Microstructural Analysis of Ultrasound-treated Rice by Synchrotron Radiation X-ray Tomographic Microscopy

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Abstract: This work investigates the effect of sonication on rice grains. Microstructural analysis of uncooked rice kernels treated with ultrasonication showed the formation of microporous surfaces and the creation of cracks and fissures. X-ray computed tomography revealed the internal fissures are directional and continuous along its width almost cutting the kernel crosswise. The technique allowed for the quantitative determination of % porosity. Results showed that the porosity of non-waxy milled rice increased to 4.30% porosity per volume, a 10-fold increase in porosity. Sonication increased the % porosity in milled rice better than the brown rice. The results offer opportunities in developing novel rice-based products.

Key Words: rice; sonication; x-ray tomography; porosity

1. INTRODUCTION

Sonication technique, which employs ultrasonic waves, creates an impact on surfaces due to acoustic cavitation, bubble growth and implosive collapse of bubbles in a liquid (Suslick, 1989). The ultrasonication technique in food processing and preservation has received much attention recently. The technique improves not only the quality and safety of the food but offers opportunities in developing novel products (Rana et al, 2017; Chung et al. 2002).

Rice is a versatile food that can be processed to different products. Sonication is one processing technique that has not been fully explored in rice (Cui et al., 2010). To our knowledge, none has yet demonstrated the effects of sonication on the surface morphology and tomography of the uncooked rice kernel. The objective of this work is to investigate the morphological and tomographical changes on the outer and inner endosperm of uncooked rice under sonication to understand its ultrastructure. Non-waxy rice was investigated as a model rice and the scope of the paper is on the microstructural changes especially on the porosity brought about by sonication.

2. METHODOLOGY

Non-waxy rice (IR64) variety of both the brown and the milled rice was obtained from the International Rice Research Institute (IRRI). Five grams of unbroken rice grains were soaked in 5 mL deionized water in a test tube and subjected to ultrasonic bath treatment (Fisher Scientific FS30; working frequency = 40 kHz; ultrasonic power = 130W) at 1 and 5 min sonication time. Water temperature during sonication process was kept constant (<10 ºC) by adding ice to the ultrasonic bath to avoid starch gelatinization. Samples were then air-dried at ambient temperature for 12 h.

The morphological changes of air-dried uncooked rice kernels were observed using scanning electron microscopy (JSM 5310, JEOL SEM) at 20kV. The gold-coated outer surface on the lateral side of the kernel was observed. Tomography of the rice kernels was done using Synchrotron Radiation X-ray Tomographic Microscopy (SRXTM) performed at XTM beamline (BL1.2W: X-ray imaging and tomographic microscopy) Synchrotron Light Research Institute (SLRI), Nakhon-Ratchasima, Thailand. To obtain fine details of whole grain, a tomographic volume was reconstructed from enlarged composite projections acquired from four scans in which the first scan was taken over 180° then the other 180° scans were taken along the vertical axis of rotation that shifted vertically and parallels to the camera. For each dataset, a total of 1,444 X-ray projections were collected. The projections were normalized by flat-field correction, image stitching, spot filtering, and reconstructing using Octopus Reconstruction software. The porosity was determined quantitaively in 3D by segmentation analysis using Octopus Analysis. The 3D representation of tomographic volume (typically comprising 1000 slices) was rendered at a voxel size of 24 µm3 using Drishti software.

3. RESULTS AND DISCUSSION

The SEM micrographs revealed that the non-sonicated control rice samples have a solid compact surface while the natural morphological structure of rice is lost upon sonication. The parenchyma cell walls are exposed and cell wall outlines became visible. Comparison between the brown and milled rice samples showed that the rice samples respond similarly under sonication. The sonication process imparts structural changes on the endosperm surface allowing the exposure of cellular contents. A notable observation is the formation of cracks and fissures upon sonication. As ultrasound waves propagate, the bubbles oscillate and collapse on the surface forming cavitational zones and producing local alternating positive and negative pressures, which causes the expansion or compression of the material (Soria et al 2018).

The effect of sonication afforded the formation of a porous surface on the rice. The inner porosity, however, has only been indirectly inferred by the increased water uptake of the kernel (Cui et al, 2010; Bonto et al., 2018). This work investigates the porosity through x-ray tomography of the rice kernels. X-ray computed tomography (CT) confirms the formation of fissures on the surface and in the core of the rice kernels, which is an effective and non-invasive tool in determining the internal cracks in the sample. Images of the x-ray tomography showed that the control milled rice (Figure 1A) is smooth with uniform distribution including the cross-sectioned surfaces. Sonication imparted physical effect on the uncooked rice samples forming visible cracks and fissures on the surface and the cross-sectioned sides of the sonicated rice kernels (Figure 1B). The fissures formed on sonicated samples are directional and continuous cracks along its width are observed, which almost cuts the kernel crosswise. Cracks along its length connecting the crosswise fissures are also visible. The formation of cracks and fissures manifests into the increased porosity of the sonicated rice. The control non-waxy milled rice has an inherent porosity of 0.43% but it increased to 2.27% porosity upon sonication. Generally, more fissures and higher % porosity were observed in milled rice samples as compared to brown rice samples due to the absence of the bran layer that serves as a thick protective layer of the kernel. Non-waxy milled rice upon five-minute sonication has the highest increase in porosity at 4.30% porosity per volume, a 10-fold increase in porosity. This indicates that the non-waxy rice is susceptible to fissure formation upon the mechanical jet impact of sonication. The improved porosity of sonicated brown rice suggests better water penetrability compared to the regular milled rice, which can translate to better cooking and eating quality.

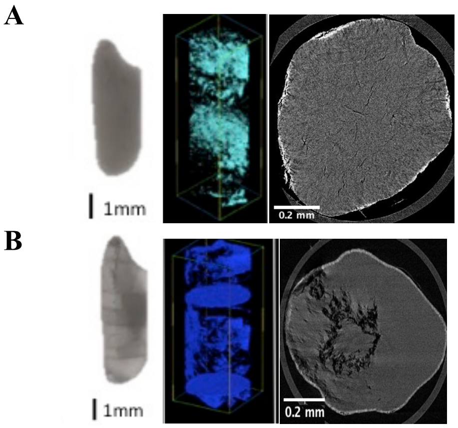

Figure 1. Synchrotron radiation X-ray tomographic images of the rice samples of non-waxy IR64 rice. A) Control rice; B) sonicated rice

The effect of ultrasonic treatment in rice is dependent on the sonication time. The ultrasound vibrations (40 kHz) for 5 minutes induced cracks and fissures on the kernel maintaining the head rice grain without breaking the kernels. Extending the sonication time to 30 and 60 minutes increases the degree of broken kernels. Increasing the frequency of the sound waves (e.g. 280, 360 kHz) breaks the grains easily and damages the starch granule surfaces (Gallant et al. 1997; Chechowska-Biskup et al. 2005). Cracks and fissures are formed due to the mechanical jet impact of sound waves creating cavitational collapse of bubbles on the rice surface allowing for increased water penetrability (Al-Juboori & Yusaf, 2012).

4. CONCLUSIONS

The influence of sonication resulted in increased porosity brought about by the formation of microporous surface and internal cracks and fissures in the kernel. The use of synchrotron radiation X-ray tomography technique allowed for visualization of internal fissures, which proved to be an effective and non-invasive way in determining the internal cracks in the sample. Moreover calculation of % porosity in rice allowed for quantitative determination. The increased porosity in rice as a result of sonication should promote easy penetration of water during the cooking process and should promote softer texture. The sonication technique and the controlled porosity in rice should be useful in developing new products from rice.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Al-Juboori, R. A., Yusaf, T.F. (2012). Improving the performance of ultrasonic horn reactor for deactivating microorganisms in water. IOP Conf. Ser. Mater. Sci. Eng. 36 (2012) 1e13.

Bonto, A.P. , Camacho, K.S.I., Camacho, D.H. (2018). Increased vitamin B5 uptake capacity of ultrasonic treated milled rice: A new method for rice fortification, LWT Food Science & Technology, 95, 32-39. https://doi.org/10.1016/j.lwt.2018.04.062.

Chechowska-Biskup, R., Rokita, B., Lotfy, S., Ulanski, P., Rosiak, J.M. (2005), Degradation of chitosan and starch by 360-kHz ultrasound. Carbohydrate Polymers, 60 (2005) 175–184. https://doi.org/10.1016/j.carbpol.2004.12.001

Chung, K.M., Moon, T.W., Kim, H.J., Chun, J.K. (2002). Physicochemical properties of sonicated mung bean, potato, and rice starches, Cereal Chemistry, 79, 631-633. https://doi.org/10.1094/CCHEM.2002.79.5.631

Cui, L., Pan, Z., Yue, T., Atungulu, G.G., Berrios, J. (2010). Effect of ultrasonic treatment of brown rice at different temperatures on cooking properties and quality, Cereal Chemistry, 87, 403–408. https://doi.org/10.1094/CCHEM-02-10-0034

Gallant, D.J., Bouchet, B., Baldwin, P.M. (1997). Microscopy of starch: evidence of a new level of granule organization. Carbohydrate Polymers, 32, 177–91. https://doi.org/10.1016/S0144-8617(97)00008-8.

Rana, A. Meena, Shweta, (2017). Ultrasonic processing and its use in food industry: A review, Int. J. Chem. Studies 5 (2017) 1961-1968. http://www.chemijournal.com/archives/2017/vol5issue6/PartAA/5-6-328-826.pdf

Soria, A.C., Villamiel, M. (2010). Effect of ultrasound on the technological properties and bioactivity of food: A review, Trends Food Sci. Technol. 21 (2010) 323-331. https://doi.org/10.1016/j.tifs.2010.04.003

Suslick, K.S. (1989) The chemical effects of ultrasound. Scientific American. February 1989 issue pp. 62-68. https://www.scientificamerican.com/article/the-chemical-effects-of-ultrasound/ (accessed 16 March 2019)