CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

Research article

CHARACTERISTICS OF EDIBLE FILM BASED ON WATER HYACINTH (*Eichornia crassipes*) AS FOOD PACKAGING INNOVATION

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https://doi.org/10.34302/crpjfst/2025.17.4.7

Article history:
Received:
March 15th, 2025
Accepted:
November 17th, 2025

Keywords
Edible film;
Food packaging;
Water hyacinth.

Abstract

This study explores the potential of water hyacinth (*Eichhornia crassipes*) cellulose in developing edible films as a sustainable alternative for food packaging. Edible films are biodegradable and eco-friendly materials that minimize plastic waste while maintaining food safety and quality. Water hyacinth, an invasive aquatic plant with a cellulose content of approximately 62.15%, offers a promising source for bioplastic production. This research investigates the effects of varying concentrations of hyacinth cellulose (3%, 4%, and 5%) and glycerol (1% and 1.5%) on edible films' physical and chemical properties, with carrageenan as a structural agent. Results indicate that higher cellulose concentrations increase tensile strength and reduce water absorption, while higher glycerol concentrations enhance flexibility and increase water absorption and thickness. The optimal combination of glycerol, carrageenan, and cellulose in the edible film formulation is necessary to balance flexibility, mechanical strength, water absorption, and the desired moisture content. Based on the film thickness, tensile strength, water absorption, and moisture content test, the best edible film is 5% hyacinth cellulose and 1.5% glycerol.

1. Introduction

Foodstuffs are prone to quality degradation because of chemical, environmental, microbiological, and biochemical factors. Water, light, temperature, and oxygen stimulate quality degradation. Proper packaging plays a role in slowing down this phenomenon (Wahyuni & Arifan, 2018). Packaging is an integral part of a food product and an important aspect that is needed to realize comsumer desires as product protector (Yusuf et al., 2018). It serves as containment, preservation, information, transportation, and storage. The most familiar packaging is plastic due to its moulding convenience, high mechanical strength, low price, lightweight, and heat sealability. On the other hand, plastic packaging has disadvantages such as being hard to degrade and incineration of it will produce toxic gases. Therefore, sustainable food packaging is experiencing an increasing trend. It has a positive impact on protecting the environment and reducing waste (Ma & Li, 2024; Pascall, DeAngelo, Richards, & Arensberg, 2022; V et al., 2022). An example of sustainable food packaging is edible film, as it reduces the problem of waste disposal (Prasetyaningrum et al., 2021). Edible film typically uses sustainable, biodegradable material in the form of a solid sheet, which is used as food wrap and is consumable. Edible film materials are classified into polysaccharides, proteins, lipids, and composites (Petkoska et al., 2021). The primary function of edible film is to prevent moisture loss and suppress adverse chemical reaction rates to improve the safety and quality of fresh and processed foods (V et al., 2022).

Water hyacinth (*Eichhornia crassipes*) is an invasive aquatic plant that becomes a threat to waters because it affects water conditions, becomes a habitat for mosquitoes, and triggers sedimentation (Prasetyo et al., 2021). The invasion of water hyacinth blocks the light, inhibits photosynthesis, and absorbs nutrients from the water (Zeleke et al., 2024). Therefore, the utilization of water hyacinth is necessary to suppress its amount. The applications of water hyacinth are biogas, liquid fertilizer, fiber reinforcement for prosthetics socket, art paper, sound absorber composite, craft material, and cellulose from membrane isolation (Hadiyarto et al., 2018; Istirokhatun et al., 2015; Natari et al., 2024; Paramitha et al., 2023; Wibawa, et al., 2023; Widhata et al., 2019). The utilization of water hyacinths contributes to lake ecosystem conservation and rehabilitation (Hidayati et al., 2018).

Water hyacinth fiber consists of 62,15% cellulose content and 14,82% hemicellulose content (Arivendan et al., 2022). The composition of water hyacinth, like cellulose, hemicellulose, and lignin, makes it a suitable candidate for biodegradable film (Kusuma et al., 2024). In addition, water hyacinth is a raw material for cellulose-base polymers with a higher economic value than the other source (Istirokhatun et al., 2015). In this study, the edible film will be made using hyacinth cellulose, carrageenan, and glycerol. Water hyacinth cellulose forms a bioplastic that potentially substitutes for non-degradable plastic in food packaging use (Anantachaisilp et al., 2021). Carrageenan is a hydrocolloid and usually called as polysaccharide which is extracted from red algae (Pratama et al., 2018). It has excellent mechanical and physical properties for making transparent films (Prasetyaningrum et al., 2021). The addition of plasticizers to manufacture edible film is necessary to increase its mechanical, barrier properties, and flexibility (Putri et al., 2024). Glycerol is the plasticizer used in this study. It is widely used and effective because its small molecular weight can improve plastic properties (Fadilah et al., 2020). This study aims to explore the effect of different hyacinth cellulose and glycerol concentrations on the physical and chemical properties of the resulting edible film and determine the optimum concentration of hyacinth cellulose and glycerol to produce the best edible film.

2. Materials and methods

2.1. Materials

Water hyacinths are obtained from waters in Demak Regency, Central Java Province, Indonesia, kappa carrageenan (IndoGum, Indonesia), glycerol (Kimia Jaya Abadi, Indonesia), aquades, HCl 0.05 N, filter paper, ethanol 96%. The tools used include analytical scales (Ohaus, China), beaker glasses (pyrex), hot plate stirrer (IKA, Malaysia), magnetic stirrer (IKA, Malaysia), thermometer, oven (members), desiccator, sieve size 100 mesh, sieve size 50 mesh, plastic mold/plate, magnetic stirrer, extraction tool 1 set, Mittoya micrometer, blender, spatula, mixer. The research was carried out using water hyacinth starch. The independent variables in this study were the cellulose mass of water hyacinth (3%, 4%, 5%)

and glycerol concentration (1% and 1.5%). The dependent variables are tensile strength, thickness, moisture content, water absorption, FTIR, and shelf life.

2.2. Methods

2.2.1. Cellulose Manufacturing

Water hyacinths are washed and cleaned until the dirt disappears, dried, and then mashed until they become powder. Hyacinth powder is sifted with a size of 50 mesh. Hyacinth powder is dissolved with 500 ml of 4% NaOH and heated for 4 hours, then washed, filtered, and dried so that hyacinth fiber is free of hemicellulose. Hyacinth powder is dissolved with 500 ml of H_2O_2 1.5% and heated for 3 hours, then washed, filtered, and dried until hemicellulose-free hyacinth fibers are obtained.

2.2.2. Edible film formulation

There were variations of hyacinth cellulose in this study, namely 3%, 4%, and 5%. Then, for the glycerol variation, use 1 % and 1.5 %, the carrageenan concentration as much as 2.5 grams. Six combination treatments were repeated three times with the following levels:

Cellulose water hyacinth 3 %, glycerol 1 % (A1B1)

Cellulose water hyacinth 3 %, glycerol 1.5 % (A1B2)

Cellulose water hyacinth 4 %, glycerol 1 % (A2B1)

Cellulose water hyacinth 4 %, glycerol 1.5 % (A2B2)

Cellulose water hyacinth 5 %, glycerol 1 % (A3B1)

Sodium hyacinth 5 grams, glycerol 1.5 % (A3B2)

In each treatment, the cellulose of water hyacinth is dissolved in 100 ml of aquadest and heated for 20 minutes until the temperature on the thermometer reaches 70°C, keeping the temperature of the cellulose solution at 70°C. Then, dissolve 2.5 grams of carrageenan in different glass beakers in 100 ml of aquadest, heat it on a hotplate, and heat it until the temperature on the thermometer shows 80°C. After 20 minutes, the solution is mixed with the carrageenan solution while maintaining a temperature of 80°C. After homogeneity, pour glycerol into the cellulose-carrageenan mixture and stir until homogeneous again. Filter and pour the solution on the mold, then dry it using a dehydrator for 15 hours at a temperature of 50°C. Repeat the same steps with different treatments.

2.2.3. Moisture content meaurement

The empty aluminum cup is heated in the oven (±105)°C for 5 hours, then cooled in the desiccator for 30 minutes. The aluminum cup was weighed and recorded; 100 grams of the sample was put into the aluminum cup. The sample cup was put in the oven (±105)°C for 3 hours. The cup and sample are left in the desicator for 30 minutes. The final weight of the cup and its contents is weighed to a constant (y gram)

2.2.4. Edible film thickness

The thickness was measured using a Mitutoyo micrometer (accuracy 0.01 mm) by placing a film between the micrometer's jaws.

2.2.5. Tensile strength

The magnitude of the force used to determine the edible film of water hyacinth is measured in Kg. Furthermore, the force must be divided by the size of the surface area of the test specimen to obtain the value of the edible tensile strength of the hyacinth film in Kg/cm^2. The value obtained must first be converted into the standard unit of the tensile strength value, namely MPa, by dividing it by the number 10.2.

2.2.6 Water absorption test

Weigh the sample's initial weight (wo) and put it into a container containing the aquadest for 10 seconds. The sample is then lifted from the container, and the water on the plastic surface is removed with paper towels, after which weighing (w) is carried out. The soaking and weighing are carried out again until the sample's final weight is constant.

2.2.7 Fourier Transform Infrared (FTIR) test

This method utilized infrared spectroscopy to analyze the absorption of infrared light by different materials, providing insights into their molecular composition and structure.

2.3. Data analysis

Data analysis uses ANOVA with a confidence level of 95%. If the difference is noticeable, continue with the Duncan Multiple Range Test (DMRT) test.

3. Results and discussions

3.1. Edible film manufacture

The first step is the mixing of NaOH to separate cellulose from lignin. The second stage, or the bleaching stage, is the addition of H_2O_2 to separate the cellulose from hemicellulose. The cellulose results of water hyacinth are yellowish-white, as shown in Figure 1. Water hyacinth has a content of about 60% cellulose, 8% hemicellulose, and 17% lignin (Abdel-Fattah & Abdel-Naby, 2012). Its high cellulose content makes it a potential resource for a variety of environmentally friendly industrial applications, such as edible films. The manufacture of hyacinth edible film also requires glycerol, which functions to provide flexibility and hardness to the edible film. Glycerol is also easy to digest and safe for making edible film. Carrageenan is also important in the manufacture of edible film because the addition of carrageenan concentration will increase the tensile strength value of edible film. The manufacture of edible film using these three ingredients produces an edible film with a clear white color, as shown in Figure 2.

Figure 1. Cellulose water hyacinth

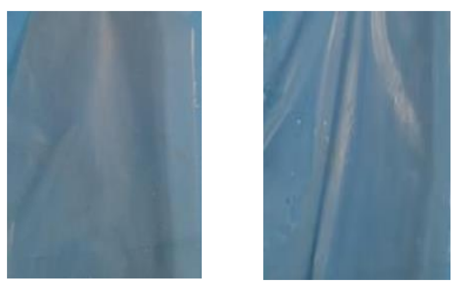

Figure 2. Edible hyacinth film

3.2. Thickness of edible film

Thickness is a very important parameter because it will affect the purpose of its use for packaging or coating products. The thickness will affect the rate of water vapor and gas transmission, thus affecting the packaged product. The higher the thickness value, the more rigid and hard the properties of the edible film produced and the safer the packaged product will be from outside influences.

Based on Figure 3, it is found that the thickness of edible film with various treatments has different thicknesses, which are around 0.08 – 0.14 mm. This result is in accordance with the thickness standard of an edible film according to the JIS (Japanese Industrial Standard), which is a maximum of 0.25 mm (Ningrum et al., 2021). The results showed that the treatment with the addition of 1.5% glycerol was able to increase the film thickness compared to the addition of 1% glycerol. The addition of glycerol tends to increase the film thickness because the glycerol molecules occupy the space between the polymer chains, causing an increase in the distance between the molecules and an increase in the thickness of the film. An increase in glycerol concentration from 0% to 0.9% led to an increase in the thickness of carrageenan and beeswax-based edible films (Harumarani et al., 2016).

Figure 3 also shows an increase in the thickness of the edible film along with the addition of cellulose. This suggests that the addition of cellulose can increase the thickness by strengthening the polymer matrix and improving the interaction between molecules. Research shows that the addition of cellulose to starch film increases the thickness and resistance to water (Arik Kibar & Us, 2017). The addition of carrageenan, a sulfate polysaccharide, acts as a gelling agent that improves the structure and strength of the film. In addition, the concentration of raw materials affects the thickness of the edible film because it will produce a lot of dissolved solids after drying so that it forms a thick edible film (Ningrum et al., 2020).

Figure 3. Thickness of edible film

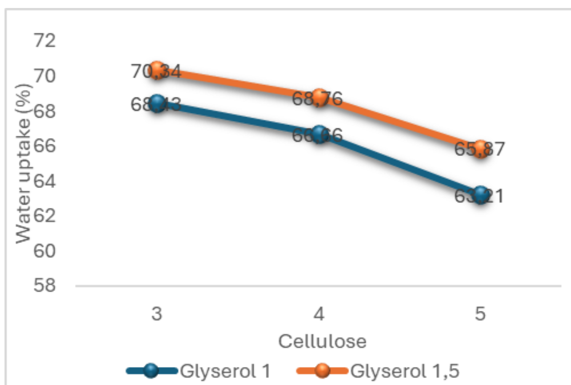

Figure 4. Water absorption

3.3. Water absorption

The water absorption test measures how much the film absorbs water. This measurement is important to determine the resistance of the edible film to moisture, which will affect the film's ability to protect against the coated material, texture stability, and shelf life of the product. Based on Figure 4, the water absorption produced by edible film in this study is around 63.21% – 70.34%. The addition of 1.5% glycerol results in a high absorption value compared to the addition of 1% glycerol. This suggests that the addition of glycerol tends to increase water absorption due to its hygroscopic properties, which allows glycerol to attract and retain water molecules from the surrounding environment. Research by (Zahra et al., 2020) shows that an increase in glycerol concentration from 1% to 2% leads to an increase in the water absorption of banana peel peptide-based edible film. The graph also shows that the higher the cellulose level, the smaller the water absorption capacity. The addition of cellulose can decrease water absorption by strengthening the polymer matrix and reducing the space between molecules that can be occupied by water. The addition of cellulose to starch film decreases water absorption and increases water resistance (Kibar & Us, 2017). Edible film is used as a food protective layer; lower water absorption is usually preferred because a film that is resistant to water and moisture will be more effective in maintaining the integrity of the product. In this study, the edible absorption yield of water hyacinth film is still high, above 60%, so further formulation is needed to reduce water absorption.

3.4. Tensile strength

Tensile strength is one of the important mechanical properties of edible film, as it is related to the ability of edible film to protect the product it is coated with. An edible film with high tensile strength is required in use as food product packaging aimed at protecting food ingredients during handling, transportation, and marketing. The following is the tensile strength produced in this study. In Figure 5, the average tensile strength of hyacinth-based edible film can be seen between 6.62-12.31 MPa. The best edible film tensile strength is between 10-100 Mpa, while edible film with a tensile strength range of 1-10 Mpa is classified as marginal. The more cellulose composition, the higher the tensile strength value of the edible film. This is also shown in the results of this study, where the higher the cellulose level added, the higher the tensile strength will also be. The tensile strength of edible film in this study is almost the same compared to edible film from star fruit pectin, which is between 6.81-8.51 Mpa (Sulistriyono et al., 2014). The addition of higher glycerol increases the tensile strength even more. Glycerol functions as a plasticizer that increases the flexibility of edible film, improves mechanical properties, maintains the film integrity, and prevents crack formation (Putri et al., 2023). However, the addition of glycerol tends to decrease the tensile strength because it reduces the interaction between polymer molecules. Research by (Harumarani et al., 2016) showed that an increase in glycerol concentration from 0% to 0.9% led to a decrease in the tensile strength of carrageenan and beeswax-based edible films.

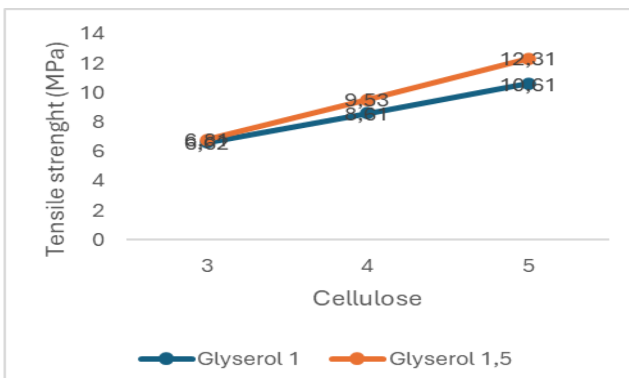

Figure 5. Tensile strength

3.5. Moisture content

The moisture content of edible film has an important role in the stability of the product. Therefore, edible film is expected to have a low moisture content so that as a primary packaging, it does not contribute water to the product, which will impact product damage and decrease shelf life. Based on Figure 6, the average moisture content of edible film is 29.21%- 35.54%. In this study, the lowest moisture content was 5 grams of cellulose with 1.5% glycerol. The concentration of cellulose and glycerol affects the moisture content of the edible film. However, in this study, the water content was still quite high. The use of hygroscopic basic materials, such as starch or cellulose, can increase moisture content due to the ability of these materials to absorb moisture from the environment. Meanwhile, in the other research, edible film carrageenan and glycerol were obtained with a moisture content of 17.14 – 20.86% (Rusli et al., 2017; Pratama et al., 2018).

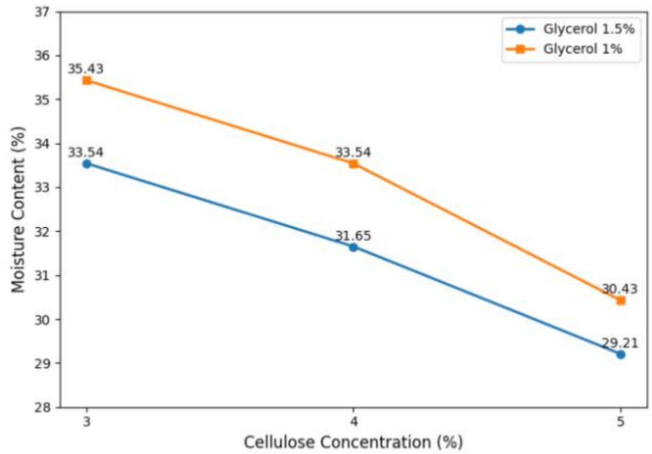

Figure 6. Moisture content

3.6.Fourier Transform Infrared Spectroscopy (FTIR)

FTIR aims to identify spectral groups and functional groups in edible films. The relationship between wavenumber and transmittance is presented in the FTIR spectra (Figure 7), allowing the identification of characteristic chemical bonds in the film matrix. Here is the FTIR spectrum of edible water hyacinth film. The black line is a 3-gram cellulose sample with 1.5% glycerol, the red line is a 4-gram cellulose sample with 1.5% glycerol, and the blue line is a 5-gram cellulose sample with 1% glycerol. In the FTIR spectral graph there a peak indicates the presence of a C-H group, which indicates the presence of a cellulose structure in the sample. However, absorption regions also indicate the presence of C-O-C groups, which are building structures of lignin compounds, indicating that the treatment given for the delignification process is less effective.

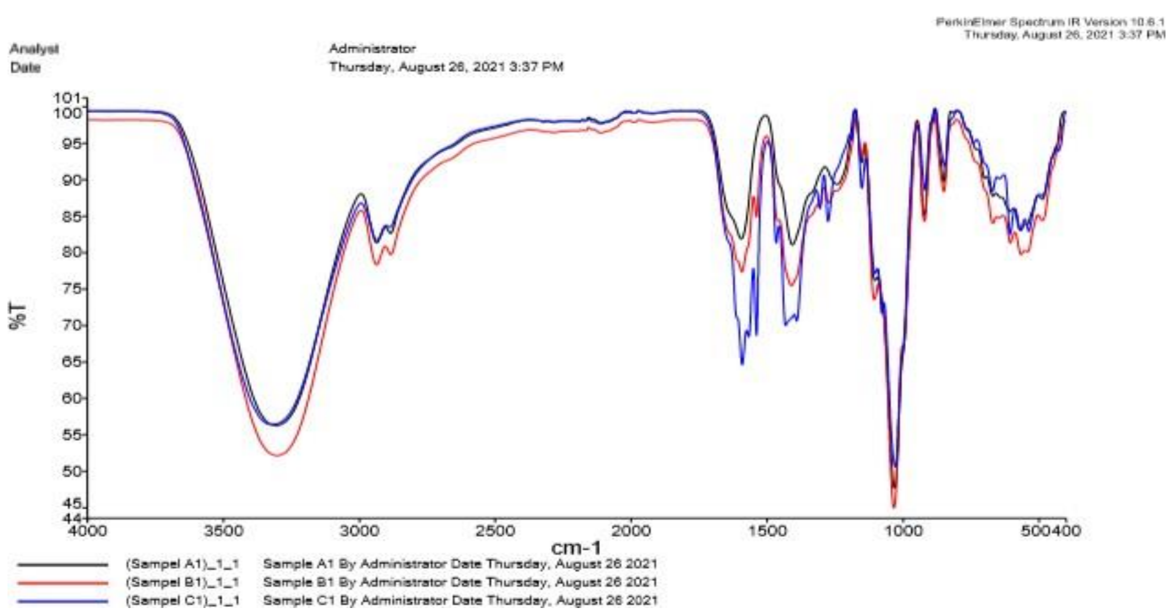

Figure 7. FTIR spectra of edible hyacinth film

4. Conclusions

The optimal combination of glycerol, carrageenan, and cellulose in the edible film formulation is necessary to achieve a balance between flexibility, mechanical strength, water absorption, and the desired moisture content. Overall, from the film thickness, tensile strength, water absorption, and moisture content test, the best edible film is with 5% hyacinth cellulose and 1.5% glycerol.

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Acknowledgment

This research is partially supported by Food Safety Scientific Consortium through the Research Implementation Agreement Contract No. 369/UN7.A/HK/X/2024.