Food Science and Technology 12(1): 71-80, 2024 http://www.hrpub.org
DOI: 10.13189/fst.2024.120106

Effect of Microwave-Assisted Extract (MAE) on Functional Properties, Digestibility, and Glycemic Index of Arrowroot Starch (Maranta arundinacea)

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Received November 16, 2023; Revised December 25, 2023; Accepted January 17, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Mimi Harni, Tuty Anggraini, Rini, Irfan Suliansyah , "Effect of Microwave-Assisted Extract (MAE) on Functional Properties, Digestibility, and Glycemic Index of Arrowroot Starch (Maranta arundinacea)," Food Science and Technology, Vol. 12, No. 1, pp. 71-80, 2024. DOI: 10.13189/fst.2024.120106.*

(b): *Mimi Harni, Tuty Anggraini, Rini, Irfan Suliansyah (2024). Effect of Microwave-Assisted Extract (MAE) on Functional Properties, Digestibility, and Glycemic Index of Arrowroot Starch (Maranta arundinacea). Food Science and Technology, 12(1), 71-80. DOI: 10.13189/fst.2024.120106.*

Abstract Arrowroot tubers are a type of tuber that is expected to reduce dependence on imported products because apart from having a high starch content, these tubers also contain antioxidants. The process of extracting starch is carried out using the extraction method. The choice of MAE extraction method is expected to maintain the functional compounds in arrowroot tuber starch. This research aims to reduce the glycemic index and digestibility without damaging the functional properties of the starch produced. The research method began by extracting arrowroot tuber starch by heating MAE for 1 – 4 minutes. The resulting observations were then compared with treatment without MAE. The data from the analysis were analyzed based on the average value, and then the standard deviation from each treatment was looked for. Observations were made on functional properties in syneresis and analysis using infrared light on starch, in vitro digestibility, and in vivo glycemic index on extracted starch. The research showed a decrease in syneresis at the end of storage, so the starch was stable at low temperatures. Infrared absorption observations can confirm the carbohydrate properties of arrowroot tuber starch, which consists of hydroxyl groups. Digestibility and glycemic index also decreased using the MAE method.

Keywords Arrowroot, Microwave-Assisted Extract, Syneresis, Fourier Transform Infrared, Digestibility, Glycemic Index

1. Introduction

Dependence on imported products should be reduced by utilizing existing natural resources. One imported product whose use is relatively high is wheat flour. Some people cannot consume wheat flour because it causes diarrhoea, which is known as celiac sufferers, plus there is a link between wheat and diabetes sufferers. According to Marietta et al. [1] and Sildorf et al. [2], increasing levels of resistant starch, especially in tubers, help control glucose and lipids to protect against diabetes. One type of tuber that has a low glycemic index and a reasonably high starch content is the arrowroot tuber.

Arrowroot tubers are a variety of tubers that are not extensively cultivated. Arrowroot tubers have relatively high starch content. According to Faridah et al. [3], arrowroot contains 98.74% carbohydrates. Most of the carbohydrates in arrowroot are starch, with a range of 98.10%. Arrowroot starch also has puerarin and is a natural source of polyphenols, which function as antioxidants [4],

[5].

Arrowroot starch has been used in the gluten-free food industry and can be used by people on a diet program [6], including in the form of bread products [7], cake [8], and noodles [9]; apart from that several studies have used arrowroot tubers as ingredients for edible films [10], bioplastics [11] and as a source of fiber [12].

The process of starch extraction involves the utilization of the extraction method. One of the extraction methods that can increase the resistant starch content is the Microwave-Assisted Extract (MAE) method. Starch extraction is usually only carried out conventionally so that the functional value of starch is not obtained.

MAE is an extraction technique usually carried out on bioactive components but can also be carried out on polysaccharide components. Microwave extraction is carried out using wave radiation, which will provide heat to the water in the cells so that the water evaporates and puts high pressure on the cell walls, which causes the cell material to become swollen (swelling). This pressure will push the cell wall from the inside, stretch it, and break the cell [13]. Furthermore, according to Li et al. [14] and Wang et al. [15], the MAE extraction method can also increase resistant starch, which occurs slowly in digestible starch (SDS).

This research aims to ensure that extraction using MAE will produce arrowroot starch with unchanged functional properties and decrease the digestibility of arrowroot tuber starch and the glycemic index so that it can be a food solution for people with diabetes and wheat flour allergies.

The effect of microwave heating on several starches has been carried out by Oyenyinka et al., Wang et al., Li et al., and Alhafiizh et al. [16], [17], [14], [18], who have examined the impact of microwave heating on various types of starch.

2. Materials and Methods

2.1. Materials and Equipment

The material in this research was arrowroot tubers of the banana type with a harvest age of 12 months obtained from the Tasikmalaya area, West Java. The solvent used in the extraction process is water. The equipment in the starch extraction process is a microwave (AQUA AEM-S2612S, 400 W), a mortar, a 60-mesh sieve, and an oven.

2.2. Arrowroot Tuber Extraction

Arrowroot tubers are sorted first and washed until clean. The arrowroot tubers are then grated using the equipment. Crushed tubers are extracted with a 1:33.81 g/ml ratio between ingredients and water [19]. The extraction process was carried out using a microwave according to the treatment with a 1 to 4-minute duration and then compared with treatment without heating. Following the heating process, proceed with the filtration procedure and allow the solution to stand at room temperature for 24 hours, ensuring that the water is replaced three times during this period. The residue was subsequently dried at 60°C, followed by further grinding using a mortar. The obtained grinding outcomes are further subjected to sieving using a 60-mesh sieve. Several observations were made, including:

2.3. Syneresis

Syneresis is an observation of the condition where the gel that initially holds fluid in the body releases the fluid [20].

Work procedures begin with the 5% (w/w) starch suspension undergoing heating at a temperature of 90°C for 30 minutes within a water bath that was controlled for temperature. Subsequently, the rest was rapidly cooled by immersing it in an ice water bath until it reached room temperature. Starch samples were held for 24, 48, and 72 hours at 40. The quantification of syneresis, expressed as a percentage (%), was conducted by determining the volume of water expelled following centrifugation at a speed of 3200 times the force of gravity (3200Xg) for 15 minutes. The weight loss during storage was measured and subsequently compared with the initial weight of the gel by a calculation.

2.4. Fourier Transform Infrared Analysis Fourier Transform Infrared (FTIR)

FTIR is a standard method for detecting the molecular structure of compounds by identifying the functional groups that make up a compound in starch [21]. The technique uses a Perkin Elmer Fourier transforms infrared absorption spectrometer. Spectrum model two was utilized to analyze the starch sample. The analysis was conducted in transmission mode within the mid-infrared band, from 4000 to 400 cm^{-1}. The substance under consideration for measurement is designated as either atoms or molecules. The infrared rays, serving as an illumination source, are bifurcated into two beams: one beam is transmitted through the sample, while the second is transmitted through the comparator. Subsequently, it proceeds to undergo fragmentation using the chopper. Against traversing a prism or grating, the beam will impinge against the detector and undergo conversion into an electrical signal, subsequently being captured by the recorder. Moreover, an amplifier is required if the generated signal is weak.

2.5. In vitro Digestibility

The measurement of starch digestibility involved the calculation of the ratio between the quantity of maltose present in the sample and the quantity of maltose derived from a standard starch. The sample suspension is made at 1% based on the starch content. The piece was heated at 90°C for 30 minutes, then cooled. A volume of 2 mL of the sample was transferred into a test tube, followed by adding 3 mL of distilled water and 5 mL of a pH seven phosphate buffer solution with a concentration of 0.1 M. The resulting mixture was then subjected to incubation at a temperature of 37°C for 15 minutes. The sample was supplemented with a 5 mL solution of α-amylase and incubated at 37°C for 15 minutes. A volume of 1 mL of the model was transferred using a pipette and combined with 2 mL of a solution containing dinitrosalicylic acid (DNS). The resulting mixture was heated at 100°C for 10 minutes. The UV-VIS spectrophotometer (Shimadzu 1240) was used to measure the absorbance of the orange-red color produced by the reagent mixture at a specific wavelength of 520 nm. Determining starch digestibility involves quantifying the proportion of maltose present in a given sample relative to the maltose content inherent in the starch.

2.6. Glycemic Index in vivo

Determination of the glycemic index value was carried out with experimental animals in the form of adult mice (20 weeks), which were given a sample of 2 grams/kg body weight (BW) compared with glucose of the same weight. The test material was given orally, and then the mice's blood was sampled at 0, 1, and 2 hours. Blood glucose levels were determined during sampling using the GOD-PAP method. Glucose levels were measured in rat blood serum. The experiment was carried out three times.

IG = (AUC of test food/AUCglucose) x 100

AUC = The value of the area under the curve.

3. Result and Discussion

3.1. Syneresis

Syneresis is a stage that occurs after gelatinization and retrogradation. Syneresis is an observation that aims to see the stability of starch at low temperatures. Syneresis values from several words can be seen below.

Table 1. Average syneresis values

Treatments	Syneresis (%) (Average ± sd)		
	24 hours	48 hours	72 hours
E (MAE 4 minute)	0.123±0.075	0.108±0.096	016±0.150
D (MAE 3 minute)	0.089±0.027	0.072±0.060	0.14±0.021
C (MAE 2 minute)	0.085±0.035	0.069±0.055	0.09±0.012
B (MAE 1 minute)	0.040±0.014	0.044±0.036	0.08±0.034
A (Without MAE)	0.01±0.0001	0.015±0.007	0.03±0.025

The syneresis value based on the table above shows that the longer the heating in the microwave, the higher the syneresis value. At the same time, the longer the cooling takes, the lower the syneresis value. The syneresis value increased due to increased water absorption and heating in the extraction process. According to Yousif et al. [20], the increase in syneresis value is influenced by several factors, such as increasing the number of cooling and thawing cycles, storage time for gelatinized starch at 4°C and modification of heat-moisture treatment. Syneresis in starch gel occurs because starch has undergone freezing and thawing caused by increased molecular bonds between starch chains, especially amylose retrogradation [22]. According to Marta et al. [23], the syneresis of natural corn starch is 8.06%, while the syneresis of starch using microwave heating is 38.85%. The syneresis value of corn starch increased due to the heat produced by the microwave.

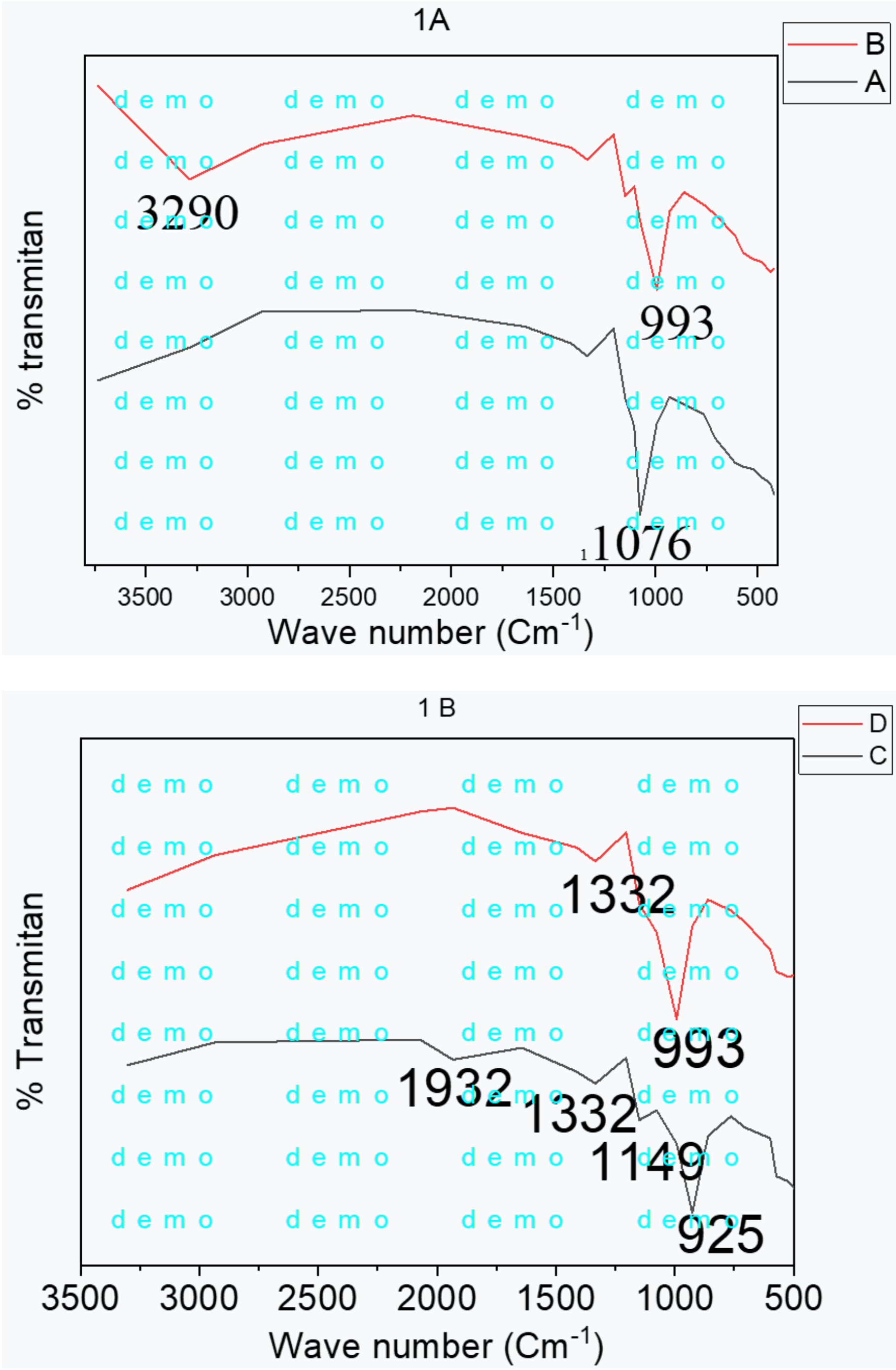
The amount of water that comes out of the material, especially gel, is an accumulation of increased inter- and inter-molecular hydrogen bonds due to aggregation (retrogradation). The amount of water that comes out is influenced by the ratio of amylose and amylopectin. The release of water molecules in the amylose and amylopectin structures is caused by hydrogen bonds between amylose-amylose, amylopectin-amylose molecules, and amylopectin-amylopectin [24].

A low syneresis value can indicate that the starch is relatively stable at low temperatures [25]. A high syneresis level indicates diminished freeze-thaw stability in food products [26]. This treatment's low syneresis percentage value aligns with the low setback viscosity value. Starches exhibiting minimal syneresis have the potential to serve as effective emulsifying agents in several food applications, including sauces, yoghurts, and jellies. The reduction of starch retrogradation effectively achieves low syneresis [27].

Starch whose percentage of syneresis is stable after the second cycle means this starch will have better freeze-thaw stability [28]. The amylose molecules undergo structural changes during gelatinization, resulting in new intermolecular interactions. In this particular context, these bonds can be established with the assistance of xanthan gum. The interaction between amylose and xanthan gum molecules decreases the likelihood of amylose-amylose association and is the central bond implicated in the retrogradation process. This bond arises from the syneresis process [29].

3.2. Infrared Absorption Spectroscopy (FTIR)

FTIR (Fourier Transform Infra-Red) is a qualitative analysis of the functional groups in the organic compounds of the arrowroot tuber starch. The results of FTIR observations of arrowroot tuber starch can be seen in Figure 1. Each absorption at a particular wavelength indicates the presence of a specific functional group.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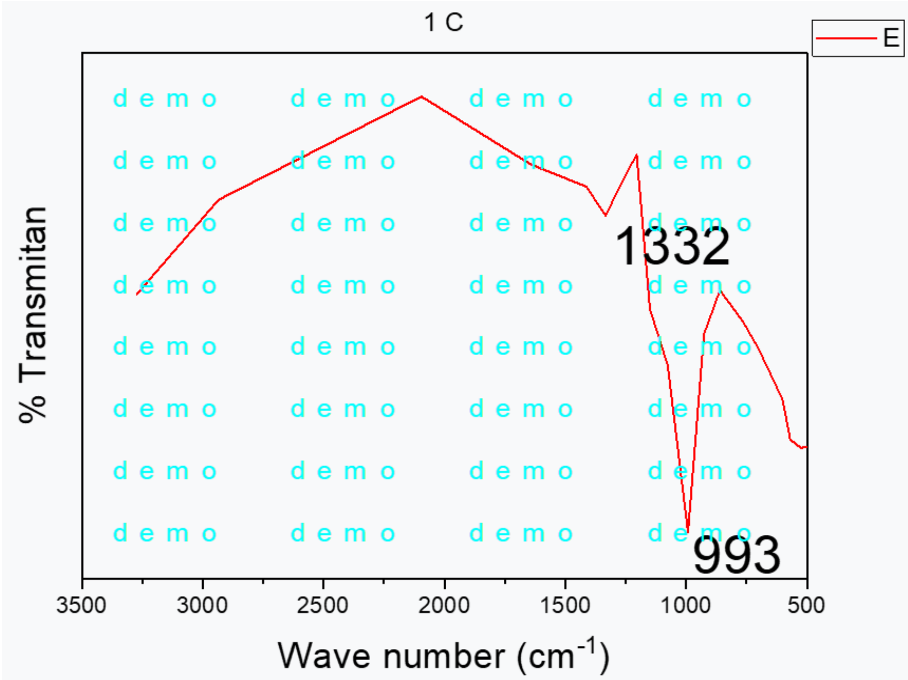

A: without MAE; B: MAE 1 minute; C: MAE 2 minutes; D: MAE 3 minutes; E: MAE 4 minutes

Figure 1. FTIR of arrowroot starch extracted MAE

Table 2. Bands found in the FTIR spectrum of arrowroot tuber starch

Functional Grub	Wave no. According to literature	A	B	C	D	E
Stretching O-H	3600-3300	3286.70	3284.77	3273.20	3302.13	3273.20
Stretching C-H	2931	2922.16	2931.80	2931.80	2931.80	2933.73
Stretching C=C	1651	1641.42	1641.42	1641.42	1641.42	1641.42
CH symmetrical bending	1385-1375	1332.81	1334.74	1334.74	1332.81	1332.81
Asymmetric stretching C - O - C	1149	1149.57	1149.57	1149.57	1149.57	1149.57
Vibration stretching C-O	1080	1076.28	1105.21	1076.28	1076.28	1076.28
Stretching C-O	1200-800	993.34	993.34	993.34	993.34	993.34
Carb ring vibration C - O - C	920, 856,758	860.25	860.25	860.25	860.25	860.25
Carb ring vibration C - O - C	920, 856,758	758.02	763.81	759.95	763.81	763.81

In MAE extraction, microwave radiation is utilized to heat the solvent more quickly. In the extract results, it was observed that there was no change in the shape of the resulting spectrum, except that in treatments B and C, there were peaks formed at 3700 and 3800. The OH group was stretched according to He et al. [30] and Lu et al. [31], 300-3700, which means a hydroxyl group is present.

Furthermore, according to Barroso & del Mastro [32] arrowroot starch, when treated with different doses of gamma radiation, the spectrum does not change substantially during irradiation; the peak at 298 then there is an extensive band at 3200 cm^{-1} and is thought to originate from O-H vibration stretching. The bands contained in the FTIR can be seen in Table 2.

The spectrum ranges from 3000 to 3500 cm^{-1} and peaks at 3269.22 cm^{-1}, suggesting stretching vibrations related to unbound hydroxyl groups inside and across molecules [33]. A slight increase at 2926.31 cm^{-1} indicates the stretching of –CH bonds in conjunction with the hydrogen atoms of the methane ring. The band's appearance at 1640.85 cm^{-1} in the amorphous region of starch is caused by the O-H twisting vibrations in the bound air [34]. The CH_2 angle band is located precisely at 1335.05 cm^{-1} [35]. The intense peaks observed at 1149.33 cm^{-1} and 1077.07 cm^{-1} are attributed to the vibrational modes of C–O bonding, C–O–H bending, and C–C stretching. The peaks recorded in the 859.48 cm^{-1} to 1077.07 cm^{-1} are linked to several events, as stated by Malki et al. [36]. The height at 859.48 cm^{-1} is caused by the hydrogen bonding of O–H groups, while the peak at 1077.07 cm^{-1} relates to vibrations in the α-1,4 glycosidic linkage framework mode and the intermediate level.

Furthermore, Alhafiizh et al. [18] stated that heat treatment during extraction using microwaves causes the leaching of amylose, thereby increasing the possibility of the molecules interacting. These interactions facilitate an increase in the number of hydrogen bonds produced between amylose molecules.

3.3. In vitro Digestibility

Digestibility is a test that looks at the quality of starch during digestion. The digestibility of arrowroot tuber starch is expected to decrease with the process. Table 3 presents the digestibility data of starch derived from arrowroot tubers.

Table 3. Average in vitro digestibility

Treatments	Digestibility % (average ± sd)
A (without MAE)	85.06 ±0.321
B (MAE 1 minutes)	82.52±0.395
C (MAE 2 minutes)	81.58±0.410
D (MAE 3 minutes)	79.60 ±0.338
E (MAE 4 minutes)	78.49±0.346

According to the findings presented in Table 3, it can be observed that the digestibility of treatment A is higher when MAE (microwave-assisted extraction) is not utilized. Conversely, including MAE extract in the treatment leads to a decrease in digestibility over time, which can be attributed to the extended duration of heating. Digestibility is expected to fall so that starch can provide functional properties to the product. MAE decreases over time due to more extended warming. Digestibility is expected to decrease so that starch can provide functional properties to the product because using MAE will help form resistant starch. Microwave heating will reduce the level of digestibility in Canna edulis Kertuber starch [37]. A decrease in digestibility occurs due to heating with electromagnetic waves, which causes changes in the starch structure.

The application of microwave treatment induces structural modifications that result in starch gelatinization and alterations in its physical and chemical characteristics. These changes subsequently impact starch digestibility and stability. Upon exposure to microwave radiation, polar molecules undergo fast rotation, generating heat via friction, which leads to the cracking and shrinking of the surface of starch granules [38].

Hydrothermal starch heats tuber starch in an oven for 24 hours at temperatures of 55 and 75°C. This technique can increase starch functionality by increasing the slow-digesting fraction [39]. Still, in the research, the highest heating temperature was 50°C with a heating time of 4 minutes in the microwave. According to Zavareze & Dias [40], heating starch can modify its physicochemical properties without damaging the granule structure. Furthermore, according to Kim et al. [41], the interaction between amylose and amylopectin affects the double-helix and crystals, thereby affecting the digestibility of starch. Amylopectin length is an essential factor influencing starch digestibility and determining amylose function.

According to Faridah et al. [3], the digestibility of wet-extracted arrowroot tuber starch is 84.35%. Compared with the research results, there was a decrease after using MAE. According to Wang et al. [17] and Li et al. [14], the MAE extraction method will improve starch properties and increase resistant starch, which occurs slowly in digestible starch (SDS). Microwave heating can also help improve the original physicochemical properties of starch [16].

3.4. The in vivo Glycemic Index

The glycemic index is seen from blood glucose levels carried out on experimental mice. The glycemic index is related to digestibility; ingredients with a low glycemic index will have low digestibility. Changes in average blood glucose can be seen in Table 4.

Table 4. Determination of the glycemic index of arrowroot tuber starch

Treatments	Average blood glucose level (mg/dl) hours			AUC (mg. hours/dl)	GI
	0	1	2		
Glucose	73.67	423.4	245.7	583.09	100
A (Without MAE)	73.00	30.15	30.01	81.66	14.00
B (MAE 1 minutes)	73.00	29.99	29.91	81.45	13.97
C (MAE 2 minutes)	78.00	27.78	28.97	81.27	13.94
D (MAE 3 minutes)	74.67	29.54	28.60	81.18	13.92
E (MAE 4 minutes)	73.00	29.79	29.48	81.03	13.90

The highest glycemic index (IG) of starch was found in the starch extraction treatment without MAE (A), while starch extracted using MAE had a lower glycemic index. The glycemic index is related to digestibility, and low digestibility will also result in a low glycemic index. According to Faridah et al. [3] and Marsono [42], the glycemic index of arrowroot starch with wet extraction is 14. The glycemic index of food ingredients varies depending on the physiology of the plant, not on the food content [43].

From the literature, the glycemic index of arrowroot tubers is already low due to the high fiber content, plus the extraction process using MAE will also increase resistant starch. It will reduce the glycemic index of the arrowroot tuber starch produced. Resistant starch is a type of starch that is difficult to digest. The microwave heating method can be used to increase resistant starch levels if it has been stored at low temperatures [44], [45], [14].

The decrease occurred due to changes in the starch structure due to heat from the microwave. Dietary fiber can influence blood glucose levels [46]. High dietary fiber content generally contributes to low GI values [47]. Fibre can slow down the rate of food in the digestive tract and inhibit enzyme activity so that the digestive process, mainly starch, becomes slow and the blood glucose response will be lower [48]. The low glycemic index is also due to the diosgenin content found in arrowroot tubers.

Diosgenin can also reduce the activity of the intestinal disaccharidase enzyme so that the breakdown of carbohydrates into monosaccharides is hampered. Diosgenin from the tubers of the Dioscorea family can inhibit α-a-glucosidase and α-amylase, enzymes that break down starch into glucose [49]. Therefore, arrowroot tubers are highly recommended as food for people with diabetes. An image of the average blood glucose level (mg/dl) over several measurements can be seen in Figure 2 below.

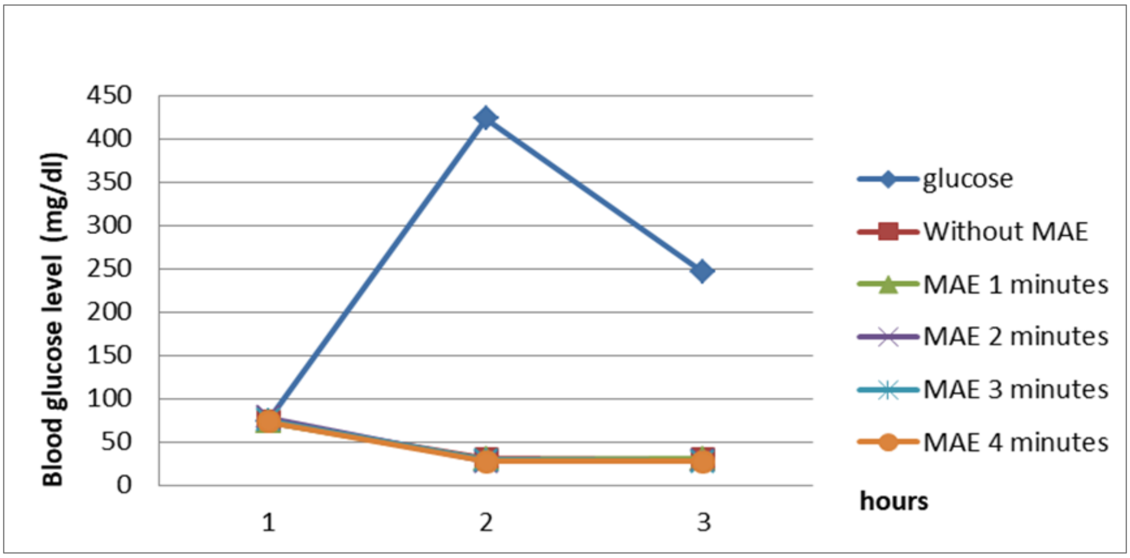

Figure 2. Mean blood glucose (mg/dl) at 0, 1, and 2 hours when measuring the glycemic index

4. Conclusions

The research results show that the extraction method using microwaves is suitable for reducing digestibility and glycemic index but affects the functional properties of starch. The longer the extraction time, the higher the syneresis value and the lower it is, the longer it is stored. This is a consideration for arrowroot starch if processed into products using low temperatures. The FT-IR spectra obtained were indistinguishable from those of starch, confirming the carbohydrate composition of arrowroot starch. The digestibility and glycemic index both experienced a drop in their digestibility levels.

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