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ARTICLE

An Evaluation on Physical Characteristics of Konjac Polysaccharides-Based Film Coating and Its Application for Strawberries Preservation

Desy Nurliasari[1], Awaly Ilham Dewantoro[1], Muhammad Adly Rahandi Lubis[2,3], Roni Kastaman[1,4,*], Mohamad Djali[3,5], Efri Mardawati[1,3], Devi Maulida Rahmah[1,3], Siti Nurhasanah[3,5], Akbar Hanif Dawam Abdullah[2,3] and Lukmanul Hakim Zaini[6,7,*]

[1]Department of Agricultural Industrial Technology, Faculty of Agro-Industrial Technology, Universitas Padjadjaran, Jatinangor, 45363, Indonesia

[2]Research Center for Biomass and Bioproducts, National and Innovation Agency, Cibinong, 1691, Indonesia

[3]Research Collaboration Center for Biomass and Biorefinery between BRIN and Universitas Padjadjaran, Jatinangor, 45363, Indonesia

[4]Research Center for Appropriate Technology, Universitas Padjadjaran, Jatinangor, 45363, Indonesia

[5]Department of Food Industrial Technology, Faculty of Agro-Industrial Technology, Universitas Padjadjaran, Jatinangor, 45363, Indonesia

[6]Department of Forest Products, Faculty of Forestry and Environment, IPB University, Bogor, 16680, Indonesia

[7]Institute of Wood Technology and Renewable Materials, Department of Material Sciences and Process Engineering, University of Natural Resources and Life Sciences, Vienna (BOKU), Vienna, 1180, Austria

[*]Corresponding Authors: Roni Kastaman. Email: roni.kastaman@unpad.ac.id;
Lukmanul Hakim Zaini. Email: lukmanhz@apps.ipb.ac.id

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ABSTRACT

Konjac is an ideal candidate for edible coatings on fruits due to its hydrophilic properties, film-forming ability, barrier properties, safety, and biodegradability. Meanwhile, the high market demand for strawberries necessitates post-harvest treatment to extend their shelf life and preserve their quality, as strawberries are known for their fragile skin and soft texture. To fully utilize konjac and develop high-quality coating films, native konjac flour (NKF) and konjac glucomannan (KGM) were extracted from its corm and used as a coating film for strawberries in the present study. Therefore, this study aimed to compare the physical properties of the film coatings between NKF and KGM, and evaluate their effects on strawberries preservation over 7 days of storage. A multistage extraction process was employed to isolate NKF and KGM, after which the glucomannan content was measured. NKF yield was 31.81%, exceeding KGM yield of 26.42%, and the glucomannan content obtained of NKF (25.93%) was higher than KGM (21.41%). Nuclear magnetic resonance spectroscopy confirmed that both NKF and KGM contain glucomannan in their structure. Furthermore, both NKF and KGM were combined with carboxymethyl cellulose (CMC) and glycerol to produce eight thin-layer films to assess their physical and mechanical properties. Compared to the KGM variant, the NKF variant generally exhibited higher moisture content, water vapor transmission rate, and tensile strength. However, NKF was less effective than KGM in extending strawberry storage life, leading to faster color changes and greater weight loss, despite maintaining similar hardness values. Nonetheless, konjac-based coatings were generally effective at maintaining the freshness and quality of strawberries compared to uncoated samples. Konjac shows promise as an edible coating, improving fresh produce shelf life and appeal, aligning with consumer preferences for natural and sustainable products.

KEYWORDS

Amorphophalus oncophyllus; coating performances; edible film; strawberry preservation

1 Introduction

Cellular respiration and transpiration are critical metabolic processes that greatly influence to fruit freshness and senescence. Respiration can damage the cellular structure of fruit by breaking down sugars as an energy source, a process that is further aggravated by transpiration, which includes cellular stress due to dehydration [1,2]. Managing these two physiological activities is essential to preserving fresh fruit, especially those with a short shelf life, such as strawberries [3]. The extremely thin skin, soft flesh, and high macro- and micro-nutrient content of strawberries contribute to high rates of respiration and transpiration [4–6]. This, in turn, accelerates fruit senescence, making it challenging to maintain strawberries in fresh condition during distribution.

Despite the rapid onset of fruit senescence and physiological deterioration, the market demand for fresh strawberries has continued to rise. Globally, the fresh strawberry market exceeded 14 billion USD in 2020 and is projected to grow by 80% over the next decade [7]. Asian countries are the largest consumers and producers of strawberries [4,8]. In Indonesia specifically, new challenges have emerged in maintaining strawberry freshness due to the tropical climate, which accelerates the physiological activity of this fruit, leading to faster senescence and decay [9,10]. Improper postharvest handling of strawberries has resulted in losses of 10%–20% of total production, amounting to billions of USD each year [11,12]. Addressing this issue is crucial to ensuring strawberries remain fresh and their quality is preserved.

A novel solution that has emerged to address the challenge of strawberry senescence, particularly in tropical countries, is innovation in fruit storage and packaging technology. Previous studies have shown that implementing various traditional and advanced storage techniques remains difficult in Indonesia [13–15]. This has led to the development of packaging technologies, with bio-based film coatings offering a promising alternative. These coatings can be made from natural materials such as polysaccharides, proteins, and lipids and are used to reduce the respiration and transpiration rates of strawberries [16,17]. Additionally, bio-based film coatings help maintain the fruit's moisture content, slow down the ripening process, and provide protection against mechanical and biological damage, all of which contribute to delaying fruit senescence [18].

Recent studies have shown that polysaccharides are the most commonly used natural materials in bio-based film coatings for strawberries. Some examples include chitosan, cellulose nanofibrils (CNF), alginate, and polylactic acid (PLA). The use of chitosan and CNF can slow oxidation and preserve the vitamin C content in strawberries [19,20]. Meanwhile, the alginate-based film coatings enhance moisture barrier properties, which are associated with reduced fruit weight loss [21,22]. Unlike the other polysaccharides, PLA, a fermented polysaccharide, offers superior moisture resistance and helps maintain the freshness of strawberries [23]. Recent advances have introduced the use of polysaccharides from konjac (*Amorphophallus sp.*), a plant widely cultivated in Indonesia but underutilized in industry. This has opened up opportunities for utilizing konjac, which is abundant in Indonesia, as a promising polysaccharide for film coating materials that can be applied to strawberries.

Konjac polysaccharides possess unique physicochemical properties that make them ideal for use as bio-based film coatings. Their high gel-forming ability and strong water-binding capacity are particularly advantageous for applications such as strawberry coatings [24]. Previous studies have shown that combining konjac with pullulan significantly reduces weight loss and maintains strawberry color for up to 14 days, outperforming synthetic film-coating materials [25]. Additionally, a film-coating composite

based on konjac polysaccharides in nanoparticle form, combined with k-carrageenan, has been proven to enhance the mechanical properties and provide excellent barrier protection for strawberries [26]. Moreover, the combination of konjac polysaccharides with polyvinyl alcohol and citric acid effectively minimized strawberry weight loss during 10 days of storage [27]. Using konjac polysaccharides offers a promising solution for developing environmentally friendly bio-based film coatings that preserve strawberry quality, particularly by reducing color changes, weight loss, and maintaining fruit hardness, as demonstrated in previous studies.

The development of konjac polysaccharide-based films faces several natural limitations that may reduce their effectiveness in preserving strawberry freshness. Konjac polysaccharides tend to be brittle, have relatively low mechanical strength, and are prone to breaking. A ruptured film coating can increase strawberries' respiration and transpiration rates, accelerating fruit senescence. These issues can be mitigated by incorporating additives such as carboxymethyl cellulose (CMC) and glycerol, commonly used in recent studies [28,29]. Adding CMC enhances flexibility, film strength, and adhesion to the fruit, thereby improving moisture barrier properties. Meanwhile, glycerol acts as a plasticizer in konjac polysaccharide-based films, making the film more elastic and less rigid. Combining these additives with konjac polysaccharides has been shown to produce films with improved mechanical properties, moisture barriers, and biodegradability [30,31]. In this way, the freshness and quality of strawberries can be maintained, helping to minimize post-harvest losses.

Previous studies have demonstrated that konjac polysaccharides have great potential for maintaining the freshness of strawberries. However, the further isolation of konjac polysaccharides to obtain konjac glucomannan (KGM) is time-consuming and costly. As a result, using non-isolated konjac polysaccharides in the form of native konjac flour (NKF) presents a promising alternative for film-coating materials. Additionally, using Indonesian konjac, specifically the species *Amorphophallus oncophyllus*, offers further potential for this application. Therefore, this study aimed to compare the physical properties of NKF- and KGM-based film coatings and evaluate their effects on the physical quality of strawberries during seven days of storage.

2 Experimental

2.1 Materials and Instrumentation

Two main materials used in this study were Java konjac corms (*Amorphophallus oncophyllus*) purchased from local farmers in Garut, West Java, Indonesia and strawberries (*Fragaria x ananassa* cv. Mencir, harvested at 60 days) purchased from local farmers in Bandung, West Java, Indonesia). The chemicals used were sodium metabisulfite, ethanol anhydrous, D-glucose, 3,5-dinitrosalicyclic acid, phenol, sodium hydroxyde, potassium bromide, carboxymethyl cellulose and glycerol obtained from Merck (Singapore, Singapore), ethanol anhydrous from Merck (Darmstadt, Germany), pottasium sodium tartrate and deuterium oxide from Scientific Laboratory Supplies (Nottingham, UK), deuterated acetone from Sigma-Aldrich (Singapore, Singapore), technical grade ethanol from Dwilab Mandiri Scientific (Bandung, Indonesia), and distilled water from Laboratory of Postharvest Technology Universitas Padjadjaran (Sumedang, Indonesia).

Several instrumentation have been used consist of Ohauss Mass Balance ME 204 220 g (Shanghai, China), Digital Hotplate Stirrer Thermo Scientific CIMAREC SP88850105 (Waltham, USA), Ball Miller Xmq 150 × 50 JKWKD (Ganzhou, China), Vibration Sieve Shaker VTSS-200-9 (Ahmedabad, India), DLAB Centrifuge T21-M (Beijing, China), IKA Laboratories Rotary Evaporator RV8-V (Selangor, Malaysia), Hywell Tray Dryer CT-C 8419399090 (Changzhou, China), UV-Vis Spectrophotometer Agilent Technologies 8453 (Santa Clara, CA, USA), Fourier-Transform Infrared (FTIR) Shimadzu Prestige-21 (Kyoto, Japan), Nuclear Magnetic Resonance (NMR) Agilent 500 MHz, Universal Testing Machine 100kN Servo Fully Automatic (Jinan, China), SHARP Refrigerant SJ-236MG-GB/GR

(Karawang, Indonesia), Minolta Chromameter CR-310 (Ramsey, MN, USA), and Fruit Penetrometer GY-2 (Jakarta, Indonesia).

2.2 Konjac Polysaccharides Preparation

2.2.1 Native Konjac Flour (NKF) Preparation

The konjac corms were washed, cleaned, manually sliced to a thickness of approximately 2–3 mm, and soaked in 1% sodium metabisulfite (wt.%) solution. Konjac chips were dried at 120°C for 40–60 min and milled into a powder. Konjac powder was sieved through a 40-mesh sieve to obtain native konjac flour (NKF). The yield and moisture content were subsequently analyzed using standard methods from the AOAC [32].

2.2.2 Konjac Glucomannan (KGM) Preaparation

The glucomannan isolation stage followed a previous study with slight modification [33]. NKF was soaked in 200 mL of 70% ethanol and stirred at 200 rpm for 90 min. The solution was then centrifuged (5000× *g*, 30 min) to separate the precipitate from the ethanol. The precipitate was diluted in 200 mL of distilled water and stirred at 200 rpm for 3 h. After further dilution to 400 mL with distilled water, the solution was centrifuged (9000× *g*, 30 min) to remove the insoluble material. The supernatant was evaporated until 1/3 of its initial volume, then precipitated with 95% ethanol and centrifuged (9000× *g*, 40 min) to obtain glucomannan mucilage. The mucilage was washed with anhydrous ethanol, vacuum filtered, and dried at 80°C for 3 h before milling into konjac glucomannan (KGM). The yield and moisture content were subsequently analyzed using standard methods from the AOAC [32].

2.2.3 Glucomannan Content Quantification

Glucomannan content was measured using the 3,5-dinitrosalicyclic acid (DNS) colorimetric assay [34]. A calibration curve was constructed using a standard solution of D-glucose (16–80 µg/mL) and providing the equation $y = 0.015x + 0.006$ ($R^2 = 0.998$). NKF and KGM (50 mg) were soaked in 40 mL of distilled water and stirred at 150 rpm for 4 h before being diluted to a final volume of 50 mL. The solution was centrifuged (4000 × g, 40 min) to separate the supernatant. A 3 mL aliquot of the supernatant was pipetted and diluted with 47 mL of distilled water to prepare the sample solution. The sample was quickly mixed with 5 mL of 1% phenol (wt.%) and 5 mL of sulfuric acid, and kept at room temperature for 10 min to prepare the sample hydrolysate. The sample was then incubated at room temperature for 20 min and measured using a UV-Vis spectrophotometer at 490 nm. The glucomannan content was calculated using Eq. (1).

$$\text{Glucomannan Content } (\%) = \frac{5000\, f\, (5T - T_0)}{m} \tag{1}$$

where f = correction factor; T = glucose content of sample hydrolysate (mg); T_0 = glucose content of sample solution (mg); m = weight of sample (mg).

2.2.4 Fourier-Transform Infrared (FTIR)

NKF and KGM were analyzed by Fourier infrared (FTIR) spectroscopy to determine their functional groups and chemical structures. The FTIR analysis was conducted with a Shimadzu Prestige-21 (4000 to 400 cm^{-1}), employing the potassium bromide pellet technique to identify the presence of functional groups in the samples.

2.2.5 Nuclear Magnetic Resonance (NMR)

NKF and KGM samples were dissolved in 0.5 N sodium hydroxide/deuterium oxide at a 5–20 g/L concentration at 303 K. The stock sample solutions were then injected into the Nuclear Magnetic Resonance (NMR) spectrometer (Agilent 500 MHz) with a console system, operating at frequencies of 500 MHz (^1H) and 125 MHz (^{13}C), using deuterated acetone as the solvent.

2.3 Konjac-Based Film Coatings

2.3.1 Film Coating Preparation

Film coating preparation followed a procedure adapted from a prior study, as illustrated in Fig. 1 [35]. Either extracted NKF or KGM was combined with carboxymethyl cellulose (CMC) and glycerol to produce eight thin-layer thin films, which were then assessed for their physical and mechanical properties. NKF and KGM were dissolved in distilled water at concentrations of 0.4%, 0.6%, 0.8%, and 1% (wt.%) and stirred at 200 rpm until temperature reached 60°C. The solution was mixed with 50 mL of 0.3% CMC (wt.%) and stirred at 200 rpm until it reached 100°C. Next, 1 mL of glycerin was added, and the mixture was stirred for 90 min until the bubbles disappeared. After cooling to 60°C, the solution was poured onto a 16 × 16 cm glass plate. The resulting film was air dried at room temperature for 24 h (average RH 80%) before moisture content analysis (AOAC standard methods) and further characterization.

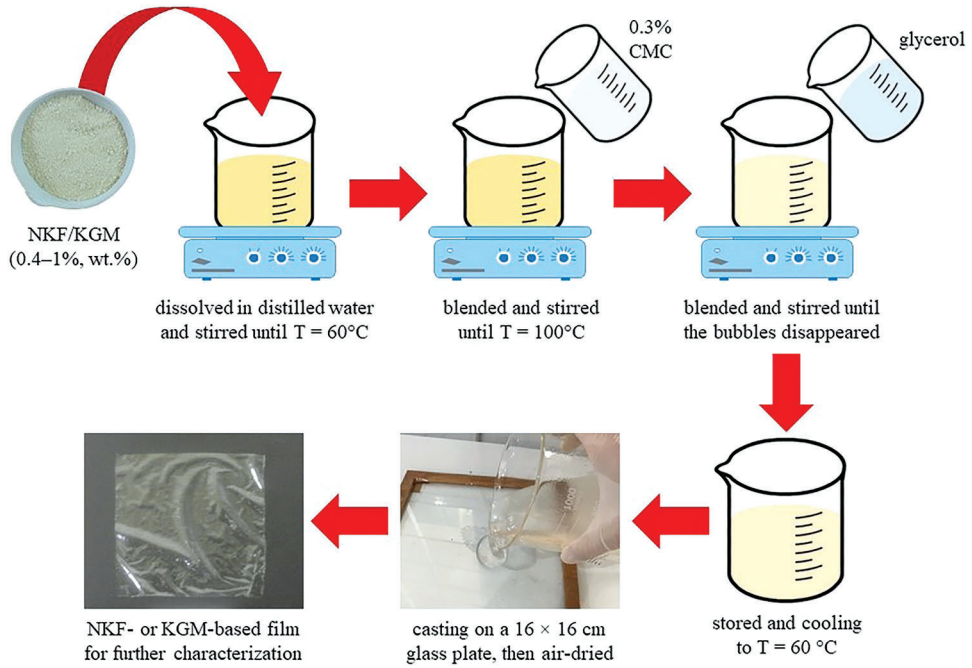

Figure 1: NKF- and KGM-based film preparation steps

2.3.2 Water Vapor Transmission Rate (WVTR) Determination

The gravimetric method was used to determine the moisture barrier properties of the konjac polysaccharide-based film coatings, following the ASTM F1249-20 procedure [36]. The coating film samples were placed in constant humidity cups within a desiccator (at room temperature and RH 80%) for 5 days. The samples were weighed daily to measure the increase in weight due to water vapor absorption from the environment. The measurement results were calculated using Eq. (2), and plotted as a time function to obtain each sample's WVTR value, expressed in g/m^2/24 h.

$$\text{WVTR} = \frac{m_n - m_0}{24 \cdot t \cdot A} \tag{2}$$

where m_n = weight of film coating in day of n (g); m_0 = weight of film coating on initial day (g); t = time (day); A = film coating areas (m^2).

2.3.3 Mechanical Properties of Film Coatings

The procedure for determining the tensile strength of the coating film, as one of its mechanical properties, followed the standard procedure outlined in the Universal Testing Machine instrument manual. The film sample was clamped at both ends, and a gradually increasing load was applied to one end of the film until it ruptured.

2.4 Application of Konjac-Based Film Coatings on Strawberries

2.4.1 Strawberries Coating Application

Fruit coating applications were performed using film coating, which performed best based on characterization results. Strawberries were dipped in the film solution for 10 s and then dried in an air-conditioned room at 25°C–26°C [37]. The coated strawberries were stored in a refrigerator (T = 5 ± 2°C and RH = 50%) for 7 days, and their physical quality was evaluated daily.

2.4.2 Color Changes Determination

Color changes in strawberries were measured using a Minolta Chromameter CR-310. Samples were prepared and placed into the instrument measuring chamber, which assessed the brightness (L*) and red-green color (a*) parameters.

2.4.3 Weight Loss Determination

Weight loss was assessed by recording the weight of strawberries on the first day of storage and then daily for 7 consecutive days [38]. The measurement results were calculated using Eq. (3).

$$\text{Weight loss } (\%) = \frac{m_0 - m_n}{m_0} \times 100\% \tag{3}$$

where m_0 = initial weight of sample (g); m_n = weight of sample on day-n.

2.4.4 Fruit Hardness Determination

The fruit hardness test was conducted according to the procedure outlined in the fruit hardness tester manual. The strawberry sample was pressed with a needle for 5 s. Measurements were taken at three different points on each strawberry, and the results were expressed in Pascals (Pa).

2.5 Statistical Analysis

All sample measured in this study were replicated in three times. The collected data were analyzed using the independent t-test ($p < 0.05$) and analysis of variances (ANOVA), followed by the Duncan Multiple Range Test ($p < 0.05$).

3 Results and Discussion

3.1 Konjac Polysaccharides Characteristics

The extraction of 1 kg of Konjac yielded NKF at 31.81 ± 0.24%. Further purification of glucomannan from NKF resulted in 26.42% ± 0.53% KGM. This result was higher compared to an earlier study, which reported 18.05% KGM [39]. The moisture content for both NKF and KGM was similar (10.91 ± 0.97% and 10.67 ± 0.23%, respectively), and lower than maximum value of 13% allowed by Indonesian National Standard [40]. Despite using a simple isolation method, the moisture level of KGM in this study was lower than that of various glucomannan isolation procedures, which range from 11.3 to 12.9% [41]. As shown in Table 1, the glucomannan content of NKF reached 25.93 ± 0.68%, while KGM exhibited a lower content of 21.41 ± 0.03% (on a wet basis). Adjusting the stirring duration during the isolation process could further increase glucomannan content [42]. Moreover, several factors such as isolation time and ethanol concentration can the glucomannan percentage. This highlights the potential for further

research, including optimizing these parameteres or utilizing modern techniques such as employing microwave-assisted extraction [43].

Table 1: Characteristics evaluation of NKF and KGM

Sample	Yield (%)	Moisture content (%)	Glucomannan content (%)
NKF	31.81 ± 0.24 [a]	10.91 ± 0.97	25.93 ± 0.68 [a]
KGM	26.42 ± 0.53 [b]	10.67 ± 0.23	21.41 ± 0.03 [b]

Note: Different symbols in each parameter indicate significant differences according to the independent *t*-test analysis ($p < 0.05$).

FTIR spectroscopy was employed to observe the characteristics of both NKF and KGM. The IR spectra are shown in in Fig. 2, with detailed values presented in Table 2. A large peak at 3415 cm^{-1} for NKF and 3404 cm^{-1} for KGM indicates O–H stretching in glucomannan [44]. The peak at 2926–2927 cm^{-1} corresponds to the stretching vibration of $–CH_2–$. Two notable peaks at around 1740 and 1630 cm^{-1} correspond to C=O stretching in acetyl and amide groups, respectively [45,46]. The intensity at 1741 cm^{-1} was higher in NKF than KGM, suggesting a greater amount of acetyl groups in NKF [47]. Similarly, the peak intensity at 1643 cm^{-1} was observed to be higher in NKF than KGM, indicating a higher protein content in NKF (amide I peak) [48]. The peak at 1640 cm^{-1} revealed the presence of functional molecules in protein amide groups (–CONH–), associated with carbonyl (C=O) stretch vibration. The greater intesinty of peaks in NKF suggests that the protein contains multiple overlapping secondary structures of the polypeptide chain. The wave number 1381–1384 cm^{-1} is associated with C–H bending, and a peak at 1060 cm^{-1} in NKF indicates the presence of similar groups not found in KGM. C–O–C stretching was observed at wave numbers 1155–1153, 1060, and 1026 cm^{-1}. A peak at 2926–2927 cm^{-1} suggests the presence of C=O group stretching, with the intensity decreasing due to reduced calcium oxalate content from NKF to KGM [43]. Additionally, the FTIR results identified β-pyranose structures, consisting of mannose and glucose, at wave numbers 875–802 cm^{-1} [46].

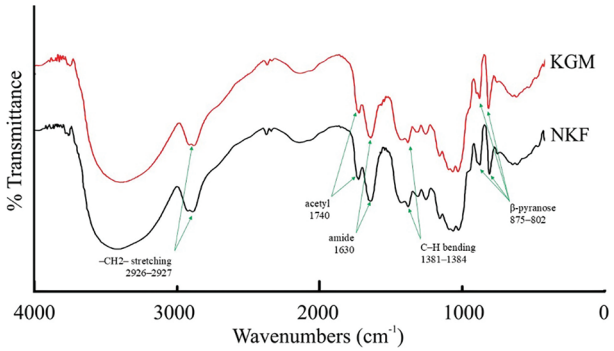

Figure 2: Comparison between the FTIR spectra of NKF and KGM

Table 2: FTIR analysis of NKF and KGM

FTIR peaks (cm^{-1})		Group	Vibration
NKF	KGM		
3415	3404	*O–H*	Strecthing
2926	2927	*$–CH_2–$*	Strecthing

(Continued)

Table 2 (continued)

FTIR peaks (cm^{-1})		Group	Vibration
NKF	KGM		
1741	1745	*C=O*	Strecthing
1643	1654	*C=O*	Strecthing
1381	1384	*C–H*	Bending
1155	1153	*C–O–C*	Strecthing
1060	–	*C–H*	Bending
1026	1026	*C–O–C*	Strecthing
875	867	β-mannosidic	Bending
808	802	β-glucosidic	Bending

The shift in the ^{1}H-NMR spectrum indicated structural changes based on the resonance signals emitted by the anomeric hydrogen, as shown in Fig. 3. Due to the complexity of the polysaccharide structure, the hydrogen bonds at C-2 to C-6 in glucomannan, composed of glucose and mannose, could not be distinctly separated. However, the signals for the anomeric hydrogen at C-1 from glucose (4.37 ppm) and mannose (4.68 ppm) were distinguishable, allowing for precisely determining the chemical shift. NKF exhibited a shift (δ) of 4.37 ppm for glucose and 4.61 for mannose, while KGM showed a shift (δ) of 4.38 and 4.68 ppm for glucose and mannose, respectively.

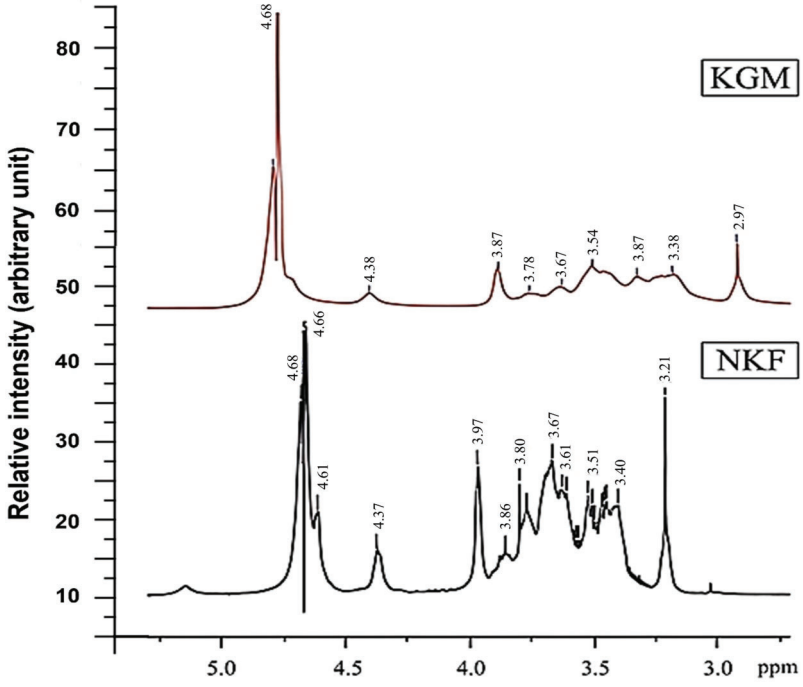

Figure 3: Comparison between ^{1}H-NMR spectra of NKF and KGM

Fig. 4 compares ^{13}C-NMR spectra of NKF and KGM. Anomeric signals were detected at 102.89–102.85 ppm for C-1 resonance of D-glucose and 100.13 ppm for D-mannose. The C-4 shift corresponding to the glucosyl and mannosyl units involved in the glycosidic bond was observed at 78.43–78.35 ppm. The resonance signals for mannose at C-5, C-3, and C-2 appeared at 76.25, 75.25, and 71.61 ppm, respectively. The C-5, C-3, and C-2 shifts for glucose were 76.31–76.26 ppm, 75.27, and 70.23 ppm, respectively. The signals at 60.56–60.54 ppm and 60.52 ppm indicated the C-6 resonance of unsubstituted glucose from the glucosyl and mannosyl.

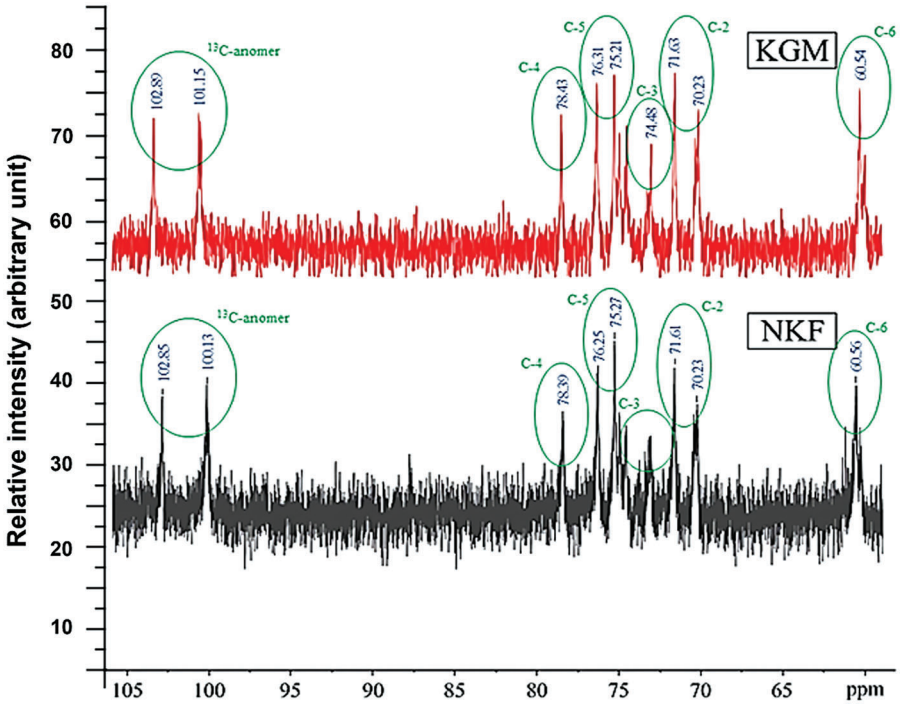

Figure 4: Comparison between ^{13}C-NMR spectra of NKF and KGM

Based on these results, it can be confirmed that glucomannan has a linear structure composed of 1,4-D-mannosyl and D-glucosyl bonds. The lower field shift observed for the C-1 anomer, which is the only carbon directly bonded to two oxygen atoms, indicates it is more deshielded compared to the other five carbons [49]. The C-4 carbon, involved in the glycosidic bond, exhibited a chemical shift of 78.00–76.30 ppm. Meanwhile, the chemical shifts for C-2, C-3, and C-5 occurred in the upfield region, likely due to the influence of the hydroxyl groups. For C-6, carbon showed a more shielded chemical shift, as no substitution occurred at this position.

3.2 Konjac Polysaccharides-Based Film Coating Performances

The moisture content in edible films plays crucial role in determining the physical properties of food packaging, particularly due to its impact on the activity of microorganisms. Good-quality edible films should have a low moisture content [50]. The results of this study revealed that increasing the amounts of NKF and KGM led to a reduction in moisture content, as depicted in Fig. 5a. This can be attributed to the higher total solid concentrations at elevated levels of NKF and KGM, which results in reduced water content. Consequently, the water content of the edible film decreases after the drying process. Given this, the lower moisture content observed in these films is an indictor of their improved quality [51].

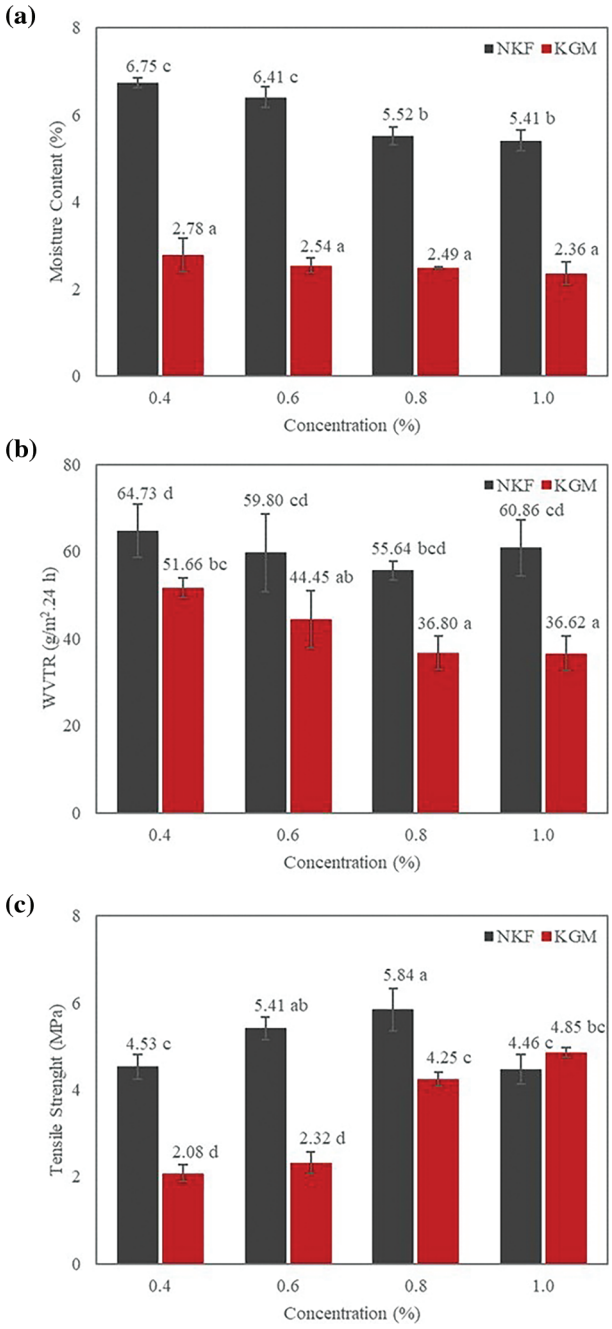

Figure 5: Physical and mechanical properties of konjac based coatings, (a) moisture content, (b) water vapor transimission rate (WVTR), and (c) tensile strength. Different symbols indicate significant differences as determined by the Duncan Multiple Range Test ($p < 0.05$)

While moisture content indicates the amout of water bound within films, WVTR reflects the amount of water vapor that can pass through a film per unit area over a specific time. WVTR is a critical parameter for assessing the permeability of films to water vapor [52]. As shown in Fig. 5b, increasing the concentrations of NKF and KGM led to a corresponding decrease in WVTR. This reduction can be attributed to the addition of

glycerol, which acts as a lubricating agent that minimizes gaps and pores within the film's matrix, thereby limiting the absorption of water vapor [53]. Furthermore, glycerol disrupts the hydrogen bond interactions between glucomannan and CMC, reducing the water uptake capacity of the film by weakening the hydrogen bonding network between glucomannan, CMC, and glycerol [54].

Fig. 5c illustrates the tensile strength of films with varying concentrations of NKF and KGM. The analysis reveals that increasing the amount of glucomannan flour results in higher tensile strength. This enhancement in tensile strength is attributed to the interaction between hydrogen bonds formed by glucomannan and CMC molecules. As the concentration of glucomannan rises, more hydrogen bonds are established within the polymer chains, strengthening the intermolecular forces. Consequently, the increased hydrogen bonding leads to stronger fil structures, thus raising the tensile strength values [55].

Based on the physical and mechanical characteristics of the films, the optimal formulation was achieved with 0.8% (wt.%) NKF and 1% (wt.%) KGM. These concentrations were selected as the best-performing formulations for film coatings. Both NKF and KGM-based films were then applied to strawberries, and their effectiveness was evaluated according to the predetermined parameters.

3.3 Film Coating Application on Strawberries

Color is a critical parameter for assessing fruit quaility, particularly for strawberries, as their color changes during storage [56]. The brightness (L*) and red color (a*) of uncoated, NKF-coated, and KGM-coated strawberries were measured over 7 days at a temperature of 5 ± 2°C. As shown in Fig. 6, uncoated strawberries began to deteriorate significantly after just one day. In contrast, strawberries coated with NKF or KGM maintained their color better, with noticeable quality decline occuring after 3 and 4 days of storage, respectively.

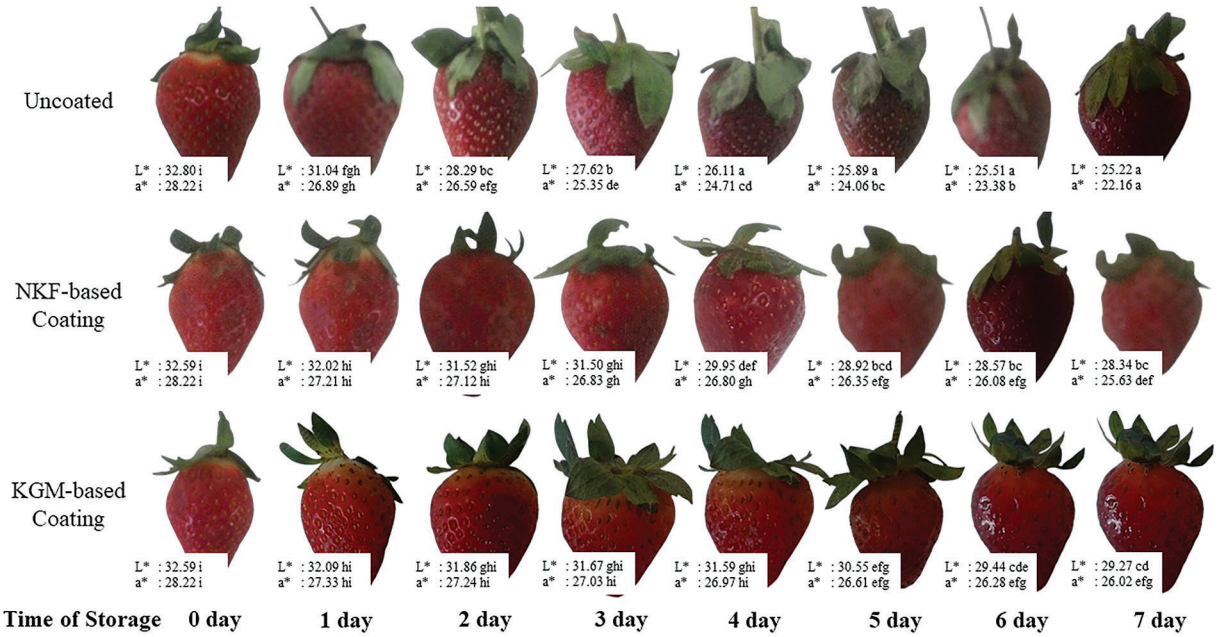

Figure 6: Brightness (L*) and red color (a*) changes on strawberries during storage. Different symbols indicate significant differences as determined by the Duncan Multiple Range Test ($p < 0.05$)

Color change in strawberries is primarily driven by a decrease in pigment content. The bright red color of strawberries results from high anthocyanin content and the degradation of chlorophyll [57]. This red

coloration serves as an indicator of fruit maturity and senescence. However, anthocyanins are sensitive to pH changes during storage, leading to reduced sour taste and gradual loss of red color due to compound degradation [58]. The NKF- and KGM-based strawberry coatings, which incorporate glucomannan, CMC, and glycerol, effectively preserve fruit brightness. This preservation is attributed to the coating' ability to shield the fruit from external damage, suppress oxidation, and maintain surface moisture, thereby slowing down senescence and keeping the fruit looking fresh [28,59]. Additionally, previous studies have shown that polysaccharide-based coatings with added fat components can better maintain fruit quality compared to those using polysaccharides alone [60].

A further variable considered during strawberry storage was fruit weight loss, as shown in Table 3. The weight loss of the uncoated strawberries was significantly lower compared to that of coated strawberries, demonstrating that coated fruits, particularly strawberries, can better maintain quality by delaying senescence. However, the NKF-based strawberry coating was less effective than the KGM-based coating in preserving fruit quality. This can be attributed to the presence of other starch substances in NKF, which are more susceptible to degradation by water vapor in the environment. Additionally, inclusion of CMC to the coating system, due to its hydrophilic properties, allows more water vapor to migrate [61]. The high content of hydrophilic materials, such as starch and CMC, facilitates water vapor migration and suggests the need for further evaluation in future studies [62].

Table 3: Changes on weight loss of strawberry during storage

Storage time (days)	Weight loss (%)		
	Uncoated	NKF-based coating	KGM-based coating
0	0	0	0
1	0.53 ± 0.47^{ab}	0.73 ± 0.40^{ab}	0.22 ± 0.05^{a}
2	1.49 ± 0.19^{bc}	1.38 ± 0.75^{bc}	0.90 ± 0.14^{abc}
3	3.13 ± 0.49^{e}	2.84 ± 0.73^{de}	1.51 ± 0.19^{bc}
4	6.46 ± 0.25^{g}	4.38 ± 0.01^{f}	1.89 ± 0.35^{cd}
5	9.30 ± 0.66^{h}	5.22 ± 0.88^{f}	2.80 ± 0.57^{de}
6	9.46 ± 0.69^{h}	5.31 ± 0.43^{f}	2.83 ± 0.94^{de}
7	9.71 ± 0.22^{h}	5.38 ± 0.39^{f}	2.90 ± 0.95^{de}

Note: Different symbols indicate significant differences as determined by the Duncan Multiple Range Test ($p < 0.05$).

Table 4 presents the results of fruit hardness testing, which initially ranged from 0.79–0.80 Pa. Both NKF- and KGM-based coatings were effective in maintaining fruit hardness better than uncoated strawberries, although the differences were not statistically significant. Uncoated strawberries experienced a significant decline in hardness, reaching a minimum value of 0.37 ± 0.09 Pa by the seventh day of storage, representing a decrease of over 50%. This decline is attrivuted to catabolic reactions that soften the fruit tissue, particularly the breakdown of pectin due to natural enzymes such as pectin esterase [63]. Pectin, which acts as an adhesive in cell walls, is weakened, leading to reduced fruit hardness. In contrast, coated strawberries better retained their quality because the coatings impact respiration and transpiration. Coating fruits can inhibit respiration and reduce the formation of natural enzymes that break down polysaccharides, while also lowering the rate of transpiration, which is directly related to the fruit's water content [64].

Table 4: Evaluation on hardness level of strawberry during storage

Storage time (days)	Hardness level (Pa)		
	Uncoated	NKF-based coating	KGM-based coating
0	0.79 ± 0.05^{f}	0.79 ± 0.02^{f}	0.80 ± 0.04^{f}
1	0.76 ± 0.04^{f}	0.79 ± 0.02^{f}	0.80 ± 0.03^{f}
2	0.70 ± 0.07^{ef}	0.79 ± 0.01^{f}	0.78 ± 0.04^{f}
3	0.63 ± 0.02^{de}	0.77 ± 0.01^{f}	0.77 ± 0.09^{f}
4	0.57 ± 0.03^{cd}	0.76 ± 0.00^{f}	0.74 ± 0.00^{ef}
5	0.49 ± 0.03^{bc}	0.74 ± 0.02^{ef}	0.74 ± 0.03^{ef}
6	0.43 ± 0.02^{ab}	0.73 ± 0.01^{ef}	0.74 ± 0.09^{ef}
7	0.37 ± 0.09^{a}	0.73 ± 0.10^{ef}	0.73 ± 0.07^{ef}

Note: Different symbols indicate significant differences as determined by the Duncan Multiple Range Test ($p < 0.05$).

4 Conclusions

Native flour (NKF) and glucomannan (KGM) were successfully extracted from konjac and used to coat strawberries. The yields of NKF and KGM were 31.81 ± 0.24% and 26.4 ± 0.53%, respectively, with their moisture content exceeding the Indonesian National Standard. The glucomannan content was up to 25.93 ± 0.68% in NKF and 21.41 ± 0.03% in KGM. Based on physical and mechanical properties, the best performances of NKF and KGM in film formulations were 0.8% and 1%, respectively. Both NKF- and KGM-based coatings effectively maintained the strawberries' color, reduced weight loss, and preserved fruit hardness. These findings suggest that such coatings can extend the shelf life and preserve the quality of strawberries during transportation. Further study is needed to explore the effectiveness of these coatings with other additives and across different strawberry varieties.

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