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Physicochemical characteristics of modified tapioca using microwave heating

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ABSTRACT

Introduction: This study aimed to assess the physicochemical characteristics of tapioca modified by microwave heat treatment. **Methods**: The assessment was carried out using a one-factor Completely Randomized Design, namely microwave heat treatment with four levels of commercial tapioca. These included microwave tapioca (TMW), microwave washing tapioca (TPMW), and microwave soaking tapioca (TPRMW) with three replications. The variables observed were chemical tests including moisture and ash content, with physical characteristics such as solubility, swelling power, water, and oil holding capacity (OHC). The data obtained were assessed using MINITAB 21 analysis of variance, followed by Tukey's test when there was a significant difference. **Results**: The best treatment was found to be a modification of starch using microwave heat in TPRMW, producing 8.01% moisture content, 0.13% ash content, 32.80% swelling power, 24.76% solubility, 218.50% water holding capacity (WHC), and 176.93% OHC. **Conclusion**: Modification treatment using microwave heat caused chemical and physical changes in tapioca to experience a decrease in moisture content, ash content, swelling power, solubility, and OHC compared to natural tapioca. However, this treatment increased WHC, which was specifically observed for TPRMW.

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INTRODUCTION

Tapioca is starch produced through the extraction process of cassava, used as an additional ingredient in the food or non-food industry. Furthermore, it is processed into derivatives such as modified starch, mannitol, glutamic acid, ethyl alcohol, glucose, monosodium glutamate, dextrin, sorbitol, oxalic acid, and citric acid (Herawati, 2006). Compared to other starch sources, tapioca is exceptional in terms of supply, affordability, and ease of extraction, with the chemical composition of 73.40-85.00% starch, 0.03-0.60% protein, 0.09-1.54% fat, 0.02-0.33% ash, 17% amylose, and 83% amylopectin (Herawati *et al.*, 2012). Tapioca granules are semi-spherical with cone-shaped tips, ranging from 5 to 35 µm. Gelatinization temperature ranges between 52-64 °C, crystallinity at 38%, swelling power at 42%, and solubility at 31%. Despite the various advantages, the indigenous application of tapioca is still limited due to its underused physical and chemical characteristics. However, its functionality can be enhanced through physical, chemical, or combined modifications (Wang *et al.*, 2022) to alter the structure and affect hydrogen bonding.

Processing can be carried out physically or chemically, causing changes in physicochemical characteristics and enzymatic strength. Chemical modification of starch, including cross-linking and/or acetylation, is a commonly used modification method. However, increasing consumer demand for "natural foods" has led to the development of safer and more natural conversion methods such as physical modification through heat, moisture, mixing, and irradiation. Choiriyah *et al.* (2020) stated that physical modification could occur through heat treatment, rubbing, irradiation, and freezing. Steam or other traditional heating methods are often used as heat generators in starch hydrolysis, which requires long start-up times and uneven heat distribution, despite stirring assistance. This limitation has prompted the use of microwave as an alternative to traditional heating methods.

Microwave ovens are heating appliances that operate at a frequency range of 300-300,000 MHz as a heat amplifier. In enzymatic starch hydrolysis processes, microwave heating outperforms the traditional method (Santoso & Handayani, 2014), offering shorter reaction times, higher yields, faster, and increased selectivity. According to Lewicka *et al.* (2015), the advantages of using microwave include rapidity, heating selectivity, volume heating, environmental friendliness, and reduced operating costs, as energy is concentrated on the material to be improved. Microwave heating also serves as a treatment used in the processing of corn starch, potatoes, chestnuts, Bambara groundnuts, etc (Wang *et al.*, 2019; Oyeyinka *et al.*, 2019; Li *et al.*, 2018; Mutlu *et al.*, 2017). This treatment causes changes in granule morphology, crystal structure, and the breaking of long dextran chains (Xie *et al.*, 2013), enhancing the physicochemical characteristics of natural starch (Oyeyinka *et al.*, 2019). A higher availability of water molecules will cause more vibrations in the starch matrix and produce more heat. Therefore, starch in this study is pre-treated by washing or soaking in distilled water before microwave heating to investigate the effects on physicochemical characteristics of modified starch compared to natural starch.

METHODS

Materials and equipment

The materials used included the commercial tapioca brand Gunung Agung. Furthermore, the equipment used included a Kris microwave Model P90D23ATL-XF (China) with a maximum power of 1400 W, a Sharp refrigerator, a Memmert oven, a Phillips crusher, a Vulcan A550 Ney furnace (USA), a Memmert water bath, a Cole Parmer vortex, and a PLC Series centrifuge.

Study procedure

The starch modification process was divided into three parts, namely microwave tapioca (TMW), microwave washing tapioca (TPMW), and microwave soaking tapioca (TPRMW).

Microwave tapioca (TMW)

Tapioca with 13% moisture content was heated using the microwave, referred to as the control treatment (TMW). Approximately 100 g of tapioca was placed in a refrigerator at 4°C for 12 hours, followed by exposure to room temperature, and microwave heating at 10% power for 30 minutes. Subsequently, modified starch was packed using a zip-lock plastic bag and stored in the refrigerator (Marta *et al.*, 2019).

Microwave washing tapioca (TPMW)

A total of 100 g of tapioca was washed with distilled water (ratio 1:1.75), placed in the refrigerator at 4°C for 12 hours, was left at room temperature. This process was followed by microwave heating at 10% power for 30 minutes (TPMW) and modified tapioca was placed in an oven at 50°C for 24 hours, crushed, sieved (60 mesh), packed with a zip-lock plastic bag, and stored in the refrigerator (Marta *et al.*, 2019).

Microwave soaking tapioca (TPRMW)

A 100 g of tapioca was soaked in water (ratio 1:5), stirred, filtered using filter paper, placed in the refrigerator at 4°C for 12 hours, and allowed to stand at room temperature. The soaked tapioca was heated using microwave at 10% power for 30 minutes (TPRMW) and the sediment was placed in an oven at 50°C for 48 hours. Subsequently, tapioca was crushed, sieved (60 mesh), packed using a zip-lock plastic bag, and stored in the refrigerator (Marta *et al.*, 2019).

Analysis of moisture content

A cup was heated in an oven at 105°C for 1 hour and the weight was measured. Subsequently, 3 g of the sample was weighed and heated in an oven at 105°C for 3 hours until a constant weight was obtained. Before weighing, the cup with the sample was placed in a desiccator for 15-20 minutes.

Ash content

A total of 5 grams of starch sample was weighed in a porcelain cup that had been previously dried and weighed. The sample was burned using an electric stove until no smoke was emitted, followed by treatment in a furnace at 650°C until white-gray ash was obtained with a constant weight. Subsequently, the ash content of the sample was determined by weighing the remaining mineral after burning the organic matter.

Swelling power and solubility

Swelling power and solubility of starch were determined by following the method of Picauly *et al.* (2017). A 10% starch sample was transferred into a clean dried test tube and reweighted (W_1). The starch was then dispersed in 10 mL of distilled water. The slurry was heated in the water bath at 95°C for 30 minutes. The starch gel was cooled, and centrifuged at 3000 rpm for 30 minutes, followed by separation of sediment and supernatant. The supernatant was dried and the residue was weighed as the soluble starch, while the sediment (gel) was weighed as the insoluble starch (W_2). Subsequently, the calculation of swelling power and solubility was carried out using Equations 1 and 2.

$$\text{Swelling power } \left(\frac{g}{g}\right) = \frac{\text{W2}-\text{W1}}{\text{sample weight}} \ldots (1)$$

$$\text{Solubility } (\%) = \frac{(\text{dry sample weight})-(\text{empty cup weight})}{\text{sample weight}} \times 100\% \ldots (2)$$

Water holding capacity (WHC)

WHC was measured following the method of Kim & Huber (2013). A total of 0.2 g of starch was suspended in 4 mL of distilled water and vortexed for 1 minute. Subsequently, the starch suspension was left for 10 minutes at room temperature and centrifuged for 15 minutes at 1000 rpm. This was followed by weight measurement of the sediment and calculation of WHC using Equation 3.

$$\text{WHC (\%)} = \frac{W_1}{W_0} \times 100 \ldots (3)$$

Note: W_0 is the initial sample weight before treatment (g) and W1 is the final sample weight (g) after treatment.

Oil holding capacity

OHC was measured according to the method of Kim & Huber (2013). Initially, 6 mL of olive oil was added to 0.5 g of sample in a 10 mL centrifuge tube, which was vortexed for 1 minute and left for 30 minutes. Furthermore, the tube was centrifuged for 25 minutes at a speed of 3000 rpm. The supernatant was discarded, followed by sediment weighting and calculation of OHC using Equation 4.

$$\text{OHC (\%)} = \frac{W_1}{W_0} \times 100 \ldots (4)$$

where: W0 is the initial sample weight before treatment (g) and W1 is the final sample weight (g) after treatment.

Data analysis

The data obtained were analyzed using analysis of variance with Minitab 20 software. When there were significant effects of treatment, Tukey's test ($\alpha = 0.05$) would be conducted to determine the difference between means.

RESULTS AND DISCUSSION

Moisture content

The success of food processing depends on the amount of moisture content. In this study, TMW, TPMW, and TPRMW treatments showed a highly significant effect ($P < 0.01$) on the starch moisture content variable, as presented in Table 1. According to Tukey's test, natural tapioca showed no significant difference compared to TMW but varied from TPMW and TPRMW. Based on the results, the moisture content of modified tapioca ranged from 8.01-12.68% and natural tapioca had higher values. In previous studies, Sago (Zailani *et al.*, 2022) and potato starch (Awokoya *et al.*, 2020) also showed that the moisture content of the sample heated in the microwave was lower compared to others.

Table 1. Chemical characteristics of natural and modified tapioca

Treatment	Moisture Content(%)	Ash Content (%)
Commercial Tapioca	13.02±0.04 b	0.26±0.03 a
TMW	12.69±0.16 b	0.22±0.01 ab
TPMW	11.47±0.96 ab	0.19±0.02 b
TPRMW	8.01±0.35 a	0.13±0.01 c

Description: TMW= Microwave Tapioca, TPMW= Microwave Washing Tapioca, TPRMW= Microwave Soaking Tapioca. Different letters behind the mean values in the rows do not show significant differences based on Tukey's test ($\alpha = 0.05$).

The decrease in moisture content after being heated using microwave was attributed to changes in starch structure. Specifically, the decrease in moisture content using TPRMW was caused by microwave heating, which could be associated with water evaporation due to drying after 48 hours. This was consistent with the previous study, where TPRMW experienced a decrease of 11.87% when heated using microwave (Awokoya *et al.*, 2020), causing the inability of starch to hold water. Starch damage occurred in TPRMW, allowing for a lower moisture content compared to others, showing a good functional property, particularly for food ingredients. Low moisture content also helps extend the shelf life of starch by reducing the possibility of fungal and bacterial growth during storage. However, the low moisture content in TPRMW differed from Zailani *et al.* (2022), where sago starch modified with microwave heating for washing and soaking method had the same moisture content of 12%.

Ash content

Ash content is a mixture of mineral or inorganic components found in food ingredients, resulting from the combustion or oxidation process of organic components. In this study, ash content was measured to determine the amount of minerals in the ingredients, related to purity and cleanliness (Liestianty *et al.*, 2016). Based on the results, TMW, TPMW, and TPRMW treatments had a highly significant effect ($P < 0.01$) on the ash content variable, as shown in Table 1. This showed that the ash content of modified tapioca was influenced by various treatments applied. According to Tukey's test, TMW was not different from natural tapioca and TPMW but varied significantly from TPRMW.

As shown in Table 1, the ash content of modified tapioca ranged from 0.13% to 0.22%, while TPMW had a higher value of 0.19% compared to TPRMW at 0.13%. This result was consistent with Zailani *et al.* (2022), where ash content in sago starch with soaking method was lower due to longer contact with water. According to Akpa & Dagde (2012), ash components in ingredients easily decompose or vaporize due to the presence of water and temperature.

Swelling power

Swelling power is the ability of starch to expand when heated, influenced by several factors such as chain length and the ratio of amylose to amylopectin. In this study, TMW, TPMW, and TPRMW treatments have a highly significant effect ($P < 0.01$) on the swelling power variable, as shown in Table 2. This showed that the swelling power of tapioca was influenced by the initial conditions before heating. According to Tukey's test, natural tapioca differed significantly from other modification treatments, while there was no substantial difference among TMW, TPMW, and TPRMW.

Table 2. Chemical characteristics of natural and modified tapioca

Treatment	Swelling Power (g/g)	Solubility (%)	WHC (%)	OHC (%)
Commercial Tapioca	38.39±2.54 a	28.57±1.42 a	204.88±7.0 ab	245.86±3.16 a
TMW	34.07±1.10 b	25.95±2.29 a	189.66±7.65 b	239.13±2.38 a
TPMW	34.06±0.28 b	21.66±1.48 ab	202.50±7.69 ab	216.53±6.81 b
TPRMW	32.80±0.54 b	24.76±0.82 b	218.50±13.25 a	176.93±3.33 c

Description: The analysis data are presented as means±standard deviations, TMW= Microwave Tapioca, TPMW= Microwave Washing Tapioca, and TPRMW= Microwave Soaking Tapioca. Different letters in the same column show significant differences based on Tukey's test ($\alpha = 0.05$).

Based on the results, the swelling power of modified tapioca ranged from 32.80 to 38.39 g/g, showing that TPRMW had a lower value compared to TPMW. According to Zailani *et al.* (2022), the high swelling power value of TPRMW was influenced by the amylose content, which leached during gelatinization and facilitated the enlargement of the gel structure. However, when amylose leached out excessively, there would be difficulty in the formation of a gel network. The decrease in swelling power in TPMW after using microwave heating could result from the rearrangement of crystal regions in starch granules, enhancing random distribution within starch granules (Zia-ud-Din *et al.*, 2017).

Solubility

Modified tapioca using microwave heating has a significant effect ($P < 0.01$) on solubility, showing the substantial influence of the treatment. According to Tukey's test, natural tapioca did not differ from TMW and TPMW but varied significantly from TPRMW, as shown in Table 2.

Based on the results, natural tapioca solubility showed a high value of 28.57% compared to microwave heating, indicating easy dissolution in water (Ariyantoro *et al.*, 2020). The results showed that TPRMW had a solubility of 24.76%, higher than TPMW at 21.66%. Zailani *et al.* (2022) reported that microwave-heated sago starch using the soaking method showed higher solubility. According to Zeng *et al.* (2015) and Ye *et al.* (2019), solubility was influenced by amylose content and low molecular weight amylopectin, which were easily converted into soluble molecules due to degradation.

WHC

The ability of food materials to absorb and retain water within the molecules is called WHC. In this study, microwave heating had a significant effect on the WHC of modified tapioca ($P < 0.05$), showing the impact of the treatment. According to Tukey's test, natural tapioca did not significantly differ from TMW, TPMW, and TPRMW, as shown in Table 2. Based on the results, WHC in natural tapioca had a higher value of 204.88% compared to TMW and TPMW but lower than TPRMW. These results show that TPRMW had the highest WHC value of 218.50%, followed by TPMW at 202.50%, and TMW at 189.66%. Similarly, Wang *et al.* (2019) reported that TPRMW with microwave heating showed an increase in WHC at 1.76% due to starch degradation into dextrin, maltose, and glucose, with higher affinity for water.

OHC

Starch has the physical ability to absorb and retain oil, known as OHC, which plays an essential role in maintaining taste and enhancing mouthfeel in food. In this study, microwave heating of modified tapioca had a significant effect ($P < 0.01$) on OHC, showing the positive impact of the treatment applied. According to Tukey's test, natural tapioca did not significantly differ from TMW but varied differs from TPMW and TPRMW.

The data analysis results showed that OHC in natural tapioca has a high value of 245.86% compared to other modification treatments, as presented in Table 2. After tapioca passed through microwave heating, a decrease was observed in OHC value for TMW 239.13%, TPMW 216.53%, and TPRMW 176.93%. Based on the results, the OHC value in TPMW was higher compared to TPRMW. Similarly, Zailani *et al.* (2022) reported that sago starch heated with microwave in the washing method had a higher OHC value, causing an increase in surface area for oil molecules to bind.

The increase in surface area due to the formation of gaps and irregularities on the granule surface during the washing process enhanced OHC (Retnaningtyas *et al.*, 2014).

CONCLUSION

In conclusion, this study showed that modification treatment through microwave heating caused chemical and physical changes in tapioca. This treatment caused tapioca to decrease in moisture content, ash content, swelling power, solubility, and OHC compared to natural tapioca but increased WHC for TPRMW.

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