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Physicochemical Properties of Edible Films Prepared from Arrowroot (*Maranta arundinacea*) Starch Extracted through Microwave-Assisted Extraction (MAE)

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Abstract. *Plastic is a commonly used packaging material due to its cheap and wide availability, especially in the food industry. However, plastic is non-biodegradable, leading to a serious problem to the environment from its widespread use. Using starch-based edible films as an alternative to plastic packaging offers a solution to this problem. As opposed to conventional methods of starch extraction for edibles, modern methods such as microwave-assisted extraction (MAE) can improve the functional properties of starch. This research aimed to determine the physicochemical properties of edible films from starch extracted through MAE. The study used a completely randomized design (CRD) with three treatments based on the amount of added starch, namely, Treatment A (3%), Treatment B (4%), and Treatment C (5%). The results from these treatments were compared against control (without MAE). Observations were conducted in triplicate, including parameters such as solubility, thickness, water holding capacity (WHC), oil holding capacity (OHC), and water content. Treatment A (3%) was found to be the best treatment, with a solubility of 76.55%, a thickness of 0.243 mm, a WHC of 38.56%, an OHC of 36.67%, and a water content of 13.79%.*

Keywords: *arrowroot starch; edible film; microwave-assisted extraction; physicochemical properties.*

Type of the Paper: Regular Article.

1. Introduction

Food packaging is commonly made of plastic and is disposed of after a single use. Given its non-biodegradable nature, prevalent use of plastic poses a problem that needs to be addressed. One viable way to deal with this problem is to produce edible films as an alternative to plastic packaging. An edible film consists of a thin coating of natural polymer constituents, such as lipids, polypeptides (proteins), and polysaccharides (carbohydrates), which are moldable into films due to their thermoplastic qualities. In addition, edible films are biodegradable, meaning that they can be broken down naturally and derive from renewable resources [1].

Polysaccharides are a fundamental component of edible films. Starch, a source of polysaccharides, is prevalent, inexpensive, and biodegradable. It is a good material for edible films because it offers strength to the produced films [2]. While starch can be derived from cereals, it is primarily extracted from tubers due to their abundance and ease of extraction. Arrowroot tubers have a relatively high starch content and low glycemic index [3]. The production of edible films

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refers to the Japanese Industrial Standards (JIS) because the Indonesian one (SNI) has yet to regulate explicitly on this matter.

Arrowroot tubers are not extensively cultivated in Indonesia, resulting in their lesser popularity than cassava or sweet potato. They are rich in starch [4]. According to Faridah et al. [3], the dry weight of arrowroot tubers contain 98.74% carbohydrates, of which starch is the major component, accounting for 98.10%. Arrowroot starch exhibits functional properties, including prebiotic water-soluble polysaccharides (WSP) and the bioactive compound diosgenin. Polysaccharides are available in the form of inulin at 0.5591/100 grams of arrowroot tubers (dry basis). Arrowroot starch also contains type II resistant starch and fibers at 2.12% and 1.7%, respectively [3,5].

Starch extraction from tubers can be carried out using a variety of methods. The extraction process it self is influenced by the composition of the material, which in turn determines the extraction method to be used. In general, extraction is performed manually using water on the grounds that water is an inexpensive solvent. Extraction with water, however, has some disadvantages. For one, the abundant water applied can damage the polysaccharide structure in the material. To address this issue, a new and environmentally friendly method named microwave-assisted extraction (MAE) is developed [6–8]. This method can be used to extract starch to produce edible films rich in bioactive compounds and provide added value to the films. According to Harni et al. [9], MAE does not influence the physical qualities of starch, although it does impact its chemical and functional properties. It has been found that an extended heating duration correlates with enhanced functional properties of starch. Therefore, it is deemed essential to investigate the influence of MAE on the quality of edible films made of starch, which drove the conduct of this study.

2. Materials and Methods

2.1. Materials

The materials used in this research consisted of arrowroot starch, which was extracted using the MAE method for four minutes at around 50°C [9], distilled water, and glycerol. The equipment used included beaker glasses, Petri dishes, a measuring cup, a spatula, a scale, and an electric stove.

2.2. Methods

The research started by making edible films by dissolving starch according to the study treatments in 100 mL of distilled water. The solution was stirred and then added with 5 mL of 99.5% glycerol. Afterward, the solution was heated to boiling. The solution was then poured into Petri dishes for molding and allowed to dry in an incubator at 35°C. The edible films produced were then removed from the Petri dishes. The making process was followed by a series of observations, which included the solubility, thickness, water holding capacity, oil holding capacity, and water content of the edible films.

2.3. Data Analysis

The data collected from observations were analyzed using a completely randomized design with three treatments and three replications. The treatments with 1% and 2% starch produced edible films that were fragile and prone to tearing upon handling. The data of the edible films produced with MEA were then compared with those of edible film produced conventionally (without MEA). Analysis of Variance (ANOVA) was carried out for data analysis, followed by the Duncan's New Multiple Range Test (DMRT) at a significance level of 5%. Data analysis was conducted using Microsoft Excel.

3. Results and Discussion

3.1. Solubility

Solubility is an essential quality determining an edible film's applicability as packaging [10,11]. It reflects the edible film's integrity in an aqueous environment, with increased solubility signifying less water resistance [12,13]. The gelatinization technique used influences the film's solubility in water, which can be enhanced using a plasticizer. The edible films produced in this study exhibited differences across treatments in terms of solubility, as presented in Table 1.

Table 1. Solubility of edible films across treatments

Treatments	Solubility (%)
Without MAE (Starch 3%)	30.24 ± 0.96
Starch 3%	76.55^a ± 0.70
Starch 4%	66.07^b ± 0.05
Starch 5%	60.54^c ± 0.30

Numbers followed by lowercase letters in the same column are not significantly different according to the DNMRT at the significance level of 5%. Values are expressed as means ± standard deviations.

Based on the table above, the solubility of edible films derived using MAE decreased as the amount of starch used increased but remained significantly higher than the film derived without MAE. As stated by Harni et al. [14], MAE increases the solubility of starch because heat is involved in the extraction process. However, since gelatinization was absent in the extraction process in this study, the structure of the starch did not change significantly. The solubility of all types of starch increases at a temperature of 75°C, especially when heated using a microwave. Nonetheless, upon reaching a temperature of 85°C, the solubility will decrease. In addition to temperature, the solubility of starch is also influenced by the amount of amylose contained in the starch [15].

The increased starch content reduces the edible film's solubility, resulting in a thicker structure that retains water. Solubility becomes lower as the quantity of components in the edible film matrix increases. According to da Silva et al. [16], incorporating composite starch into an edible film enhances the film's durability in water, rendering it less prone to dissolution in aqueous environments. In this study, the value of the edible films' solubility across treatments fell within the designated range, namely, 48–75% [17].

According to Fan et al. [18], amylose generally readily dissolves in water, whereas higher-molecular-weight fractions, such as amylopectin, persist within the starch granules, causing them to dissolve less easily in water. Arrowroot starch contains 24.64% amylose and 73.46% amylopectin[3]. Increasing arrowroot starch in the production of edible films will result in less solubility of the edible films.

3.2. Thickness

The thickness of an edible film is primarily affected by the quantity of starch incorporated during production, since a higher starch content enhances the polymer composition of the film matrix. As the total solids of the edible film increase, the film will become thicker. The edible film made of starch without MAE was thinner than those made with MAE. This happened because the heat involved in MAE produced higher starch levels, in line with Harni et al. statement [14]. The radiation in MAE facilitates the release of starch from the material. Direct interaction between the material and microwave radiation excites the material's molecules, creating heat and frictions between molecules. The thickness of the edible films in this study exhibited considerable variation, as presented in Table 2.

Table 2. Thickness of edible films across treatments

Treatment	Thickness (mm)
Without MAE (Starch 3%)	0.17 ± 0.05
Starch 5%	0.36^{a} ± 0.02
Starch 4%	0.32^{b} ± 0.01
Starch 3%	0.24^{c} ± 0.05

Numbers followed by lowercase letters in the same column are not significantly different according to the DNMRT at the significance level of 5%. Values are expressed as means ± standard deviations.

According to the Japanese Industrial Standards (JIS) [19], the maximum thickness of an edible film is 0.25 mm. Therefore, as shown in the table above, the treatment with 3% starch met this standard. The 0.25 mm thickness is the optimum point between mechanical strength and flexibility and shows the best performance in water vapor and oxygen penetration tests. Edible film thickness over 0.25 mm may restrict gas exchange, thus accelerating the decomposition of the packaged product [20]. According to Aisyah et al. [21], an edible film composed of polysaccharide components will exhibit substantial thickness and elevated viscosity. Meanwhile, viscosity is influenced by the amylose concentration in starch [22]. Basiak et al. [23] state that starch with an elevated amylose content yields a thick film layer, whereas starch with a diminished amylose concentration produces a thin film. The thickness of the film in turn affects the transmission rate of vapors, gases, and volatile chemicals, as well as mechanical qualities, including tensile strength and elongation at break [22,24].

3.3 Water Holding Capacity (WHC)

WHC is directly proportional to the solubility of edible films, where high WHC causing starch solubility to increase. In this study, WHC differed significantly across treatments ($p < 0.05$). According to Malki et al. [25], arrowroot starch has a low WHC. High-WHC starch exhibits a looser starch polymer structure, whereas low WHC starch tends to have a more compact structure. In this study, the WHC of the edible film made without MAE was much lower than that of the edible films made with MAE. According to Harni et al. [9], MAE causes an increase in the WHC value because of the heat involved in the extraction process. The WHC data of the edible films according to treatment are presented in Table 3.

Table 3. WHC of edible films across treatments

Treatment	WHC (%)
Without MAE (Starch 3%)	36.84 ± 0.14
Starch 3%	38.56^{a} ± 0.24
Starch 4%	38.34^{b} ± 0.24
Starch 5%	37.85^{c} ± 0.17

Numbers followed by lowercase letters in the same column are not significantly different according to the DNMRT at the significance level of 5%. Values are expressed as means ± standard deviations.

According to Warkoyo et al. [26], the amylose concentration in starch affects the properties of edible films. Starch with an elevated amylose concentration exhibits an increased WHC due to the efficient water absorption properties of amylose. In contrast, starch with more amylopectin displays a reduced WHC. In other words, starch with a higher amylose concentration generally has a greater WHC than starch with more amylopectin. This is because amylose, a linear chain of glucose molecules, can form a denser structure that effectively absorbs and retains water. On the other hand, the branched structure of amylopectin reduces its ability to hold water, resulting in a lower WHC. Starch with a high amylose content will have a higher WHC because amylose absorbs water very easily. Arrowroot starch comprises around 24–30% amylose and 70–76% amylopectin [3]. Thus, edible films with an increased arrowroot starch concentration displayed a reduced water absorption capability. Moreover, if the starch content in the edible films is increased, the crystalline bonds within the starch will impede water absorption. According to Villas-Boas and Franco [4], arrowroot tubers are composed of type A crystalline structures. Robust type A crystalline structures diminish hydrophilic groups in the film's constituent material, hence impairing the film's capacity to interact with water and dissolve [27].

3.4. Oil Holding Capacity (OHC)

OHC is the ability of food ingredients to absorb oil. The average OHC decreases with increasing starch content. In this study, the average OHC values of edible films across treatments are presented in Table 4.

Table 4. OHC of edible films across treatments

Treatment	OHC (%)
Without MAE (Starch 3%)	36.81 ± 0.18
Starch 3%	36.67^{a} ± 0.55
Starch 4%	34.72^{b} ± 0.21
Starch 5%	34.40^{c} ±0.56

Numbers followed by lowercase letters in the same column are not significantly different according to the DNMRT at the significance level of 5%. Values are expressed as means ± standard deviations.

In starch extracted through MAE, the oil absorption is higher than the water content absorption because of the increase in starch surface area. After all, there are irregularities on the surface of the starch granules [28]. Microwave heat induces the creation of shorter amylose chains and promotes the development of double helices, thereby diminishing the hydrophilicity of starch granules and enhancing their affinity for oil [29]. Starch absorbs oil through capillary action, allowing the oil to penetrate the amorphous regions, thus enhancing its oil-binding capacity [30].

For the edible films in this study, the oil absorption value was slightly lower than that of water absorption. Water is hydrophilic to starch, allowing it to penetrate the edible films more easily. On the other hand, oil is hydrophobic to starch, causing it to be absorbed more slowly to the edible films and prolonging the product’s life. Starch-based edible films can safeguard products against oxygen, carbon dioxide, and oil, thus enhancing the products’ integrity [26].

3.5. Water Content

Starch obtained using MAE has a reduced water content because the extraction procedure employs heat to absorb additional moisture. The quantity of starch incorporated in the edible film production affects the water content in the edible film. The mean water content values of the edible films in this study are shown in Table 5.

Table 5. Water content of edible films across treatments

Treatment	Water Content (%)
Without MAE (Starch 3%)	14.59 ± 0.29
Starch 3%	13.79^{a} ± 0.35
Starch 4%	13.48^{b} ± 0.32
Starch 5%	12.97^{c} ± 0.04

Numbers followed by lowercase letters in the same column are not significantly different according to the DNMRT at the significance level of 5%. Values are expressed as means ± standard deviations.

Table 5 indicates that increased starch quantity correlates with decreased water content. This is attributed to the expansion of the matrix constituting the edible films. Elevating the starch concentration will increase the quantity of polymers constituting the film matrix. The water content of edible films in this study remained below the maximum level allowed by SNI 06-3735-1995, namely, 16%. According to Amaliya and Putri [31], an increase in the polymer content of the film matrix correlates with a higher solid content, resulting in a reduced water content in the edible film. The minimal water content of the edible film indicates its efficacy in safeguarding the packaged product and inhibiting food decomposition [33]. The water concentration in edible films is determined by the primary ingredients and other elements used [32].

4. Conclusion

From the research results, it can be concluded that the best treatment was the addition of 3% starch (A), which produced a thickness of 0.24 mm, below the maximum thickness threshold of 0.25 mm allowed by the Japanese Industrial Standards, a solubility of 76.55%, a water holding capacity of 38.56%, an oil holding capacity of 36.67%, and a water content of 13.79%. Increasing the amount of starch will increase the thickness but reduce the solubility, water holding capacity, oil holding capacity, and water content of the edible film produced.

Abbreviations

Not applicable.

Data availability statement

Data will be disseminated upon request by the readers.

CRediT authorship contribution statement

Mimi Harni: Conceptualization, Methodology, Resources, Writing, Original Draft. **Rivo Yulse Viza**: Formal Analysis, Validation, Data Curation. **Rilma Novita**: Review & Editing, Data Curation, Conceptualization. **Yenni Muchrida**: Methodology, Resources, and Formal Analysis.

Declaration of Competing Interest

The authors of this manuscript declare no conflict of interest or competing interest.

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