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Development and Characterization of Edible Films from Sodium Alginate and Arrowroot Starch Plasticized with Sorbitol

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ABSTRACT. The demand for eco-friendly packaging is growing in industrial applications. This study aimed to develop edible films using sorbitol, sodium alginate (SA), and arrowroot starch (ARS). Sorbitol, serving as a plasticizer, was evaluated for optimal concentration, while various SA:ARS ratios were tested for film formation. Physicochemical properties, including thickness, color, tensile strength, elongation, moisture content, opacity, water solubility, water vapor transmission rate, biodegradability, FTIR, and SEM morphology were analyzed. Results indicated that 0.5% sorbitol produced films with ideal thickness, color, tensile strength, and elongation. SA:ARS ratios significantly influenced film properties, with the 0.9:0.1 ratio yielding a thin, smooth, and highly biodegradable film. This formulation provides a basis for further edible film research and food industry applications.

Keywords: Arrowroot starch, edible film, sodium alginate, sorbitol

INTRODUCTION

The development of environmentally friendly food packaging is an emerging request for better sustainability in the food industry. Plastic packaging is one of the leading sources of environmental pollution since it is extremely difficult to degrade in nature. Biopolymer films made of renewable resources, usually obtained from natural raw materials such as starch and sodium alginate (Murrieta-Martínez et al., 2018; Shanbhag et al., 2023), would be an excellent alternative to plastic film. Starches derived from various botanical sources are an important polymer contributing to the development of biofilms (Wibowo et al., 2020). Arrowroot (*Canna edulis* KERR) starch has been investigated to develop starch films due to its high amylose content, offering the film superior physicochemical properties such as better tensile strength and flexibility (Nogueira et al., 2019; Tarique, et al., 2021). Arrowroot starch-based films have been developed by incorporating different materials such as carnauba wax (de Oliveira Filho et al., 2020), blackberry pulp (Nogueira et al., 2019). Plasticizer use in arrowroot starch–based films has been limited, and, based on current literature, glycerol appears to be the only plasticizer documented to date (Nogueira et al., 2018; Tarique et al., 2022). Conversely, alternative plasticizers have not yet been reported in this context. Sorbitol has been widely used as a plasticizer in starch-based films such as corn, tapioca, and potato starches (Nogueira et al., 2019). However, the investigation of using sorbitol as a plasticizer in arrowroot starch-based film is quite limited. The interaction between sodium alginate and starch has been reported (Siddaramaiah et al., 2008). Sodium alginate extracted from seaweed is valued in sustainable packaging for its biodegradable, safe, and superior film-forming properties (Deepa et al., 2016). Although sodium alginate produces transparent and flexible films (Gheorghita et al., 2020), its low mechanical strength often necessitates blending with other materials to improve performance. Sodium alginate/starch system has been used to develop biodegradable films (Wang et al., 2013; Abduwaiti et al., 2021). The combination of sodium alginate, arrowroot starch, using sorbitol as a plasticizer for producing edible film has not been studied yet and the interactions between sorbitol, sodium alginate and arrowroot starch in edible films have not been fully investigated. This study aimed to develop edible films based on a sodium alginate/arrowroot starch system with sorbitol as a plasticizer. To achieve this aim, specific objectives were set as follows: determine the

suitable concentration of sorbitol as a plasticizer, and then investigate the impact of the sodium alginate/arrowroot starch ratio on the physicochemical properties of the film.

EXPERIMENTAL SECTION

Materials

Sodium alginate (PT Samiraschem, Indonesia), arrowroot starch (CV Progress Jogja, Indonesia), and food grade sorbitol that were obtained from Prima Chemical Store (Indonesia).

Determining Suitable Sorbitol Level in Arrowroot Starch-Alginate Film

The experimenta l procedure is illustrated in **Figure 1**. The film-casting method followed Otoni et al. (2017). Sorbitol was tested at 0.5,1.0, and 1.5% to the mixture of sodium alginate (SA) and arrowroot starch (ARS). The composite film formulation consisting of SA and ARS was consistently maintained for each treatment in the sorbitol application. The mixture was prepared into a slurry and stirred at 500 rpm for 30 minutes at 70–80 °C using a heated magnetic stirrer. Sorbitol was then added, followed by an additional 20 minutes of stirring. After cooling to 30 °C, 100 mL of the solution was poured into molding dishes and dried at 35 °C for 20 hours. The films were collected, stored on parchment paper at 25±2 °C and 55±1% relative humidity (RH), and analyzed for color, thickness, tensile strength, and elongation. The experiment was performed in triplicate.

Effect of Sodium Alginate:Arrowroot Starch Ratio on The Film Properties

The second phase of this experiment, was to produce arrowroot starch-based edible film, using five variations of sodium alginate (SA) and arrowroot starch (ARS) ratio (SA:ARS ratio), as described in **Table 1**. The same film-casting protocol was applied. Films were analyzed for physicochemical properties, including moisture content, thickness, color, opacity, tensile strength, elongation, solubility, water vapor transmission, biodegradability, and SEM morphology. Each film was tested in four replicates.

Physicochemical Properties Characterization

Moisture content

The moisture content of film was evaluated by gravimetric method according to the procedure described by Júnior et al. (2021). The 5 g of the film samples were determined using an analytical balance. The samples were heated to 105 °C for 24 hours in an oven, and after they were cooled, their weight was measured. Moisture content (%) was determined by the following equation:

$$Moisture\ content = \frac{W_1 - W_2}{W_1} * 100$$

Where by,

W_1 is the initial mass of the film

W_2 is the final mass of the film.

Thickness

The thickness of films was measured using an outside micrometer (Keawpeng et al., 2022). Each film was tested for thickness at ten random sites. The results were expressed in millimeters.

Color

Color was analyzed using a colorimeter (CS 10 CS-10 CHNSPEC, Zheijiang Co. Ltd., China), as described by Bhatia et al. (2023). The instrument was calibrated using a black and white panel available from the device before use. Color analysis was carried out by putting the optic probe on a film sheet. Results of color analysis were displayed on the screen using L*, a*, and b* values. Analysis was made on 10 different points and the data given were average of these replications.

Opacity

Opacity was analyzed using spectrophotometry UV-Vis based on a study of Zhao et al. (2022). Samples were cut into 4 x 1 cm (length x width) and shaped into a cuvette with a similar size to ensure the light path from the spectrophotometer can pass through properly. Then the cuvette was placed in a spectrophotometer and the absorbance was measured at 600 nm wavelength (A_{600}). The calculation of opacity was calculated using the following equation:

$$Opacity\ (mm^{-1}) = \frac{A_{600}}{Thickness\ (mm)}$$

Tensile strength and elongation

The tensile strength and elongation were measured using a universal testing machine (UTM), Stable Microsystem (UK) based on a study by Yu et al. (2023). The film was cut into 100 x 20 mm (length x width) and mounted centrally in the UTM grips. The film was stretched at a constant speed of 5 mm/min until failure. The tensile strength and elongation were calculated as follows:

$$Tensile\ strength\ (MPa) = \frac{Maximum\ Tensile\ force}{cross\ sectional\ area}$$

$$Elongation\ (\%) = \frac{Distance\ of\ Max.Tensile\ force}{the\ initial\ length\ of\ the\ film} \times 100\%$$

Water solubility

The ability to be dissolved in water of the films was measured using the method described by Behera et al. (2022). The dry films were cut (2 x 2 cm) and weighed to record the initial weight (a_1). The films were then immersed in 100 mL of distilled water in a glass beaker. Subsequently, the glass beaker was placed on the magnetic stirrer and the sample was stirred for 2 hours at the speed of 500 rpm. After 2 hours, the non-solubilized samples were filtered by using filter paper (pore size 15-20 μm). The insoluble part was dried and the dry mass was measured (a_2). Solubility was calculated as follows:

$$Solubility\ (\%) = \frac{a_1 - a_2}{a_1} \times 100$$

Water vapor transmission rate (WVTR)

The water vapor transmission rate was measured as described in a study by Behera et al. (2022). The

films were cut into 4.1 cm diameters to determine the water vapor transmission rate (WVTR). Each vial contained 2 grams of silica gel, and a suitable adhesive was used to seal the films. The complete setup was weighed and kept at room temperature for 24 hours. The WVTR was calculated using the following equation:

$$\text{WVTR}(g/m^2.hour) = \frac{\text{weight difference (gram)}}{\text{time (hours)}} \times \text{surface area } (m^2)$$

Biodegradability

Biodegradability testing, which evaluates decomposition ability and impact on the environment, followed a method suggested by Beghetto et al. (2020). Biodegradability measurement was determined using a soil burial degradation test. The film was cut into small pieces (2 x 2 cm), and then they were buried in garden soil and observations were made at 5, 15, and 30-day intervals until the samples were decomposed.

Scanning electron microscopy (SEM)

The film samples were adhered to double-sided carbon tape and subsequently mounted onto aluminum stubs before being placed into the SEM chamber of the TM4000plus instrument (Hitachi, Japan). An accelerating voltage of 5 kV was employed to optimize the visualization of the membrane surface with a working distance of approximately 6 mm. Images were acquired at a magnification of 1000X.

Fourier-transform infrared spectroscopy (FTIR)

Each membrane sample was positioned and firmly pressed onto the ATR base of the FT/IR 4700 spectrometer (Jasco, Japan). FTIR spectra were recorded within the wavenumber range of 4000–400 cm^{-1} with a resolution of 2 cm^{-1}.

RESULTS AND DISCUSSION

Optimal Sorbitol Concentration for Edible Film Casting

Thickness, tensile strength and elongation

The sorbitol concentration significantly affected film formation and morphology (**Figure 1**). Imaging showed that 0.5% sorbitol enabled proper film formation. The sorbitol concentration significantly ($p<0.05$) affected film formation and morphology (**Figure 1**). At 0.5% sorbitol, which was applied as a plasticizer, proper film formation was enabled. Increased plasticizer concentration enhanced the polymer matrix and total dissolved solids, thickening the film (Suyatma et al., 2005). **Table 2** presents the average thickness values. The thickness of the films ranged from 0.06 to 0.09 mm, aligning with the findings of Hatmi et al. (2020), who reported a thickness of around 0.06 to 0.125 mm in cassava and canna starch-based films, respectively. The highest thickness (0.09 mm) was observed at 1.5% sorbitol, while the lowest (0.06 mm) was at 0.5%. Different plasticizers and concentrations influence edible film properties like density, thickness, and solubility. Ideally, edible films should be under 0.25 mm thick (Skurtys, 2010), making thinner films preferable. Here, the 0.5% sorbitol film was the thinnest, suggesting its potential as an optimal plasticizer concentration for further edible film research.

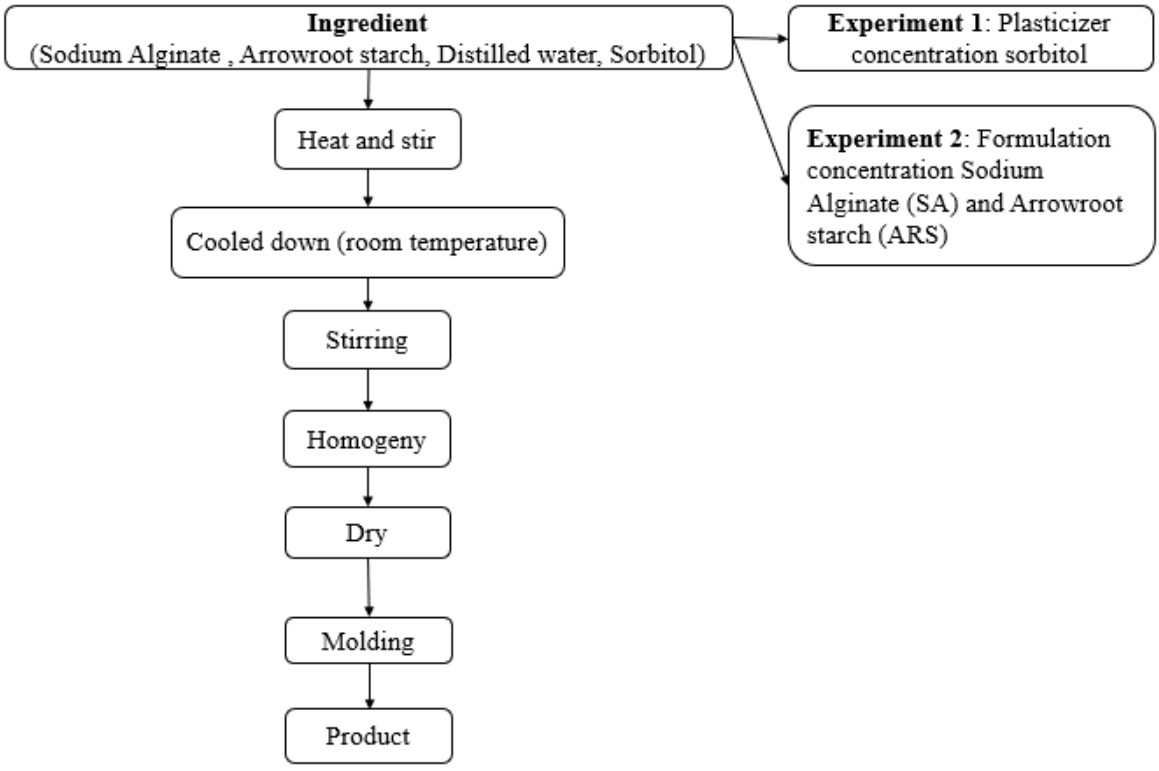


Figure 1. Edible film casting procedure and experimental design

Table 1. Sodium alginate (SA) and arrowroot starch (ARS) ratios used to formulate edible film

Name samples	SA:ARS ratio (of total 1% w/v)
SA:ARS (C1D)	0.9:0.1
SA:ARS (C2D)	0.7:0.3
SA:ARS (C3D)	0.5:0.5
SA:ARS (C4D)	0.3:0.7
SA:ARS (C5D)	0.1:0.9

Table 2. Thickness, tensile strength, and elongation at the break of films cast from various sorbitol concentrations

Sorbitol added (%)	Thickness (mm)	Tensile strength (MPa)	Elongation (%)
0.5	0.06 ± 0.01^{b}	0.26 ± 0.12^{a}	7.56 ± 2.64^{b}
1.0	0.08 ± 0.02^{a}	-	-
1.5	0.09 ± 0.02^{a}	0.06 ± 0.01^{b}	78.01 ± 17.00^{a}

The values are mean ± standard deviation (n =3). Different letters in the same column showed statistically different ($p<0.05$). "-" not available, due to the edible film being thin and sticking together, making it impossible to shape for experiments

Table 2 shows that orbitol concentration significantly affected tensile strength and elongation in edible films. The highest tensile strength (0.26 MPa) was at 0.5% sorbitol, while the lowest (0.06 MPa) was at 1.5%. As a plasticizer, sorbitol reduces hydrogen bonds and increases molecular spacing, enhancing flexibility (Yu et al., 2023). Higher sorbitol concentrations weaken tensile strength but increase elongation, as seen in previous studies (Khoiriyah, 2018; Martins et al., 2022). Elongation ranged from 7.56% (0.5% sorbitol) to 78.01% (1.5% sorbitol). Plasticizers reduce polymer intermolecular forces, increasing flexibility (Khwaldia et al., 2004). Both elements of edible films are affected by the concentration of plasticizer added. Since sorbitol acts as a plasticizer, this causes the possibility of hydrogen bonds to be reduced and molecular spacing to increase, resulting in a more flexible and edible film structure (Yu et al., 2023). Besides, the addition of plasticizers can also reduce the intermolecular forces of the polymer to increase the toughness of the edible film. According to other experiments, as the sorbitol concentration increases, the elongation rate also increases. Increasing the sorbitol concentration resulted in a significant decrease in tensile strength and a large increase in elongation (Martins et al., 2022). Generally, higher sorbitol increases elongation but lowers tensile strength (Rahmawati et al., 2019). While 0.5% sorbitol had lower elongation, its tensile strength was acceptable, whereas 1.5% led to excessive stretching. Thus, 0.5% sorbitol would be the optimal plasticizer concentration.

Effect of Different Sodium Alginate (SA) And Arrowroot Starch (ARS) Ratios on The Physicochemical Properties of The Edible Film

Moisture content

The ratio of SA:ARS showed a significant ($p<0.05$) effect on the moisture content of the edible films (**Table 3**). Moisture content of the films ranged from 12.44% (C5D) to 18.42% (C1D) in the combined treatment of various concentrations of ARS. An increased trend in the moisture content was observed with an increase in the percentage of SA added. The results of this study are in agreement with a study by Xiao et al. (2000), who reported that increasing SA from 5.1 to 56.1% lead to a linear increase in the moisture content of film. SA is an anionic polysaccharide of L-guluronic and D-mannuronic acids (Akbar et al., 2023), containing highly hydrophilic functional groups such as hydroxyl and carboxyl, which readily interact and retain water. Higher moisture content may enhance the molecular mobility of the film and increase the free volume in the film matrix (Zhang et al., 2018). As water molecules penetrate the film matrix, they form new hydrogen bonds with polar groups (such as hydroxyl and carboxyl), thereby weakening the original polymer-polymer interactions. This disruption increases molecular mobility, allowing the polymer chains to move more freely relative to one another. The enhanced mobility, in turn, contributes to an increase in free volume within the film structure. Water content in food affects the stability, appearance, texture, and taste of food, as well as controlling the growth of microorganisms. The edible film that has low moisture would reduce microbial damage and thus extend the shelf life of foodstuffs.

Thickness

Data analysis showed that SA and arrowroot starch variations did not significantly affect film thickness (**Table 3**), which ranged from 0.056 to 0.072 mm. The thickest film (0.072 mm) was at 0.1% arrowroot starch (C1D), and the thinnest (0.056 mm) was at 0.9% (C5D). Film thickness may depend on polymer composition and structure, with branched polymers forming thicker films. It was reported that increasing sodium alginate (SA) concentration results in thinner

Table 3. Moisture, thickness, and color parameters of the films obtained from different sodium alginate and arrowroot starch ratios

Sample	Moisture (%)	Thickness (mm)	Color		
			L	a*	b*
C1D	18.42 ± 0.54^{a}	0.072±0.019^{a}	89.55±0.37^{a}	-0.04±0.08^{d}	2.66±0.26^{c}
C2D	17.04 ± 0.60^{ab}	0.069±0.012^{a}	89.40±0.24^{a}	-0.01±0.13^{d}	2.96±0.56^{b}
C3D	15.21 ± 1.35^{bc}	0.056±0.011^{a}	88.92±0.29^{b}	0.13±0.06^{c}	2.95±0.23^{b}
C4D	13.69 ± 0.79^{cd}	0.060±0.010^{a}	88.92±0.26^{b}	0.20±0.63^{b}	3.01±0.31^{b}
C5D	12.44 ± 1.13^{d}	0.056±0.010^{a}	88.35±0.42^{c}	0.28±0.14^{a}	3.54±0.33^{a}

The values are mean ± standard deviation (n =4). Different letters in the same column showed statistically different ($p<0.05$).

Table 4. The opacity, water solubility, and water vapor transmission rate of the films with different sodium alginate and arrowroot starch ratios

Samples	Tensile strength (MPa)	Elongation (%)	Opacity (mm^{-1})	Water solubility (%)	WVTR (g/m^2hour)
C1D	0.46 ± 0.12^{a}	17.86 ± 4.36^{c}	2.41±0.19^{c}	96.53±1.89^{a}	1.86 ± 0.15^{a}
C2D	0.36 ± 0.09^{b}	25.84 ± 4.95^{b}	2.41±0.65^{c}	90.23±0.30^{b}	1.43 ± 0.23^{ab}
C3D	0.64 ± 0.17^{a}	18.81 ± 5.43^{c}	3.32±0.39^{b}	89.84±0.49^{b}	1.29 ± 0.19^{b}
C4D	0.43 ± 0.05^{b}	31.44 ± 5.80^{b}	3.58±0.39^{ab}	87.66±0.39^{c}	1.27 ± 0.26^{b}
C5D	0.32 ± 0.05^{c}	42.19 ± 5.60^{a}	4.33±0.31^{a}	60.97±0.07^{d}	0.12 ± 0.16^{b}

The values are mean ± standard deviation (n =4). Different letters in the same column showed statistically different ($p<0.05$).

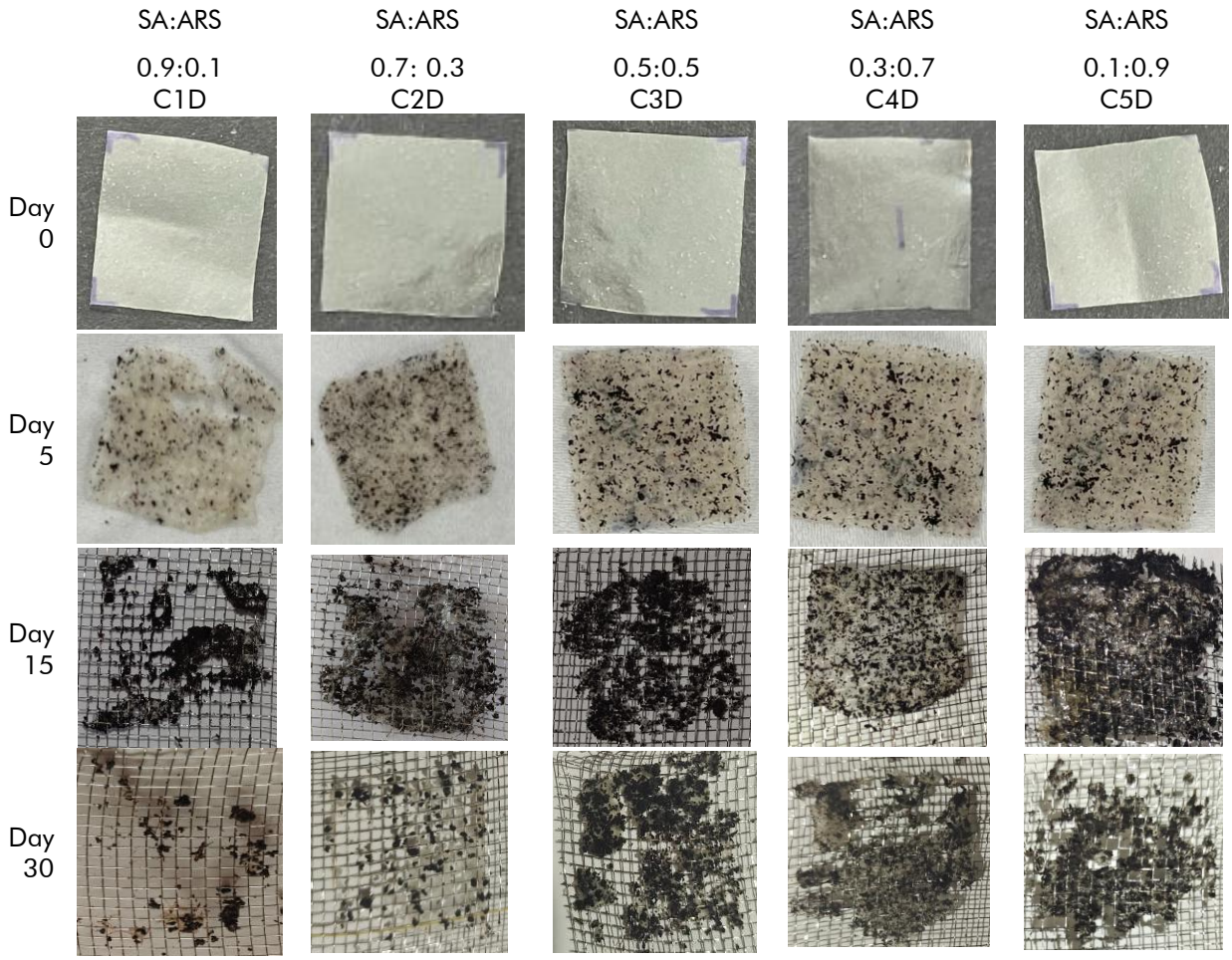


Figure 2. Biodegradability of films obtained from different SA:ARS ratios. Samples were observed at day 0, 5, 15, and 30 films after burying.

films, whereas higher starch concentrations tend to increase film thickness (Galus & Lenart, 2013; Tavassoli-Kafrani et al., 2016). However, the trend was not found in this study. The low total polymer concentration (1%) used in this study may not have been sufficient to induce noticeable changes in the film thickness. Additionally, the incorporation of sorbitol in the film formulation may have interfered with the structural or interactive properties of ARS and SA, potentially diminishing their functional performance. Further investigation is necessary to clarify this effect.

Color

The color characteristic value of edible films is one of the important physical properties that affect the attractiveness of the product contained within the film. Previous studies have shown that white and high brightness are positively related to enhanced edible film quality (Ali et al., 2023). **Table 3** shows that the SA:ARS ratio significantly affected film color. L* values (brightness) differed statistically ($p<0.05$), decreasing from 89.55 to 88.35 as ARS increased. This trend aligns with Zhao et al. (2022), who observed lower brightness with higher starch content. Arrowroot starch contains up to 40.86% amylose (Sandoval Gordillo et al., 2014) may cause retrogradation during the film drying process. The reassociation of amylose may form a semi-crystalline region within the film matrix, consequently resulting in a reduction of surface brightness. Brightness preference depends on application-high for fruits/vegetables, lower for meat/nuts (Moore et al., 2006). Films with a SA:ARS ratio of 0.9:0.1 had higher brightness and transparency, ideal for visually appealing products. Increasing ARS (from 0.1% to 0.9%) shifted a* values from green (-0.04) to red (0.28) and increased yellowness (b* value). The lowest b* (2.66) was at a 0.9:0.1 ratio. Color influences product appeal, and previous studies link high brightness to better film quality (Ali et al., 2023). Thus, a SA:ARS ratio of 0.9:0.1 is optimal for color quality.

Tensile strength and elongation

Table 4 shows that the SA:ARS ratio significantly affected tensile strength and elongation ($p<0.05$). A SA:ARS ratio of 0.5:0.5 (C3D) had the highest tensile strength (0.64 MPa), while 0.9% ARS had the lowest (0.32 MPa). Higher SA likely increased monomer linkages, strengthening the film matrix, as suggested by Beghetto et al. (2020). Unlike previous studies, this research did not observe an increase in tensile strength with higher concentrations of arrowroot starch (ARS). For instance, Strnad et al. (2019) reported enhanced tensile strength when ARS was incorporated into a keratin-based film, while Beghetto et al. (2020) found a similar trend using carboxymethyl cellulose (CMC) as the film matrix. In contrast, our study employed a combination of ARS and sodium alginate (SA) as the base materials, which may have resulted in different polymer-polymer interactions and a less rigid film structure. The difference in the polymer types probably contributes to the overall structure of edible films and, consequently, reduces the tensile strength.

Films with poor flexibility or strength can lead to breakage or cracking during production, handling, storage, or use. The high elongation value is very important for edible films to be resistant to normal pressure during their food application. High environmental relative humidity conditions would increase the value of elongation because the elongation of the film possibly increases due to the nature of hydrophilic film-forming materials, such as sodium alginate and arrowroot starch contain hydroxyl groups that readily absorb moisture from the environment (Titone et al., 2021). Elongation also varied significantly ($p<0.05$). The lowest elongation (17.86%) was at 0.9% SA, while the highest (42.19%) occurred a SA:ARS ratio of 0.1:0.9 (C5D). Similar trends were reported by Tarique, et al. (2021) that the elongation of cellulose/konjac glucomannan films decreased as the ARS content increased to a certain level. Low flexibility may cause cracking, whereas greater elongation enhances durability in food use. As aforementioned, humidity promotes elongation due to the moisture-absorbing hydrophilic groups (Titone et al., 2021). The elongation value of the edible film can be inversely proportional to the tensile strength. Low elongation value, the tensile strength is high, and vice versa on edible film with a high elongation value, the tensile strength is low. This is due to the molecular bond between the sodium alginate, arrowroot starch, and the plasticizer in the form of sorbitol and matrix film, which can reduce the tensile strength but increase the value of film elongation (Purwanti, 2010). According to the Japanese Industrial Standard (1997), the films met the elongation requirement (>10%), indicating their potential for food applications.

Opacity

Table 4 shows that film opacity varied with the SA:ARS ratio. The highest opacity (4.3 mm^{-1}) occurred a SA:ARS ratio of 0.1:0.9, as increased ARS reduced transparency by limiting light transmission. This suggests ARS- based films can help protect food from light damage. Sodium alginate was found to have colorless physical characteristics, allowing it to decrease the opacity of edible films and produce transparent film sheets. Tarique, et al. (2021) noted that the decrease in opacity is attributed to increased polymer chain mobility and intermolecular distances in the film matrix, which promote light transmittance. The opacity of edible films is an important trait regarding the sensorial aspect, allowing for an increase in the overall acceptance by consumers, as it mimics the transparent polymeric packaging materials (Zhao et al., 2022). So, a film with low opacity is preferable because the high transparency allows the customer to view the content inside the packaging. However, a high opacity film may be required to protect light-sensitive foods, preventing nutrient loss via photooxidation and extending the

product's shelf life. However, high-opacity films are beneficial for protecting light-sensitive foods and preventing nutrient loss.

Water solubility

The edible films were characterized by a solubility ranging from 60.97 to 96.53% (**Table 4**). The results showed that the SA:ARS ratios had a significant effect on the water solubility ($p<0.05$). Sample C1D (SA:ARS ratio of 0.9:0.1) had the highest water solubility (96%), followed by C2D (SA:ARS ratio of 0.3:0.7, 90%). The sample C5D (SA:ARS ratio of 0.1:0.9) had the lowest water solubility with a value of 61%. The higher the solubility value, the lower the moisture resistance of the edible film. The value of solubility in edible coatings is used to determine the film integrity under humid conditions. Although high-solubility edible films dissolve efficiently in water, they typically exhibit poor moisture retention, which may compromise their structural stability and barrier functionality in humid conditions. High-solubility edible films dissolve easily but cannot retain water (Santos et al., 2022). It was observed that an increase in sodium alginate increased solubility. Sodium alginate is hydrophilic, so the high concentration of alginate causes the edible film to absorb more water and more easily dissolve in water (Jyothi et al., 2009). The decrease in the solubility value of the film was also caused by the interaction of SA and ARS which formed a strong and compact network, thereby reducing the opportunity for water to enter the polymer matrix and reducing the solubility of edible films by (Jyothi et al., 2009). The solubility of films obtained in this study was in a range that was previously reported by Santos et al. (2021).

Water vapor transmission rate (WVTR)

The results of determining the water vapor transmission rate (WVTR) are presented in **Table 4**. The WVTR values significantly differed along with changes in SA:ARS ratios ($p<0.05$). The highest WVTR value was obtained in treatment C1D (1.86 g/m²hour) followed by the treated values C2D (1.43 g/m²hour), C3D (1.29 g/m²hour), C4D (1.27 g/m²hour), and C5D (0.12 g/m²hour). The findings of this study are in agreement with the WVTR water standard (grade 4, in the range of 0.8334 to 4.16 g/m²hours) for food packaging films reported by Yulistiani et al. (2020). The WVTR may correlate to the thickness of the film. In our study, a slight decrease in WVTR value was observed following a decrease in the thickness (Table 3). An increase in film thickness is caused by a high solid concentration in the polymer matrix and thus produces a potential barrier for water vapor (Santos et al., 2021). Alginate films can absorb water from the environment and increase their plasticity so that water diffuses more easily (Racmayani & Husni, 2020).

Biodegradability

The films obtained from different SA:ARS ratios showed a variation in biodegradability. The film generated from SA:ARS ratio of 0.9:0.1 had the highest degradability visually observed from days 5, 15 and 30 of burying (**Figure 2**). At day 5, this film absorbed moisture and swelled as signs of biodegradability. On day 15, the surface deterioration of this film was observed, indicating a clear degradation. On day 30, this film was completely degraded. In contrast, the film cast from SA:ARS ratio of 0.1:0.9 showed the lowest degradability. The films were not completely degraded after 30 days of burial, indicating a slower rate of decomposition. The biodegradability of the films has been correlated to mechanical properties such as tensile strength, elongation (Lim et al., 2011), and water solubility (Beghetto et al., 2020). It seems that the water solubility predominantly affects the biodegradability since the results in this study indicate that the film obtained from SA:ARS ratio of 0.9:0.1 had the highest water solubility and biodegradability. The biodegradability (about 15 days) of the films in this study was somewhat slower compared to that reported in the literature (12 days) (Beghetto et al., 2020). Nevertheless, the results showed that films generated from sodium alginate and arrowroot starch have biodegradable properties. Further investigation should focus on the application of this film as an eco-friendly packaging material.

Fourier-transform infrared spectroscopy (FTIR)

FTIR analysis was conducted to examine the structural and functional groups of films with different SA:ARS ratios. The spectra (**Figure 3**) displayed characteristic polysaccharide peaks, including hydroxyl (-OH), carboxylate (COO^-), glycosidic (C-O), and aliphatic (C-H), confirming the presence of SA and ARS, consistent with previous polysaccharide-based film studies. A broad O-H stretching band (3252–3274 cm^{-1}) indicated hydrogen bonding between SA and ARS. Strong COO^- asymmetric (1597–1647 cm^{-1}) and symmetric (1408–1412 cm^{-1}) stretching peaks were more evident in SA-rich films (C1D, C2D), reflecting higher carboxylate content, while these peaks were weaker in starch-rich films (C4D, C5D), aligning with other polysaccharide blend findings (Siddaramaiah et al., 2008). C-O stretching vibrations (1076–1148 cm^{-1}), representing glycosidic linkages, appeared in all samples, while starch-rich films (C4D, C5D) exhibited enhanced saccharide-related vibrations (930–999 cm^{-1}), suggesting a greater structural contribution from ARS (Azucena Castro-Yobal et al., 2021; Siddaramaiah et al., 2008).

Scanning electron microscopy (SEM)

The SEM images (**Figure 4a**) showed notable surface changes with increasing ARS content. At lower ARS levels (10–50%, C1D–C3D), surfaces appeared

heterogeneous with visible solid particles, indicating partial phase separation due to limited SA-ARS compatibility, consistent with prior polysaccharide blend studies (Galus & Lenart, 2013). In contrast, higher ARS levels (70–90%, C4D, C5D) produced smoother, more uniform surfaces, suggesting ARS as the dominant matrix enhanced SA dispersion, aligning with findings on starch-dominant systems (Nogueira et al., 2019). SEM cross-sections (**Figure 4b**) showed dense, compact structures without voids or delamination, indicating strong SA-ARS compatibility through hydrogen bonding, supporting previous research on cohesive polysaccharide blends (Xiao et al., 2000).

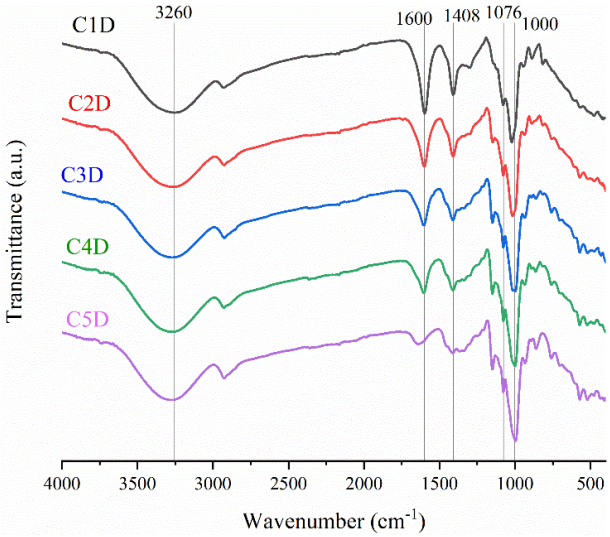
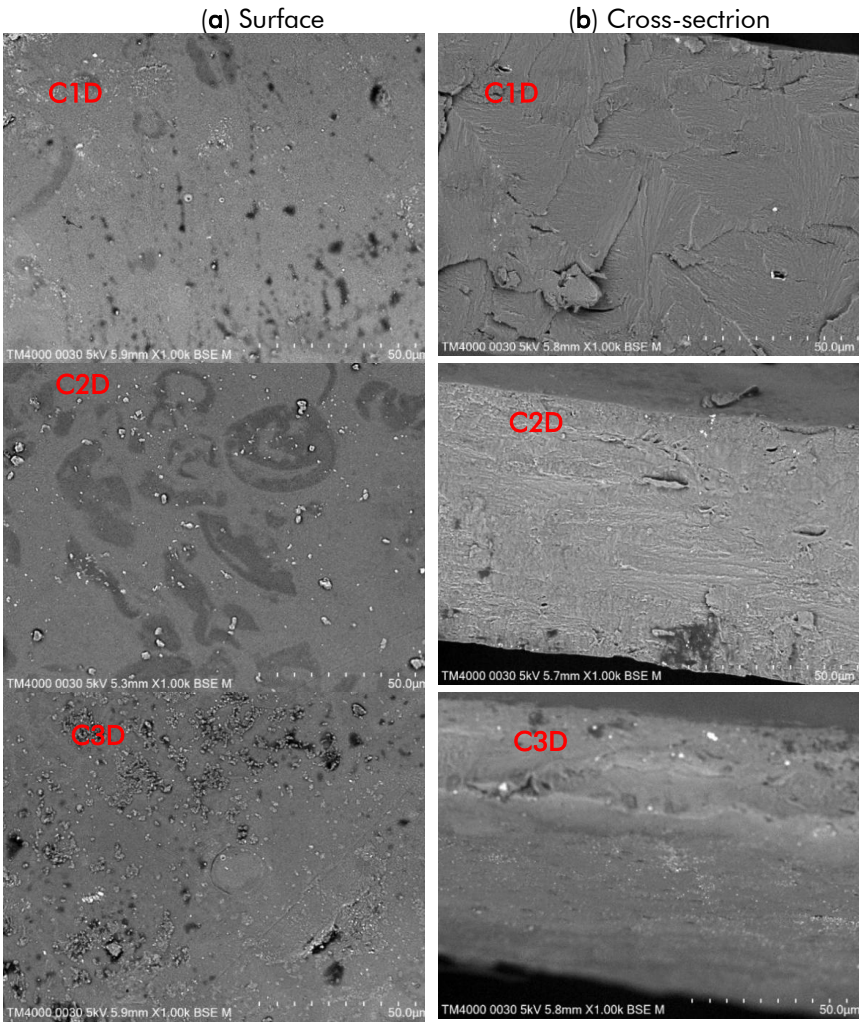


Figure 3. FTIR spectra of SA-ARS films.



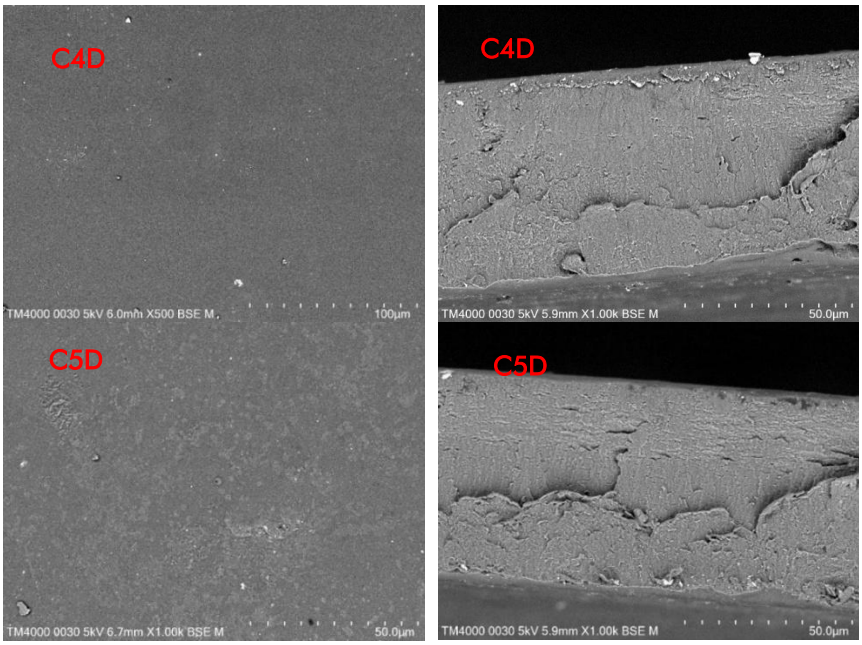


Figure 4. SEM micrographs of surface (**a**) and cross-section (**b**) of SA-ARS films at 1000X magnification.

CONCLUSIONS

Edible films were successfully made from sorbitol, sodium alginate, and arrowroot starch. Sorbitol at 0.5% was the most effective plasticizer, providing suitable thickness, color, tensile strength, and elongation. The SA:ARS ratio of 0.9:0.1 produced a thin, smooth film with high solubility, WVTR, biodegradability, and acceptable mechanical properties, degrading within 15 days in compost. These findings highlight arrowroot starch, sorbitol, and alginate as promising materials for edible films. Further research should focus on enhancement of flexibility, heat sealability, and further explore applications in soluble packaging for instant products like tea and coffee.

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