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A SIMPLE METHOD FOR MEASUREMENT OF POISSON'S RATIO FOR TISSUE OF AGRICULTURAL PRODUCTS

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ABSTRACT Poisson's ratio, which characterizes mechanical properties of a material, was measured by means of image analysis from a digital photograph. A tissue of boiled Japanese radish or carrot, which is too fragile to measure their Poisson's ratio by traditional methods, was used as sample materials. Cylindrical samples were cut out of the tissue using a precise apparatus and their dimensions were set to 15 mm height and 30 mm diameter. The samples were then compressed. The stress of the samples against compression was measured using a creep meter apparatus. The compressed deformation of the samples was captured by a digital camera, which could obtain high resolution images and analyze its transformation accurately. The Poisson's ratio was calculated from such transformations. A Young's modulus was also measured by the creep meter. As a result, the Poisson's ratio of boiled Japanese radish was found to decrease with boiling elapsed time. The Poisson's ratio of carrot also decreased with boiling time, and its value was smaller than the Japanese radish's. On the other hand, the Young's modulus for each sample decreased sharply when boiling started but after 4 minutes of boiling it was stabilized at low values.

Keywords: Agricultural Products, Tissue, Boiling, Elasticity, Imaging

INTRODUCTION A mechanical property of foodstuffs is one of the major attributes to evaluate their texture. Therefore, lots of studies concerning with mechanical property for food and agricultural materials have been reported (Chappell et al., 1968, Sarkar et al., 1983, Gawda et al., 1983, Hoki, 1988, Murase et al., 1988, Murata et al., 1994). A Poisson's ratio is one of the mechanical properties for an object, and is defined as the ratio of strain in the direction perpendicular to the applied force to the strain in the direction of the applied force (Sahin et al., 2006). The Poisson's ratio is sometimes employed as a parameter for evaluation of food quality (Sarkar et al., 1983).

Usually, a Poisson's ratio is measured by means of micrometer a kind of precious caliper (Murata et al., 1994), however, such usual method can not be applied to softened material e.g. boiled vegetables because of its uncertain state for contact between compressive utensil and sample object. Therefore, it has been developed and applied a non contact method by means of ultrasonic (Gawda et al., 1983), special microscopy (Murase et al., 1988), etc. to a Poisson's ratio measurement for foodstuffs. However, these methods were not applied to softened materials.

A new and simple method for the measurement of a Poisson's ratio of softened foodstuffs and agricultural products calculated from transformations in the captured digital images of compressed and deformed samples. The changes in the apparent Poisson's ratio and Young's modulus for the cylindrical samples of Japanese radish and carrot during boiling were measured and compared in this paper.

MATERIALS AND METHODS

Materials Japanese radish (*Raphanus sativus* L.) and carrot (*Daucus carota* L.), harvested in 2008 in Hokkaido, were purchased at local supermarket in Matsudo and used for this experiment.

Sample preparation Because softened materials such as boiled vegetable tissue was difficult to cut and to form for measurement of Poisson's ratio, the empirical samples were preciously cut and formed by special ordered cutting apparatus.

A cylindrical tissue (25 mm diameter) was cut from the center part of the root along the growth direction by means of precious cutting apparatus with a sharp cylindrical knife, and the height of the cylinder was set 50 mm for preparation of boiling.

The pre-formed cylindrical tissues were heated by soaking in the boiled water. The samples were put into 1L of boiled water in a pot, heated by an electric cooking stove, one by one. The boiling time was set 1, 2, 4 and 6 min, respectively. The center part temperature was measured by fiberoptic thermometer (FL-2000, Anritsu, Tokyo, Japan). Boiled pre-formed samples were placed into a refrigerator and cooled down for homogenizing of thermal distribution for 30 min.

The formed cylinder (15 mm diameter) as an empirical sample of this experiment was carefully cut from the center part of the pre-formed cooled down cylindrical sample and the height of the formed cylinder was set 30 mm by the precious slicer (see figure 1). The formed samples were checked their horizontal by means of a level.

Measurement procedures The samples were compressed from the sectioned plane of the cylinder using a creep meter (RE2-3305S, Yamaden, Tokyo, Japan) with a plane type plunger. The load against compression and the compress ratio were also measured by the creep meter. The initial point of contact between sample and plunger was set as 100%. The trigger force on the apparatus was 0.2 N. The compression speed was 1 mm/s. The load was converted to stress divided by section area of the cylinder. The Young's modulus (E) was calculated form the values of normal stress (σ) and compressive strain (ε) (see equation (1)).

$$E = \frac{\sigma}{\varepsilon} \qquad (1)$$

Changes in diameter of the compressed cylinder width were measured by differences in the pixel number of captured digital images as shown in figure 2. The images were captured by a digital camera (E-510, Olympus, Tokyo, Japan) with macro lens (35MM, Zuiko, Tokyo, Japan) of which capturing position was fixed during experiment. The camera could obtain high resolution digital images (3648 x 2736 pixels). The changes of width (diameter of the cylinder) and length (height of the cylinder) were calculated from difference in the pixel number between the images before and after compression. The Poisson's ratio (μ) was calculated by the ratio of changes in width (ΔW) per unit width (W) and changes in length (ΔL) per unit length (L) (see equation (2)).

$$\mu = \frac{\Delta W / W}{\Delta L / L} \qquad (2)$$

The verification of accuracy of this method for Poisson's ratio measurement was achieved as a preliminary experiment by comparing with ordinary method using micrometer (CLM1-15DK, Mitutoyo, Kawasaki, Japan) and rubber samples, which were sufficient hard to measure its width change by physical contact method.

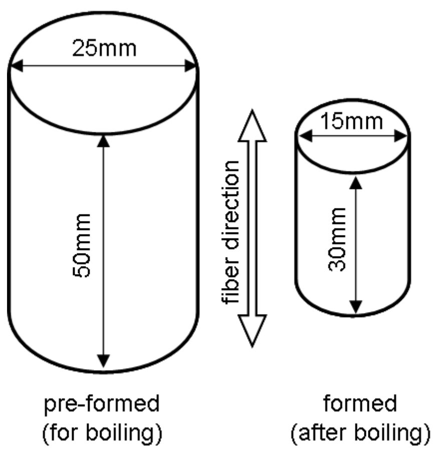

Figure 1. Schematic diagram of cylindrical samples.

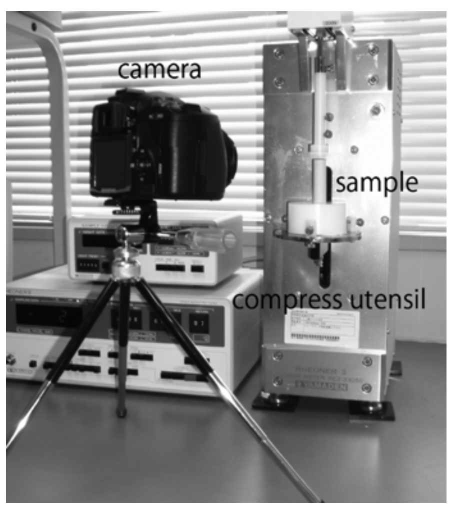

Figure 2. Photograph of measuring system.

RESULTS AND DISCUSSION

Properties of the cylindrical samples Figure 3 shows a stress-strain curve for the cylindrical sample of fresh Japanese radish. Because Young's modulus can be strictly defined for the elastic object as a Hookean solid or elastic region of compressive strain, the elastic region for the sample, which appears a line in the stress-strain curve, must be decided. In the figure 1, the line appeared from 0 to approximately 3 % of the strain. Therefore, the Young's modulus for an individual sample was calculated by averaging of the modulus at 1, 2 and 3% of the strain. The Young's modulus for each experimental condition was an average of the modulus of 5 samples each.

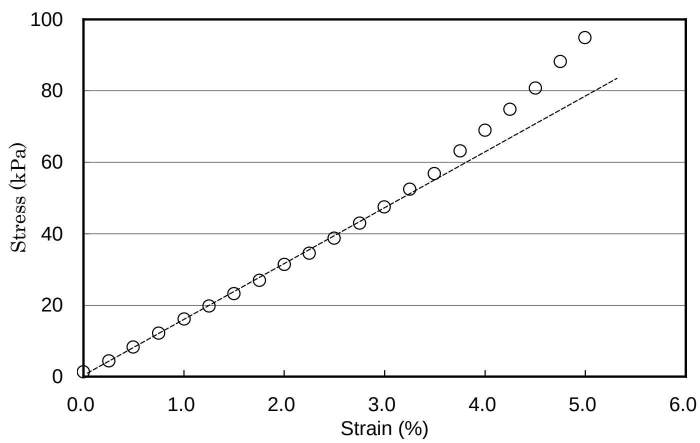

Figure 3. Stress-Strain curve for the cylindrical sample of fresh Japanese radish.

Figure 4 shows changes in temperature at the center part of the sample cylinder during boiling. The surface temperature must be immediately rose to 100 °C after soaking because sufficient amount of boiling water comparison with the sample size. On the other hand, the center temperature rose to 80 °C within 5 min as shown in the figure 4, the boiling time was set 6 min in this experiment.

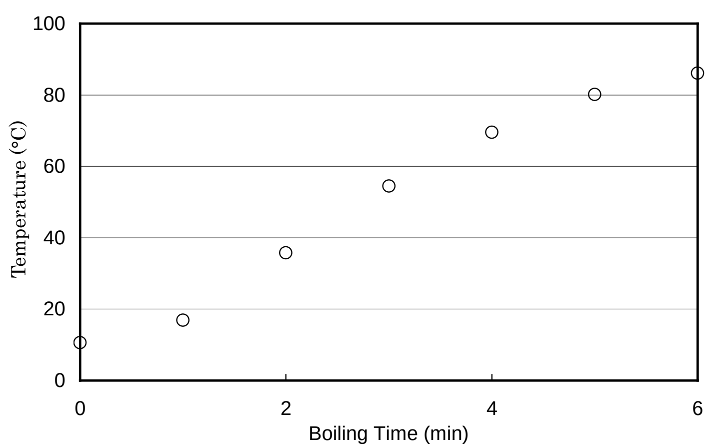

Figure 4. Changes in temperature at the center part of cylindrical Japanese radish sample during boiling.

Changes in Young's modulus and Poisson's ratio during boiling Figure 5 shows changes in the Young's modulus for the cylindrical samples of the Japanese radish and the carrot during boiling. The moduli were sharply decreased from around 1.6 to 0.5 MPa within 2 min. The moduli were almost same and constant around 0.4 MPa after 2 min. It was thought that these results were concerning with the elution or denaturation of the constituents such as pectin in the tissue, which influenced in firmness of the plant material (Tamura, 1993).

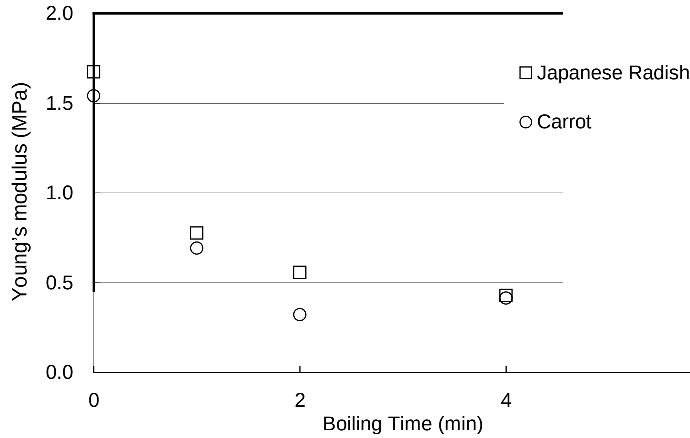

Figure 5. Changes in the Young's modulus for the cylindrical samples of Japanese radish and carrot during boiling.

Figure 6 shows changes in the Poisson's ratios for the samples during boiling. Although the ratio for Japanese radish was slightly larger than for carrot, the ratios were almost constant at between 0.3 and 0.4 or slightly decreased. This trend was different from changes in the Young's modulus. This result should indicate that the physical structures of the tissue such as arrangement of cell matrices at this experimental condition might not be changed by boiling. The tissue structures and constituents should be measured for beyond study.

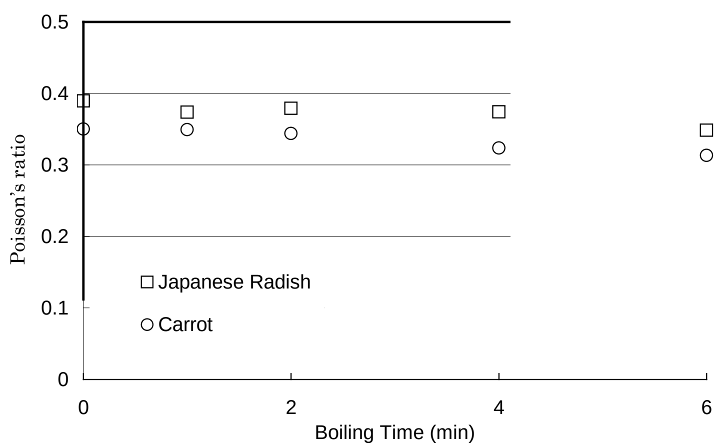

Figure 6. Changes in the Poisson's ratio for the cylindrical samples of Japanese radish and carrot during boiling.

CONCLUSION The results in this study showed a tendency of changes in the Young's modulus of Japanese radish and carrot was different from the Poisson's ratio's tendency during boiling. This difference should be influenced in the texture such as fracturability, firmness, and chewiness, etc.

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