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The Effect of Lecithin and Carboxymethyl Cellulose (CMC) Concentrations on the Physical Characteristics of Sago Starch-Based Edible Films

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Abstract: Microplastics have begun to be detected in human food sources such as water and marine fish. One of the solutions that has been increasingly studied and developed is edible film. Sago starch holds significant potential to be developed as a raw material for edible film production. However, the physical characteristics of edible films made from pure sago starch tend to be brittle, water-soluble, and mechanically weak. To enhance their physical quality, additives such as lecithin and carboxymethyl cellulose or CMC are required. This study aimed to evaluate the physical properties of sago-based edible films, including thickness, solubility, tensile strength, and water vapor transmission rate (WVTR), at various concentrations of lecithin (0.3%, 0.5%, 0.7%, and 1.5%) and CMC (0.1%, 0.3%, 0.5%, and 0.7%) to determine the optimal formulation for use as food packaging. The research employed experimental research, using Completely Randomized Design. Data were analyzed using one-way ANOVA followed by Duncan's post hoc test. Results showed that both lecithin and CMC concentrations significantly affected the physical characteristics of the edible films. Based on these observations, treatment B4 was identified as having the best overall physical characteristics, providing a good balance between mechanical strength and water resistance with adequate film thickness.

Keywords: CMC; Edible film; Lechitin; Sago starch

Introduction

Plastic waste is a global problem faced by the world, especially in developing countries such as Indonesia. This is because plastic-based packaging has long been the primary option in the food industry due to its low cost and ease of molding, which allows for the creation of more attractive packaging designs. However, the danger of microplastic pollution—affecting not only land but also the world's water bodies—can have severe health implications for humans (Kühn & van Franeker, 2020). Therefore, alternative packaging solutions are needed to reduce the excessive use of plastic, particularly in instant food packaging applications.

One potential solution to minimize plastic usage is the development of packaging that can be consumed along with the food it contains. Edible film offers a promising option for this concept. In addition, edible films serve as barriers to external moisture and oxygen, which can help prolong the shelf life of perishable food products (Dirpan et al., 2023). Starch-based films, in particular, have been extensively studied because of their eco-friendly characteristics and renewability. Edible films can be developed from various natural

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sources such as polysaccharides, proteins, and starches—including sago starch (Aguirre et al., 2018).

Sago is a local variety native to South Sulawesi and is recognized as one of the region's flagship commodities. Nutritionally, sago offers advantages over other staple food sources (Fatah et al., 2015). In South Sulawesi, sago is primarily processed into dry or wet sago flour, serving as a raw material for several traditional foods, including dange, kapurung, sinole, bagea, and kue ongol-ongol. However, the utilization and processing of sago, particularly as a regional commodity, remain underdeveloped (Haruna et al., 2022). Sago starch has great potential to be used as a raw material for the production of edible coatings or edible films (Julyaningsih et al., 2020). Nevertheless, native sago starch tends to form edible films that are cracked, brittle, and highly water-soluble (Syafri et al., 2019) (Ehara & Toyoda, 2018), which limits its application. To improve these limitations, emulsifiers or stabilizers need to be incorporated into the formulation to enhance the film's physical properties for food packaging purposes.

Lecithin is a natural emulsifier commonly derived from soybeans or egg yolks. It is a natural phospholipid with amphipathic properties, meaning it contains both hydrophilic and lipophilic regions (Hamad et al., 2022). The use of lecithin in edible films has been shown to improve film flexibility and reduce water vapor transmission rates (Désiré et al., 2018). Meanwhile, CMC (Carboxymethyl Cellulose) is a cellulose derivative frequently used in the food industry as a film-forming agent, thickener, and stabilizer (Yusra, 2019). CMC is a white, odorless powder with hydrocolloid properties and is known for enhancing the mechanical strength of edible films.

The physical characteristics of edible films are strongly influenced by the composition and formulation of their constituent materials. Previous studies have shown that increasing starch concentration generally improves the physical performance of the film (Julyaningsih et al., 2025). Similarly, the use of glycerol as a plasticizer affects flexibility—films become more brittle and prone to breaking when lower glycerol concentrations are used (Julyaningsih et al., 2025).

Method

Materials

The raw material used in this study was commercial sago starch produced by PT. Citra Sukses International. The emulsifier used was soy lecithin, the plasticizer was glycerol, and the stabilizer was powdered carboxymethyl cellulose (CMC). Equipment used in the development of the edible film solution included an analytical balance, beakers, measuring cylinders, a magnetic stirrer, silicone molds, and a hot plate. The drying process of the film was carried out using a food dehydrator. The thickness of the film was measured using a micrometer screw gauge, tensile strength was tested using a universal testing machine, and WVTR was determined using an oven-based gravimetric method.

Methods

This research was conducted from April to June 2025 at the Food Microbiology and Biotechnology Laboratory, Department of Food Science and Technology, Hasanuddin University. The study consisted of two stages: preparation of the edible film and analysis of its physical characteristics. A previous study on the development of sago starch-based edible films using several starch concentrations identified 7% (w/v) sago starch as the optimal concentration. In this study, 7 grams of sago starch were dissolved in 100 mL of distilled water and homogenized using a magnetic stirrer (Julyaningsih et al., 2025). The solution was then heated on a hot plate until it reached 70°C. Once the gel began to form, 3% (v/v) glycerol was added as a plasticizer, followed by the addition of lecithin (A1 = 0.3%, A2 = 0.5%, A3 = 0.7%, A4 = 1.5%) and CMC (B1 = 0.1%, B2 = 0.3%, B3 = 0.5%, B4 = 0.7%) according to each treatment. A control treatment without lecithin or CMC was also prepared for comparison.

The gel solution was poured into silicone molds and dried in a food dehydrator at 45°C for 24 hours. Once dried, the edible films were carefully removed from the molds and stored in containers containing silica gel to maintain dryness. The films were then subjected to physical property analysis, including tensile strength (cN), water solubility (%), water vapor transmission rate (WVTR), and thickness (mm) (Dhumal et al., 2019).

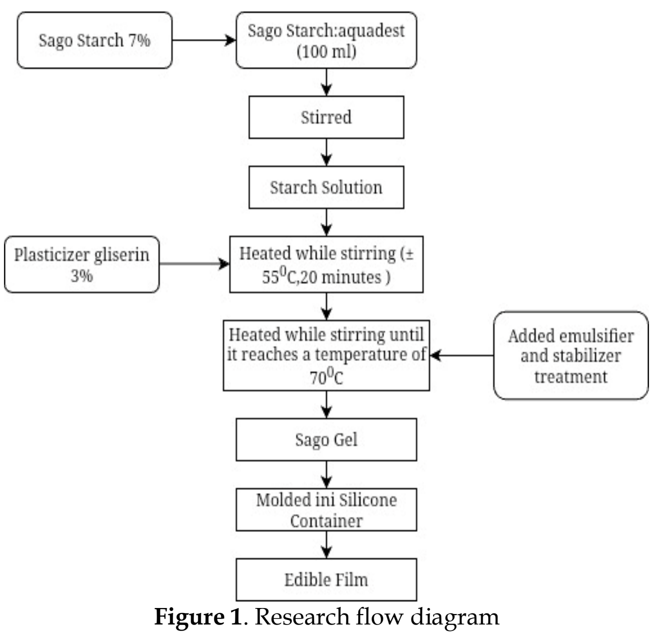

Figure 1. Research flow diagram

This study was conducted using a Completely Randomized Design (CRD) with three replications. The physical property data were analyzed using analysis of variance (ANOVA), followed by Duncan's multiple range test (DMRT) to determine significant differences among treatments.

Study Stages

Thickness Test (mm)

The thickness of the edible film was measured using a micrometer screw gauge with a precision of 200 mm to 0.01 mm. Each film sample was measured at five different points, and the average thickness was calculated for analysis (Dhumal et al., 2019).

Water Solubility Test (%)

Each edible film sample was cut into a 2 × 2 cm square. The sample and filter paper were pre-dried in an oven at 105°C for 24 hours. After drying, the film and filter paper were weighed separately using a digital balance, and the weights were measured as the initial weight (W1). The film sample was then soaked in 50 mL of distilled water and continuously stirred for 6 hours. After soaking, the mixture (film + water) was filtered using the pre-dried filter paper. The undissolved residue of the film, along with the filter paper, was oven-dried again at 105°C for 24 hours. Once dried, the sample was weighed to obtain the final weight (W2) (Dewi et al., 2021). The percentage of undissolved material was then calculated using the following formula:

$$\%\,Solubility = \frac{W_1 - W_2}{W_1} \times 100\% \quad (1)$$

Tensile Strength Test (mPa)

Each edible film sample was cut into a size of 35 × 55 mm. One end of the film sample was fixed onto the clamp of a universal testing machine, while the other end was clamped onto the movable grip of the device. The movable grip was then gradually pulled until the film sample tore apart (Hazirah et al., 2018). The force required to tear the film was recorded by the testing machine. The tensile strength was calculated using the following formula:

$$Tensile\ strength\ (mPa) = \frac{F}{A} \quad (2)$$

Water Vapor Transmission Rate (WVTR)

This test was carried out using the gravimetric cup method. Edible film samples were cut into circular shapes to match the diameter of the testing cups, and their initial weight (W1) was recorded. The empty cups were also weighed, then 3 grams of silica gel were introduced into each cup. The edible film samples were then sealed over the top of the cups using melted wax to ensure complete coverage. The cups, covered with the edible films, were stored at room temperature for 24 hours. After the storage period, the edible film samples were reweighed to obtain the final weight (W2) (Dewi et al., 2021). The water vapor transmission rate (WVTR) was calculated using the following formula:

$$TUA = \frac{W_1 - W_2}{t \times A} \quad (3)$$

Result and Discussion

Thickness Test Results

The thickness of the edible film was strongly influenced by the formulation of each material used (Warkoyo et al., 2014). In general, increasing the concentration of either lecithin or CMC led to an increase in the thickness of the resulting edible film. This trend was supported by the results of the ANOVA analysis.

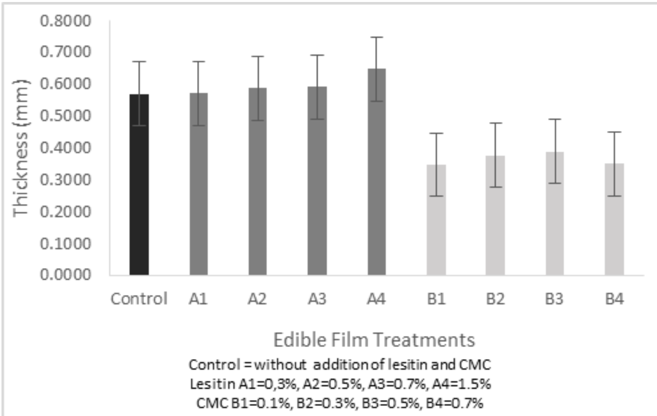

Figure 2. Comparison of film thickness across treatments

Based on the ANOVA results ($p < 0.001$) comparing the control and lecithin treatments at various concentrations, a statistically significant difference in film thickness was observed. Similarly, the ANOVA results between the control and CMC treatments ($p < 0.05$), as well as across all treatments ($p < 0.01$), also indicated significant differences. The Duncan's post-hoc test further revealed that only treatment A4 differed significantly from all other treatments, with A4 exhibiting the highest film thickness compared to both the control and all CMC-based treatments. Meanwhile, Duncan's test comparing the control and CMC treatments showed that only the control differed significantly, whereas the various CMC concentrations did not differ significantly from one another.

The higher the concentration of lecithin used, the thicker the resulting film (Mukaila et al., 2024). This result can be attributed to the emulsifying properties of lecithin, which interacts with starch molecules, increasing the viscosity of the film-forming solution and resulting in a thicker, denser dried film layer (Oke et al., 2010). In contrast, the negatively charged polysaccharide structure of CMC interacts linearly with starch molecules, forming a uniform and homogeneous polymer network without significantly increasing the film volume (Muhammad et al., 2023).

When comparing lecithin (treatment A) to CMC (treatment B), it can be concluded that lecithin addition resulted in thicker edible films than those formed with CMC. This is because lecithin acts as an emulsifier that promotes better dispersion of starch and glycerol during film preparation (Dickinson, 2009). At higher concentrations, lecithin can form aggregates that help maintain the solid matrix volume during drying, leading to thicker films. In contrast, CMC tends to form a compact network and functions as a strong binder (Zhao et al., 2022); as water evaporates, CMC pulls together the starch and glycerol chains, forming a tighter structure.

Water Solubility Test Results

The ANOVA analysis showed that the control treatment differed significantly from the treatments with varying concentrations of lecithin (A), CMC (B), and from the overall set of treatments. Duncan's post-hoc test between the control and lecithin treatments indicated that only A3 and A4 differed significantly from the control.

Meanwhile, Duncan's test comparing the control and CMC treatments showed that the control and B1 were not significantly different. When Duncan's test was applied to the combined group of control, lecithin (A), and CMC (B) treatments, the results indicated that: The control and B1 were not significantly different; A1 and A2 belonged to the same homogeneous group; A3, B2, and B3 were statistically similar; A4 and B4 formed another homogeneous group.

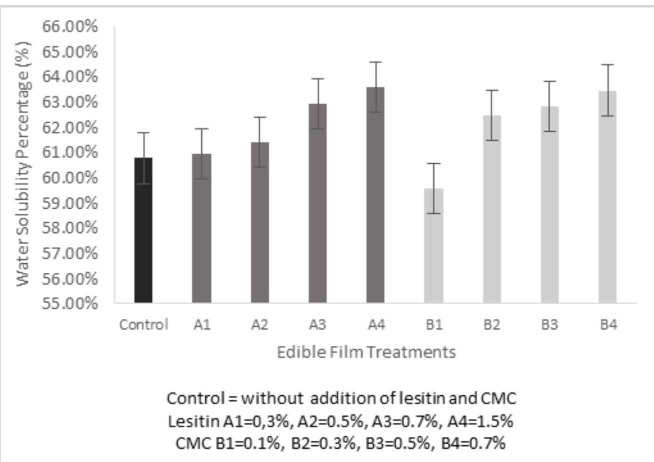

Figure 3. Comparison of water solubility across treatments

The results of the ANOVA analysis showed that the control treatment differed significantly from the treatments with varying concentrations of lecithin (A), CMC (B), as well as from the overall group of treatments. Duncan's post-hoc test between the control and lecithin treatments revealed that only A3 and A4 differed significantly from the control. Meanwhile, Duncan's test comparing the control with CMC treatments indicated that the control and B1 were not significantly different. When Duncan's test was extended to include all treatments (control, A, and B), the results showed that control and B1 were statistically similar, A1 and A2 formed one homogeneous group, A3, B2, and B3 formed another, and A4 and B4 were grouped together.

Lecithin is a type of phospholipid with an amphiphilic structure, having a hydrophilic "head" and a hydrophobic "tail" (Santamaria-Echart et al., 2021). Sago starch contains hydroxyl (–OH) groups that can interact with water, but in dense film structures, not all hydroxyl groups are exposed and able to react with water. When lecithin is added, its hydrophobic tail interacts with the starch chains, while its hydrophilic head faces outward (He et al., 2024). This orientation allows more hydrophilic groups to interact with water molecules more readily. As the concentration of lecithin increases, a greater number of hydrophilic groups become exposed and available for interaction, increasing the solubility of the film (Henao-Ardila et al., 2024). Treatments A1 and A2 showed no significant difference from the control because the lecithin concentration was still too low, limiting the number of hydrophilic groups available to interact with water during the solubility test.

CMC, on the other hand, is produced by substituting the hydroxyl groups of cellulose with carboxymethyl groups ($–CH_2COOH$), which are negatively charged and highly polar. This makes CMC highly hydrophilic (Henao-Ardila et al., 2024). As the concentration of CMC increases, more hydrogen bonds form between CMC and water molecules, leading to increased water uptake during the solubility test—especially for B2, B3, and B4, which contained higher CMC concentrations.

Overall, CMC treatments (B) resulted in edible films with greater water solubility compared to lecithin treatments (A). This can be attributed to the fact that lecithin has a lower hydrophile-lipophile balance (HLB) value than CMC (Chung et al., 2019). For instance, soy lecithin has an HLB value of around 7, whereas CMC has an HLB value between 12 and 18 (Charpentier-Valenza et al., 2005). The higher the HLB value, the more hydrophilic the surfactant is.

Tensile Strength Test Results

The tensile strength of edible films is highly influenced by the thickness of the film. In general, the greater the film thickness, the higher the tensile strength it can exhibit. The effect of varying concentrations of lecithin and CMC is presented in Figure 3. The results of the ANOVA test at the 0.01 significance level indicated significant differences between the control treatment and the various lecithin concentrations (A), between the control and the CMC treatments (B), and also among all treatments overall.

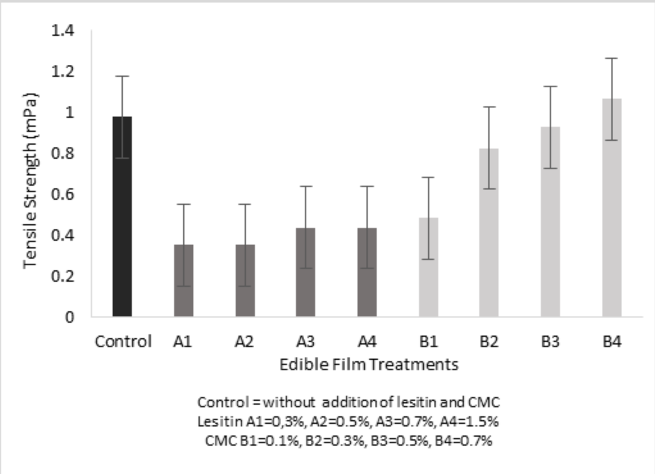

Figure 4. Comparison of tensile strength across treatments

Duncan's post-hoc test comparing the control and lecithin treatments showed that only the control differed significantly, while all lecithin treatments (A1–A4) were statistically similar. In the comparison between control and CMC treatments, only the control and B3 were statistically similar, while the rest differed significantly. When Duncan's test was applied across all treatments, it was observed that the control, B2, B3, and B4 each formed separate groups, indicating significant differences among them.

The variation in lecithin concentration did not produce a sufficiently large effect to show a significant difference in tensile strength. The control treatment exhibited higher tensile strength than all lecithin-treated samples. This is likely because lecithin acts as a secondary plasticizer in the edible film—primarily due to its lipophilic region. The lipophilic interaction of lecithin with starch and glycerol chains may reduce intermolecular hydrogen bonding between starch molecule (Liang & Ludescher, 2015). This weakens the interactions in the polymer network, allowing the chains to move more freely and thus increasing the film's flexibility and elongation (He et al., 2024). As a result, the edible films formed are easier to stretch but less resistant to applied tensile forces, making them more prone to breaking (Mukaila et al., 2024).

As shown in Figure 3, tensile strength increases with higher CMC concentrations in the film. Treatments B1 and B2 showed lower tensile strength than the control, likely because low concentrations of CMC may behave like plasticizers, enhancing flexibility rather than strength. This occurs because when CMC comes into contact with glycerol, the hydrogen bonds within the CMC polymer chains are disrupted by the glycerol, weakening the intermolecular interactions between CMC molecules. As a result, the polymer network becomes less rigid and more flexible (Suryanto et al., 2025). In contrast, B4 showed a tensile strength that exceeded the control, indicating that adding CMC at concentrations above 0.7% can improve the tensile strength of edible films compared to films without CMC (Putri et al., 2018).

The addition of CMC to the edible film solution increases its viscosity due to the negatively charged carboxymethyl groups in CMC, which form hydrogen bonds with water molecules left unbound by starch hydroxyl groups (Tavares et al., 2020). During drying, this high viscosity results in a denser, more homogeneous, and cohesive film structure. The strong cohesive matrix formed enhances the film's ability to resist tensile forces before eventually breaking.

Water Vapor Transmission Rate Test Results

Water Vapor Transmission Rate (WVTR) is a quantitative measure used to quatify the amount of water vapor that can travels through a material or film per unit area and per unit time. A higher WVTR value indicates that water vapor can penetrate the film more easily, which can negatively affect the quality of the packaged product.

The results of the ANOVA analysis between the control and the various lecithin concentrations (A) showed no significant difference. However, the ANOVA analysis between the control and the CMC treatments (B) indicated a significant difference at the 0.05 level. The Duncan post-hoc test revealed that among all treatments, only B4 was statistically significat difference.

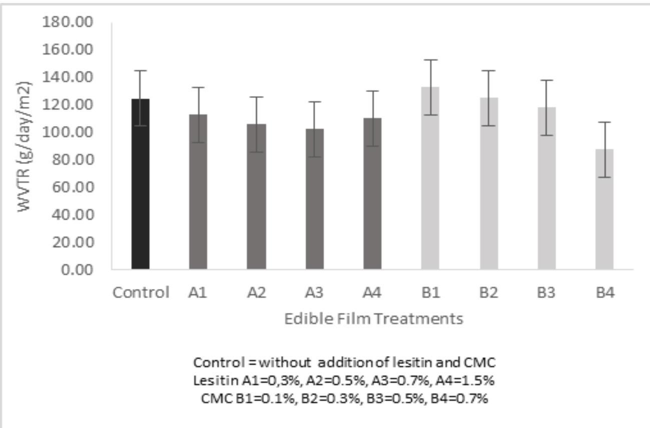

Figure 5. Comparison of WVTR across treatments

Although the increasing concentrations of lecithin (A) showed a downward trend in WVTR values, the concentrations used were not sufficient to effectively enhance the barrier properties of the edible film against water vapor. The WVTR results were also correlated with the thickness test findings. Films with CMC addition tended to be thinner, more compact, and denser. The denser the film structure, the fewer free spaces are available between molecules for water vapor to diffuse through (Figueroa-Lopez et al., 2024). This is because CMC forms strong hydrogen bonds with both starch molecules and other CMC chains, resulting in a tight and cohesive polymer network (Figueroa-Lopez et al., 2024). These strong interactions lead to a film structure that is more resistant to water vapor transmission.

Conclusion

The results of this study demonstrated that the addition of lecithin (A) and CMC (B) had a significant effect on the physical characteristics—including thickness, water solubility, tensile strength, and water vapor transmission rate (WVTR)—of edible films formulated with 7% sago starch and 3% glycerol. The findings also indicated that increasing concentrations of lecithin and CMC in the film-forming solution tended to increase solubility and tensile strength, while decreasing WVTR of the resulting edible films. Among all treatments, B4 (0.7% CMC addition) produced edible films with the most desirable physical properties: thin film thickness (0.349 mm), the highest tensile strength (1.0619 MPa), and the lowest WVTR (87.5 g/day/m²). Although B4 exhibited relatively high water solubility, this drawback was compensated by its superior mechanical protection and barrier properties against water vapour. The A4 is most suitable as a primary packaging film intended for instant food products that are meant to be dissolved directly in hot water along with their packaging, due to its high water solubility and lower tensile strength, which enables rapid and complete disintegration in hot water. Further studies are required to evaluate the influence of different types of emulsifiers that could be applied in the production of edible films for use as primary or secondary packaging materials

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Author Contributions
Conceptualization, A. H. J, A. N. F. R., F. I. P. H.; data collection, A. H. J.; analysis, A. H. J.; writing and editing, A. H. J.; supervision, A. N. F. R. and F. I. P. H.

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Conflicts of Interest
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