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Antioxidant Edible Films Derived from Belitung Taro Tubers (*Xanthosoma sagittifolium*) Incorporated with Moringa Leaf Extract (*Moringa oleifera*)

Sitti Rahmawati[1], Yassaroh Yassaroh[2], Melvina Theodora[1], Tahril Tahril[1], Afadil Afadil[1], Tri Santoso[1], Suherman Suherman[1], and Yuli Nurmayanti[1]

[1]Chemistry Education Study Program, Faculty of Teacher Training and Educational Sciences, Tadulako University, Palu 94118, Indonesia
[2]Research Center for Polymer Technology - National Research and Innovation Agency (BRIN), KST BJ. Habibie Building 460, Tangerang Selatan 15314, Indonesia

ABSTRACT: Edible films are thin films frequently manufactured using natural bioresources and are employed in food packaging to safeguard food quality. This research prepared edible films from renewable biomass consisting of Belitung taro tuber starch (*Xanthosoma sagittifolium*) and incorporated sorbitol as a plasticizer, carboxymethyl cellulose as a reinforcing agent, and moringa leaf extract (*Moringa oleifera*) as an antioxidant. The physicochemical characteristics of the resulting edible films were examined. The most favorable treatment was identified in an edible film containing 3% (v/v based on the total volume of 100 mL) of moringa leaf extract. This exhibited a tensile strength of 6.86 N/mm^2, percent elongation of 73.71%, elasticity of 9.37×10^{-3} kgf/mm^2, water absorption of 349.03%, solubility of 93.18%, and water vapor transmission speed of 3.18 g/h m^2. Its shelf life was five days at ambient temperature. The edible film was found to have 135.074 ppm of half maximal inhibitory concentration (IC_{50}) based on the antioxidant analysis of inhibition concentration (IC_{50}) value measurements, and was classified as having moderate antioxidant activity. Additionally, the biodegradability assessment revealed that the edible films degraded within 14 days. Based on this data, it can be deduced that adding moringa leaf extract enhances the physicochemical and functional characteristics of the film. These edible films can be used as substitutes for nonrenewable and nonbiodegradable packaging materials.

Keywords: antioxidants, biodegradable plastics, edible films, moringaoleifera, taro starch

INTRODUCTION

Plastic materials are used in various applications, such as packaging, agriculture, construction, etc. These commercial plastics are frequently polymers derived from nonrenewable fossil fuel-based resources and are environmentally unfriendly. One of the alternatives to replace nonrenewable synthetic polymers is bioplastics based on biomass. The estimated data for bioplastics production in 2024 is 2.43 million tons, and almost 70% is used for packaging applications (Thakwani et al., 2023). Another type of eco-friendly food packaging material is edible film. In general, edible films are prepared from biodegradable polymers/biomass. They are processed to form thin sheets of food-grade material and are applied as barriers between foodstuffs and the environment to maintain the food's features (Coimbra et al., 2023). Edible films offer several benefits, including being biodegradable, recyclable, food-grade, biocompatible, made from abundant renewable resources, and inexpensive (Matheus et al., 2023; Zhang et al., 2023a). Food-grade films manufactured from hydrocolloids are readily soluble in water, resulting in homogeneous films with high barrier properties against oxygen transport, water, heat, carbohydrates, carbon, and lipids (Sason and Nussinovitch, 2021; Zibaei et al., 2021). Thus, edible films, mainly made of biodegradable biomass, can decrease reliance on nonrenewable plastics for food packaging.

Starch is one of the most abundant forms of natural biomass and has great potential for various applications, including use as a packaging material. There are many botanical sources of starch, including wheat, cassava, sago, corn, rice, etc. (Yassaroh et al., 2019; Rahmawati et al, 2021). Biofilms made of only native starch tend to have low mechanical properties (Patil et al., 2021; Muscat et al., 2012), so fillers contribute to strengthening the me-

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Correspondence to Sitti Rahmawati, E-mail: sittirahmawati.q3a@gmail.com

chanical properties of the materials. Filler materials include biopolymers such as cellulose, carboxymethyl cellulose (CMC), lignocellulose, etc., as well as synthetic polymers such as carbon fibers, nano clays, etc. (Patil et al., 2021; de Freitas et al., 2022). CMC is classified as a polysaccharide, and is naturally abundant, inexpensive, and has excellent film-forming properties (Tran et al., 2023).

Taro is among the plentiful starchy tuber plants found in Indonesia. Taro tubers have a reasonably high starch content of 80%, comprised of 5.55% amylose and 74.45% amylopectin (Puspita et al., 2022). Several studies have examined edible films derived from taro starch and investigated the effects of adding palmitic acid as a plasticizer (Puspita et al., 2022), adding glycerol (Puspita et al., 2022), and the effects of various starch gelatinization temperatures. Yet, within the research field of edible films derived from taro starch, few studies have incorporated active agents such as antioxidants and antimicrobials. Plasticizers have been utilized to increase the flexibility of films, and some, such as sorbitol, glycerol, fatty acids, and ethylene glycol, have been applied to develop biofilms.

In addition to their mechanical capabilities, packaging films' functionality can be enhanced by incorporating bioactive compounds such as antioxidant agents (Muruzović et al., 2016; Mondal et al., 2022; Wu and Chen, 2022). These compounds can impede, slow, and inhibit oxidation (Rice-Evans et al., 1997; Mondal et al., 2022). Antioxidant compounds can be obtained through extraction from natural materials such as plants. Many plant parts can be used for extraction, such as leaves (Wang et al., 2023), flowers (Ningsih et al., 2021), seeds (Thakwani et al., 2023), wood (Romruen et al., 2022), and fruit (Lee et al., 2020). Natural antioxidant compounds are generally phenolic or polyphenolic compounds and include flavonoids, cinnamic acid derivatives, and polyfunctional organic acids (Martillanes et al., 2017; Almeida et al., 2023). One source of natural antioxidants is moringa leaves. The Moringa (*Moringa oleifera*) is an Indonesian plant with leaves that are rich in antioxidants and has been used to prevent and treat various diseases. Moringa leaves possess bioactive flavonoid compounds that function as antioxidants, effectively neutralizing and stabilizing free radicals (Badejo et al., 2014). The functionality of moringa leaves as an antioxidant agent is affected by both intrinsic factors, such as the specific variety and age of the plant, and external factors, such as the solvent varieties applied during extraction, geographical location, harvesting period, and various postharvest factors (Nobossé et al., 2018). This study creates and assesses edible films made from Belitung taro tubers, with added CMC, sorbitol, and moringa leaf extract. It evaluates the effects of several moringa leaf extract concentrations on the physicochemical and functional features of the resulting films.

MATERIALS AND METHODS

Materials

Sodium bisulfite (Na_2SO_3), ethanol, aquades, 2,2-diphenyl-1-picrylhydrazyl (DPPH), sorbitol, and effective microorganism-4 (EM4) were obtained from the Advanced Chemistry Laboratory of FKIP, Tadulako University, Indonesia. CMC was obtained from the Nuhidayah Chemical Company, Palu City, Central Sulawesi. Belitung taro tuber starch (*Xanthosoma sagittifolium*) was obtained from Makmur village, Palolo subdistrict, Sigi district, and Moringa leaf extract (*M. oleifera*) was collected from the streets of Palu City, Central Sulawesi.

Extraction of Belitung taro tuber starch

Two kilograms of Belitung taro tubers were peeled and cleaned. After cutting, the taro tubers were rinsed with distilled water. The taro tubers were then pulverized at low velocity while incorporating 0.12% Na_2SO_3 (2.3 g of Na_2SO_3 in 2 liters of distilled water). The resulting mixture was subsequently compressed through a fine porous cloth until all the juice had been extracted. The residual sediment was discarded, and the remaining liquid was left undisturbed for 24 h. The starch precipitate was then washed and filtered using No. 1 Whatman filter paper in a Buchner funnel. The dry solid was then dehydrated at 50°C for 12 h. The resulting dehydrated residue was crushed and passed through a 100 mesh screen to produce Belitung taro starch.

Extraction of active compounds from moringa leaf (*M. oleifera*)

Dried moringa leaves were mashed and filtered through a 100-mesh screen to make powder. Five grams of moringa leaf powder were macerated in 100 mL of 50:50 ethanol and water in an Erlenmeyer flask and covered with aluminum foil. Maceration continued for 24 h at 25°C. The mixture was filtered using No. 1 Whatman filter paper in a Buchner funnel to extract the moringa leaf. The filtrate was concentrated using a rotary evaporator.

Preparation of edible films

A total of 3 g of Belitung taro starch was measured and placed in a glass beaker. Solutions with 2% (w/v) sorbitol and moringa leaf extract at varying concentrations (1.5%, 2.0%, 2.5%, and 3.0% v/v relative to the total volume of the extract of 100 mL) were then introduced. Next, 80 mL of distilled water was added and heated while stirring at 80°C for 15 min. One gram of CMC was then added to the solution. The heating continued for 7 min at a constant temperature. The solution was then cast in a 20×20 cm glass mold and was oven-dried for 18 h at 50°C. The drying process continued overnight at room temperature. After drying, the films were removed from the mold, sealed, and stored in a desiccator.

Films characterizations

***Film thickness*:** The films' thicknesses were measured using a screw micrometer at five distinct locations, with a precision of 0.01 mm. The mean film thicknesses were determined by calculating the mean values of these measurements.

***Mechanical properties*:** The films' mechanical strength was analyzed using a Shimadzu universal testing machine at 5 kN per the ASTM D638 standard. The test was conducted using an 80×40 mm sample. The speed was set at 700 mm/min, the grip weight was 50 N/5 kgf, and the sample area (A) was calculated as (80×40) mm^2.

$$\text{Tensile strength (N/mm}^2) = \frac{F\,max}{A}$$

Where:
$F\,max$=sample stress value (N)
A=sample area (mm^2)

$$\text{Elongation }\% = \frac{\Delta L}{Lo} \times 100\%$$

Where:
ΔL=difference in film length
Lo=initial length of the film

Elasticity could be determined by comparing the tensile strength and elongation.

***Functional group analysis*:** Fourier transform infrared spectroscopy (FTIR) was utilized to determine whether the films were formed via physical or chemical interactions by studying functional groups. At the outset, every specimen was positioned on a designated holder and subsequently scanned within the wavenumber interval of 400~4,000 cm^{-1}. The resulting data depicted a correlation between wavenumber and intensity within the spectrum.

***Film morphologies*:** Field emission scanning electron microscopy (FESEM) (Thermo Scientific Quattro S) was utilized to observe the film's morphology at a 5 kV accelerating voltage. Before observation, each sample was placed on an aluminum support.

***pH test*:** The pH analysis was conducted utilizing a pH meter. Initially, 1 g of the film was weighed and dissolved in 10 mL of distilled water. The electrode was submerged in the solution, and the numerical value displayed on the pH meter was recorded.

***Water-resistant properties*:** To measure the water absorption properties of the films, a 2-g film sample was weighed as the initial weight (D). This was then immersed in a container of aquadest for 10 seconds. Subsequently, the specimens were extracted from the receptacle and cleaned, then the films were weighed. The circular process was repeated until the weight of the sample reached a steady state (C). The following equation was used in determining the percentage of water absorption:

$$\text{Water absorption }\% = \frac{C-D}{D} \times 100\%$$

In which:
C=final weight (g)
D=initial weight (g)

The measurement of the film's solubility was conducted by weighing a 2-g sample of the film. This was placed in a container and brought to 100°C for 30 min in an oven. Subsequently, the film samples were weighed (Y). The edible films then underwent a 24-h soaking period and the insoluble film was extracted and subsequently dried for 2 h in an oven at 100°C. The films were then placed inside a desiccator and left undisturbed for 10 min. Later, the specimens were weighed to determine the mass of the dehydrated edible layer after immersion (Z). The solubility percentage for edible films was calculated as follows:

$$\text{Film solubility }\% = \frac{Y-Z}{Y} \times 100\%$$

Where:
Y=initial weight (before immersion) (g)
Z=final weight (after immersion) (g)

The water vapor transmission rate (WVTR) was measured following the method of Ningsih et al. (2021). Specifically, the WVTR of the food-grade film was assessed using a porcelain cup in a desiccator at 75% relative humidity and containing 40% sodium chloride solution. Next, 3 g of film and 5 g of activated silica gel were placed in the cup and sealed. The cup containing film and silica gel was then weighed and put in the conditioned desiccator. The WVTR was measured at hourly intervals for 5 h. The vapor transmission rate toward the edible coating was estimated using the following formula:

$$\text{TR} = \frac{Mv}{t.A}$$

Where:
Mv=addition/reduction of the mass of water vapor (g)
t=weighing period (h)
A=edible film area tested (cm^2)

***Antioxidant test*:** The spectrophotometric technique using DPPH reagent was used to assess antioxidant activity. A 10 mg sample of the provided extract was weighed and transferred to a 10 mL volumetric flask. To achieve 1,000 ppm of solution, an appropriate volume of ethanol solvent was added to the flask. Subsequently, the solutions were diluted to obtain various concentrations of 20, 40, 60, 80, and 100 ppm. Using a pipette, 1 mL of the prepared solution was transferred and followed by the addition of 3 mL of a DPPH solution with a concentration of 50 μM. This mixture was homogenized and then incubated for 30 min in a light-deprived environment.

Additionally, absorption measurements were conducted at a specific wavelength of 517 nm. The inhibition percentage was calculated based on the following formula:

$$\text{Inhibition}=\frac{\textit{Abs Blanc}-\textit{Abs Sample}}{\textit{Abs Blanc}}\times 100\%$$

Where:

Abs Blanc=absorbance of DPPH 50 μM

Abs Sample=absorbance of the test sample

Next, the inhibition percentage curve was made and the half maximal inhibitory concentration (IC_{50}) was calculated according to the regression equation.

***Shelf life analysis*:** The edible film's shelf life was measured using the acceleration method. This analysis employed the optimum composition of the prepared edible film which contained 3% (v/v) moringa leaf extract. A series of potato slices were wrapped with and without film. These consisted of K_1 (without wrapping), K_2 (wrapped in the prepared edible film), and K_3 (wrapped in commercial oil paper). These foods were stored in an open space (30°C) or in a cold room (16°C).

***Biodegradability test*:** The biodegradability assessment, which explicitly examined the decomposition capacity of bioplastics, was conducted by immersing the edible film specimens in EM4. The edible film was divided into 2×2 cm^2 square pieces and immersed in a culture of EM4 bacteria in a petri dish. Alterations were noted until the edible films underwent degradation over several days. Notably, EM4 microbes are commonly utilized to ferment organic substances found in soil.

RESULTS

In this research, taro starch extracted from Belitung taro tubers was the main component used to prepare edible film. The edible taro starch films were prepared by incorporating CMC and sorbitol as fillers and plasticizers. Furthermore, adding moringa leaf extract as an antioxidant further improved its functional properties. The addition of moringa leaf extract varied in different concentrations based on the total volume of the extract (100 mL) used during the maceration process. These included samples S0 (0%), S1 (1.5%), S2 (2.0%), S3 (2.5%), and S4 (3.0%). The prepared films are shown in Fig. 1. The films were then analyzed for their physicochemical and functional properties.

Film thicknesses and their mechanical properties

The thickness of S1 was 0.18 mm and was the thinnest among the samples. The thicker films were 0.20 mm, 0.21 mm, and 0.22 mm thick for S2, S3, and S4, respectively. The films' mechanical characteristics, such as tensile strength, elongation, and elasticity, are presented in Table 1. Using moringa leaf extract at 1.5% (v/v) yielded the highest observed tensile strength value for the S1 film (7.76×10^{-3} N/mm^2). The tensile strength of the film decreased with increasing extract concentrations. The lowest tensile strength was 6.86×10^{-3} N/mm^2 in the S4 film (contained 3.0% extract). A similar trend was also observed for the elongation properties of the film. Adding moringa leaf extract decreased the percent elongation values from 133.23% for the S1 film to 73.71% for the S4 film as shown in Table 1. However, a film with 2.0% extract displayed the lowest elongation at breakage (63.32%). Film elasticity can be measured based on tensile strength and elongation values. Hence, it was observed that the elasticity of the S1 film (1.5% extract), 5.82×10^{-3}, increased to 11.13×10^{-3} for the S2 film (2.0% extract), and then decreased to 9.37×10^{-3} and 9.30×10^{-3} for the S3 (2.5%) and S4 (3.0%) films, respectively. The films exhibited the lowest stiffness when adding 1.5% (v/v) extract, resulting in maximum elasticity. The edible film pH test revealed that the addition of moringa leaf extract produced an alkaline edible film (Table 1). The pH of the edible film containing 1.5% extract was 8.7, and decreased to 8.1 with the addition of 3% of the extract, which is attributed to higher hydrogen ion concentrations.

Functional group analysis

FTIR was utilized to characterize the functional groups among the edible films. These films demonstrated the

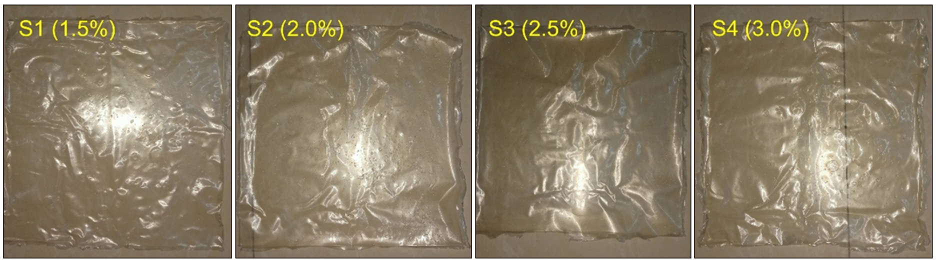

Fig. 1. Edible films prepared from Belitung taro tuber starch and containing moringa leaf extract at various concentrations.

Table 1. Physicochemical characteristics of taro starch edible films at various concentrations of moringa leaf extract samples

Parameter	Sample			
	S1 (1.5%)	S2 (2.0%)	S3 (2.5%)	S4 (3.0%)
Thickness (mm)	0.18	0.20	0.21	0.22
Tensile strength (N/mm^2)	7.76×10^{-3}	7.05×10^{-3}	7.36×10^{-3}	6.86×10^{-3}
Elongation (%)	133.23	63.32	78.54	73.71
Elasticity (kgf/mm^2)	5.82×10^{-3}	11.13×10^{-3}	9.37×10^{-3}	9.30×10^{-3}
pH	8.7	8.5	8.4	8.1
Water absorbance (%)	290.70	273.73	293.26	349.03
Solubility (%)	59.38	68.00	100.00	93.18
WVTR (g/h m^2)	1.91	2.84	2.42	3.18

WVTR, water vapor transmission rate.

presence of various functional groups through wavelengths, including O-H alcohol stretching vibration at around 3,566~3,523 cm^{-1}, O-H carboxylic acid stretching band at 2,671~2,480 cm^{-1}, C-H alkane symmetric stretching at 2,929~1,456 cm^{-1}, C-H alkene at 929~925 cm^{-1}, C-H aromatic ring at 887~854 cm^{-1}, C≡C alkyne at 2,148~2,144 cm^{-1}, C=C alkene at 1,645~1,614 cm^{-1}, NO_2 at 1,327~1,321 cm^{-1}, C-N amine and amide at 1,240~1,159 cm^{-1}, and C-O stretching vibration at 1,083~1,078 cm^{-1} for films S0~S4 containing various concentrations of the moringa leaf extract (Fig. 2 and Table 2) (Ningsih et al., 2021). By comparing the spectra of all films, it is observed that the peak intensities of S3 and S4 films increased while they decreased for S1 and S2 films when compared with the S0 film at wavelengths of 3,566~3,523 cm^{-1}, 2,148~2,144 cm^{-1}, and 1,645~1,614 cm^{-1}. These results can be attributed to the stronger vibrations in O-H, C≡C, and C=C alkene functional groups in the films containing 2.5% and 3% extract. However, the peak positions remained almost the same. This implies that there were no new chemical bonds formed.

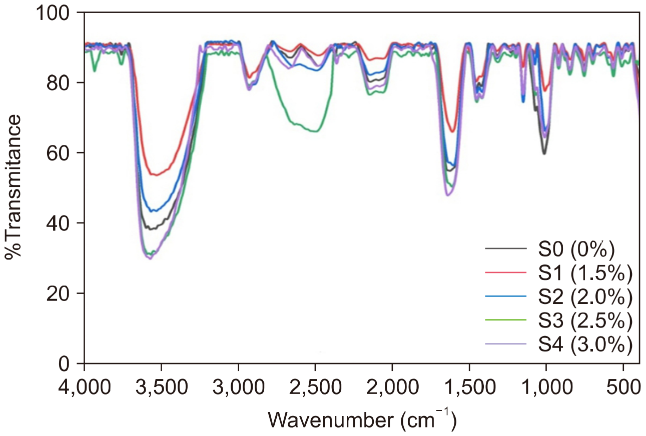

Fig. 2. Fourier transform infrared spectroscopy analysis of the edible films with different moringa leaf extract concentrations.

Film morphology

FESEM was utilized to observe the morphological structure of each film. All films were observed to contain small white particles on the surface, indicating the existence of CMC particles on the films (Fig. 3). This suggested that the dispersion of the CMC was uneven. The S0 (neutral film) displayed a compact morphology and

Table 2. Interpretation of the fourier transform infrared spectroscopy spectrum of taro starch edible films containing different concentrations of moringa leaf extract

Functional group	Wavenumber range (cm^{-1})	Wavenumber (cm^{-1})				
		S0 (0%)	S1 (1.5%)	S2 (2.0%)	S3 (2.5%)	S4 (3.0%)
O-H alcohol	3,600~3,200	3,566.38	3,523.95	3,560.59	3,562.52	3,566.30
O-H carboxylic acid	3,400~2,400	2,659.84	2,661.77	2,646.34	2,632.83	2,671.41
		2,482.39	2,480.46	2,492.03	2,492.03	2,486.24
C-H alkane	2,970~2,850	2,929.87	2,924.09	2,927.94	2,922.16	2,927.94
	1,470~1,340	1,460.11	1,458.18	1,456.02	1,456.26	1,458.18
C≡C alkyne	2,260~2,100	2,144.84	2,148.70	2,146.77	2,148.70	2,148.70
C=C alkene	1,680~1,610	1,627.92	1,614.42	1,639.49	1,616.35	1,645.28
NO_2 nitrous compound	1,370~1,300	1,323.17	1,327.03	1,327.03	1,321.24	1,321.12
C-N amine, amide	1,360~1,180	1,159.00	1,159.22	1,240.23	1,238.30	1,240.23
CO alcohol, ether, ester, sourcarboxylates	1,300~1,000	1,078.21	1,083.99	1,082.07	1,082.29	1,083.29
C-H alkene	995~675	929.69	925.83	927.76	927.76	929.69
C-H aromatic ring	900~690	858.20	854.47	887.26	885.33	856.39

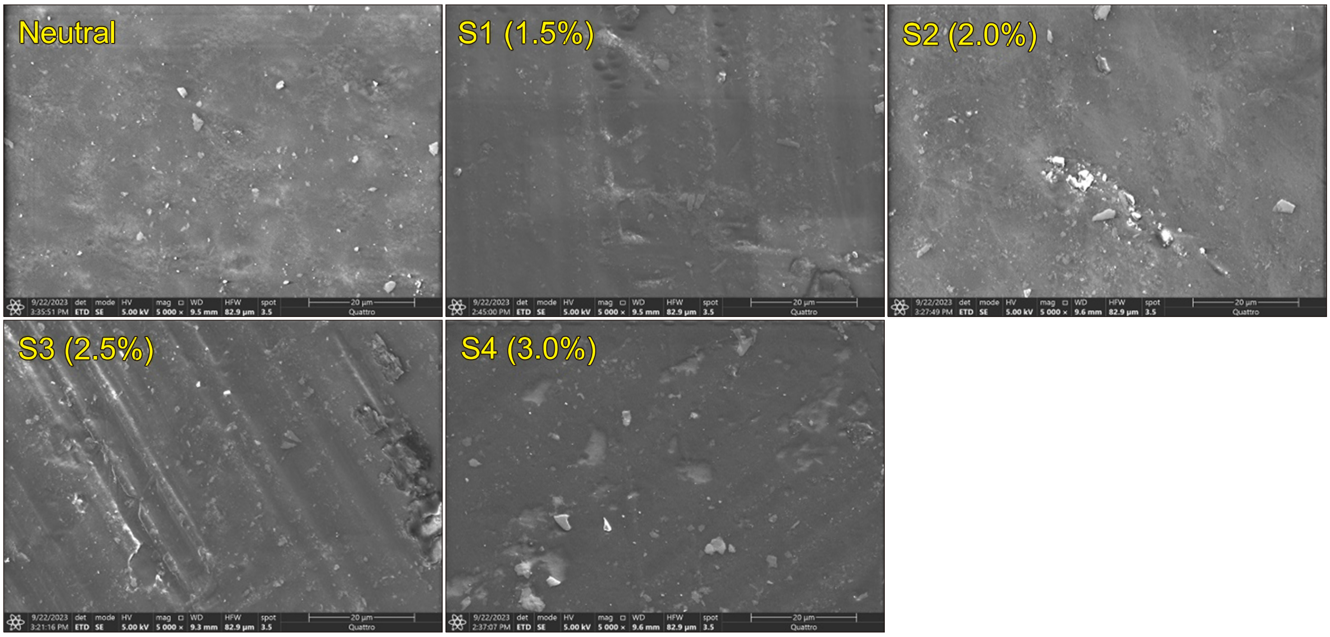

Fig. 3. Field emission scanning electron microscopy images of taro starch edible films containing different concentrations of moringa leaf extract.

only uneven CMC dispersion on the surface. However, the other films containing moringa leaf extract showed some visible cracks on the film surfaces. These cracks were more prominent at higher extract concentrations. Furthermore, the roughness of the films also increased following the addition of moringa leaf extract. The cracks and roughness on the film surfaces might be attributed to the formation of H-bonds among the hydrophilic compounds (Zhang et al., 2023b).

Water-resistant properties

Water absorption, film solubility, and WVTR were investigated to measure water-resistant properties. The findings are presented in Table 1. The most negligible absorption of water indicates the greatest resistance toward water. It can be concluded that films containing 2.0% (v/v) moringa leaf extract resulted in the highest water resistance compared to other samples. Table 1 shows that the solubility of the films exhibited an upward trend with increasing extract concentrations. Based on the Table 1 data, the greatest solubility value was obtained in the S3 film containing 2.5% (v/v) moringa leaf extract, which exhibited complete solubility. Meanwhile, the S1 film containing 1.5% (v/v) moringa leaf extract showed the least solubility (59.38%). WVTR refers to the speed at which water molecules permeate into the film under specific conditions (Zhang et al., 2016). The film containing 1.5% (v/v) moringa leaf extract exhibited the lowest WVTR value. The WVTR value increased along with increasing concentrations of moringa leaf extract. This is attributed to the increased hydrophilic nature of the films. The WVTR is also correlated to water vapor permeability as high WVTR might increase water vapor permeability.

Antioxidant test

The antioxidant activity measurement aimed to verify the antioxidant ability of the edible films containing various moringa leaf extract concentrations. Antioxidant activity is measured using the IC_{50} value, which represents the amount of the antioxidant agent required to inhibit 50% of the free radicals (Molyneux, 2004). Based on the IC_{50} value, the antioxidant activity is categorized as very strong (<50 ppm), strong (50～100 ppm), moderate (100～150 ppm), weak (150～200 ppm), and very weak (>200 ppm) (Molyneux, 2004). The lower the IC_{50} value, the stronger the sample inhibits free radicals. Thus, the sample has stronger antioxidant activity against free radicals. Furthermore, the IC_{50} value is estimated using a linear regression equation derived from the curve correlated to the sample concentration and the corresponding inhibition percentage. The equation used was $y=ax+b$, where the x-axis represented the sample concentration (ppm), and the y-axis represented the inhibition percentage value. The inhibition percentage refers to the antioxidant activity of an edible film, which is measured by the barrier it creates against the absorption of DPPH radicals (Molyneux, 2004). The results revealed that inhibition (%) increased with increasing moringa concentrations (Fig. 4). The IC_{50} of the blank film (S0) was 214.400 ppm and decreased to 135.074 ppm for the S4 film (3.0% extract) (Table 3). Thus, the antioxidant activity improved from very weak to moderate. The edible films containing a 3% extract exhibited the greatest antioxidant activity among the concentrations evaluated. These results re-

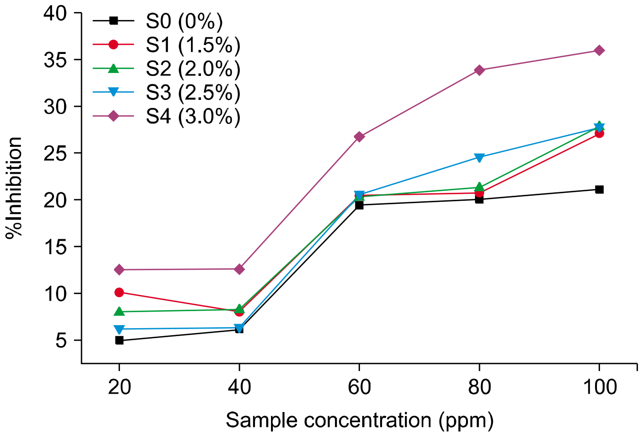

Fig. 4. Percent inhibition of films at different moringa leaf concentrations.

veal that the edible film with 3% extract exhibited moderate antioxidant properties.

Shelf life

To examine the shelf life of food, potato slices were wrapped with the prepared films and then compared to potato slices wrapped with commercial oil paper, both without coverings. The observation findings are briefly presented in Table 4. The potato slices easily wrinkled and turned to blackish brown when no film or cover was applied. Wrapping the potato with film or paper resulted in fewer wrinkles and fewer brown potatoes, particularly when the potato was wrapped with edible antioxidant films. The physical degradation was faster when the potato slices were kept at a higher temperature (30°C) than in a cooler room (16°C). At 30°C, some fungi appeared on the sliced potato without a wrap, whereas no fungi were observed on the potato wrapped with antioxidant edible film. The findings suggest that including 3% moringa leaf extract in the film could effectively prolong the shelf life of potato slices.

Biodegradability analysis

The biodegradability test was conducted by immersing the films in EM4 solution. EM4 is a brownish liquid containing a mixture of various microbes, including lactic acid bacteria (*Lactobacillus* spp.), fermentation fungi, photosynthetic bacteria (*Rhodopseudomonas* spp.), *Actinomycetes* spp., phosphate solubilizing bacteria, and yeast. EM4 is commonly used in agriculture for fermentation and to decompose organic materials in soil. Polymer degradation was used to express physical changes due to chemical reactions and changes, which include macromolecule bond breaking. It was found that films having moringa leaf extract became partially degraded after seven days and were completely degraded within 14 days (Fig. 5). These findings suggest that all evaluated films have good biodegradability.

DISCUSSION

Edible films derived from Belitung taro tuber starch which incorporated CMC as a reinforcing agent, sorbitol as a plasticizer, and moringa leaf extract to function as an antioxidant agent were successfully prepared and characterized. These edible films were made from abundant natural resources, which is more sustainable than petroleum-based films for food packaging materials. Furthermore, these edible films are biodegradable; thus, more environmentally friendly.

Moringa leaf is consumed extensively in Southeast Asia,

Table 3. Half maximal inhibitory concentration (IC_{50}) values of taro starch edible films containing different concentrations of moringa leaf extract

Edible film sample	Regression value y = ax+b	IC_{50} value (ppm)	Antioxidant activity
S0 (0.0%)	y = 0.2309x+0.4950	214.40±0.00	Very weak
S1 (1.5%)	y = 0.2340x+3.2519	195.04±6.71	Weak
S2 (2.0%)	y = 0.2641x+1.2719	184.35±0.23	Weak
S3 (2.5%)	y = 0.3061x+1.2594	165.42±2.89	Weak
S4 (3.0%)	y = 0.3415x+3.8722	139.61±6.41	Moderate

Table 4. The physical condition of potato slices after shelf life test

No	Application against potato	Room temperature (°C)	Shelf life (power)	Physical condition
1	Wrapped in edible film	16	7	Fine, less wrinkled, the color of the potato remained the same
2	Wrapped in oil paper	16	6	Slightly wrinkled and slightly brown
3	No wrapping	16	4	Wrinkled and the potato turned black
4	Wrapped in edible film	30	5	Less wrinkled, not moldy, and the potato was slightly black
5	Wrapped in oil paper	30	3	Wrinkled and slightly moldy, and the potato was marginally black
6	No wrapping	30	2	Wrinkled, slightly moldy, and the potato turned black

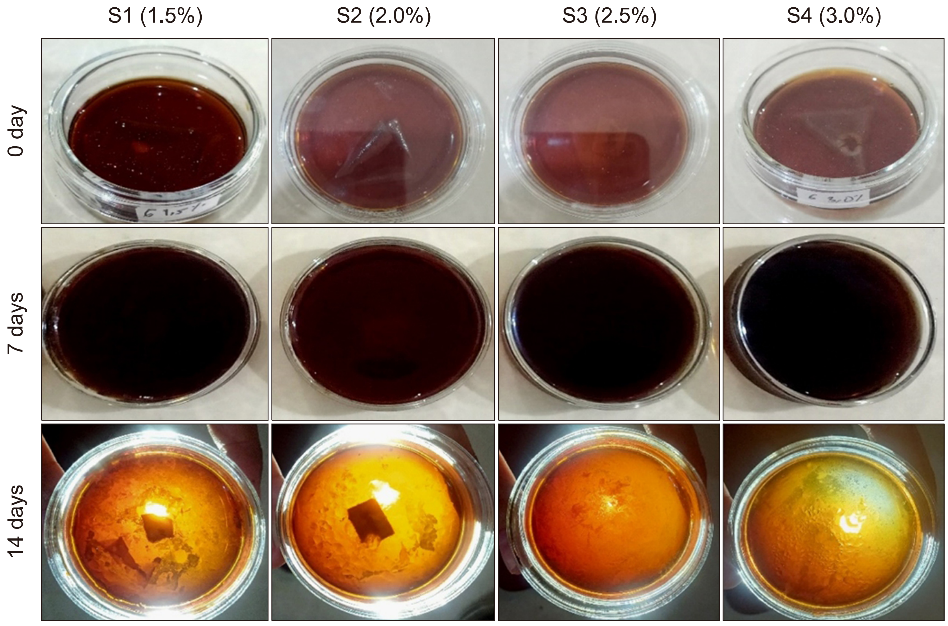

Fig. 5. Edible film degradation of samples containing different concentrations of moringa leaf extract in effective microorganism-4 bacteria.

either as a vegetable or as a traditional medicine. Moringa contains various nutrients and is identified as an antioxidant agent. Badejo et al. (2014) utilized moringa leaf extract to make functional beverages, such as tiger nut drink, and successfully improved the antioxidant properties of the drink. However, the application of moringa leaf extract as an additional active compound for food packaging film as a substitute for petroleum-based film remains limited. In this study, various extract concentrations resulted in various film thicknesses, ranging from 0.18 mm for film containing 0.1% extract to 0.22 mm for film containing 3.0% of the extract. Additionally, the more compounds are added, the more interactions might form among the components used in film preparations (Thakwani et al., 2023). Generally, moringa leaf extract was found to increase film roughness. These observations implied the development of hydrogen bonding among the hydrophilic compounds (Zarandona et al., 2020; Zhang et al., 2023b). The higher the moringa leaf extract concentration, the more H-bonds formed, resulting in a higher degree of heterogeneity.

A mechanical stress, known as tensile strength, was applied and measured to determine the maximum force required to induce the highest strain on each area unit of the film, leading to its rupture. Edible films with high tensile strength are expected to protect foods from mechanical disturbances. Furthermore, the film's tensile strength was found to be influenced by the formulation of the material used in preparing the films. Elongation refers to the quantifiable alteration in length determined by calculating the percentage of change observed when a film is subjected to stretching until it breaks (Kurt and Kahyaoglu, 2014). Elasticity is a fundamental property that quantifies the rigidity of a polymer material. The percentage of elongation determines the elasticity of the films. The elasticity is greater at higher elongation values. The tensile strength and elongation upon breakage of the edible taro starch films decreased with increasing moringa leaf extract concentrations. Shanmathy et al. (2021) investigated the effect of bentonite concentrations as a reinforcing agent in taro starch bioplastic film and found that there was an optimum concentration of bentonite for use in taro starch film. Additionally, they found that higher extract concentrations might weaken the intermolecular forces between starch-starch and H-bonds between starch-sorbitol-CMC. In the present study, the edible taro starch films fulfilled the elongation value standard of the Japanese Industrial Standard (2019), which is >50% (JSA, 2019).

A water absorption assessment was employed to identify the amount of water absorbed by the edible films. A good biofilm is a film that absorbs as little water as possible and is therefore characterized by a smaller percentage of water absorption. Here, the water absorption and the solubility of the taro starch films tend to increase with increasing moringa leaf extract percentages. This finding could be explained by phenolic compounds contained in moringa leaf extract that are naturally hydrophilic, causing increased water absorption and the solubility of the edible films. Furthermore, a rather high water content in edible films containing high moringa leaf extract concentrations affected solubility. Films with high solubility indicate low water resistance and can be applied to ready-to-eat products. They are also suggested to be more easily digested. The WVTR of edible taro starch films was found to increase at higher extract concentrations and higher resistance to water vapor was observed in edible films with lower WVTR. The limited WVTR may impede the product's moisture loss, thereby hindering hydrolysis and microbial degradation. Ningsih et al. (2021) investigated the effect of rosella flower extract concentrations on the physicochemical properties of jackfruit seed starch film and found that the WVTR was not affected much by the extract concentration. The obtained outcome meets the WVTR criterion specified by the Japanese Industrial Standard (2019), which sets the upper limit for the WVTR of edible films at 7 g per 24 h per square meter (JSA, 2019).

Moringa leaf contains flavonoid compounds, which provide antioxidant properties to the films. Flavonoid compounds are a class of polyphenolic constituents that are widely distributed in many plant species. Flavonoids release hydrogen atoms from their hydroxyl groups which connect to free radicals and act as antioxidants, ultimately leading to their neutralization (Duda-Chodak et al., 2023). Stable free radicals possess the ability to impede chain reactions, so they serve as a protective mechanism against potential harm to lipids, proteins, or DNA. Moringa leaf extract may reduce food oxidation and free radicals. Edible films' antioxidant activity increased with moringa extract concentrations. The films' increased antioxidant activity can be attributed to more phenolic and polyphenolic compounds present in the films at higher extract concentrations. Mondal et al. (2022) developed an antioxidant-rich edible film using ethanolic green algae extract and reported that the DPPH antioxidant activity gradually increased with increasing extract concentrations. Here, a shelf life study of sliced potatoes was conducted and analyzed and found that potato freshness and physical properties could be maintained for a prolonged period.

The edible films prepared in this study are not only food-safe due to food-grade ingredients but also environmentally friendly. Here, the taro starch-moringa leaf extract films biodegraded within 14 days. Yet, Ningsih et al. (2021) reported that the edible film produced from jackfruit seed starch and rosella flower extract was completely degraded in only 7 days when exposed to EM4 bacteria. This biodegradation process occurs through anaerobic and aerobic processes. When degradation occurs, a hydrolysis process occurs, resulting in the polymer matrix having more hydroxyl groups capable of decomposing more quickly into small pieces that will eventually disintegrate. The functional groups present in the films possess the potential to undergo degradation, qualifying them as environmentally sustainable bioplastics. Moreover, the findings suggested that integrating moringa leaf extract into the edible film did not result in the formation of new functional groups. Instead, it led to a physical blending of the extract with the film, characterized by hydrogen bonds between the polymer chains. Hydrogen bonding was observed between sorbitol molecules, which engaged in interactions with hydrogen derived from Belitung taro starch, moringa leaf extract, and CMC. Based on the characterizations of Belitung taro tuber edible films containing varying amounts of Moringa leaves extract, the optimum extract concentration was found to be 3% (v/v).

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Concept and design: SR, YY. Analysis and interpretation: SR, YY, MT. Data collection: MT. Writing the article: SR, YY, MT. Critical revision of the article: SR, YY, TT, AA, TS, SS, YN. Final approval of the article: all authors. Data analysis: SR, YY, MT. Obtained funding: SR, YY. Overall responsibility: SR, YY.

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