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Sound velocity measurements in Japanese radish, watermelon and potato

Pak-Kon Choi[1] and Takashi Ikeda[2]
([1]Dept. of Physics, Meiji Univ., Tama-ku, Kawasaki 214-8571, Japan)
([2]Dept. of Agriculture, Meiji Univ., Tama-ku, Kawasaki 214-8571, Japan)

1.Introduction

Several ultrasonic studies have been performed to investigate the firmness and ripeness of fruits and vegetables. Povey [1)] reported that ultrasound at 500 kHz did not transmit through fruits and vegetables except potatoes. Mizrach et al. [2)] measured sound velocity at 50 kHz in potato, carrot, melon, apple, etc. and reported that the velocity ranged from 180 m/s to 380 m/s. Ha et al. [3)] measured the ultrasonic attenuation in the frequency range of 100 kHz to 1 MHz, and demonstrated that defective potatoes showed large attenuation values compared with normal potatoes. A major reason why ultrasonic studies are scarce is the large ultrasound attenuation owing to the presence of gas content in tissue. Reliable values of the longitudinal- and shear-wave velocities in fruits and vegetables are required to estimate ripeness or firmness using acoustic methods. Choi et al. [4)] recently reported that the firmness of watermelon and melon can be obtained from the velocity dispersion of surface-acoustic waves (SAW) at frequencies around 1 kHz. The use of low-frequency sounds is preferable for investigating the acoustical properties of fruits and vegetables. The present paper descibes the measurements of pulsed-wave sound in the frequency range of 0.4-27.4 kHz in cylindrically shaped Japanese radish (daikon), watermelon, and potato, which provided longitudinal- and shear-wave velocity.

2. Methods

Sound propagation in solid cylinder has been analyzed by Pochhammer–Chree dispersion equation given by [5)]

$$\frac{2\alpha}{a}(\beta^2+k^2)J_1(\alpha a)J_1(\beta a)-(\beta^2-k^2)^2J_0(\alpha a)J_1(\beta a)$$
$$-4k^2\alpha\beta J_1(\alpha a)J_0(\beta a)=0 \qquad (1)$$

Here J_0 and J_1 are zeroth- and first-order Bessel functions, respectively. k is the wavenumber, and α and β are defined by

$$\alpha^2=\frac{\omega^2}{C_L^2}-k^2, \quad \beta^2=\frac{\omega^2}{C_S^2}-k^2 \qquad (2)$$

C_L and C_S are longitudinal- and shear-wave velocities, respectively. Eq.(1) was derived for continous wave propagation, and many modes were predicted because of wave interference. For the fundamental mode, the velocity in the low-frequency limit corresponds to the extensional-wave velocity C_E, which is determined by Young's modulus. For the second mode, a low-frequency cutoff exists and the velocity in the high-frequency limit is predicted to agree with the shear-wave velocity. However, many experimental studies using pulsed ultrasound have shown that longitudinal-wave velocity is obtained if the wavelength is much smaller than the radius of the cylinder.

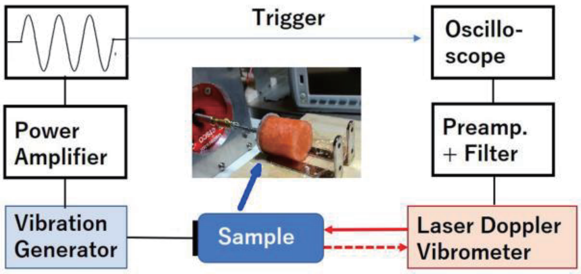

Fig. 1 Experimental system for measuring the velocity of acoustic pulsed waves propagating in fruits and vegetables. The inset shows a cylindrical watermelon sample attached to an oscillator.

3. Experimental system

Figure 1 shows an experimental system for measuring the sound velocity. Pulsed waves with duration of three or five cycles were amplified and applied to a vibration generator. An aluminum plate with a diameter of 30 mm, bonded to an M4 screw head, was assembled in the generator, and used as an oscillator. An inset picture demonstrates a cylindrical sample of watermelon attached to the oscillator using a coupling gel. The pulsed acoustic waves were detected with a laser Doppler vibrometer, amplified, and displayed on an oscilloscope.

Japanese radishes (Aokubi daikon) with a length of 350–400 mm, watermelons with a diameter of approximately 170 mm, and potatoes (Irish Cobbler) with a weight of 0.18–0.2 kg were purchased from a local market. For Japanese radish, samples with a typical length of 65 mm were cut out from the part 50 mm apart from the top end. For watermelons and potatoes, each specimen was hollowed out from the center of the whole piece using a metal cylindrical pipe to form a cylinder with a diameter of 27 mm. No seeds or apparent voids were observed.

4. Results and discussion

The pulsed waves observed in the watermelon at 600 Hz and 4 kHz are shown in Figs. 2(a) and 2(b), respectively. The pulsed waves were obtained in samples with lengths of 28, 48, and 68.5 mm, as denoted by black, red, and blue lines, respectively. Time positions of the first positive peaks were recorded, and the plot of the time position as a function of length gives the value of the phase velocity. The round-trip echo signals reflected at the end planes may interfere with the main signal; and therefore the positions of the first positive peaks were measured.

Figure 3 shows the measured velocity in three samples of watermelon. The experimental values indicate the existence of two different modes, which are the fundamental and second modes predicted in eq. (1). Eq. (1) was solved to fit the experimental values, as indicated by the blue and red dashed lines. This resulted in C_L and C_S values of 82 m/s and 36 m/s, respectively. Poisson's ratio can be derived from

$$\frac{C_L}{Cs} = \sqrt{\frac{2(1-\sigma)}{1-2\sigma}} \qquad (3)$$

and σ=0.38 was determined. The SAW velocity C_R can be obtained from the above results, and a comparison with previous studies will support the validity of the present result. The SAW velocity C_R calculated from the Poisson's ratio and Cs was 34 m/s, which is in agreement with the result of SAW velocity of 30.4–34.2 m/s [4] showing no dependence

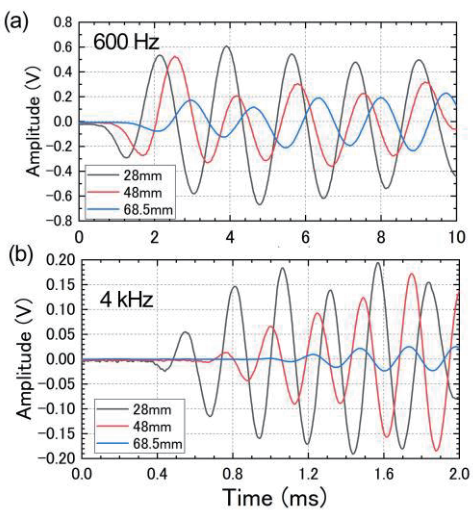

Fig. 2. Pulsed waves detected for three different lengths of watermelon at 600 Hz (a) and 4 kHz (b).

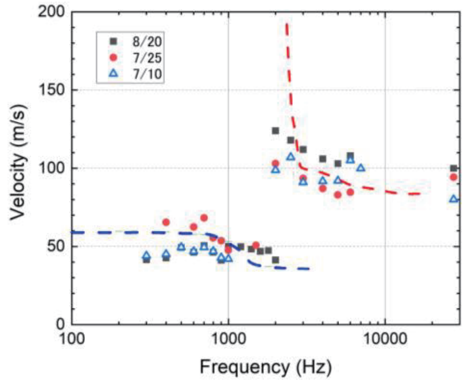

Fig. 3. Measured velocity as a function of frequency for three watermelon samples with a diameter of 27 mm. Blue and red dashed lines

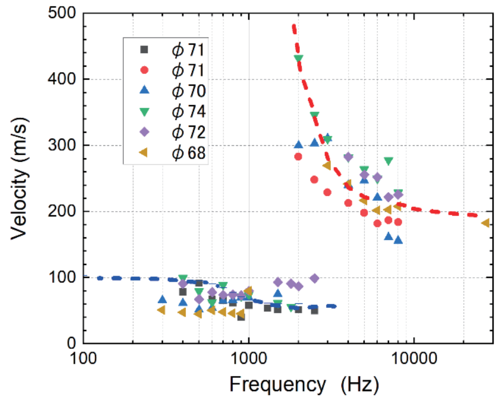

Fig.4. Measured velocity as a function of frequency for six samples of Japanese radish with diameters of 68,70, 71, 71, 72 and 74 mm. Blue and red dashed lines indicate the fitted curves of the fundamental and second modes, respectively.

on frequency ranging from 0.4 to 2 kHz.

Figure 4 shows the results of the velocity measurements of the six Japanese radish samples. Blue and red dashed lines indicate the calculated curves fitted to the experimental values. This gives the values of C_L=202 m/s and C_S =61 m/s, respectively. Similar results obtained for potato provided C_L=571 m/s and Cs=80 m/s with a large variation of the longitudinal-wave velocity from sample to sample.

References

1. M. J. Povey, J. Food Engi. **9**, 1-20 (1989).
2. A.Mizrach, Postharvest Biol. Technol. **48**, 315-330 (2008).
3. K.-L. Ha et al., Jpn J. Appl. Phys. **30** (S1), 80-82 (1991).
4. P.-K. Choi, Y. Sugashima, and T. Ikeda, Jpn. J. Appl. Phys. **61**, 097001 (2022).
5. D. Bancroft, Phys. Rev. **59**, 588-593 (1941).