

Characteristics of Avocado Seed Starch in Ultrasound-Assisted Extraction**Novian Wely Asmoro^{*}, Retno Widyastuti, Catur Budi Handayani, Heru Febrianto, Titis Rahmatika Wardani, Fitria Rahmawati**

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ABSTRACT

Avocado seeds are one of the agro-industrial wastes that have potential but have not been optimally utilized. This study aims to evaluate the effect of ultrasound technology on the starch extraction process based on the high starch content in avocado seeds, rendering it a viable raw material for high-value products such as bioplastics, edible films, and other food applications. The research process starts with grinding avocado seeds that have been cut into small pieces, using a blender in the presence of a NaHSO₃ solution. The ground solution is then subjected to sonication treatment using ultrasonic waves with an amplitude of 35 kHz. The sonication duration varies according to the treatment, namely 0, 10, 20, 30, and 40 minutes. After treatment, the extracted starch will be analyzed to determine the yield, water content, Water Holding Capacity (WHC), Oil Holding Capacity (OHC), and morphology. The study results are expected to contribute to the development of more efficient and environmentally friendly extraction methods, while supporting the utilization of agro-industrial waste for value-added products. These findings also have the potential to be the basis for the development of extraction technology in food and biotechnology. The data obtained from the characteristic analysis were calculated statistically using SPSS 17 software with the ANOVA method, then continued with Duncan's Multiple Range Test (DMRT) if there was a significant difference between treatments. The results revealed that the application of ultrasound treatment to avocado seeds significantly decreased the starch yield, suggesting that sonication may disrupt starch structure. The highest avocado seed starch yield was 7.26% in the sonication for 10 minutes. The ultrasound-assisted avocado seed starch extraction process affected the physical and morphological characteristics of the starch produced.

Keywords: *Avocado seeds, extraction, starch, ultrasound*

INTRODUCTION

Indonesia is one of the countries that produces many avocados (*Persea americana*). Data from the Central Statistics Agency (BPS, 2024) show that from 2021 to 2023, Indonesia's avocado production reached more than 600 thousand tons per year. About 13-17% of the total avocado weight consists of seeds, which generally become waste and have not been optimally utilized. Avocado seeds are rich in various functional and bioactive components: polysaccharides, proteins, lipids, minerals, and vitamins. They also have a relatively high starch content. Among all macromolecules contained in avocado seeds, carbohydrates are the main component, with a content of 64.9%, of which 91.2% consists of starch (Bangar et al., 2022). This starch content provides an opportunity to be utilized as an alternative raw material, especially for developing food and non-food products. Avocado seed starch can be used in the production of food products such as natural sweeteners, thickeners (Martins et al., 2022), and wheat flour substitutes (Zai & Sidabalok, 2021) as well as in the manufacture of edible films as an alternative to conventional plastics (Muhammad et al., 2021). In addition, this starch also has potential applications in the pharmaceutical industry as a tablet binder (Surya et al., 2017).

Starch extraction is an important process in utilizing avocado seeds as raw materials for various industrial applications, including food, pharmaceuticals, and biodegradable packaging. However, one of the drawbacks of conventional starch extraction methods is the relatively long processing time and limited efficiency, prompting the need for innovation in faster and more efficient extraction techniques. The conventional method of extracting starch from avocado seeds involves several steps. First, the avocado seeds are washed and cut into small pieces, and then soaked in 0.2% (v/v) sodium metabisulfite solution for 24 hours to prevent oxidation. The next process involves crushing the material using a mixer, screening it through a fine sieve (200 mesh), followed by decantation and centrifugation to separate starch from other compounds. The starch residue is then dried in an oven at 40-60°C for 12-24 hours (Martins et al., 2022; Surya et al., 2017). This method requires a relatively long time and results in a low starch yield. In another study, optimization of avocado seed starch extraction by microwave-assisted extraction (MAE) method using a temperature of 161.09 °C for 56.23 minutes obtained a starch extraction yield of 49.52%, while avocado seed starch extraction by conventional methods obtained a starch yield of 39.04% (Araújo et al., 2020).

This indicates the need for new, more effective, and efficient approaches in avocado seed starch extraction methods. One promising alternative is the use of ultrasonic technology to accelerate the extraction process and improve starch yield and characteristics. The ultrasonic method can enhance extraction efficiency because ultrasonic waves break cell walls and release intracellular contents into the extraction medium (Rifkia & Revina, 2023). Several studies have shown that ultrasonic-assisted extraction can increase yield compared to conventional methods. Ultrasonic application can enhance starch extraction yields by up to 80–90%, depending on parameters such as frequency, amplitude, and duration (Adhiksana, 2017; Fatmawati et al., 2013).

Ultrasonic waves generate microbubbles within the liquid that create high pressures, damaging the cellular matrix and facilitating the release of starch from the seed tissue (Cui & Zhu, 2020). Studies have shown that starch obtained using ultrasound tends to have a finer granule structure, better rehydration capacity, and more stable gelatinization properties than starch extracted conventionally (Rahaman et al., 2021). Ultrasound also induces structural modifications in starch particles, mainly by altering particle morphology and reducing crystallinity. Longer treatment times significantly affect gelatinization characteristics, paste viscosity, and gelling capacity, while improving in vitro starch digestibility (Cui & Zhu, 2020). Structural changes in polysaccharides after ultrasonic treatment lead to modifications in their physicochemical and biological properties. The degree of change is influenced by ultrasound frequency and intensity, duration, solvent temperature, and the source and composition of the polysaccharides. In addition to improving extraction productivity, this method supports environmentally friendly processing in the food and biotechnology industries. Although its potential has been extensively studied in materials such as corn, potato, and cassava, research specifically on avocado seed starch extraction remains limited. Therefore, further investigation is required to evaluate the effectiveness of this method.

Based on this background, this study aims to evaluate the effect of ultrasound technology on the extraction of starch from avocado seeds. The study analyzes the starch yield, physical and chemical characteristics, and potential applications of the extracted starch. The results are expected to contribute to the development of efficient and

environmentally friendly extraction technologies while promoting the utilization of underused local resources.

Ultrasound technology has been widely applied to increase the extraction efficiency of bioactive compounds, essential oils, hydrocolloids, and proteins through acoustic cavitation that disrupts cell walls (Kunarto et al., 2024; Setyantoro et al., 2019). In starch extraction, ultrasound has shown potential to enhance yield and modify starch characteristics in materials such as sweet potato, potato, and cassava (Maria Ulfa et al., 2022). However, its application to avocado seeds is still limited. This study is therefore innovative in evaluating the effect of sonication duration on the yield and characteristics of avocado seed starch, providing a new contribution to the development of agro-processing technology.

METHODS

Material & Tools

The materials used in this study were fresh avocado seeds, sodium metabisulfite, and distilled water. The equipment utilized included an ultrasonic system (VEVOR 60 W), analytical balance (Sartorius), water bath, hot plate stirrer, oven (IK Oven Carbolite), desiccator, spatula, filter paper, thermometer, pH meter, centrifuge, and UV–Vis spectrophotometer. Additional supporting tools included a knife, cutting board, sieve, electric blender, and aluminum tray.

Research Design

This research was conducted in two stages. The first stage involved the preparation of avocado seed raw materials, while the second stage consisted of the extraction of avocado seed starch using ultrasound technology, followed by the analysis of its chemical and physical characteristics. The evaluation of starch characteristics included yield, moisture content, color degree, water-binding capacity, oil-binding capacity, and starch morphology.

The experimental design used in this study was a Completely Randomized Design (CRD) with one factor, namely sonication duration (amplitude: 35 kHz), consisting of five treatment levels: 0 minutes (control, without ultrasound), 10 minutes, 20 minutes, 30 minutes, and 40 minutes. The observed parameters included starch yield, moisture content, color degree, water-binding capacity, oil-binding capacity, and starch morphology. The data obtained were statistically analyzed using SPSS version 17 software with the Analysis of Variance (ANOVA) method, followed by Duncan's Multiple Range Test (DMRT) to determine significant differences among treatments. Graphs and tables were prepared using Microsoft Excel software.

Avocado Seed Starch Extraction Process

Avocado seeds were washed to remove impurities, peeled, and cut into small pieces. The starch extraction method referred to Muñoz-gimena et al., (2024) with several modifications. A total of 100 g of avocado seeds were peeled, cut into small pieces, and immersed in a sodium bisulfite (NaHSO₃) solution (1500 ppm) at a ratio of 1:5 (w/v) to prevent oxidation. The seeds were ground in the NaHSO₃ solution using a blender for 1 minute at low speed, followed by 3 minutes at a higher speed. Sonication was then performed using an ultrasonic device at an amplitude of 35 kHz for the designated treatment durations (0, 10, 20, 30, and 40 minutes). The resulting suspension was filtered

through a fine sieve or filter cloth. The filtrate obtained was allowed to stand for 12 hours to allow starch precipitation. The precipitate was then rinsed and subjected to a second precipitation step for 24 hours. Finally, the obtained starch was dried in an oven at 60 °C for 6 hours until the moisture content reached approximately 8–10%.

Test Parameters

Some of the starch characteristic analyses carried out include:

Avocado Seed Starch Yield

The starch yield analysis was conducted by comparing the weight of dry starch obtained from the extraction process with the initial weight of the avocado seed raw material. The starch dried to constant weight was weighed using an analytical balance to determine the final weight. The yield calculation was executed using Equation 1.

$$\text{Yield} = \frac{\text{dry starch weight (g)}}{\text{Initial weight of avocado seed}} \times 100\% \dots\dots\dots (1)$$

Water Content

One gram of the starch sample was weighed using an analytical balance and placed in a weighing bottle, then put into an oven at a temperature of 105°C for 4 hours to evaporate the water content. Weigh the sample and repeat the weighing of the weight change of the sample after ovening. The water content can be calculated using the Equation 2.

$$\text{Water content} = \frac{\text{Initial Sample Weight (g)} - \text{Final Sample Weight (g)}}{\text{Initial Sample Weight (g)}} \times 100\% \dots\dots\dots (2)$$

Color

Color can be measured using a chromameter that shows the spectrum intensity L, a, b (L: lightness, a: greenness-redness, and b: blueness-yellowness). The color difference (ΔE) can be calculated using the Equation 3.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \dots\dots\dots (3)$$

Water Holding Capacity (WHC)

Water Holding Capacity (WHC) testing is carried out to measure the ability of starch to hold water. A one-gram starch sample is weighed using an analytical balance and placed in a centrifuge tube. Then, 10 mL of distilled water is added to the sample. This mixture is homogenized by shaking or stirring slowly using a vortex for 1 minute to ensure that the starch evenly absorbs the water. After homogenization, the mixture is incubated at room temperature for 30 minutes to allow enough time for the starch to absorb water. After that, the mixture is centrifuged at 3,000 rpm for 15 minutes to separate free water from water bound by starch. The supernatant (free water) is discarded, and the remaining residue (wet starch) is weighed. WHC can be calculated using Equation 4.

$$\text{WHC (g water/g starch)} = \frac{\text{Wet Starch Weight (g)} - \text{Dry Starch Weight (g)}}{\text{Dry Starch Weight (g)}} \dots\dots\dots (4)$$

Oil Holding Capacity (OHC)

Oil Holding Capacity (OHC) testing aims to determine the ability of starch to absorb and retain oil. A 1-gram starch sample is weighed using an analytical balance and placed into a centrifuge tube. Next, 10 mL of cooking oil is added to the tube. The mixture is homogenized by shaking or using a vortex for 1 minute to ensure the starch is evenly distributed and absorbs the oil. The mixture is then incubated at room temperature for 30 minutes to allow the starch to absorb the oil. After incubation, the mixture is centrifuged at 3,000 rpm for 15 minutes to separate the free oil from the oil bound to the starch. The supernatant (free oil) is discarded, and the remaining residue (oily starch) is weighed. The OHC value can be calculated using equation 5.

$$\text{OHC (g oil/g starch)} = \frac{\text{Weight of Oily Starch (g)} - \text{Weight of Dry Starch (g)}}{\text{Weight of Dry Starch (g)}} \dots\dots\dots (5)$$

Starch Morphology

Starch morphology testing using Optilab light microscope to observe the shape, size, and distribution of granules. Dry starch samples were placed on a glass slide, added with a dispersing solution (10% glycerol), and covered with a cover glass. Images were taken using an Optilab camera at 40x–100x magnification and analyzed with software to measure the parameters of granule diameter and shape.

RESULT AND DISCUSSIONS

Avocado Seed Starch Yield

The analysis of avocado seed starch yield showed that overall, sonication of avocado seeds significantly affected the yield of starch produced. There was a tendency for yield to decrease as the duration of sonication increased. These results indicate that the duration of sonication is an essential factor that can affect the starch extraction process.

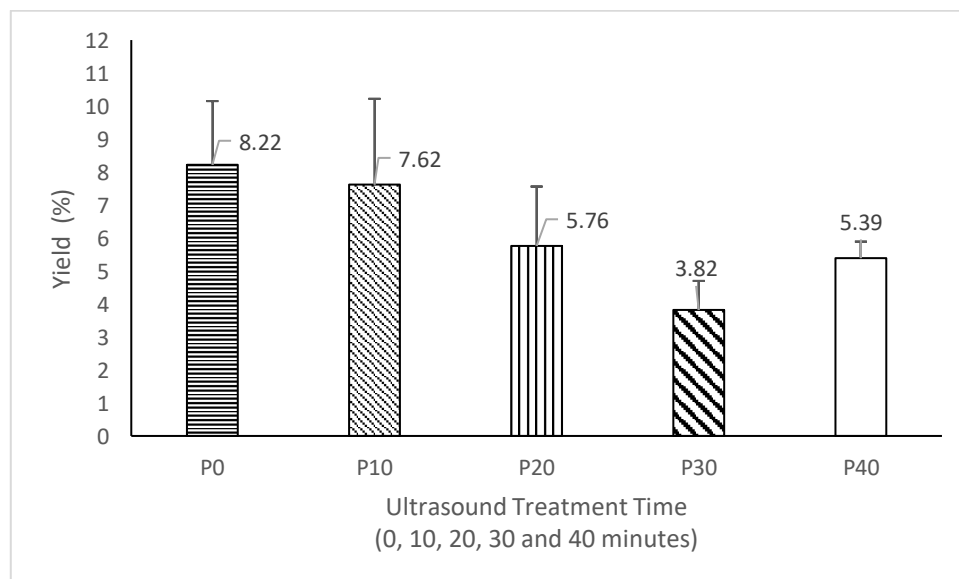


Figure 1. Avocado seed starch yield.

Figure 1 shows the highest yield obtained in the treatment without ultrasound (P0) of 8.22%, which is not statistically significantly different from the 10-minute treatment (P10)

with a yield of 7.62%. This shows that short-duration ultrasound exposure (10 minutes) has not had a negative impact on the results of avocado seed starch extraction. Treatment with a longer ultrasound duration, namely 20 minutes (P20), decreased yield to 5.76%, and reached the lowest value in the 30-minute treatment (P30) of 3.82%, which is statistically significantly different from P0 and P10. Starch yield increased slightly in the 40-minute treatment (P40) to 5.39%, but did not show a statistically significant difference. The yield results were still lower than the control. The decrease in yield at a longer ultrasound duration is thought to be caused by damage to the cell structure and degradation of starch granules due to the cavitation effect produced by ultrasound waves. The mechanical impact of high-intensity ultrasound for a long duration can cause disintegration or even partial dissolution of starch in the solvent medium, thus reducing the amount of starch that can be effectively extracted. Ultrasonic treatment mainly increases the movement of starch molecular chains through mechanical effects, cavitation effects, and thermal effects, changing the physicochemical properties of starch through the influence on starch granules' surface and internal structure (Li et al., 2023). Therefore, sonication duration must be carefully optimized to achieve maximum extraction efficiency without compromising starch quality and recovery. The phenomenon of cavitation is the basis for various ultrasound applications in food processing, such as extraction, structural modification, solubility enhancement, and process efficiency enhancement. The energy generated from cavitation in the ultrasound process can cause granule cracking, changes in particle size distribution, and increased porosity and surface reactivity (Zhang et al., 2018).

From an application standpoint, prolonged ultrasonic treatment—although reducing yield—may enhance certain functional properties of starch, such as increased solubility, porosity, and enzymatic digestibility due to granule disruption and surface modification. These changes can be advantageous for applications that require high reactivity or faster gelatinization, such as in biodegradable films, thickeners, or pharmaceutical binders. However, for applications that require high-purity or intact granule structures, such as native starch used in food formulations, excessive sonication could be detrimental (Suri et al., 2025 & Violalita et al., 2025). Thus, the optimal ultrasound duration should balance between maintaining yield and achieving desirable starch functionality for specific end uses.

Water Content

Based on the results in Figure 2, the duration of sonication has an effect, but is not significant, on the water content of avocado seed starch. There is no tendency for a linear increase or decrease in water content as the duration of treatment increases. Sonication for 10 minutes (P10) produces the highest water content, which is 8.71%, and is statistically significantly different from treatment for 30 minutes (P30), which produces the lowest water content of 5.89%. Treatment without ultrasound (P0) shows a water content of 7.20%, while treatments for 20 minutes (P20) and 40 minutes (P40) each provide water content of 6.88% and 8.56%.

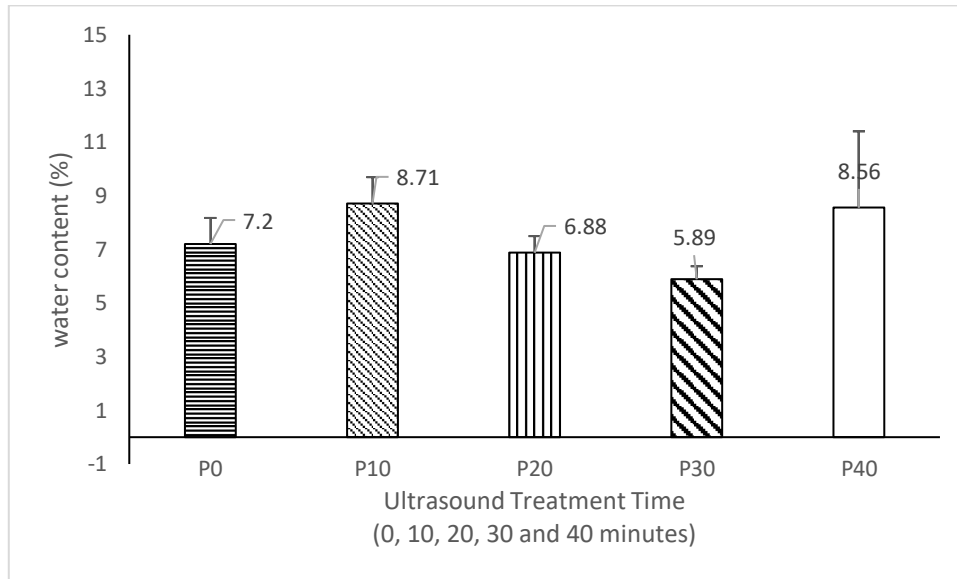


Figure 2. The water content of avocado seed starch.

The difference in water content is related to changes in the physical structure of starch granules due to sonication. Low to medium intensity ultrasound waves, such as in the 10-minute and 40-minute treatments, can increase network porosity and form microchannels that can hold water during the drying process, resulting in a higher water content in the final product. Conversely, longer treatments, such as 30 minutes, may cause greater structural damage to starch granules, facilitating more efficient water release during drying.

Starch color

Sonication affects the color parameters (L^* , a^* , b^*) and the whiteness index (WI) of avocado seed starch. The measurement results are presented in Table 1. The L^* value, which indicates the brightness level of starch, was not significantly affected by increasing the duration of sonication. Control starch (P0) had an L^* value of 86.36, while in the 40-minute treatment (P40), this value decreased to 80.30. The decrease in the L^* value reflects a reduction in the brightness level, which can be associated with changes in the surface structure of starch granules due to the cavitation effect of ultrasound waves (Majid et al., 2015).

Table 1. Color profile and whitening index of avocado seed starch

Sonication Time (minutes)	Color Profile			WI (%)
	L^*	a^*	b^*	
0	86.36 ^a	4,31 ^a	9,92 ^a	82,41 ^a
10	86.65 ^a	3,71 ^{ab}	10,36 ^a	82,59 ^a
20	83.01 ^a	4,12 ^{ab}	8,77 ^a	80,07 ^a
30	83.20 ^a	3,52 ^{ab}	9,17 ^a	80,58 ^a
40	80.30 ^a	2,30 ^b	5,76 ^b	82,10 ^a

This mechanical effect causes surface cracks or even the release of color compounds that can affect the visual characteristics of starch. Meanwhile, the a^* value, which reflects the intensity of the red color, decreased from 4.13 at P0 to 2.43 at P40. The decrease in

the a^* value indicates a color shift towards green or neutral. The b^* value, which means the intensity of the yellow color, also decreased gradually from 9.99 (P0) to 5.76 (P40), indicating a decrease in the yellowish hue of the starch as the ultrasound duration increased. The reduction in the a^* and b^* values is likely due to the degradation of natural pigments dissolved by sonication. The average Whiteness Index (WI) value is 80.07-82.59%. The duration of ultrasound on avocado seed starch does not significantly affect WI. The WI value is close to perfect white with an L degree of 100%. Suweg flour produced from the blanching process and sodium metabisulfite soaking has an L value ranging from 83.26-84.23% (Ferdiansyah et al., 2007). Natural starch extracted from cassava has a brightness level value of 84.81% (Satmalawati et al., 2024).

Water Holding Capacity (WHC) and Oil Holding Capacity (OHC)

Sonication of avocado seed starch significantly affected the water absorption capacity (WHC) and oil absorption capacity (OHC). The data are shown in Table 2.

Table 2. Water Holding Capacity and Oil Holding Capacity of avocado seed starch

Sonication Time (minutes)	WHC (%)	OHC (%)
0	85,38 ^{bc}	152,62 ^b
10	94,35 ^c	119,36 ^a
20	74,73 ^a	103,04 ^a
30	81,33 ^{ab}	113,37 ^a
40	79,45 ^{ab}	94,39 ^a

The highest WHC value was obtained in the sonication for 10 minutes (P10) at 94.35%, significantly different from other treatments. In contrast, the 20-minute treatment (P20) showed the lowest WHC value, 74.73%. In general, the WHC value fluctuated, not showing a linear trend against the duration of treatment. Control starch (P0) had a WHC of 85.38%, which was in the moderate category and was not significantly different from the P30 and P40 treatments. The increase in WHC in the P10 treatment was likely caused by the modification of the microstructure of starch granules due to the mechanical effects of ultrasonic waves, which caused the formation of pores and an increase in the effective surface area, allowing more water molecules to be retained (Indriyati et al., 2016). Too long a duration, such as P20 and P40, can cause excessive structural disruption or molecular compaction, thereby reducing the ability of the granules to bind water.

In the OHC parameter, control starch (P0) has the highest capacity to hold oil, which is 152.62%, statistically significantly different from sonication. Sonication causes a decrease in OHC value, with the lowest value at P40 of 94.39%. This indicates that sonication actually reduces the affinity of starch for oil, which can be associated with degradation of hydrophobic bonds or a decrease in the ability of the tissue to physically absorb oil molecules. The decrease in OHC can also be caused by the loss of hydrophobic structure due to microstructural damage due to prolonged ultrasound waves. Some amylose will be released from starch granules due to the ultrasound process. Reduced amylose will cause a decrease in starch capacity, especially water and oil binding capacity (Zhang et al., 2018).

Furthermore, the increase in water-holding capacity (WHC) and the decrease in oil-holding capacity (OHC) observed in this study align with the general trend reported by Liu et al. (2022), who found that ultrasonic modification enhances hydrophilicity while reducing lipid-binding sites due to structural loosening of the granule matrix. The results therefore support the potential of ultrasound as a green, non-chemical method to tailor starch functionality, particularly in applications requiring high water absorption, such as instant or rehydratable food systems.

Starch Morphology

Observation of the morphology of avocado seed starch granules using an optical microscope showed changes in starch granules due to sonication with different durations (Figure 2). Starch granules in the control sample (P0) appeared intact, oval to elliptical in shape, with a smooth surface, and showed no damage or pores.

Sonication for 10 minutes (P1), began to show changes on the surface of the granules, in the form of fine cracks and a surface that was no longer homogeneous. Treatment for 20 minutes (P2) caused increased structural damage, characterized by a rougher surface and the beginning of the formation of micropores. This condition indicates the disruption of the granule wall due to the cavitation effect of ultrasonic waves.

Granules in the 30-minute treatment (P3) showed more obvious damage, with the surface of the granules appearing irregular, cracks, and some granules appearing fragmented. Similar things were also observed in the 40-minute treatment (P4), where surface damage spread further and the granule morphology became more difficult to distinguish. This more damaged structure indicates that too long an ultrasound duration can cause significant granule degradation. The morphology and size of polysaccharides from various sources are affected by ultrasound (Cui & Zhu, 2021). Morphological changes are caused by the cavitation mechanism that occurs during the sonication process. The ruptured cavitation bubbles cause the release of energy in the form of shock waves, high local pressure, and strong microflows. The formation of friction or shear forces is sufficient to degrade polymers that show depressions and small gaps on the surface of the granules that can cause fragmentation and pore formation in starch granules. These morphological changes also affect the functional properties of starch, such as water and oil absorption capacity, and gelatinization characteristics. Corn starch and cassava starch, SEM analysis results show that ultrasonic treatment has a significant effect on the structure and size of starch molecules (Rahaman et al., 2021).

Ultrasound modification has the potential as a physical method to change the structure and functional properties of starch, but it needs to be controlled at an optimal duration so that the damage is not destructive to the functionality of the material. Morphological changes in starch granules due to sonication have a direct effect on the functional properties of starch, such as the ability to bind water (Water Holding Capacity/WHC) and oil (Oil Holding Capacity/OHC). Intact starch granules with smooth surfaces, as seen in the control sample (P0), generally show stable absorption capacity because their structure is still compact. However, sonication causes the formation of pores, cracks, and damage to the granule surface, which increases the specific surface area. This allows water to enter and be absorbed more easily into the granule structure, which explains the increase in WHC values in the P10 treatment. On the other hand, damage to the granule structure can also disrupt its internal integrity, so that its ability to hold oil actually decreases, as reflected by the decrease in OHC in most treatments. This phenomenon is in line with the

theory that physical modifications such as ultrasonic cavitation can disrupt the crystalline and amorphous order in granules, thereby affecting the interaction of starch with water and oil. Increasing the duration of ultrasonic, the molecular bonds in starch granules will break, so that the granules become loose and starch molecules are easily dissolved from the granules (Zhang et al., 2018). Thus, changes in granule morphology are not only indicators of physical damage due to sonication, but also play an important role in determining the potential technological applications of the starch, either as a thickener, gelling agent, or stabilizing agent in various food systems.

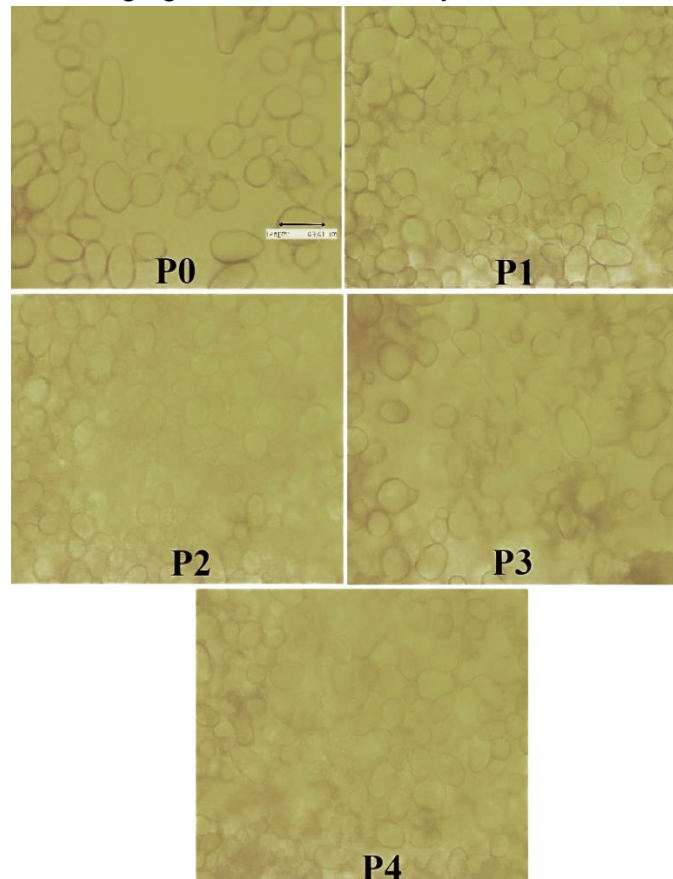


Figure 3. Morphology of avocado seed starch

In addition to affecting physical and functional properties, changes in granule morphology also reflect the level of disruption of the internal structure of starch due to sonication. Based on microscopic observations, the increase in cavitation intensity that occurs at longer sonication times causes more significant granule disintegration. This condition contributes to a decrease in the granules' structural integrity, which reduces the oil binding capacity, because the surface's ability to hold hydrophobic molecules is reduced. The sonication process can cause damage to the granule surface and release of the amylose fraction, reducing the binding capacity to oil. The structure of granules that have been physically modified by ultrasound tends to have a more porous surface, thereby increasing water absorption. Still, it is not always positively correlated with oil absorption, mainly if internal structure degradation occurs. This shows that the effect of ultrasound on granule structure is selective depending on the treatment parameters (frequency, power, and time) and the type of starch used (Cui & Zhu, 2020). The structure of polysaccharides changes after ultrasonic processing, causing modifications to their physicochemical and

biological properties. The frequency and intensity of ultrasonication, processing time, solvent temperature, and the source and composition of polysaccharides influence the level of these changes. Therefore, in the context of developing functional food ingredients, modification with ultrasound must be adjusted to the characteristics of the target application, for example, for products with high water binding capacity requirements (such as instant food preparations). Mild sonication conditions, such as in P10, can provide optimal results.

CONCLUSION

Sonication of avocado seeds significantly influenced the yield and characteristics of the starch produced. Prolonged ultrasound treatment tended to decrease starch yield due to structural disruption of the granules caused by cavitation effects. Nevertheless, ultrasound-assisted extraction demonstrated potential as an environmentally friendly technique to modify the physical and morphological properties of starch, improving its functionality for specific applications such as water-binding or instant food formulations. Future research should focus on optimizing sonication parameters—such as amplitude, duration, and temperature—to enhance extraction efficiency while maintaining starch quality, and to further explore its potential in food and biodegradable material development.

ACKNOWLEDGMENTS

Thank you to the Research and Community Service Institute of Veteran Bangun Nusantara University for providing a research grant with the Competitive Research Scheme in the Field of Science for 2024/2025.

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