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# Effects of ultrasonication on the physical properties of Herba rice grain

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**Abstract**

The main cause of obesity is overconsumption. The idea of enhancing satiety and satiation is considered an effective way to control appetite and regulate energy and food intake. The principal objective of this study was to make rice healthier for consumption through texture and structure modification of rice grain using ultrasound treatment. Sonication alters the microstructure of rice grain by degradation of rice starch to manipulate the water absorption ability of rice during cooking. Greater porosity of rice grains from sonication treatment allows better water absorption. Herba rice was sonicated at different amplitudes (0 to 60 µm). The water absorption ratio was calculated, and texture properties (hardness, cohesiveness, gumminess, and chewiness) were determined using a texture analyzer. This paper concluded that Herba rice was most suitable for sonication analysis relative to Basmati rice and Calrose rice due to its relatively consistent physical properties under soaking. It was proven that sonication is a useful and effective way to modify rice grain texturally and structurally, with texture analysis showing enhancement in cohesiveness, gumminess, and chewiness, while scanning electron microscopy (SEM) images confirm substantial microstructural changes after sonication. It was concluded that sonication can significantly improve cooked rice texture (cohesiveness +5%, gumminess +5%, chewiness +20%) and water absorption ratio (+10%) of Herba rice, with significant microstructure modifications using amplitudes of 60 µm. This study showed a new methodology of rice modification to control appetite. This novel way of modification is easy to operate and simple to introduce. Rice is the most common staple food, and an improved rice will benefit a significant part of the population to prevent overconsumption and obesity.

## 1. Introduction

In the food industry, there is increasing interest in emerging technologies such as ultrasound with huge application potential. Current food applications of ultrasound are primarily for quality enhancement and process control. There are various examples of ultrasound application in mass transfer, emulsification, crystallisation, homogenisation and inactivation of microorganisms and enzymes (Camacho *et al*., 2018; Li *et al*., 2019; Diao *et al*., 2019).

The trend in the food industry is to use technologies to modify certain properties of rice. Exploring and understanding the principles of structure and texture modification can help identify key issues relating to rice modifications. Current food applications of ultrasound are primarily for quality enhancement and process control. A summary of food technologies used in rice-related modification is shown in Table 1.

In general, swelling is associated primarily with higher amylopectin (lower amylose), leading to waxy rice being more capable of swelling than its non-waxy counterparts. Gelatinised starch has no crystallites, as the crystalline areas of starch transform into amorphous zones after gelatinisation. However, depending on storage conditions, including temperature, time and moisture content (Chakraborty *et al*., 2022), non-equilibrium recrystallisation of gelatinised starch can happen during storage. This process is described as retrogradation and is identified as the reassociation of gelatinised starch molecules in an orderly structure (Yan *et al*., 2021). The hardening of cooked rice or a starch gel upon storage describes the primary reason for the

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Table 1. Current food technologies in rice modifications.

| Authors | Food Technology | Purpose | Findings |
|---|---|---|---|
| Camacho *et al.* (2018) | Ultrasonication of rice | Vitamin fortification | Sonication led to a porous rice surface. Sonication led to the disintegration of starch, leaving more room for vitamin absorption. |
| Cui *et al.* (2010) | Ultrasonication of rice | Reduce cooking time | Optimal cooking time was reduced after sonication, with higher temperatures leading to greater cooking time reduction. |
| Diao *et al.* (2019) | Adding a reducing agent to rice | Restoration of fresh texture in cooked rice | Agents restored texture by enhancing swelling properties, reducing hardness and increasing adhesiveness. |
| Li *et al.* (2019) | Ultrasonication of rice | Hydration and physicochemical properties change | Sonication led to less soaking time, microstructure alteration led to lower hardness and higher water binding. |
| Phongthai *et al.* (2016) | Sonication-assisted extraction | Rice bran protein extraction | Sonication-assisted extraction led to reduced extraction time with better yield than the conventional method. |
| Yang *et al.* (2017) | Addition of emulsifiers to rice flour and gel | Increase quality and shelf life | Emulsifier agents can reduce starch degradation in rice flour, improve quality and extend shelf life. |

deterioration of texture properties in cooked rice (Hu *et al*., 2022).

Power ultrasound generates different effects when passing through a material where acoustic cavitation plays a pivotal role. The cavitation is formed by localised pressure differentials over several microseconds of forming and collapsing gas bubbles. These cavitation effects involve either physical or chemical mechanisms. The mechanical effect is deterioration due to cavitation bubble collapse. The chemical effect is the formation of free radicals. Ultrasonic cavitation causes a temperature rise where the bubble collapses due to localised intense hydrodynamic shear forces. Ultrasonication can alter food structure with effects on texture and consistency. The main interest is in ultrasound in the structural modification of food products. Numerous studies have shown improvement in texture retention in low-intensity ultrasound pre-treatment. The various ultrasound effects are either physical or chemical cavitation effects.

The areas where ultrasound has been employed exploit both its chemical and mechanical effects. The significance of the two effects differs depending on the frequency employed (Gallo *et al*., 2018). At lower frequencies, such as 20 kHz to 100 kHz, the mechanical effect resulting from unstable cavitation is predominant, and as the frequency reaches 20 kHz, the bubbles collapse with increasing intensity. At medium frequencies such as 200 kHz to 500 kHz, the chemical effect becomes predominant, as a higher number of bubbles form that collapse less intensely. At higher frequencies beyond 1 MHz, both the physical and chemical effects associated with cavitation are insignificant, while the impact of the acoustic flow predominates. Typically, the higher frequencies are utilised for diagnostic purposes.

Power ultrasound, a high-power low-frequency ultrasound, has gathered considerable interest recently as it has a broad range of usages within numerous sectors, making it an adaptable processing technology (O'Sullivan *et al*., 2017). Uses such as the modification, alteration and creation of different microstructures. It has the capacity to mechanically change protein structures in solution without the need for biological or chemical additives or any extra heat due to ultrasonic cavitation. It can also improve the explicit surface area in emulsion systems by generating nanosized emulsion droplets.

This paper illustrates the beneficial effects of ultrasound application in Herba rice grain, focusing on the effects of sonication on grain hardness, water absorption ability, grain microstructure and cooked texture profile.

## 2. Materials and methods

### *2.1 Grain dimensions comparison*

Grain length and width were recorded from random samples using a digital micrometre, and the mean values were calculated. A total of thirty-five samples of Herba rice grains were chosen to give sufficient data for a valid and reliable ANOVA analysis. Grain aspect ratio was calculated by:

$$\text{Grain aspect ratio} = \frac{\text{Grain length}}{\text{Grain width}}$$

Basmati and Calrose rice were used as a comparison.

### *2.2 Sonication*

A total of fifteen batches of rice (5 g) samples were taken and placed into a 150 mL beaker with distilled water (60 mL). The sonicator with a digital amplitude control panel and an insulation case (Fisher, 505 W) was used throughout the study, with an amplitude setting 0%

 

to 50%. All tests were done with 2 mins continuous sonication. The variables were rice samples and ultrasound amplitude. Amplitude was set at every 5% from 0% to 50% (the amplitude at 100% is 120 µm, each test's wave amplitude from 0 µm to 60 µm at every 6 µm interval). Once sonicated, the rice samples were drained and dehydrated before further analysis or tests.

*2.3 Water absorption ability of sonicated grain*

The swelling power (SP) and the water solubility (S) of Herba were measured according to the method of Adebooye and Singh (2008) and Li and Yeh (2001) with some modifications. Volume expansion ratio was determined as volume of cooked rice to volume of raw rice. The water absorption ratio was calculated by dividing the weight of cooked rice by that of raw rice. Rice (10 g) was taken in a 100 mL beaker (in triplicate) already filled with distilled water (30 mL), and the increase in volume was recorded as the volume of raw rice. Then all the samples were soaked for 30 mins in water. Then, cooking was done using a hotplate (Fisher) at 330°C for 15 mins. Immediately after cooking, the water was drained out and cooled using cold water. Rice kernels were completely drained out first by a sieve, then by filter paper, and the increase in volume was measured by a cylinder. The increase in weight of batches of 20 randomly selected rice grains was measured using a digital scale. Water absorption was calculated by the formula below:

$$Water\ Absorption = \frac{20\ cooked\ rice\ grains\ weight}{20\ raw\ rice\ grains\ weight}$$

A total of fifteen replicates were performed for each of the ultrasound amplitude ranges used (0 µm – 60 µm) as per section 2.2.

*2.4 Texture profiles of sonicated rice grain*

After cooking, the cooked grains were held for 20 mins for cooling. The texture of cooked grains was determined by a texture analyser (Brookfield CT3). TPA tests consist of compressing the sample twice to replicate the action of mastication. Data from a TPA test is arranged into a force-time curve where a variety of textural properties can be measured that will correlate to sensory evaluation.

The fifteen batches of five cooked grains were randomly selected and placed at 5 mm above the base. A two-cycle compression was used with a pre-test, test and post-test speed at 1 mm/s. A compression place of 75 mm diameter with a load cell of 5 kg was used for texture determination of cooked rice samples. Cohesiveness, gumminess and chewiness values were measured from the area covered under the different peaks. Dry hardness was also measured using pre-cooked rice grain using the same two-cycle compression test perimeters. Hardness is defined as the maximum peak force during the first compression cycle. Cohesiveness is defined as the ratio of the positive force area during the second compression to that during the first compression. Gumminess is defined as the product of hardness and cohesiveness. Chewiness is the mouthfeel sensation of laboured chewing due to sustained, elastic resistance from the food. It is defined as the product of gumminess and springiness. It can be interpreted as the energy required to chew solid food.

*2.5 Scanning electron microscopy*

Two differently treated Herba rice samples were sent to the laboratory (Histocenter, Kuala Lumpur, Malaysia) for scanning electron microscopy (SEM) analysis. The samples include (A) control with no sonication, (B) rice with sonication at 60 µm amplitude for 2 mins. A total of 3 runs of each sample, totalling 6 runs, were done. Results obtained were used to compare the differences in the microstructure of the two sets of samples.

*2.6 Statistical analysis*

IBM SPSS Statistics 23 was used, and all analyses were done using the SPSS program.

## 3. Results

*3.1 Grain dimensions and grain selection*

Dimensions of three different rice types were studied and compared. Three rice types were Basmati, Herba and Calrose. These were chosen based on their different grain family: long grain (Basmati rice), medium grain (Herba rice) and short grain (Calrose rice). ANOVA analysis was used to determine any missing values or outliers, and results were recorded in Figure 1. For the long-grain Basmati rice, the mean grain length was 8.73 mm, which, as expected, was the longest of the three rice

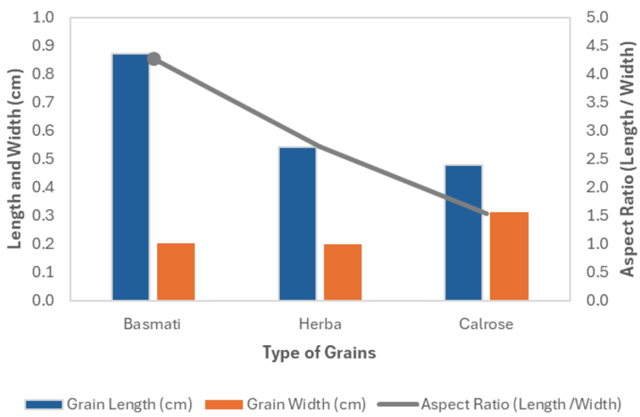


Figure 1. Comparison of grain dimensions between Basmati, Herba and Calrose. Data are presented as mean±SD of 35 replicates. Bars with different superscripts are statistically significantly different ($p<0.05$).

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types. The mean grain length of Herba rice was 5.44 mm, while the mean grain length for Calrose rice was the shortest at 4.78 mm. The mean grain aspect ratio also followed the expected trends based on their rice type family, with Basmati rice having the highest mean grain aspect ratio of 4.27 mm, with Herba rice at 2.73 mm and Calrose rice the roundest at 1.54 mm. The grain lengths for each rice type are significantly different to each other as expected, confirming their respective grain family size criteria.

Pre-soaked samples were cooked, their texture analysed, and the results are shown in Table 2. Based on the known characteristics of the long grain, medium grain and short grain rice, the chewiness for Calrose rice was expected to be the highest due to the fact short grain rice has the highest relative starch content and Basmati was expected to have the lowest chewiness due to the lowest relative starch content of long grain rice. For Basmati rice, the mean chewiness was 1,231 g, while for Herba rice, the mean chewiness was 3,856 g, and for Calrose rice, the mean chewiness was highest at 5,418 g. The mean chewiness for the three different rice grains was all significantly different from each other and followed the expected chewiness trend of Basmati rice being the lowest and Calrose rice being the highest. Long -grain rice (Basmati) generally has lower starch content, while short-grain rice (Calrose) generally has high starch content, and it is the high levels of amylopectin starch that give Calrose its characteristic chewy nature.

Soaked sample grains (room temperature for 2 mins) were dehydrated and cooked. Their texture profiles are shown in Table 3. The effects of 2 mins soaking on the changes in texture properties of three different grains can be observed in Figure 2. Soaked Herba rice showed the least percentage change in mean hardness, mean cohesiveness, mean gumminess and mean chewiness, suggesting its texture properties are least affected by the effect of soaking in water. Since all sonication required soaking of rice samples either in a water bath or a solution, Herba is considered better suited for this study than the other two grains, as results from sonication in a water bath or solution would be least distorted by the effect of soaking. Another consideration was the rice characteristics based on the rice family. Long grain rice had relatively low starch content, which would limit the effect of sonication (leaching of amylose), while short grain rice had relatively high chewiness, which also limits the effect of texture modification by sonication (water absorption and chewiness).

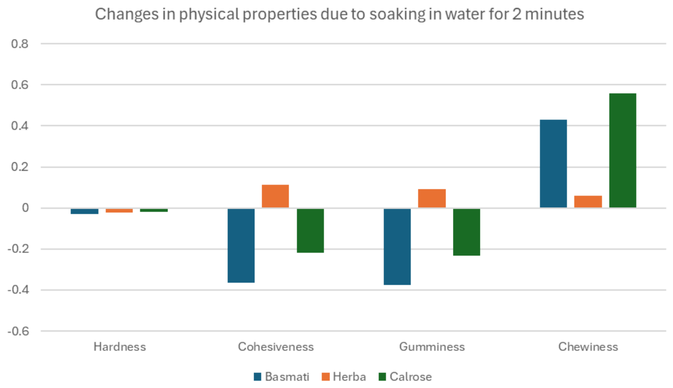


Figure 2. Grain texture distortion by soaking for Basmati, Herba and Calrose. Data are presented as mean±SD of 12 replicates.

### *3.2 Effect of sonication on water absorption*

The range of ultrasound amplitude used was 0 µm up to 60 µm at 12 µm intervals. These were chosen based on the settings available on sonicator as well as the maximum ultrasound amplitude the rice grains can withstand before obvious physical breaking occurred. Results were recorded in Figure 3.

For control, the mean water absorption was 2.32±0.00. As the ultrasound amplitude increased, the water-absorbing ability of the rice grains increased. The mean water absorption ability of the Herba rice grains increased from 2.32 (no sonication, control) to 2.55 (or

Table 2. Texture analysis of three rice types without soaking.

| Rice Type | Hardness (g) | Cohesiveness | Gumminess (g) | Chewiness (g) |
|---|---|---|---|---|
| Basmati | 10731±172$^{a}$ | 1.05±0.02$^{b}$ | 11222±147$^{b}$ | 1231±28$^{c}$ |
| Herba | 10665±112$^{a}$ | 0.71±0.01$^{c}$ | 7512±93$^{c}$ | 3856±43$^{b}$ |
| Calrose | 10640±129$^{a}$ | 1.11±0.02$^{a}$ | 11790±159$^{a}$ | 5418±54$^{a}$ |

Values are presented as mean±SD of 12 replicates. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

Table 3. Texture analysis of three rice types (2 mins of soaking and dried).

| Rice Type | Hardness (g) | Cohesiveness | Gumminess (g) | Chewiness (g) |
|---|---|---|---|---|
| Basmati | 10406±104$^{a}$ | 0.67±0.01$^{c}$ | 7010±67$^{c}$ | 1763±13$^{c}$ |
| Herba | 10410±72$^{a}$ | 0.79±0.01$^{b}$ | 8197±92$^{b}$ | 4087±66$^{b}$ |
| Calrose | 10403±104$^{a}$ | 0.87±0.01$^{a}$ | 9061±139$^{a}$ | 8440±100$^{a}$ |

Values are presented as mean±SD of 12 replicates. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

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+9.91 %) when the ultrasound amplitude was at 60 µm.

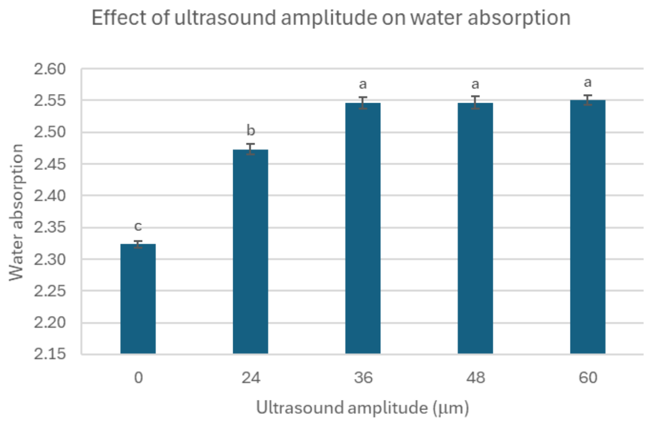


Figure 3. Effect of sonication amplitude on water absorbing ability of Herba rice. Data are presented as mean±SD of 12 replicates. Bars with different superscripts are statistically significantly different ($p<0.05$).

### *3.3 Effect of sonication on texture (cohesiveness, gumminess and chewiness)*

As ultrasound amplitude increased, the effect on all three cooked rice texture perimeters improved significantly (cohesiveness +5.41%, gumminess +5.21%, chewiness +20.17% with comparing 60 µm to control) (results were recorded in Table 4). As ultrasound amplitude increased, effects on all three perimeters (cohesiveness, gumminess and chewiness) were minimal.

Table 4. Summary of Effects of sonication on Herba rice properties.

| Rice properties | Control (no sonication) | Sample 2 (sonication 60 µm) | Change % |
|---|---|---|---|
| Dry hardness (g) | 9218±151 | 4291±88 | -53.45 |
| Cohesiveness | 0.37±0.01 | 0.39±0.01 | 5.41 |
| Gumminess (g) | 1840±33 | 1936±23 | 5.21 |
| Chewiness (mJ) | 16.96±0.73 | 20.38±1.37 | 20.17 |
| Water absorption ratio | 2.2233±0.049 | 2.5508±0.0079 | 14.73 |

Values are presented as mean±SD of 12 replicates.

Although the differences in cohesiveness, gumminess and chewiness between sonication amplitudes were insignificant, it was clear that all sonicated samples had significant increases in these perimeters as compared to the control (no sonication). Cohesiveness was published to enhance with reducing amylose content in the whole grain (Li *et al*., 2017), and to increase the total amount of amylopectin. Gumminess is directly related to the moisture or water content of the grain. High levels of amylopectin starch give rise to higher chewiness. Since sonication enhanced leaching of amylose, sonicated samples had significantly less amylose content, higher water absorption ratio and relatively higher amylopectin starch ratio due to the loss of amylose. Therefore, sonication significantly improved cohesiveness (due to lower amylose), improved gumminess (due to better water absorption ratio) and improved chewiness (due to higher amylopectin to amylose ratio). Figures 4-6 show the effect of ultrasound amplitude on cohesiveness, gumminess and chewiness.

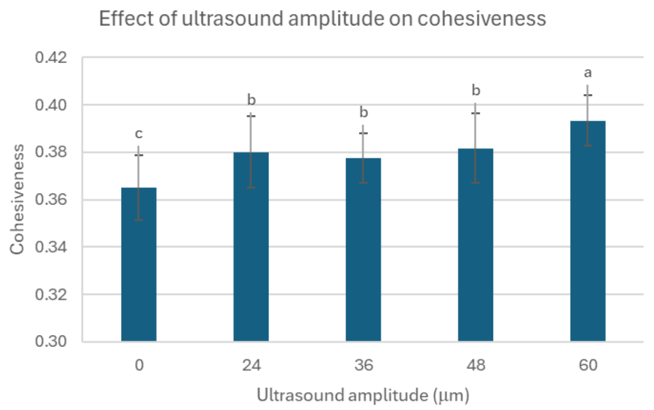


Figure 4. Effect of sonication amplitude on cohesiveness. Data are presented as mean±SD of 12 replicates. Bars with different superscripts are statistically significantly different ($p<0.05$).

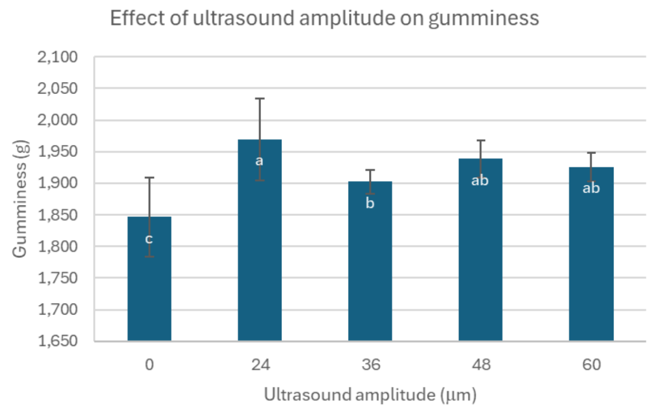


Figure 5. Effect of sonication amplitude on gumminess. Data are presented as mean±SD of 12 replicates. Bars with different superscripts are statistically significantly different ($p<0.05$).

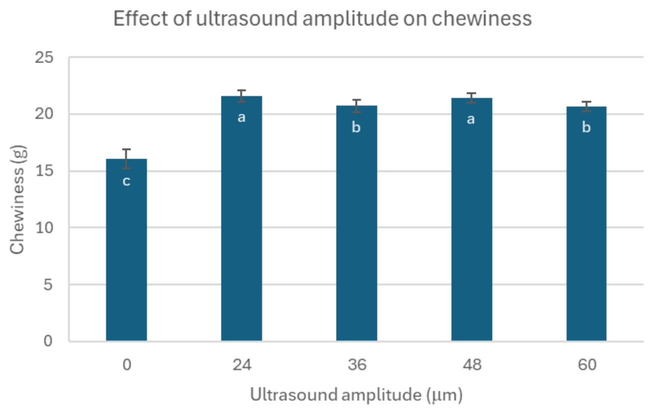


Figure 6. Effect of sonication amplitude on chewiness. Data are presented as mean±SD of 12 replicates. Bars with different superscripts are statistically significantly different ($p<0.05$).

*3.4 Effect of sonication on grain dry hardness*

As ultrasound amplitude increased, the hardness of the dehydrated rice grains decreased (results can be observed in Figure 7). The mean hardness of the Herba rice grains decreased quite linearly from 9,218 g (no sonication, control) to 4,291 g when the ultrasound amplitude was at 60 µm.

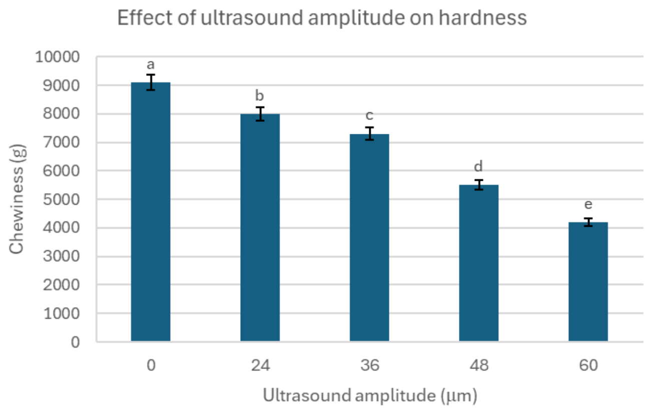


Figure 7. Effect of sonication amplitude on dry grain hardness. Data are presented as mean±SD of 12 replicates. Bars with different superscripts are statistically significantly different ($p<0.05$).

The hardness was reduced by 54% by the time the amplitude increased from 0 µm to 60 µm, supporting the hypothesis that grains become more porous due to the removal of amylose.

*3.5 Effect of sonication on microstructure by scanning electron microscope*

To observe the effect of sonication on Herba rice microstructure, three runs of each sample were done using SEM. The images (Figures 8 and 9) were obtained using zooms at 20× and 1000×. SEM images of the two samples showed that sonication significantly changed the microstructure of the rice grains. The microstructure of sample A showed one pattern, and sample B showed a different pattern with greater porosity. Since sample A was without sonication while sample B was sonicated, it can be deduced that sonication significantly changed the microstructure or increased the porosity of Herba rice. More importantly, the new microstructures created by sonication with bigger gaps and greater inner surface area suggested greater matter loss (leaching of amylose) after sonication. Sample A had very compacted microstructures with less inner surface area than sample B.

SEM showed that the more porous structure created by sonication provided greater inner surface area where water can be absorbed more easily, and hence, higher water absorbing ability was observed for sonicated rice.

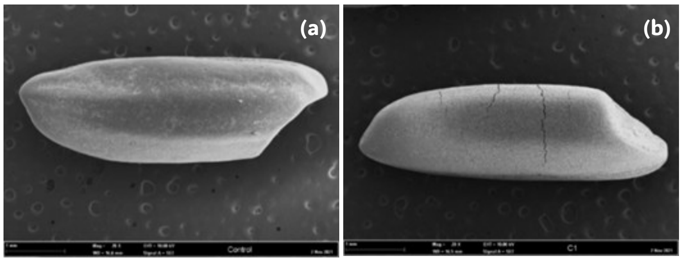


Figure 8. Sample A (no sonication) and sample B (sonication at 60 µm for 2 mins) at 20×.

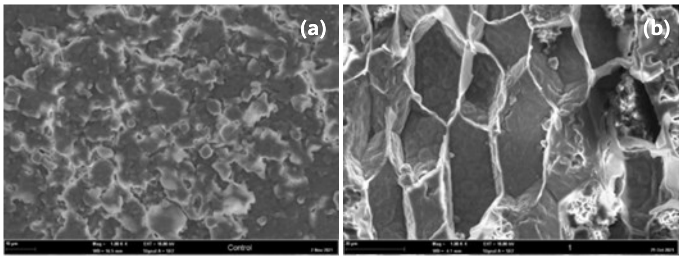


Figure 9. Sample A and sample B at 1000× (biggest gap/void measured at 200 µm).

## 4. Discussion

Sonication in a water bath had several effects on Herba rice. As ultrasound amplitude increased, the hardness of pre-cooked grain decreased, supporting the hypothesis that grains become more porous due to the removal of amylose. This is consistent with results found by Camacho (2018) and Li (2019). Ultrasound had led to cavitation from collapsing bubbles in an aqueous medium. Sonication also induced microporous formation, cell wall exposure, and rice matrix loosening (Bonto, 2021). In this study, rice grain surface eroded via cavitational collapse in the surrounding liquid, resulting in rice surface destruction and grain fragmentation. The voids in the sonicated rice grain structure were observed through SEM, which confirmed the removal of matter to form a porous microstructure after sonication.

Water absorbing ability of rice during cooking increased as the ultrasound treatment amplitude increased. The observation was the result of a higher degree of porosity produced by sonication-enhanced hydration process (Miano, 2018), supporting the idea that sonication creates greater surface area due to reasons in hardness reduction and therefore better water absorption. The crystalline structure of the starch granules was disrupted due to the breakage of hydrogen bonds when starch was heated in excess water, and water molecules form hydrogen bonds to the exposed hydroxyl groups of amylose and amylopectin, which resulted in an increase in granule swelling and solubility (Xu *et al.*, 2021). Sonication significantly improved cohesiveness (due to lower amylose), improved gumminess (due to better water absorption ratio) and improved chewiness (due to higher amylopectin to amylose ratio). SEM images confirmed that sonication created more gaps

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within the microstructure and thus greater inner surface area for water absorption to take place. There were significant changes to the microstructures in sample B, supporting that sonication led to microstructural changes in Herba rice at an ultrasound amplitude of 60 μm.

## 5. Conclusion

Ultrasound can alter the physical properties of Herba rice. This paper aims to understand how ultrasound can modify Herba rice physicochemical properties. Sonication broke down the amylose by resonance, the voids created from the dissolution of amylose resulted in more gaps in the microstructure and therefore a more porous structure. This led to weaker integrity and lower grain hardness. The porous structure created by sonication provided greater inner surface area where water can be absorbed easily, and hence higher water absorbing ability for sonicated rice. Higher amplitude had higher energy and enhanced amylose leaching. The application of sonication to Herba rice creates several possibilities in the search for better rice quality with this modification.

## Conflict of interest

The authors declare no conflict of interest.

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