

Functional Properties of Heat-Moisture-Treated Arrowroot (*Maranta arundinacea* L.) Flour for Instant Porridge Application

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Abstract

Instant porridge, usually made from high glycemic index rice flour, can be substituted with arrowroot flour, which has a lower glycemic index. Heat moisture treatment (HMT) can enhance the water absorption capacity of arrowroot flour. This research aims to determine the effect of HMT temperature and time on the physicochemical characteristics and functional properties of arrowroot flour, to obtain the optimum HMT conditions based on water absorption capacity, and to determine the physicochemical characteristics and functional properties of the resulting instant arrowroot porridge. The HMT treatment was conducted at temperatures of 100°C, 110°C, and 120°C for 30 min, 60 min, and 90 min. The experimental design was a Completely Randomized Design (CRD) with two factors arranged in a 3 × 3 factorial scheme, with three replications per treatment. This research was conducted in 3 stages of laboratory scale experiment: (i) preparation of arrowroot flour, (ii) arrowroot flour modification, and (iii) instant arrowroot porridge production. The results showed that HMT increased yield, water absorption capacity, total dietary fiber content, and resistant starch content of the arrowroot flour. Meanwhile, moisture content, total carbohydrate content, and glycemic carbohydrate decreased. The selected conditions for HMT arrowroot flour treatment were at 110°C for 60 min, which resulted in the highest water absorption capacity (2.11 g/g). The characteristics of instant arrowroot porridge include 11.03% moisture content, 2.32 g/g water absorption capacity, 2.69 ml/g rehydration capacity, 25.89 s/g rehydration time, 70.70% total carbohydrate content, 6.60% dietary fiber content, 64.10% glycemic carbohydrate, and 5.62% resistant starch content. This study shows that HMT-modified arrowroot flour could be a healthier alternative to rice flour in food products manufacturing, offering a lower glycemic index. The improved functional properties, specifically the higher water absorption and dietary fiber content, make it suitable for the preparation of various food products designated to control blood sugar levels.

Keywords: arrowroot flour; glycemic index; heat moisture treatment; instant porridge; water absorption capacity

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INTRODUCTION

Diabetes Mellitus (DM) is a chronic disease indicated by a high blood glucose level that affects

human metabolism. According to the International Diabetes Federation (IDF), Indonesia ranks fifth in the world, with 19.5 million people aged 20–79 living

with diabetes in 2021 with Type II diabetes contributed the most common type. In fact, poor blood sugar levels management can lead to more serious complications, such as heart disease, kidney failure, and nerve damage. A key way to manage diabetes is by consuming foods with a low glycemic index (GI), which helps maintaining blood sugar levels steady (Afandi, 2019). Carbohydrates-rich foods can induce the raise of blood sugar levels. This is because carbohydrates can be categorized into glycemic carbohydrates (which are digested and absorbed by human digestion system) and non-glycemic carbohydrates (like dietary fiber and resistant starch, which are not absorbed by human digestion system). Consumption of foods with high glycemic carbohydrates have a high glycemic index, which can lead to higher blood sugar levels (Devindra *et al.*, 2017).

Nowadays, many people prefer fast food, making instant products popular. One of the common fast foods is instant porridge, which is usually made from rice flour with a moderate glycemic index of 62.8 (Afandi, 2019). In general, instant porridge is prepared from cereals, which rice flour becomes the most popular choice in Indonesia (Khoirina *et al.*, 2019). However, alternative raw materials, such as cassava flour and Kimpul flour have also been utilized for instant porridge preparation (Kasih and Murtini, 2017). Since rice-based instant porridge has a high glycemic index that leads to significant increase in risk of type II diabetes, obesity, and other metabolic disorders prevalence. flours with lower glycemic indices can be the healthier substitutes. For instance, banana flour has been reported to enhance dietary fiber, resistant starch, and antioxidant activity in instant porridge formulations (Loypimai and Moongnarm, 2015).

Arrowroot (*Maranta arundinaceae* L.) has a much lower glycemic index (14) compared to rice, potato, and cassava, whose glycemic indexes are 67, 82, and 79, respectively. It also has a lower glycemic index than other tubers like kimpul, gembili, sweet potatoes, and canna, with a glycemic index of 95, 90, 179, and 105, respectively (Afandi, 2019). This makes arrowroot safe for consumption by people with diabetes mellitus (Slamet *et al.*, 2019). Arrowroot can be further processed into arrowroot flour and then utilized in the preparation of instant porridge. However, arrowroot flour has a low water absorption capacity, which is 1.13 g/g dry weight (Marta *et al.*, 2023). This impacts the rehydration capacity and the time taken to achieve rehydration of the instant porridge and therefore reduces its effectiveness. In this case, arrowroot flour can be treated through Heat Moisture Treatment, or HMT to increase water absorption and improve rehydration capacity. Heat Moisture Treatment (HMT) is a physical modification process in which the moisture content of the starch granules is reduced below 35% and then heated between 84–120°C for a given time. Marta *et al.* (2023) observed that arrowroot flour modified with

HMT at 100°C for 8 h has a water absorption capacity of 1.35 g/g dry weight, while the natural arrowroot flour has a water absorption capacity of 1.13 g/g dry weight. In the same way, Damat *et al.* (2022) investigated the effect of HMT at 105 °C for 16 h on arrowroot flour, and it positively affected the resistant starch content in analog rice. Furthermore, a study by Guo *et al.* (2014) showed that the HMT of chestnut flour could enhance total dietary fiber, which ranged from 7.06 to 13.42 g/100 g.

Several studies have explored the use of HMT on arrowroot flour or other types of flour to improve specific characteristics or to develop products by mixing arrowroot with other flours. However, these studies mostly focused on general starch modification or different end products, not on instant porridge. There is limited research that specifically applies HMT to pure arrowroot flour for the production of instant porridge, especially to improve its functional properties such as texture, rehydration, and nutritional value. The specific objectives of the study are to: Determine the effect of HMT temperature and time on the physicochemical properties and functional properties of arrowroot flour, Determine the optimum HMT temperature and time based on the water absorption capacity of arrowroot flour, Identify the physicochemical properties and functional properties of instant arrowroot porridge prepared with the selected HMT temperature and time.

This study aims to fill the gap in research by applying HMT to arrowroot flour for instant porridge. By improving the flour's properties, the research hopes to create a healthier instant porridge option. This could provide a useful food choice for people with diabetes and those who are looking for better food alternatives.

MATERIALS AND METHODS

Material Collection

The main raw material used in the study was arrowroot tubers sourced from Tasikmalaya, West Java (aged 14 months), which served as the base ingredient for flour and instant porridge production. Various food additives and seasonings such as premium granulated sugar (Rosebrand, PT Sungai Budi, Indonesia), salt (Dolpin, PT Susanti Megah, Indonesia), soy sauce (Indofood, PT Indofood Sukses Makmur Tbk, Indonesia), garlic powder (Koepoe-Koepoe, PT Gunacipta Multirasa, Indonesia), and white pepper powder (Koepoe-Koepoe, PT Gunacipta Multirasa, Indonesia) were used for instant porridge formulation. Sodium metabisulfite (Merck, Germany) was applied as a preservative during the flour production process to prevent browning. For chemical analysis, Anthrone reagent (Sigma-Aldrich, USA), glucose (Merck, Germany), sulfuric acid (H₂SO₄, Smart-Lab, Indonesia), α -amylase, β -amylase, pepsin, phosphate buffer pH 7, 1 N HCl, and 1 N NaOH (all from Merck, Germany) were used. Ethanol (95%), acetone, distilled water, and silica gel (Merck,

Germany) were also used for extraction and purification steps during the analysis.

Production of arrowroot flour

In the preliminary stage, arrowroot flour was prepared by washing the tubers and then peeling them. The tubers were then cut into about 5 mm thick slices and treated with sodium metabisulfite solution (0.2 g / 100g). The arrowroot slices were treated with air-drying for 15 h at a temperature of 50°C in a cabinet dryer. After drying, the slices of arrowroot were crushed with a grinder. The obtained powder was passed through an 80-mesh sieve to get arrowroot flour, which was followed by physicochemical characteristic analysis.

Sodium metabisulfite was added during the flour preparation step to prevent browning caused by enzymatic reactions. This compound acts as an antioxidant and is commonly used in food processing. The concentration used was within safe limits according to food safety standards.

HMT modification of arrowroot flour

HMT is a method used to change the properties of arrowroot flour by heating it at different temperatures and times. Main research phase I involved the HMT modification of arrowroot flour, analysis of its physicochemical characteristics, and determination of the optimal HMT temperature and time based on water absorption capacity. In this phase, a Completely Randomized Design (CRD) with two factors and a 3×3 factorial arrangement was employed. The first factor was the HMT temperature applied to the arrowroot flour (100°C, 110°C, and 120°C), and the second factor was the treatment duration (30, 60, and 90 min). Each treatment combination was replicated three times. To produce HMT-modified arrowroot flour, 500 g of arrowroot flour was weighed, and its moisture content was adjusted by adding distilled water until it reached 20% moisture content. The amount of distilled water added was calculated using the following equation:

$$(100\% - MC_1) \times W_1 = (100\% - MC_2) \times W_2 \quad (1)$$

Where:

MC_1 = initial moisture content (% wet basis)

W_1 = initial weight of the flour

MC_2 = desired moisture content of the flour (% wet basis) (moisture content analysis was not performed)

W_2 = weight of the flour after reaching MC_2

This was followed by placing of the suspension on a tray and covering it with aluminum foil. The suspension was then transferred to a tray and the tray was placed in the refrigerator at 4°C for 24 h. The suspension was then heated in an oven according to the HMT treatment at different temperatures (100-120°C and durations (30-90 min). Subsequently, it was dried in a cabinet dryer at 50°C for 8 h, ground

with grinder and sieved using an 80 mesh sieve to obtain HMT-modified arrowroot flour.

Production of instant arrowroot porridge

In this phase, instant arrowroot porridge powder was prepared by applying the selected HMT temperature and time and the samples were analyzed for their physicochemical properties and functional value. The instant arrowroot porridge powder was prepared by blending the formulation of arrowroot flour, sugar, salt, soy sauce, garlic powder, pepper powder and chicken broth in a pot. Table 1 shows the formulation for the instant arrowroot porridge which was used in the preparation of the final product.

Table 1. Formulation of instant arrowroot porridge powder

Ingredient	Amount
Arrowroot flour (g)	100
Sugar (g)	5
Salt (g)	2
Chicken broth (ml)	1000
Garlic powder (g)	2.5
White pepper powder (g)	1
Soy sauce (ml)	5

The next step involves heating the ingredients on a stove at 100°C while stirring until thoroughly mixed. The mixture is then cooled, transferred to a container, covered with plastic wrap, and stored in the freezer for one day. After one day, the porridge mixture is thawed to room temperature and poured onto a tray. The porridge mixture is then dried in a cabinet dryer at 50°C for 15 h. Once dried, the porridge mixture is ground using a grinder and sifted through a 60-mesh sieve, resulting in instant arrowroot porridge powder.

Determination of Physicochemical Properties

The preliminary research and Phase I analysis parameters include yield analysis, moisture content, water absorption capacity, total carbohydrate content, total dietary fiber content, glycemic carbohydrate, and resistant starch content for both arrowroot flour and HMT-modified arrowroot flour. The analysis parameters for Phase II include moisture content, water absorption capacity, rehydration capacity, rehydration time, total carbohydrate content, total dietary fiber content, glycemic carbohydrate, and resistant starch content for the instant arrowroot porridge.

The yield is calculated based on the ratio between the weight of the arrowroot flour produced and the weight of the arrowroot tubers used to make the flour. The yield of HMT-modified arrowroot flour is calculated by comparing the weight of the flour after HMT with the weight before HMT (Indriyani *et al.*, 2013).

Moisture Content, measured using the gravimetric method with an oven. First, an empty

evaporating dish was dried at 105°C until its weight stabilized, then placed in a desiccator for 30 min. Next, 5 g of the sample was added to the dish and weighed. The dish with the sample was then dried in the oven at 105°C for 1 h, placed in the desiccator for 15 min, and weighed again. This process was repeated until the weight remained constant (AOAC, 2010). The moisture content was calculated using the formula:

$$\text{Moisture content (\%db)} = \frac{(W1-W2)}{W2} \times 100\% \quad (2)$$

where: W1 = weight after drying, W2 = weight before drying

Water absorption capacity is measured using the centrifugation method. A 1 g sample is mixed with 10 ml of distilled water in a centrifuge tube and vortexed for 20 s. The sample is left at room temperature for 1 h and then centrifuged at 3500 rpm for 30 min. The supernatant volume is separated and measured (Marta *et al.*, 2023). The water absorption capacity on a dry basis is calculated using the formula:

$$\text{WAC (g/g db)} = \frac{\text{final sample weight} - \text{initial dry sample weight}}{\text{initial dry sample weight}} \quad (3)$$

Rehydration capacity is also measured using the centrifugation method. A 1 g sample is mixed with 10 ml of water and stirred. The sample is then left at room temperature for 30 min, followed by centrifugation at 3500 rpm for 30 min. The supernatant is separated and measured (Palijama *et al.*, 2020). Rehydration capacity is calculated using the formula:

$$\text{Rehydration capacity (ml/g)} = \frac{\text{initial water volume (ml)} - \text{supernatant (ml)}}{\text{sample weight (g)}} \quad (4)$$

Rehydration time is measured by adding hot water at 95°C to a 1 g sample until it is completely dissolved. The rehydration time is recorded from the moment the hot water is added and stirred manually until the sample forms a porridge-like texture (Kasih and Murtini, 2017).

Total Carbohydrate Content determined using the Anthrone method and calculated in dry basis (Guo *et al.*, 2014). First, a small amount of the sample is dissolved in water to extract the carbohydrates. The sample is then mixed with an Anthrone reagent, which reacts with the carbohydrates to produce a greenish-blue color. The mixture is heated to allow the reaction to fully occur, and then cooled. The intensity of the color is measured using a UV-Vis spectrophotometer (D-LAB SP V1000, DLAB Scientific Co., Ltd.) at the wavelength of 620 nm, with the color intensity being proportional to the amount of carbohydrates in the sample. Finally, the carbohydrate content is calculated by comparing the color of the sample to a standard curve made using known carbohydrate concentrations.

Total Dietary Fiber Content was analyzed using a multi-enzyme method. About 0.5 g of the sample was mixed with phosphate buffer (pH 7) and α -amylase, then incubated in a water bath at 100°C for 30 min. After cooling, distilled water, HCl, and pepsin were added, followed by another incubation. Then, NaOH and β -amylase were added, and the mixture was incubated again. The solution was filtered to separate the insoluble fiber, which was washed, dried in an oven at 105°C overnight, cooled in a desiccator, and weighed. The filtrate was then mixed with ethanol to precipitate the soluble fiber, which was also filtered, washed, dried, and weighed. The total dietary fiber content was calculated by adding the weights of the insoluble and soluble fiber (AOAC, 1995).

Glycemic Carbohydrate (AOAC, 2012; Devindra *et al.*, 2017). Glycemic carbohydrate is calculated using the formula:

$$\text{Glycemic Carbohydrate (\%)} = \frac{\text{Total carbohydrate content} - \text{Total dietary fiber content}}{\text{Total carbohydrate content}} \quad (5)$$

Resistant starch was measured using the multi-enzyme method. A total of 0.5 g of the sample was placed in an Erlenmeyer flask and added with 0.1 M phosphate buffer solution (pH 7), then stirred. About 0.1 ml of α -amylase enzyme was added. The Erlenmeyer flask was covered with aluminum foil and incubated in a water bath at 100°C for 15 min while stirring. The sample was then removed and cooled, followed by the addition of 20 ml of distilled water and 5 ml of 1 N HCl. Then, 1 ml of 1% pepsin enzyme was added to the flask, covered, and incubated in a water bath for 30 min. After that, 20 ml of distilled water and 5 ml of 1 N NaOH were added, along with 0.1 ml of β -amylase enzyme. The flask was covered and incubated in a shaking water bath for 30 min. The sample was then filtered using filter paper, and the residue was washed, dried, and analyzed. The resistant starch content was determined by hydrolyzing the residue with anthrone reagent, and the absorbance was measured using a spectrophotometer at 630 nm. The resistant starch content was then calculated based on a glucose standard curve (AOAC, 2007).

Statistical Analysis

Data analysis was performed using ANOVA and processed with IBM SPSS Statistics 26th version software. Data were analyzed using Analysis of Variance (ANOVA) to determine whether there were significant differences between treatments. ANOVA helps compare the means of multiple groups to see if at least one is statistically different. A significance level (α) of 0.05 was used, meaning a p-value less than 0.05 indicates a statistically significant difference. When ANOVA showed significant results, further analysis was done using post-hoc (Duncan's multiple range test) to identify which specific treatments were different.

RESULTS AND DISCUSSION

Effect of HMT Temperature and Time on Arrowroot Flour Yield

The yield of control arrowroot flour was calculated based on the weight of the flour produced from arrowroot tubers, considering the condition of the tubers before peeling. The yield of arrowroot flour in this study was 7.14%, which is lower than the yield reported by Malki *et al.*, (2023), which was $12.23 \pm 0.62\%$. This discrepancy is due to the use of a finer 80 mesh sieve in this study, resulting in less amount of flour passing through the sieve compared to the 425 μm or 40 mesh sieves used in the previous study.

The yield of HMT treated arrowroot flour was calculated from the arrowroot flour which was subjected to HMT treatment. Statistical analysis using ANOVA showed that the temperature ($p=0.015$) and heating time ($p=0.000$) had a significant effect on yield as did their interaction ($p=0.004$). The variations in yield values due to the interaction of temperature and heating time are presented in Figure 1.

As shown in Figure 1, increasing the temperature and extending the heating time generally led to higher arrowroot flour yield, particularly with the combination of HMT treatments. This finding contrasts with the study by Novita *et al.*, (2023), who observed a decrease in yield of suweg flour modified by HMT at 105°C for 4, 5, and 6 hours. The difference in trends may be attributed to variations in both the raw material and the treatment conditions. In the present study, arrowroot flour was treated at higher temperatures, but with shorter heating durations compared to Novita *et al.* (2023). Although the initial moisture content of the samples before HMT was similar, the differences in yield may be associated with the degree of starch rearrangement and retrogradation occurring during the process. Moderate HMT conditions could promote structural stabilization and improved starch recovery, while excessive heating might cause partial degradation of polysaccharide chains or loss of fine starch particles during post-treatment handling. These structural changes can influence the physical integrity of the flour, thus affecting the overall yield.

According to the Indonesian National Standard (SNI 01-6057-1999) for arrowroot flour, the fineness standard requires that at least 95% of the flour passes through a 100-mesh sieve. However, the arrowroot flour produced in this research does not meet this standard. This shortfall may be attributed to insufficient grinding time, which resulted in a coarser flour that could not pass through the finer sieve. In addition, the lower fineness of the HMT-modified flour may also be associated with agglomeration during the heat-moisture treatment process. At elevated temperatures and limited moisture levels, starch granules may partially fuse or aggregate, forming larger particles that are more difficult to grind and pass through fine sieves (Ariyantoro *et al.*, 2020).

Effect of HMT Temperature and Time on the Moisture Content of Arrowroot Flour

The moisture content results are presented in percentage on a dry basis. The results also show that the temperature, heating time, and their interaction all have a significant effect ($p<0.001$) on the moisture content of arrowroot flour. The variation of moisture content with temperature and heating time is presented in Figure 2.

The results shown in Figure 2 indicate that HMT temperature, time, and both temperature and time have a tendency to reduce the moisture content. This reduction is due to the fact that heat reduces the hydrogen bonds and water is able to penetrate the starch granules and cause an expansion of the structure of the granules. As a result, the granules become porous and have the ability to allow water to evaporate during the drying process (Pratiwi *et al.*, 2020). However, some variability was observed. For example, the treatment at 120°C for 90 min did not follow this trend and resulted in a higher moisture content. This may be caused by variations in the HMT process, for instance, the uneven thickness of the sample during the drying process or poor storage conditions (Budiarti *et al.*, 2021). This could also be related to structural changes in the starch granules that occur at high temperatures and longer heating times, such as partial collapse, fusion, or reduced porosity, which limit further water release. Similar structural alterations at excessive HMT conditions may also explain the slight decrease in water absorption capacity observed in Figure 3, where overheating likely caused partial damage to the starch matrix, reducing its ability to absorb and retain water effectively (Ariyantoro *et al.*, 2020). Despite this variation, all samples subjected to HMT treatment met the moisture content regulation set by the Indonesian National Standard, SNI 01-6057-1999, which allows the maximum moisture content in arrowroot flour of 16%. Thus, the arrowroot flour produced in this study is in compliance with the SNI.

Effect of HMT Temperature and Time on the Water Absorption Capacity of Arrowroot Flour

The statistical analysis results show that heating temperature has a significant effect on the water absorption capacity of arrowroot flour ($p=0.002$). On the other hand, there is no significant effect on heating time ($p=0.284$) and the interaction between temperature and time ($p=0.342$). Figure 3 shows the variations in water absorption values according to different heating temperatures.

Figure 3 indicates that HMT treatment increased the water absorption capacity of arrowroot flour. All samples subjected to HMT showed higher levels of water absorption compared to control samples. This enhancement may be attributed to partial rearrangement and reorganization of starch granules during HMT, which alters the molecular structure without causing full gelatinization. The treatment likely disrupts some hydrogen bonds and

increases the availability of amorphous regions within the granules, allowing more water molecules to penetrate and be retained. However, at 120° there was a slight decrease in water absorption, but it remained higher than the untreated sample. This pattern suggests that moderate heating improves the starch structure by creating more spaces between molecules, allowing more water to be absorbed. However, overheating may lead to structural modifications or damage, ultimately lowering its ability to form gels essential for hydration and the ability to absorb water effectively (Ariyantoro *et al.*, 2020).

Effect of HMT Temperature and Time on the Total Carbohydrate Content of Arrowroot Flour

Statistical analysis indicates a significant effect of heating temperature ($p < 0.001$) and heating time ($p < 0.001$) on the total carbohydrate content of arrowroot flour. However, the interaction between temperature and time does not significantly affect ($p = 0.091$) the total carbohydrate content. Differences in total carbohydrate content based on heating temperature and time can be seen in Figures 4 and 5. Figures 4 and 5 show that HMT-treated arrowroot flour has a lower carbohydrate content compared to the control, and that the temperature and time of HMT can decrease the total carbohydrate content of the flour. This finding contrasts with the study by Sopawong *et al.*, (2022) on lotus seed flour, where HMT modification resulted in a higher carbohydrate content compared to unmodified natural lotus seed flour. The difference may be due to the type of raw material, the calculation method, and the preparation method used. In the lotus seed study, carbohydrate content was calculated by difference, and the HMT preparation method involving soaking, which could lead to a reduction in protein content. A decrease in protein content would result in a higher calculated carbohydrate content. In the present study, heating above 80°C during HMT may also cause protein denaturation; however, this should theoretically increase the carbohydrate content when calculated by difference. Therefore, the observed decrease in carbohydrate content is likely related to partial starch degradation or conversion of available carbohydrates into resistant starch fractions during the HMT process, leading to a lower measurable carbohydrate level.

The reduction in carbohydrate content through HMT has valuable implications for developing instant porridge with potentially lower glycemic impact. Lower carbohydrate levels can help reduce the rise in blood sugar after eating, which is good for people with diabetes (Wheatley *et al.*, 2021). This makes HMT-treated arrowroot flour a good raw material option for developing instant porridge with a lower glycemic impact.

Effect of HMT Temperature and Time on the Total Dietary Fiber Content of Arrowroot Flour

Statistical analysis shows a significant effect of heating time ($p = 0.005$) on the total dietary fiber

content of arrowroot flour. However, the heating temperature ($p = 0.146$) and the interaction between temperature and time ($p = 0.060$) do not significantly affect the total dietary fiber content. Total dietary fiber content based on heating time is shown in Figure 6.

As seen in Figure 6, HMT-treated arrowroot flour has a higher dietary fiber content compared to the control. Additionally, increasing the HMT time leads to an increase in the total dietary fiber content of the flour. This is consistent with the research by Iuga *et al.* (2021) on HMT-modified wheat flour treated for 1, 2, and 3 h at different temperatures. The results showed an increase in total dietary fiber with extended HMT time. This increase is attributed to changes in the amylose-amylopectin chain structure due to the migration of heat energy and water molecules. Moreover, the rise in total dietary fiber is also associated with the increase in resistant starch content during HMT treatment, as resistant starch exhibits physiological behavior similar to dietary fiber (Iuga *et al.*, 2021). These findings suggest that HMT-treated arrowroot flour could be beneficial for developing high-fiber food products, supporting digestive health and offering potential advantages for individuals seeking to improve their dietary fiber intake.

Effect of HMT Temperature and Time on Glycemic Carbohydrate Content of Arrowroot Flour

Statistical analysis indicates a significant effect of heating temperature ($p < 0.001$), heating time ($p < 0.001$), and the interaction between temperature and time ($p = 0.022$) on the glycemic carbohydrate content of arrowroot flour. Differences in glycemic carbohydrate content based on heating temperature, time, and their combinations are shown in Figure 7.

As shown in Figure 7, HMT-treated arrowroot flour has lower glycemic carbohydrate values compared to the control. Both the heating temperature and time of HMT, as well as their combinations, can reduce the glycemic carbohydrate content of the flour. This finding aligns with the research by Iuga *et al.* (2020), which found that HMT modification can increase slowly digestible starch (SDS) and resistant starch, resulting in a lower glycemic index due to the interactions between starch components that make the starch structure more resistant to enzymatic hydrolysis. A lower glycemic index is associated with reduced glycemic carbohydrate content. Thus, HMT treatment can effectively lower glycemic carbohydrate levels (Iuga *et al.*, 2020). This suggests that HMT-treated arrowroot flour has the potential for use in low-glycemic food products, making it suitable for people with diabetes or for promoting healthier blood sugar control.

Effect of HMT Temperature and Time on Resistant Starch Content of Arrowroot Flour

Based on statistical analysis, there is a significant effect of heating time ($p = 0.016$) on the resistant starch content of arrowroot flour. However,

heating temperature ($p=0.133$) and the interaction between temperature and time ($p=0.055$) do not have a significant effect on the resistant starch content. Differences in resistant starch content based on heating time are illustrated in Figure 8.

Figure 8 shows that HMT-treated arrowroot flour has a higher resistant starch content compared to the control. Additionally, longer heating times during HMT increase the resistant starch content. This finding is consistent with research by Babu and Mohan (2019) on millet starch. The increase in resistant starch is due to strong interactions between amylose-amylose and amylose-amylopectin structures during HMT. This reorganization process makes the starch structure more compact, enhancing its resistance to enzymatic hydrolysis. This increase in resistant starch suggests that HMT-treated arrowroot flour may offer improved health benefits, such as better blood sugar control and enhanced dietary fiber content, making it a suitable ingredient for functional food applications.

Selection of Optimal HMT-Treated Arrowroot Flour

The selection of arrowroot flour with the optimal HMT modification was based on water absorption capacity. Statistical analysis of water absorption indicated that heating temperature significantly affected the water absorption, with the highest value observed for the flour treated at 110°C , which was 2.04 ± 0.18 g/g dry weight (dw). Regarding HMT time, descriptive statistics showed that the highest water absorption value was achieved with HMT for 60 min, at 1.95 ± 0.22 g/g dw. Therefore, the selected treatment for arrowroot flour is HMT at 110°C for 60 min, resulting in a water absorption capacity of 2.11 ± 0.3 g/g dw. The selected arrowroot flour was used to formulate instant porridge in order to enhance its nutritional and functional properties.

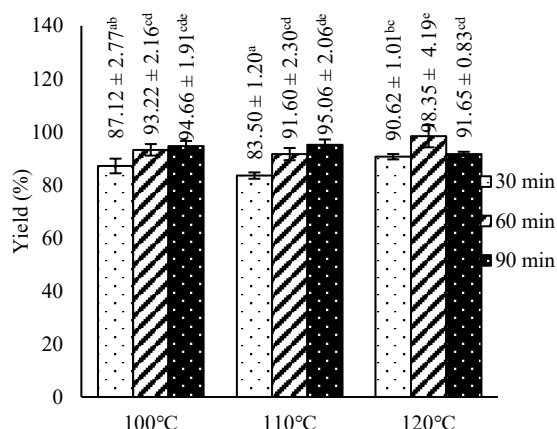


Figure 1. Dry Basis Yield of HMT Arrowroot Flour Based on HMT Heating Temperature and Time

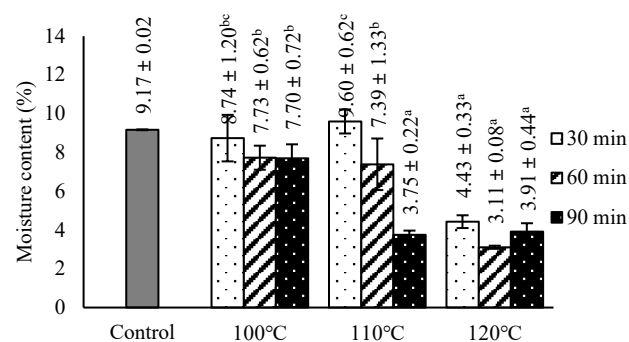


Figure 2. Moisture Content of Arrowroot Flour Based on Temperature and Heating Time of HMT

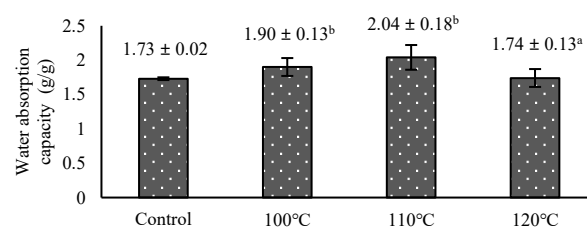


Figure 3. Water Absorption Capacity of Arrowroot Flour Based on Heating Temperature of HMT

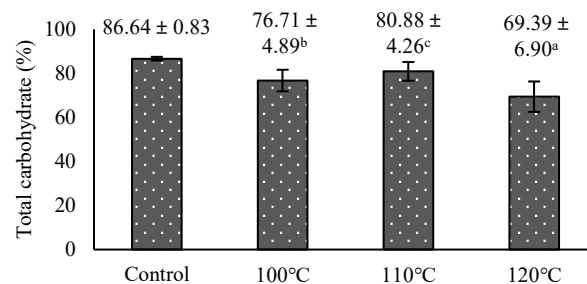


Figure 4. Total Carbohydrate of Arrowroot Flour Based on Heating Temperature of HMT

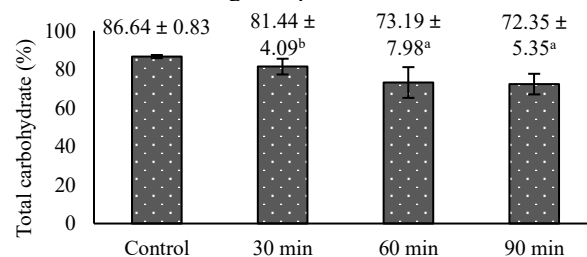


Figure 5. Total Carbohydrate of Arrowroot Flour Based on Heating Time of HMT

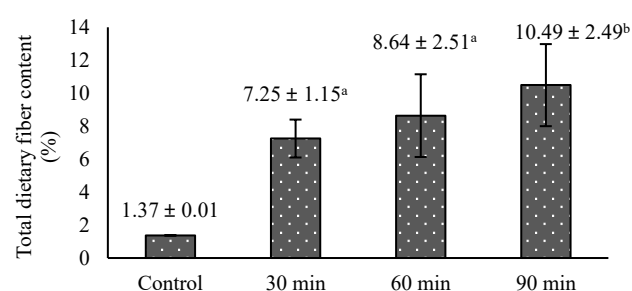


Figure 6. Total Dietary Fiber of Arrowroot Flour Based on Heating Time of HMT

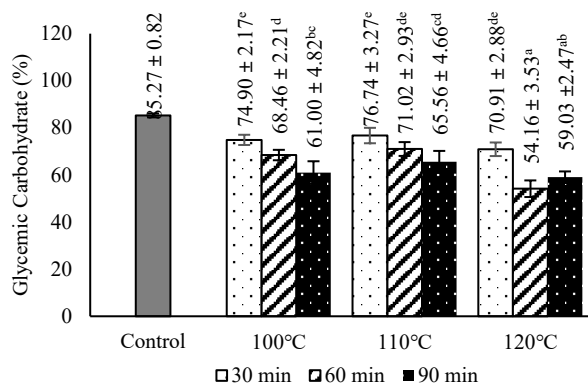


Figure 7. Glycemic Carbohydrate of Arrowroot Flour Based on Temperature and Heating Time of HMT

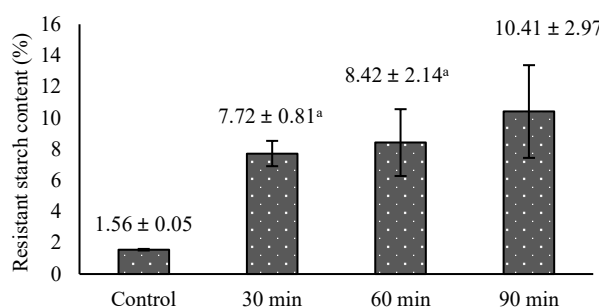


Fig. 8 Resistant Starch Content of Arrowroot Flour Based on Heating Time of HMT

Physicochemical and Functional Properties of Instant Arrowroot Porridge

The physicochemical characteristics and functional properties of the instant arrowroot porridge prepared using arrowroot flour selected HMT treatment are presented in Table 2.

Moisture content of instant arrowroot porridge

Table 2 shows that the instant arrowroot porridge prepared in this study has a moisture content of $11.03 \pm 0.05\%$ (dry weight basis). This moisture content is higher than previous studies (Mahgoub *et al.*, 2020; Musundire *et al.*, 2021). The difference in moisture content between the raw materials is most likely the cause of this deviation. Mahgoub *et al.* (2020) suggests that dried products with a moisture content of below 10% are generally having longer shelf life, as microorganisms cannot grow well in those with a moisture content of less than 8%. Conversely, a high moisture content of more than 18% can cause an increase in microbial growth. According to SNI 01-7111.4-2005 for Instant Complementary Foods (MP-ASI) Powder, the maximum moisture content should be 4%. Therefore, the results of this study do not meet the SNI standard. This may be due to the hygroscopic nature of the flour, which easily absorbs moisture from the surrounding ambient air, especially in tropical countries including Indonesia. Storage conditions can contribute to an increase in the moisture content of the flour.

Table 2. Physicochemical Characteristics and Functional Properties of Instant Arrowroot Porridge Compared to Literature

Parameter	Instant arrowroot porridge (research result)	Literature
Moisture content (%db)	11.03 ± 0.05	8.20 ± 0.20 (Musundire <i>et al.</i> , 2021) 6.77 ± 0.03 (Mahgoub <i>et al.</i> , 2020)
Water absorption (g/g db)	2.32 ± 0.24	1.81 (Surahman <i>et al.</i> , 2019) 6.62 ± 0.02 (Mahgoub <i>et al.</i> , 2020)
Rehydration capacity (ml/g)	2.69 ± 0.15	3.56 (Palijama <i>et al.</i> , 2020) 2.69 (Fatimah <i>et al.</i> , 2022)
Rehydration time (sec/g)	25.89 ± 0.68	43.60 ± 3.31 (Khoirina <i>et al.</i> , 2019) 24.78 (Fatimah <i>et al.</i> , 2022)
Total carbohydrate (%bk)	70.70 ± 2.49	80.53 (Palijama <i>et al.</i> , 2020) 57.15 (Khoirina <i>et al.</i> , 2019)
Total dietary fiber (%)	6.60 ± 0.04	9.07 (Haliza and Widowati, 2021) 6.96 (Surahman <i>et al.</i> , 2019)
Glycemic carbohydrate (%)	64.10 ± 2.46	$IG = 51.51$ (Hanifa <i>et al.</i> , 2020) $Glycemic carbohydrate = 58.92$, $IG = 43.35$ (Mado <i>et al.</i> , 2020)
Resistant starch (%)	5.62 ± 0.01	4.51 (Fadlila <i>et al.</i> , 2024) 0.19 (Slamet <i>et al.</i> , 2019)

Water absorption of instant arrowroot porridge

Table 2 shows that the water absorption capacity of the instant arrowroot porridge produced in this study is 2.32 ± 0.24 g/g dry weight basis (dwb). This value is greater than those found in earlier studies (Surahman *et al.*, 2019). This increase is attributed to the modification of the arrowroot flour using HMT, which enhances the flour's water absorption capacity and improves the granule's ability to absorb water and form a gel when hydrated (Malki *et al.*, 2023). However, the water absorption value in this study is lower than that reported by Mahgoub *et al.* (2020), who found an absorption capacity of 6.62 ± 0.02 for instant porridge made from wheat bulgur supplemented with mung beans. Their study has a higher value because of the high protein content in mung beans, which enlarges water absorption.

Rehydration capacity of instant arrowroot porridge

Table 2 displays that the instant arrowroot porridge has a rehydration capacity of 2.69 ± 0.15 ml/g, which is in accordance with the findings of Fatimah *et al.* (2022) findings. This value is lower compared to Palijama *et al.* (2020), likely due to the

lower moisture content in their instant porridge made from glutinous corn flour and red bean flour (5.54%) compared to the moisture content in this study ($11.03 \pm 0.05\%$). Higher moisture content can lead to poorer rehydration capacity (Fatimah *et al.*, 2022).

Rehydration time of instant arrowroot porridge

Instant arrowroot porridge in this study has a rehydration time of 25.89 ± 0.68 s/g. The results presented here are identical to those of Fatimah *et al.* (2022), who reported a rehydration time of 24.78 s/g for instant baby porridge made from carrots and mocaf flour. The rehydration speed of instant arrowroot porridge in this study is better compared to previous research (Khoirina *et al.*, 2019), possibly because of the HMT treatment applied to the arrowroot flour. Fatimah *et al.* (2022) suggests that high temperatures cause starch granules that bond with water to gelatinize, facilitating water entry into the starch granules. When the starch matrix is dried, the water fraction evaporates, leading to the formation of a porous and easier to rehydrate matrix. The release of hydrogen bonds between amylose molecules during rehydration eases the binding of more water molecules, hence accelerating the rehydration process.

Total carbohydrate content of instant arrowroot porridge

As per Table 2, instant arrowroot porridge has a total carbohydrate content of $70.70 \pm 2.49\%$, while raw arrowroot flour has $80.63 \pm 2.77\%$ carbohydrates. This value is less than what was previously reported (Palijama *et al.*, 2020), which is a result of the ingredients being formulated so that less arrowroot flour is used as the primary carbohydrate source. However, the total carbohydrate content in this study is higher compared to the study by Khoirina *et al.* (2019) because their raw materials included red rice flour and tempeh flour, which both have lower carbohydrate content than arrowroot flour.

Total dietary fiber content of instant arrowroot porridge

Instant arrowroot porridge has a total dietary fiber content of $6.60 \pm 0.04\%$, as indicated by the results presented in Table 2. This value is lower than those previously reported by Haliza and Widowati (2021) and Surahman *et al.* (2019). The decrease in dietary fiber content is likely due to the processing of the arrowroot flour into instant porridge, which involves high-temperature cooking. According to Haliza and Widowati (2021), a food product can be considered a good source of dietary fiber if it contains 3-6 g/100 g. Therefore, the instant arrowroot porridge has already met the criteria for dietary fiber source.

Glycemic carbohydrate of instant arrowroot porridge

Table 2 shows that instant arrowroot porridge has a glycemic carbohydrate content of $64.10 \pm 2.46\%$. The glycemic carbohydrate content of the

instant arrowroot porridge is $64.10 \pm 2.46\%$, as shown in Table 2. This value is higher than previous studies (Hanifa *et al.*, 2020; Mado *et al.*, 2020) because arrowroot flour has a high carbohydrate content. The glycemic carbohydrate value of arrowroot flour is affected by its high carbohydrate content, despite its low glycemic index (Mado *et al.*, 2020).

Resistant starch content of instant arrowroot porridge

Table 2 presents that the resistant starch content in instant porridge is $5.62 \pm 0.01\%$. This value is higher than previous studies (Fadlila *et al.*, 2024; Slamet *et al.*, 2019) due to the HMT treatment, which increases the resistant starch content in arrowroot flour. However, the resistant starch content in instant porridge is lower due to incomplete retrogradation during the cooking process. Retrogradation is the process where starch cools, which results in recrystallization and an increase in resistant starch levels. Starch may not fully return to its resistant form if retrograded incompletely (Damat *et al.*, 2022).

CONCLUSION

This research showed that heat-moisture treatment (HMT) has a significant impact on the physicochemical and functional properties of arrowroot flour and its use in instant porridge preparation. The yield, moisture content, dietary fiber, and resistant starch content were all enhanced by increasing the HMT temperature and duration, but moisture, total carbohydrate, and glycemic carbohydrate levels were all decreased by increasing it. The optimum HMT conditions were found to be at 110°C for 60 min, which produced arrowroot flour with the best functional properties, particularly a water absorption capacity of 2.11 ± 0.30 g/g, making it appropriate for instant porridge formulation. The instant porridge produced exhibited enhanced nutritional and functional properties, characterized by higher dietary fiber and resistant starch, with potential to lower glycemic carbohydrate content. The findings highlight the potential of HMT-modified arrowroot flour as a promising raw material for creating functional food products that contain essential nutrients and promote a healthier diet.

CONFLICT OF INTEREST

Financial contributions and any potential conflict of interest must be clearly acknowledged under the heading 'Conflict of Interest'. Authors must list the source(s) of funding for the study. This should be done for each author.

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