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Physical and Antioxidant Properties of Porang Glucomannan-based Edible Film with the Addition of Arabic Gum and Citronella Oil

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ABSTRACT

Background: Edible films prepared solely from glucomannan exhibit several limitations, including low mechanical strength, poor resistance to water vapor and the absence of antibacterial properties, which restrict their potential application as edible film materials. This study aims to investigate the influence of arabic gum and citronella oil additions to enhancing the physical characteristics of glucomannan-based edible films.

Methods: The characteristics of the edible film tested include water solubility, water vapor transmission rate, tensile strength, elongation at break, film microstructure and antibacterial activity.

Result: The edible films obtained with varying concentrations of arabic gum and citronella oil exhibited water solubility values ranging from 53.04% to 72.06%, water vapor transmission rates between 0.0015 and 0.0035 g/h·m², tensile strength values from 40.83 to 90.56 N/m² and elongation at break values ranging from 11.11% to 21.11%. This study revealed a decrease in the water vapor transmission rate, tensile strength and elongation of the edible film, along with an increase in water solubility as the concentration of arabic gum was increased. This study also found a decrease in the water solubility, water vapor transmission rate and tensile strength of the glucomannan-based edible film, accompanied by an increase in elongation with the addition of higher concentrations of citronella oil. The antibacterial test results showed that the edible film samples exhibited moderate inhibition against *E. coli* (inhibition zone diameter of 10.5 mm) and mild inhibition against *S. aureus* (inhibition zone diameter of 8.23 mm).

Key words: Arabic gum, Citronella oil, Edible film, Essential oil, Glucomannan, Porang flour.

INTRODUCTION

The main purpose of food packaging is to protect food products from damage due to external environmental factors. Increased awareness of the negative effects of using non-biodegradable packaging on the environment has led to an increase in the use of biodegradable and environmentally friendly packaging in the food industry to keep food products safe and healthy for consumption (Zhang *et al.*, 2018). Therefore, biodegradable edible films based on polysaccharides, proteins, fats, or their composites are being developed as alternatives to non-biodegradable packaging (Chandla *et al.*, 2020; Gumilar *et al.*, 2025). Edible films that serve as protective coatings on the surface of food products can prevent product damage by reducing nutrient loss, aroma loss, solid loss and controlling the permeability of water vapor and gases (Sahraee *et al.*, 2019).

Glucomannan is a water-soluble polysaccharide composed of glucose and mannose residues linked by β-1,4 glycosidic bonds. *Amorphophallus muelleri* Blume, commonly known as porang in Indonesia, is rich in water-soluble glucomannan (Mubarok and Samesta, 2024). Glucomannan obtained from the extraction process of porang or konjac is biodegradable and has good film-forming abilities (Putri *et al.*, 2024). However, films made from pure glucomannan have some weaknesses, such as low mechanical strength, weak resistance to water vapor and a lack of antibacterial properties, which hinder its application as an edible film material (Liu *et al.*, 2021). The ability to inhibit water vapor in edible films can be enhanced by adding hydrophobic components. Previous research results have shown that adding essential oils such as perilla oil, thyme oil and oregano oil has been proven to improve water vapor inhibition properties and antibacterial activity in edible films (Hosseini *et al.*, 2015; Zhang *et al.*, 2018; Liu *et al.*, 2021). In this study, citronella oil obtained from *Cymbopogon nardus* L. was added as a component

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in the production of porang glucomannan-based edible films. Citronella oil contains citronellal, geraniol and citronellol which possess antibacterial activity (Timung *et al.*, 2016).

The properties and mechanical strength of porang glucomannan edible films can be improved by adding or blending them with other biodegradable components that have film-forming properties. Previous research has shown that the addition of chitosan, carboxymethyl cellulose and ethyl cellulose can enhance the mechanical properties and water vapor resistance of edible films (Bhattacharya, 2017; Wang *et al.*, 2017). This study will investigate the use of arabic gum to improve the properties and mechanical strength of porang glucomannan-based edible films. Arabic gum is a complex mixture of glycoproteins and polysaccharides composed of galactose and arabinose. Adding arabic gum, which has good biocompatibility properties, will modify and enhance the physicochemical properties of glucomannan-based edible films (Xu *et al*., 2019). The addition of arabic gum in edible film production can also increase the retention of added essential oils (Xu *et al.*, 2018), thus in this study, arabic gum is expected to maintain the retention of citronella oil added during the production of porang glucomannan-based edible films.

This work aims to determine the role of arabic gum and citronella oil in enhancing the functional properties of glucomannan-based edible films. Previous studies have widely reported the use of glucomannan and essential oils in the development of edible films, particularly for improving water vapor barrier and antibacterial properties. Essential oils such as thyme and oregano have been incorporated into edible films (Liu *et al.*, 2021; Ma *et al.*, 2023), the application of citronella oil in combination with porang glucomannan has not been extensively explored. This study also investigates the effect of arabic gum concentration on enhancing the physicomechanical and antibacterial properties of glucomannan-based edible films. The findings are expected to provide new insights into the formulation of biodegradable films from locally available biopolymers, while also expanding the application potential of citronella oil as a natural functional additive in edible film technology.

MATERIALS AND METHODS

Location

This study was conducted at the Laboratory of Food Processing Technology and the Laboratory of Food Microbiology, Faculty of Agricultural Technology, Universitas Brawijaya, Indonesia. The experimental period was established from October 2023 to June 2024.

Materials

The materials used in this research are porang flour (*Amorphophallus muelleri* Blume, which contains 73.5% glucomannan), citronella oil (100% pure essential oil), arabic gum were purchased from Ingredion, glycerol, sodium chloride and distilled water.

Experimental design

This research employed a randomized complete block design (RCBD) factorial method. The research variables involved 2 treatment factors, namely the addition of arabic gum and the addition of citronella oil. There were 3 levels in the variation of the arabic gum addition treatment factor (0.5%, 1.0% and 1.5%) crossed with 3 levels of variation in the citronella oil addition treatment factor (0.50%, 0.75% and 1.00%). Each treatment unit was replicated 3 times, resulting in a total of 27 experimental units. The obtained data were statistically analyzed using ANOVA and if a significant difference was found, it was followed by Fisher's Least Significant Difference (LSD) test at a 5% significance level using Minitab 19 software.

Edible film preparation

0.8 grams of porang flour were dissolved in 100 mL of distilled water, then 0.3 mL of glycerol was added. The mixture was stirred and heated to a temperature of 60°C for 30 minutes. Then, arabic gum and citronella oil were added at concentrations corresponding to the experimental units. The mixture was homogenized with an ultra-turrax homogenizer at a speed of 10,000 rpm for 3 minutes, then poured into a petri dish and dried in a dehydrator at 60°C for 8 hours. The thickness of the films produced under various treatments ranged from 0.07 to 0.12 mm.

Water solubility analysis

The water solubility (WS) of the film samples was analyzed using a modified version of the method described by Shojaee-Aliabadi *et al.* (2014). The initial weight of the film sample (sized 4 cm × 4 cm) was recorded before immersing it in 50 mL of distilled water at room temperature for 24 hours. Afterward, the wet film was dried in an oven at 105°C for 24 hours and weighed. Water solubility was determined using the following formula:

$$WS\ (\%) = \frac{W_d - W_r}{W_d} \times 100\%$$

Where
W_f = Final dry weight of the film (g).
W_d = Initial weight of the film (g).

Water vapor transmission rate (WVTR) analysis

The analysis of water vapor transmission rate in the film samples was conducted following the method of Wu Ying *et al.* (2009). Polypropylene tubes (with a capacity of 50 mL) containing 30 g of desiccant silica gel were sealed with the tested film (5 cm × 5 cm) and placed in a desiccator filled with a saturated sodium chloride solution at 25°C. The tubes were then weighed every 30 minutes for a period of 8 hours. The water vapor transmission rate was determined from the slope of the curve obtained from the change in tube mass over time.

Mechanical properties

The mechanical properties of the edible film, namely tensile strength (TS) and elongation at break (EAB), were analyzed using a universal testing machine (Brookfield Texture Analyzer). Testing was conducted on film samples with dimensions of 1.8 cm × 10.0 cm and a pulling speed of 50 mm/minute (Matsakidou *et al.*, 2019).

Film microstructure analysis

The surface microstructure of the prepared films was analyzed using a scanning electron microscope (FEI Quanta FEG 650) operating at an accelerating voltage of 10 kV. Before imaging, the film samples were coated with gold using an E-1045 sputter coater to enhance conductivity.

Antibacterial activity analysis

The antibacterial activity was determined using the agar diffusion method following the procedure applied by Hosseini *et al.* (2015). Two types of pathogenic bacteria, *Staphylococcus aureus* and *Escherichia coli*, were used in the testing. Disks (with a diameter of 6 mm) were cut from prepared films and placed in agar plates that had previously been inoculated with 0.1 mL of inoculum containing indicator microorganisms at a concentration of 106 CFU/mL. After incubation at 37°C for 24 hours, the diameter of the inhibition zone around the disk was recorded as the analysis result.

RESULTS AND DISCUSSION

Water solubility

The effect of arabic gum and citronella oil concentrations on the water solubility of porang glucomannan-based edible films is shown in Fig 1. The treatment with varying arabic gum concentrations, did not produce a significant difference ($p>0.05$) in the water solubility of the edible film. This is presumed to be due to the relatively low concentration of arabic gum added, which resulted in non-significant differences in the solubility of the edible film. Despite the lack of statistical significance, water solubility exhibited an increasing trend with higher arabic gum concentrations in the production of porang glucomannan-based edible films. The properties of arabic gum make it useful for forming thin layers that are easily soluble or dispersed in water. Several factors contribute to the increased water solubility of edible films with the addition of arabic gum. As a hydrophilic substance with a strong affinity for water, arabic gum can bind or attract water molecules when incorporated into edible film formulations and it tends to absorb the free water present in the film solution (Setyorini and Nurcahyani, 2016). This hydration process contributes to the formation of gel-like structures within the film. The swelling of arabic gum within the film matrix facilitates water penetration, thereby enhancing film dissolution. As a hydrocolloid, arabic gum forms networks that interact strongly with water molecules. This network structure increases the hydrophilicity of the film and contributes to its higher water solubility. These results are in agreement with the findings of Kim *et al.* (2015), who reported that various gums, including arabic gum, were evaluated for their ability to enhance the water solubility of edible films.

The treatment with varying concentrations of citronella oil showed a significant difference ($p<0.05$) in the solubility of the edible film. Further analysis using Fisher's LSD test showed that all three concentrations of citronella oil differed significantly from one another. The 0.5% citronella oil treatment (mean = 69.95%) yielded the highest value, followed by the 0.75% treatment (mean = 60.18%), while the 1.0% treatment (mean = 55.83%) produced the lowest value. These results indicate a clear decreasing trend in the response variable with increasing concentrations of citronella oil.

Water solubility tends to decrease with the increasing concentration of citronella oil added during the production of porang glucomannan-based edible films. Citronella oil is an essential oil derived from citronella containing various components such as citronellal, geraniol and citronellol. The water solubility of edible films can decrease with the addition of citronella oil due to several factors. Citronella oil contains hydrophobic components such as terpenes and other non-polar compounds. When citronella oil is added to the film matrix, these hydrophobic components can interfere with the water solubility of the film. Hydrophobic interactions between the oil components and water molecules can reduce the overall solubility of the film in

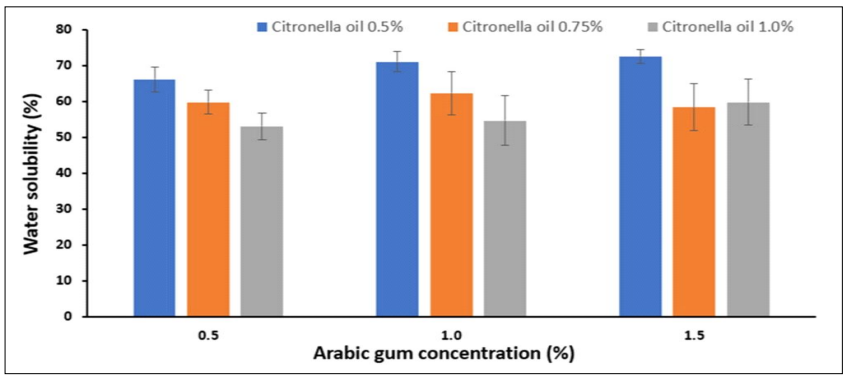


Fig 1: Effect of arabic gum concentration and citronella oil concentration on the water solubility of edible film.

water. The addition of citronella oil can disrupt intermolecular interactions within the film matrix. The hydrophobic components of citronella oil can interact with hydrophilic groups in the film matrix, leading to changes in the film structure and a decrease in water solubility (Tongnuanchan *et al.*, 2014).

Water vapor transmission rate

The influence of adding concentrations of arabic gum and citronella oil on the water vapor transmission rate of porang glucomannan-based edible films is shown in Fig 2. In both treatments, namely variations in arabic gum concentration and citronella oil concentration, there was a significant difference ($p<0.05$) in the water vapor transmission rate of the edible film.

Fisher's LSD test revealed that 0.5% concentration (mean = 0.0032 g/h·m²) and 1.0% concentration (mean = 0.0029 g/h·m²) arabic gum treatments were not significantly different from one another. However, 1.5% concentration treatment (mean = 0.0018 g/h·m²) was significantly lower. These results indicate that reducing the concentration of arabic gum led to a significant decrease in the response variable. The water vapor transmission rate tends to decrease with the increasing concentration of arabic gum added during the production of porang glucomannan-based edible films. Incorporation of gum arabic enhanced the compactness of the film and reduced surface porosity, thereby improving its water barrier properties (Tahsiri *et al.*, 2019). At an appropriate concentration, arabic gum can form a hydrogel network or a compact matrix within the film, thereby creating a more tortuous path for water vapor diffusion.

According to Fisher's LSD test, the treatments containing 0.5% (mean = 0.0029 g/h·m²) and 0.75% (mean = 0.0026 g/h·m²) citronella oil did not differ significantly, whereas the 1.0% concentration (mean = 0.0022 g/h·m²) resulted in a significantly lower value. The water vapor transmission rate tends to decrease with the increasing concentration of citronella oil added during the production of porang glucomannan-based edible films. The incorporation of hydrophobic citronella oil into the edible film progressively reduces its water vapor permeability. Essential oils have been widely investigated as functional additives in edible and biodegradable emulsified films and coatings. Owing to their lipid-based characteristics, incorporation of essential oils is anticipated to decrease the water vapor permeability of hydrophilic films (Atarés and Chiralt, 2016).

Tensile strength

The influence of adding concentrations of arabic gum and citronella oil on the tensile strength of porang glucomannan-based edible films is shown in Fig 3. The treatments with varying concentrations of arabic gum showed a significant difference ($p<0.05$) in the tensile strength of the resulting edible film. The results of Fisher's LSD test indicated that the treatments with 0.5% arabic gum (mean = 75.50 N/m²) and 1.0% arabic gum (mean = 63.98 N/m²) did not differ significantly from each other, whereas the 1.5% concentration treatment (mean = 41.77 N/m²) showed a significantly lower value.

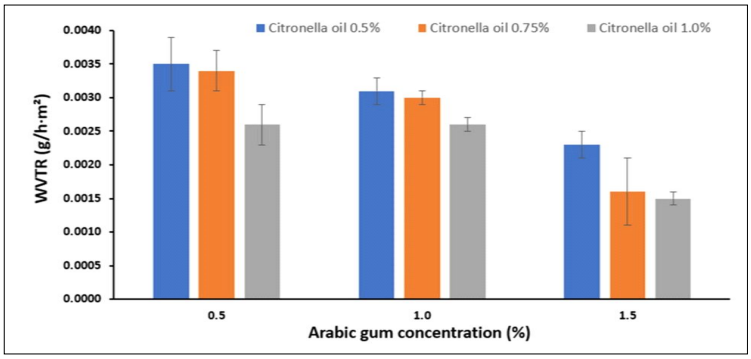


Fig 2: Effect of arabic gum concentration and citronella oil concentration on the water vapor transmission rate of edible film.

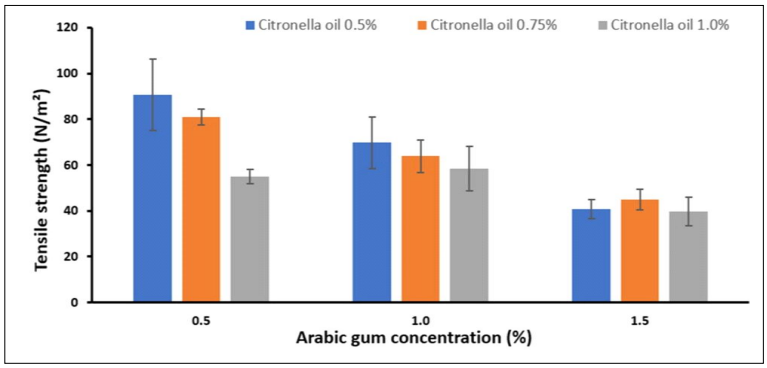


Fig 3: Effect of arabic gum concentration and citronella oil concentration on the tensile strength of edible film.

The tensile strength tends to decrease with the increasing concentration of arabic gum added during the production of porang glucomannan-based edible films. The addition of arabic gum may interfere with the arrangement and bonding of molecules within the film matrix. This interference can weaken the overall structural integrity of the film, resulting in lower tensile strength. Arabic gum can alter the properties of the film, such as flexibility and elasticity. These changes can affect the ability of the film to withstand stretching forces without breaking, contributing to a decrease in tensile strength. Arabic gum's hygroscopic nature can also lead to an increase in water content within the film. High water content can weaken the film's structure and reduce its tensile strength. Water molecules strongly interact with the hydroxyl groups in arabic gum, leading to swelling and a reduction in intermolecular hydrogen bonding strength (Han *et al.*, 2011).

The tensile strength of the edible films was significantly affected ($p<0.05$) by the variation in citronella oil concentration. Based on Fisher's LSD test, no significant difference was observed between the 0.5% (mean = 67.04 N/m^2) and 0.75% (mean = 63.25 N/m^2) citronella oil treatments; however, the 1.0% concentration (mean = 50.96 N/m^2) was significantly lower. The tensile strength tends to decrease with the increasing concentration of citronella oil added during the production of porang glucomannan-based edible films. Citronella oil is a hydrophobic substance, meaning it repels water. When incorporated into the film matrix, citronella oil can disrupt the bonding between film components, leading to a decrease in tensile strength. The reduction in tensile strength is likely due to the ability of the essential oil to easily penetrate the biopolymer network, thereby weakening the intra- and intermolecular interactions (Zhou *et al.*, 2021). Citronella oil can reduce the cohesion between film components, making the film less resistant to stretching forces. This reduction in cohesion contributes to a decrease in tensile strength as the concentration of citronella oil increases. Incorporating citronella oil can alter the mechanical properties of the film, such as flexibility and elasticity (Suput *et al.*, 2016).

Elongation

The influence of adding concentrations of arabic gum and citronella oil on the elongation at break of porang glucomannan-based edible films is shown in Fig 4. Significant differences ($p<0.05$) in film elongation were observed among treatments with different arabic gum concentrations. Fisher's LSD test revealed that the treatments with 0.5% arabic gum (mean = 18.89%) and 1.0% arabic gum (mean = 17.04%) did not differ significantly from each other, whereas the 1.5% concentration treatment (mean = 12.60%) showed a significantly lower value. Based on the observational data, an increase in the concentration of arabic gum was associated with a decrease in the elongation at break percentage of the edible film. This reduction can be attributed to the film's compositional changes. Erben *et al.* (2019) reported that variations in the elongation of edible films are influenced by the amount of arabic gum incorporated. Higher concentrations of arabic gum reduce film elongation, as the interaction between molecules becomes tighter, making the film less able to stretch.

The addition of citronella oil tends to increase the percentage of elongation, but no significant difference ($p>0.05$). This result suggests that, within the tested concentration range, citronella oil did not markedly influence the structural flexibility of the polymer matrix. Essential oil exhibits a strong plasticizing effect, enhancing the mobility of polymer chains and increasing the flexibility of the film (Zhou *et al.*, 2021). Elongation at break is closely related to the mobility of polymer chains; thus, the incorporation of citronella oil may not have been sufficient to either disrupt or reinforce intermolecular interactions within the biopolymer network. Similar findings have been reported in previous studies, where the addition of rosemary essential oil leads to softer and more flexible film, but no significant differences were found between the mechanical parameters of chitosan-based films (Abdollahi *et al.*, 2012).

Film microstructure

The microstructure of the film is influenced by the interactions among its components, which significantly impact its

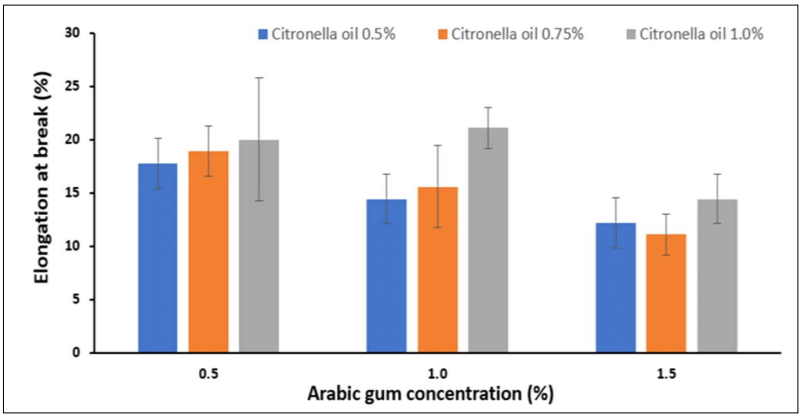


Fig 4: Effect of arabic gum concentration and citronella oil concentration on the tensile strength of edible film.

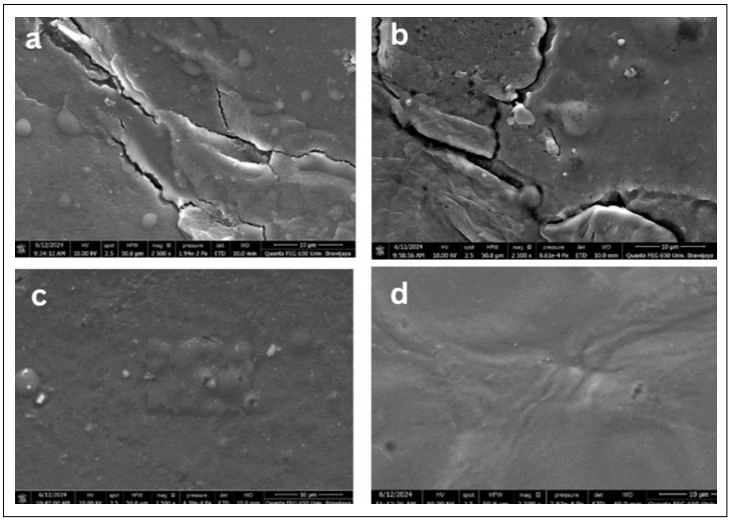


Fig 5: Microstructure of edible film with 1% arabic gum and various concentrations of citronella oil: (a) 0%, (b) 0.5%, (d) 0.75%, (d) 1%.

Table 1: Antibacterial activity of edible film with 1% arabic gum and various concentrations of citronella oil.

Sample	Inhibition zone (mm)	
	E. coli	*S. aureus*
Amoxicillin (control)	22.50	16.12
0.5% citronella oil	8.50	8.00
0.75% citronella oil	10.25	8.10
1.0% citronella oil	10.50	8.23

physical, optical, mechanical and barrier properties. Scanning electron microscopy (SEM) analysis was conducted to better understand the relationship between the film's structure and its performance. The SEM images of the surface of the porang glucomannan-based edible films were presented in Fig 5. The surface of the film without citronella oil appeared uneven, with visible cracks observed. This phenomenon might be attributed to the addition of arabic gum in the glucomannan-based film. A high concentration of arabic gum may result in phase separation and a reduction in miscibility within the multi-phase system (Xu *et al.*, 2019). With the addition of higher concentrations of citronella oil, the film surface became smoother, reducing cracks and gaps. These findings are in agreement with the study by Pirouzifard *et al.* (2020), which incorporated *S. officinalis* essential oil in the preparation of composite films from potato starch/Zedo gum, where the addition of essential oil improved the smoothness of the film surface. This phenomenon may occur due to the oily nature of the essential oil, which, owing to its hydrophobic properties, covers the surface of the film and closes the gaps (Pirouzifard *et al.*, 2020).

Antibacterial activity

The antibacterial activity test was conducted to ensure that the active ingredient added, namely citronella oil, has the desired antibacterial activity and to determine the effect of the concentration of citronella oil used on the antibacterial activity of the edible film. The results of the antibacterial activity test of the porang glucomannan edible film using the disk diffusion method against the test microbes *E. coli* and *S. aureus* are shown in Table 1. The table presents data on the clear zone sizes formed by each sample and the control. The antibiotic control, amoxicillin, exhibited very high activity against both test microbes.

The edible film samples exhibited clear inhibition zones, confirming that citronella oil possesses natural antibacterial properties effective against *E. coli* and *S. aureus*. The largest inhibition zone was observed in the edible film containing 1.0% citronella oil, with values of 10.50 mm against *E. coli* and 8.23 mm against *S. aureus*. The antibacterial test results indicated that the edible film samples inhibited the growth of pathogenic bacteria, falling within the moderate inhibition category (inhibition zone diameter >10.0 mm) against *E. coli* and the mild inhibition category (inhibition zone diameter <10.0 mm) against *S. aureus* (Ahmad *et al.*, 2005). These findings are consistent with previous studies reporting that citronella oil possesses strong antibacterial activity against both *S. aureus* and *E. coli* (Yanwong and Threepopnatkul, 2015; Motelica *et al.*, 2021).

CONCLUSION

This study investigates the addition of arabic gum and citronella oil in the production of porang glucomannan-based edible films. The use of arabic gum aims to improve the properties and mechanical strength of the resulting edible film. The addition of citronella oil is intended to enhance the film's resistance to water vapor transmission rate and provide antimicrobial properties to the edible film. The research results show that water solubility tends to increase with the increasing concentration of arabic gum

and tends to decrease with the increasing concentration of citronella oil added. The water vapor transmission rate tends to increase with the increasing concentration of citronella oil added during the production of porang glucomannan-based edible films. This may be due to the fact that the addition of citronella oil can reduce the overall integrity of the film. The tensile strength of the resulting edible film tends to decrease with the increasing concentration of arabic gum and citronella oil added. Arabic gum, being hydrophilic, can increase the water content of the edible film, while citronella oil, being hydrophobic, can disrupt the bonding between film components, leading to a decrease in tensile strength. Increasing the concentration of citronella oil resulted in a smoother film surface, minimizing the presence of cracks and gaps. The results of the antibacterial test showed that the edible film samples were capable of moderately inhibiting the growth of pathogenic bacteria.

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Disclaimers

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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