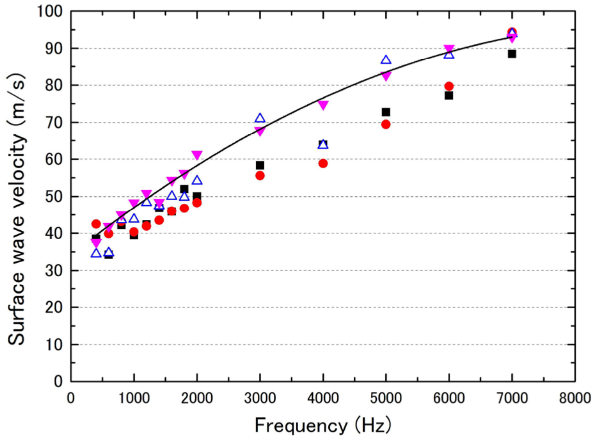

Fig. 2. Surface-wave velocity measured on a pericarp of watermelon for four samples. The solid line shows a quadratic curve fitted for closed triangles.

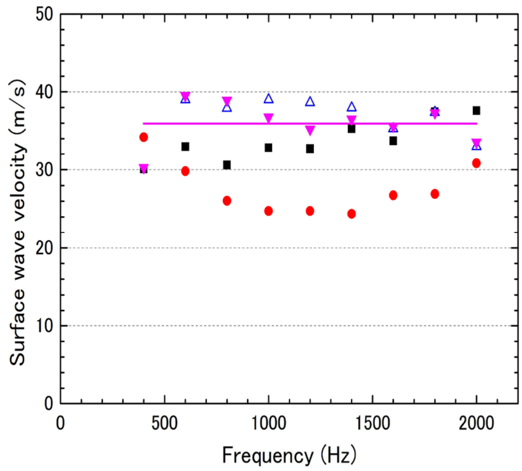

Fig.3. Surface-wave velocity measured on a flesh of watermelon. Symbols are corresponding to those in Fig.2.

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References
[1] I.T. Sun, K. H. Huang, H. Xu, Y. Ying, J. Food Eng. 100 (2010) 569.
[2] B. Diezma-Iglesias, M. Ruiz-Altisent, P. Barreiro, Biosyst. Eng. **88** (2004) 221.
[3] J. Sugiyama, K. Otobe, S. Hayashi, S. Usui, Trans. ASAE **37** (1994) 1235.
[4] T. Ikeda, P.-K. Choi, T. Ishii, I. Arai, M. Osawa, J. Food Eng. **160** (2015) 28.
[5] G. W. Farnell and E. L. Adler, “Elastic wave propagation in thin layers” in Phys. Acoust. Vol.9, (Academic, 1972) p.35.