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FULL PAPER

# The effect of konjac glucomannan and Aloe vera gel concentration on physical and mechanical properties of edible film

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## Abstract

Glucomannan from konjac can be used as an ingredient for edible films. However, the use of glucomannan as an edible film has a high water vapour transmission rate and water solubility. Aloe vera is known to have the ability to reduce water vapour transmission and solubility, thus, it is suitable to improve these properties of glucomannan edible film. The purpose of this study was to determine the effect, interaction, and best treatment between three levels of glucomannan flour concentration (1%, 1.3%, 1.6%) and the addition of Aloe vera gel (0%, 5%, 10%) on the physical (thickness, water-solubility, optical transparency) as well as mechanical characteristics (tensile strength, elongation at break, water vapour transmission rate) of the edible film using randomized block factorial experimental design. The results showed that there were interactions between the concentration of glucomannan flour and the addition of Aloe vera gel on the elongation of the film. Glucomannan flour addition had a significant effect on thickness, solubility, tensile strength, and elongation of edible films. The addition of Aloe vera gel significantly affected the elongation of the edible film. The best treatment in this study was the treatment with 1.6% glucomannan flour and 10% Aloe vera gel which obtained a thickness value of 0.105 mm; tensile strength 0.854 MPa; elongation 9.53%; water solubility 54.72%; transparency 2.925 A.mm$^{-1}$; and WVTR value 3.889 g.m$^{-2}$.day$^{-1}$.

## 1. Introduction

Konjac (*Amorphophallus oncophyllus* P.), locally called porang, is a tuber crop that grows in Indonesia. However, it is not preferred to be consumed since it has a high amount of calcium oxalate that can stimulate itchiness and health disorder (Pillay *et al.*, 2020). In spite of that, konjac is a highly demanded export commodity in the form of fresh tuber, chips, and flour due to its high level of glucomannan content. Glucomannan is a non-ionic polysaccharide that consists of glucose and mannose residue linked by β-(1–4) glucosidase with the ratio of 1:1.6 (Tester and Al-Ghazzewi, 2013). Glucomannan is a common food additive compound that has been widely used in various industries such as food, pharmaceutical, cosmetic, and chemical (Yanuriati *et al.*, 2017). In the food industry, glucomannan is considered to be generally recognized as safe (GRAS) by the FDA and it can be used as an emulsifier (da Silva *et al.*, 2016), thickener (Wei *et al.*, 2021), dietary supplement (Kaats *et al.*, 2015; Tester and Al-Ghazzewi, 2013), as well as edible film ingredient (Kurt and Kahyaoglu, 2014; Hashemi and Jafarpour, 2020).

Several studies on the production of biodegradable edible film packaging, particularly made from biopolymers, have recently been conducted. Edible film from biopolymer has been used in food products to extend the shelf-life as well as to improve their appearance since it can minimize the migration of moisture, oxygen, and carbon dioxide of the products as the substitute for the use of conventional petroleum-based food packaging which is non-biodegradable and has caused concerns with land disposal (Azmi *et al.*, 2019; Zahiruddin *et al.*, 2019). The important factors to determine the physical and mechanical properties of glucomannan edible film are thickness, water-solubility, transparency, tensile strength, elongation, as well as water vapour permeability (WVP). Glucomannan can be a great edible film ingredient since it is a non-ionic polysaccharide that has a high molecular weight and relatively low branch number (Nieto, 2009; Mikkonen and Tenkanen, 2012). However, glucomannan edible film has a high water vapour transmission rate (WVTR) and solubility, meaning water is able to pass through the film and absorb into the food products, so the food

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deterioration will occur faster which makes it less favourable in industry. In addition, it is less elastic than any other edible film such as polypeptide-based edible polymers (Shit and Shah, 2014).

In order to increase the WVTR value of glucomannan film, it is necessary to add another component that can improve the water vapour barrier property of glucomannan film. Khoshgozaran-Abras *et al.* (2012) reported that adding 20% Aloe vera gel into the chitosan film will reduce its WVP and water solubility, as well as increase the mechanical properties including tensile strength, elongation, and elastic modulus values of the film. Aloe vera gel was reported to have natural film-forming starch-based polymer matrixes which are responsible to give supporting properties to edible films, such as cellulose, acetylated mannan, glucomannan, acetylated glucomannan, galactogalacturan, glucogalactomannan, galactoglucoarabino-mannan (Choi and Chung, 2003). In addition, antioxidants in Aloe vera gel will also support polysaccharides to improve plasticizing properties and flexibility of edible polymers (Bajer *et al.*, 2020). Therefore, the purpose of this study was to investigate the effects and the interactions between glucomannan and Aloe vera gel concentration on the physical and mechanical properties of glucomannan edible film. This report will also provide the best treatment among those factors.

## 2. Materials and methods

### *2.1 Preparation of glucomannan flour*

Glucomannan flour was obtained from konjac harvested after 2 years of cultivation in the 200 m.a.s.l farm. According to Siswanti *et al.* (2013), the konjac was washed, peeled, and cut into chips with 4-5 mm of thickness, then it was submerged in the 1% (w/v) Na-bisulphite solution for 5 mins to avoid browning. The chips were dried, ground, and sifted through a 50 mesh sieve to obtain the konjac flour. The flour was then mixed with distilled water (1:50 (w/v)), then heated to 55°C for 1 hr and stirred periodically. The supernatant then was obtained from the filtered puree. Subsequently, the supernatant was macerated in 400 mL of 96% ethanol until agglomerates were formed. The maceration was done twice to get the white-bluish glucomannan agglomerates, then it was dried at 60°C for 24 hrs. The coarse glucomannan was ground and sifted through an 80 mesh sieve to get glucomannan powder.

### *2.2 Glucomannan-Aloe vera gel edible film production*

The production of glucomannan edible film was conducted corresponding to Siswanti *et al.* (2013) with modification. Calcium dihydroxide solution was prepared by adding 0.2% (w/w glucomannan flour) $Ca(OH)_2$ with 150 mL distilled water. The glucomannan flour was added into the solution with different concentration (1%, 1.3%, 1.6%) (w/v). Aloe vera gel (mucilage) obtained from the middle part (parenchyma) of the Aloe vera was mashed, filtered with a 1 mm filter, and added into the mixture with different concentrations (0%, 5%, 10%) (w/v) as well as 0.3% (w/v) glycerol. The mixture was placed above an induction stove and heated for 15 mins. Subsequently, the 150 mL mixture was poured into a 200×200×30 $mm^3$ cast and dried at 60° C for 24 hrs. The film was then subjected to physical and mechanical properties analysis.

### *2.3 Physical properties analysis*

#### *2.3.1 Thickness*

The thickness of the edible films was measured according to Yoshida and Antunes (2004). The measurement was conducted in each specimen using a micrometre (Mitutoyo Mfg Co. Ltd., Japan) at 5 distinct places to the nearest 0.001 mm. The average was determined to be the film thickness.

#### *2.3.2 Water solubility*

For determining the film water solubility, a method described by Saberi *et al.* (2016) was used. The film was cut to 1×1 cm in size, weighed for its initial dry weight ($W_0$), and placed on a petri dish containing 15 mL distilled water for 24 hrs. After submerging, the samples were taken, drained, and the water on the samples' surface was removed using tissue paper. Subsequently, the samples were placed in an oven for 24 hrs. The dried samples were weighed for their final dry weight ($W_1$) and the absorbed water was determined. The percentage of film water solubility was calculated using the formula below:

$$Water\ solubility\ (\%) = \frac{W_0 - W_1}{W_0} \times 100$$

#### *2.3.3 Optical transparency*

Determination of film transparency was conducted according to a method described by Al-Hassan and Norziah (2012) with slight modification. The film sample was cut into 1×4 cm in size, then the thickness was measured. The samples were then placed inside of the spectrophotometer cuvette and the transparency was determined using spectrophotometer UV-Vis (Shimadzu, Japan) at 546 nm wavelength. The following equation was used to compute the transparency (T) of films:

$$T = \frac{A_{546}}{x}$$

Where $A_{546}$ denotes the absorbance at 546 nm and $x$ denotes the thickness of the film (mm). A higher T value indicates a lower degree of transparency, according to this equation. For each film sample, tests were performed in triplicate.

### 2.4 Mechanical properties analysis

#### 2.4.1 Tensile strength and elongation at break

The film tensile strength measurement was performed according to ASTM standard number D882-12 (ASTM, 2012) using Universal Testing Machine. The sample was cut into 20×50 mm in size then tested by giving load and pulling force. The value of tensile strength was calculated by the following equation:

$$Tensile\ strength\ (\tau) = \frac{F_{max}}{A}$$

Where $F_{max}$ is maximum tensile force (N) and $A$ is surface area (cm$^2$). Tests were run in triplicates for each type of film.

#### 2.4.2 Elongation at break

The film elongation measurement was performed according to ASTM standard number D882-12 (ASTM, 2012) using Universal Testing Machine. The sample was cut into 20×50 mm in size and then tested by giving load and pulling force. The value of tensile strength was determined by the film's ability to extend under the applied forces and was calculated using the following equation:

$$Elongation\ (\%) = \frac{d_{after} - d_{before}}{d_{before}} \times 100$$

Where d is the distance between the clamps of the sample holder before or after the sample is pulled until it breaks. For each film sample, tests were performed in triplicate.

#### 2.4.3 Water vapour transmission rate (WVTR)

Determination of WVTR was performed according to ASTM standard number E96/E96M-16 (ASTM, 2016). A 30 mL dish was filled with 2 g silica gel, and then its edges were covered with film samples and tightly secured using rubber bands. The sample and dish were weighed for the initial weight. Subsequently, they were placed in a container containing 100 mL 40% NaCl at 25°C then it was tightly closed. The dish and sample were measured for their weight for 6 days and the data were used to determine the linear regression equation and the slope by dividing increasing weight (g/day) and film surface area (cm$^2$). WVTR values were determined using the following equation:

$$WVTR = \frac{\Delta W}{t \times A}$$

Where $\Delta W$ is the change in film weight after 24 hrs (g), $t$ is time (24 hrs), and A is surface area (cm$^2$). For each film sample, tests were performed in triplicate.

### 2.5 Statistical methods

A randomized block factorial experimental design was used for determining the effects and interactions of two factors on the characteristics of edible films, the factors are glucomannan flour concentration (1%, 1.3%, 1.6%) (w/v), and Aloe vera gel concentration (0%, 5%, 10%) (w/v) with 3 replications, so there were 27 samples in total. The samples' mean differences were compared using analysis of variance (one-way ANOVA). If there were differences in means, Duncan's Multiple Range Test (DMRT) was used to make multiple comparisons (confidence level, α = 0.05). The best treatment was determined using the De Garmo method.

## 3. Results and discussion

### 3.1 Physical properties

#### 3.1.1 Thickness

There was no interaction between the glucomannan concentration and the Aloe vera gel concentration on the film thickness, according to ANOVA (data not shown). In particular, glucomannan flour increased the thickness of edible film significantly (α = 0.05) between 1% and 1.6% of glucomannan flour (Table 1). This result is in accordance with Siswanti *et al.* (2013), Halim and Katherina (2019), and Safitri *et al.* (2020) who reported that a high concentration of glucomannan as the based-polymer, will increase total solids as well as its film-forming matrix polymer, resulting in increasing film thickness. The film thickness is also affected by cast area and suspension volume (Purnavita and Utami, 2018). However, there was no significant difference in the film thickness affected by Aloe vera gel concentrations (Table 1). The film thickness value affects the water vapour and oxygen permeability, mechanical properties, as well as transparency of the film. According to the Japanese Industrial Standard (1997), the standard thickness of the edible film is 0.25 mm or less. Thus, the film thickness in this study has been in accordance with the mentioned standard.

Table 1. The effect of glucomannan flour concentration and Aloe vera gel concentration on the thickness of edible film

| Component | Concentration (%) | Thickness (mm) |
|---|---|---|
| Glucomannan | 1 | 0.080±0.0154[a] |
| | 1.3 | 0.086±0.0001[ab] |
| | 1.6 | 0.093±0.0098[b] |
| Aloe vera gel | 0 | 0.084±0.0078 |
| | 5 | 0.087±0.0123 |
| | 10 | 0.088±0.0175 |

Values are presented as mean±SD. Values with different superscript are significantly different (α = 0.05).

### 3.1.2 Water solubility

The film solubility in water is an essential property of edible films. The desired water solubility value is determined by the application or intended use. For instance, food products with high moisture content or high hygroscopicity require edible film with low water solubility (Kurt and Kahyaoglu, 2014). The result of this study showed that glucomannan concentration affected the film water solubility significantly ($\alpha$ = 0.05) and KGF3 had the highest water solubility (Table 2). According to Tester and Al-Ghazzewi (2013), glucomannan is a hydrophilic substance since it consists of polysaccharides that have a large number of hydroxyl groups. Therefore, adding more glucomannan to the film suspension will increase the water solubility.

Table 2. The effect of glucomannan flour concentration and Aloe vera gel concentration on the film water solubility

| Component | Concentration (%) | Water solubility (%) |
|---|---|---|
| Glucomannan | 1 | 44.48±2.504[a] |
| | 1.3 | 46.94±3.813[a] |
| | 1.6 | 59.93±3.748[b] |
| Aloe vera gel | 0 | 51.52±7.405 |
| | 5 | 50.16±9.201 |
| | 10 | 49.67±6.959 |

Values are presented as mean±SD. Values with different superscript are significantly different ($\alpha$ = 0.05).

The result showed that Aloe vera gel concentration slightly reduced the film water solubility but did not give a significant effect on it (Table 2). In comparison with a study by Chin *et al.* (2017), the author reported that the water solubility of biopolymer film decreased significantly as Aloe vera increased. This could be due to the hydrophilic property of glucomannan as the major polymer and water tend to easily permeate the film which had the lowest Aloe vera gel concentration (Chin *et al.*, 2017). The reduction of film water solubility as Aloe vera gel concentration increases was also reported by Khoshgozaran-Abras *et al.* (2012). However, there was no interaction between the glucomannan concentration and Aloe vera gel concentration on the film water solubility (data not shown).

### 3.1.3 Optical transparency

The optical properties of the edible film, such as colour and transparency, are important factors for its overall appearance and consumer acceptance. In this study, the result showed that glucomannan concentration slightly lowered the edible film transparency but not significantly. The 1.0% glucomannan concentration produced the edible film with a 3.93 A.mm$^{-1}$ transparency value, then it was decreased to 3.41 A.mm$^{-1}$ when the glucomannan concentration was increased to 1.6% (Figure 1A). Meanwhile, Aloe vera gel seemed to not give any effect on the transparency of the edible film. In Figure 1B, The result showed that from 0% to 10% of Aloe vera gel concentration, it produced the edible film with 3.65-3.77 A.mm$^{-1}$ transparency value.

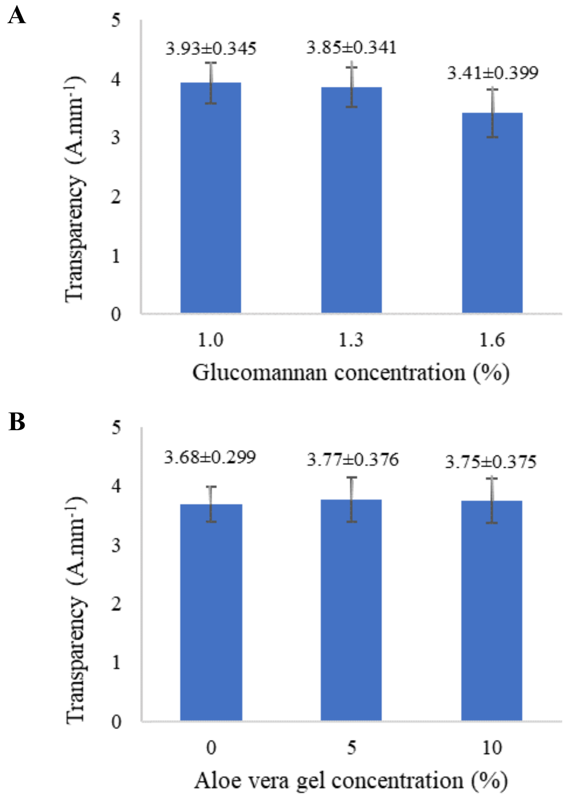


Figure 1. Optical transparency of edible film with different glucomannan concentration (A) and Aloe vera gel concentration (B). Values are presented as mean±SD.

## 3.2 Mechanical properties

### 3.2.1 Tensile strength

Since food quality and safety depend on the capacity to preserve integrity, the ability to endure tensile stress is a vital parameter of food coating or packaging using edible film. Tensile strength is the highest tensile stress a material can bear without breaking during a test (Yoo and Krochta, 2011). Tensile strength values of the edible films affected by glucomannan concentration are shown in Table 3. The result showed that from 1% to 1.6% glucomannan concentration, the tensile strength values were increased significantly from 0.77±0.073 MPa to 1.19±0.109 MPa, respectively. The increasing tensile strength values were obtained because glucomannan as the main film-forming polymer had also been enhanced and it made the polymer became denser, as well as the matrix bonding became stronger and more compact (Chambi and Grosso, 2011; Raharjo *et al.*, 2012; Halim and Katherina, 2019). However, Aloe vera gel addition decreased the tensile strength of the edible film but not significantly. In Figure 2 we can see that from 0% to 10% of Aloe vera gel addition, the tensile strength was slightly lowered from 0.99±0.195 to 0.95±0.213, respectively. This might be due to the Aloe vera gel as a plasticizer reducing the intermolecular forces along polymer chains, lowering the matrix firmness while increasing edible film flexibility (Kurt and Kahyaoglu, 2014). According to the Japanese Industrial Standard (1997), the standard tensile strength value of an edible film is 0.392 MPa. Thus, the film tensile strength in this study has been in accordance with the mentioned standard.

Table 3. Tensile strength of the edible films with different glucomannan concentration

| Glucomannan Concentration (%) | Tensile strength (MPa) |
|---|---|
| 1 | 0.77±0.073[a] |
| 1.3 | 0.96±0.070[b] |
| 1.6 | 1.19±0.109[c] |

Values are presented as mean±SD. Values with different superscript are significantly different (α = 0.05).

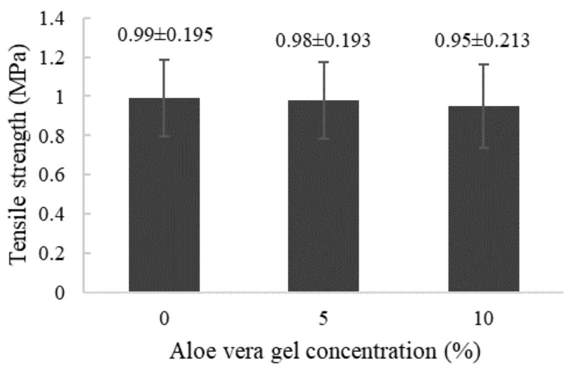


Figure 2. Tensile strength of edible films affected with Aloe vera gel concentration

### 3.2.2 Elongation at break

Elongation at break (E%) is the increase in the sample length from its initial length to the breakpoint. E% is used to evaluate the edible films' mechanical properties and it is related to the chemical structure of the film. This parameter is also the indicator of the film strength and flexibility, along with tensile strength (da Rosa Zavareze *et al.*, 2012). In this study, there are correlations between glucomannan flour and Aloe vera gel addition in the E% value of the film. From Table 4, we can conclude that the lowest level of glucomannan flour (1%) and the highest level of Aloe vera gel (10%) gave the highest E% value of the films (14.30±0.345). The increasing concentration of glucomannan flour decreased the E% value significantly (α = 0.05). This might occur because the addition of high glucomannan concentration would lower its ratio with the plasticizer. The plasticizer enhances the plasticizing properties and flexibility of the polymeric molecular chain (Bajer *et al.*, 2020). Thus, increasing plasticizer concentration will also increase the ability of the film to expand from the original length and *vice versa*. Zahiruddin *et al.* (2019) reported that the E% value usually is inversely proportional to elongation at break, with an increase in tensile strength value resulting in a drop in elongation at break. The result in this study was in accordance with the aforementioned report which showed a significant drop in E% value while tensile strength value was increased significantly (Table 3) in the manner of glucomannan flour addition. According to the Japanese Industrial Standard (1997), the standard E% value of an edible film is around 10-50%, so it can be concluded that the samples with 1% glucomannan and 0-10% Aloe vera gel are the samples that are in accordance with the standard.

Table 4. E% value of edible films with different glucomannan and Aloe vera gel concentrations

| Treatments | E (%) |
|---|---|
| 1% glucomannan flour + 0% Aloe vera gel | 12.02±0.466[d] |
| 1% glucomannan flour + 5% Aloe vera gel | 12.45±0.249[d] |
| 1% glucomannan flour + 10% Aloe vera gel | 14.30±0.345[e] |
| 1.3% glucomannan flour + 0% Aloe vera gel | 8.29±1.121[bc] |
| 1.3% glucomannan flour + 5% Aloe vera gel | 9.51±0.730[c] |
| 1.3% glucomannan flour + 10% Aloe vera gel | 9.05±0.744[bc] |
| 1.6% glucomannan flour + 0% Aloe vera gel | 5.80±0.415[a] |
| 1.6% glucomannan flour + 5% Aloe vera gel | 7.91±0.358[ab] |
| 1.6% glucomannan flour + 10% Aloe vera gel | 9.53±1.313[c] |

Values are presented as mean±SD. Values with different superscript are significantly different (α = 0.05).

### 3.2.3 Water Vapour Transmission Rate (WVTR)

The water–vapour transmission of the package films has a great influence on the food shelf life. Water vapour transmission is the rate at which water vapour moves through an area in a given amount of time and at a given humidity temperature (Basha *et al.*, 2011). However, there was no interaction between glucomannan and Aloe vera concentration in the film WVTR. Both parameters also did not give any effect on the film WVTR (Figure 3). It is assumed that the concentration addition between treatments is very small, resulting in the water vapour transmission rate was not significantly different. This result was in accordance with Apriyani and Sedyadi (2015) that reported that the addition of Aloe vera gel did not significantly affect the WVTR of edible films. Many factors influence the rate of water vapour transmission, including the edible film's integrity, the ratio of hydrophilic to hydrophobic, the ratio of crystalline to amorphous regions, and the mobility of the polymer chain (Souza *et al.*, 2010). Water vapour migration generally occurs in the hydrophilic parts of the film, thus the ratio between the hydrophilic to hydrophobic parts of the film components will exert an influence on the value of the water vapour transmission rate. The greater the hydrophobic, the lower the water vapour transmission rate of the film (Siswanti *et al.*, 2013). According to the Japanese Industrial Standard (1997), the standard WVTR of an edible film is 7 $g.m^{-2}.day^{-1}$ or below. The film WVTR in this study was around 3.83-4 $g.m^{-2}.day^{-1}$ so it was in accordance with the mentioned standard.

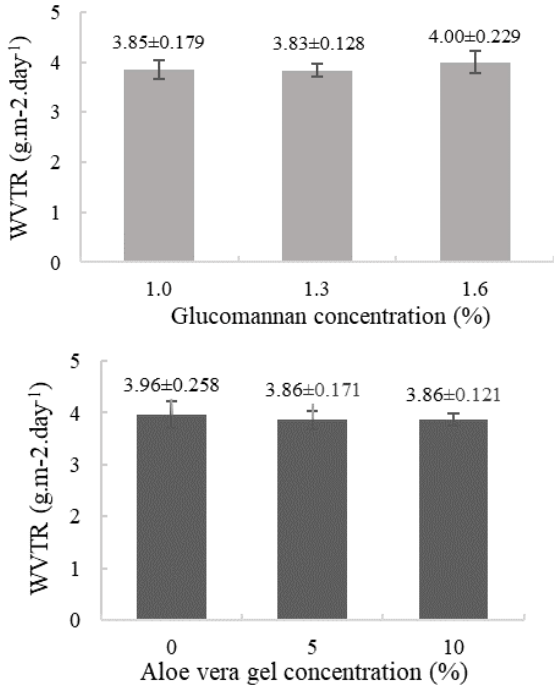


Figure 3. WVTR of the edible film affected by glucomannan and Aloe vera gel concentration.

## 4. Conclusion

Based on the data obtained from the research, it can be concluded that there were interactions between the treatment of glucomannan flour concentration and the addition of Aloe vera gel on the E% value of the edible film. Treatment of glucomannan flour concentration significantly affected the thickness, solubility, tensile strength, and elongation of the edible film. The addition of Aloe vera gel significantly affected the E% value of the edible film. The best treatment in this study was the treatment with 1.6% glucomannan flour and 10% Aloe vera gel which obtained a thickness value of 0.105 mm; tensile strength 0.854 MPa; elongation 9.53%; water solubility 54.72%; transparency 2.925 $A.mm^{-1}$; and WVTR value 3.889 $g.m^{-2}.day^{-1}$.

## Conflict of interest

The authors have no conflict of interest to declare.

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