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Seaweed-Based Edible Film for Food Packaging: Formulation and Characterization

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Abstract

This study focuses on the formulation and characterisation of an edible film derived from seaweed for potential applications in food packaging. The increasing environmental concern over synthetic plastic waste has driven the exploration of biodegradable and eco-friendly alternatives. In this research, seaweed was selected as the primary biopolymer due to its film-forming ability, abundance, and biodegradability. Two film samples incorporating varying concentrations of sage extract were prepared using seaweed, gelatin, agar, and glycerin. The films were tested for solubility, tensile strength (TS), elongation at break (%E), microbial load, pH, and chemical composition. Solubility was assessed by immersing (2 cm × 2 cm) film samples in distilled water at 37 °C, followed by drying and weight comparison. The antimicrobial effect was evaluated through serial dilution and plating on Plate Count Agar (PCA), with colony counts expressed in colony-forming units per micrometre (CFU/µm). Fourier Transform Infrared Spectroscopy (FTIR) was conducted to identify functional groups, and TS and %E were measured using a universal testing machine. The resulting film exhibited a tensile strength of 35.4 MPa and an elongation at break of 4.29%. Additionally, the film showed a solubility of 12.5% and microbial strength measured at 65 colony-forming units per micrometre (CFU/µm). These results indicate successful development of a biodegradable, safe, and functional packaging material with favourable mechanical and microbial stability characteristics, supporting the potential of plant-based films as viable alternatives to plastic.

1. Introduction

Agar, derived from red seaweed, is an edible biopolymer used in food packaging films and coatings [1] due to its high polysaccharide content and beneficial properties for biodegradable packaging. Agar-based films can enhance active and intelligent food packaging by incorporating bioactive ingredients with antifungal, antibacterial, and antioxidant effects, helping to reduce oxidation, microbial growth, and texture changes during storage [2]. While plastic packaging is popular for its durability and cost-effectiveness, it poses health and environmental risks [1], as harmful chemicals can leach into food, particularly affecting vulnerable groups like children and pregnant women. Plant-based edible films from renewable sources like seaweed offer a sustainable alternative to address these concerns [3]. These biodegradable and non-toxic films reduce chemical exposure

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and environmental damage while aligning with growing consumer demand for safe, eco-friendly packaging solutions [4].

This project aims to develop a plant-based edible film for food packaging and analyse the resulting film's physical and chemical properties. This research focuses on creating biodegradable, non-toxic, environmentally friendly packaging that is safe for consumption, aiming to address the growing need for sustainable alternatives to conventional plastic packaging. However, the properties of edible films such as tensile strength, solubility, and microbial resistance were significantly influenced by formulation parameters like the concentration of biopolymers and additives [5], with variations in agar and glycerol concentrations also affecting the mechanical and water-related properties of the resulting films [6]. Variability in these parameters could result in inconsistent film performance, limiting practical application.

A gap remained in understanding the optimal composition required to balance mechanical strength, solubility, and microbial resistance in seaweed-based edible films, particularly for local-scale use. Limited studies had specifically addressed the effects of natural additives, such as sage powder, on the performance of seaweed-based edible films under controlled testing conditions. This study aimed to address that gap by formulating a plant-based edible film using agar, gelatin, food-grade glycerin, and sage powder, and evaluating its physical and chemical characteristics. The focus was placed on developing a safe, biodegradable packaging solution suitable for small local businesses and community-scale use, with the potential to enhance food safety and environmental sustainability.

2. Materials and Methods

2.1 Materials

The raw materials used in this research, including food-grade glycerin, gelatin, and sage powder, were obtained from a bakery at Pagoh, Johor. Agar-agar powder was purchased from Eazy Bake, while a large rectangular silicone tray mould was purchased at YY Biz. A hotplate and cold water are typically obtainable from laboratory suppliers, such as UTHM Pagoh. Various analyses were conducted in the Instrumentation Lab at UTHM Pagoh, including Fourier Transform Infrared Spectroscopy (FTIR), tensile strength tests, pH measurement, solubility tests, and microbial tests.

2.2 Preparation of Seaweed-Based Edible Film

First, a film-forming solution was prepared by dissolving agar (1.0 g), distilled water (400 mL), gelatin (5.0 g), sage powder as a functional additive (0.5 g) and glycerin (1 mL). This procedure necessitates heating the solution to 90 °C and subjecting it to thorough mixing to attain the desired consistency. Subsequently, the film-forming solution was poured onto a flat mould at room temperature and spread evenly to create a thin layer. The film was dried over five days to remove the moisture content to a stable mass of the film. Once dried, the edible film is cut to a size (5 cm × 7 cm), ready for food product packaging. Fig. 1 shows the formulation method of the film.

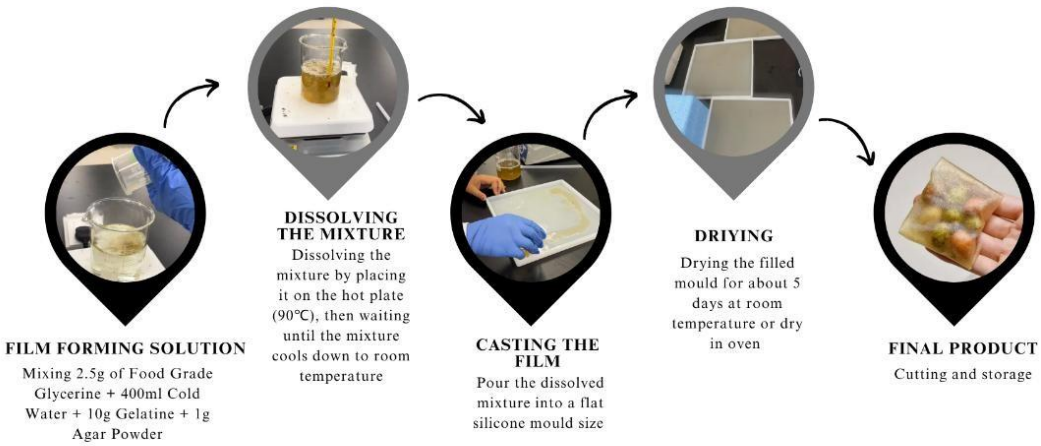

Fig. 1 *Formulation method of seaweed-based edible film*

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2.3 Properties of Seaweed-based Edible Film

2.3.1 Solubility

Two edible film samples differed in sage concentrations, which are Sample A (1.0 g) and Sample B (0.5 g). Samples were measured (2 cm × 2 cm), weighed to obtain the initial dry weight (W1) and placed in two beakers filled with distilled water. Samples were kept at room temperature, 37 °C, and stirred, respectively, to ensure uniform exposure. After the soaking period, undissolved residues were filtered, rinsed and dried.

$$\text{Solubility (\%)} = \left(\frac{W1 - W2}{W1} \right) \times 100 . \quad (1)$$

The final weight (W2) was measured and the percentage of solubility was calculated according to equation (1). The pH level of the liquid state of the film is determined by a Sartorius pH Meter.

2.3.2 Microbial Stability

This procedure compares the natural microbial load in edible film-forming solutions without sage (Sample A) and with sage (Sample B) extract to evaluate the antimicrobial effect of sage on naturally occurring microorganisms. Sterile materials, including saline, test tubes, pipettes, spreaders, Plate Count Agar (PCA), and Petri dishes, were prepared. A volume of 1 mL of each film-forming solution was added to 9 mL of sterile diluent to create a 10^1 dilution. Next, serial dilutions were performed up to 10^6, but only two dilutions (for example, 10^3 and 10^4) were used for plating. A volume of 100 µL from each dilution was spread onto PCA plates in triplicate to ensure accuracy. The plates were incubated at 37 °C for 24 to 48 hours.

$$\frac{\text{CFU}}{\text{mL}} = \left(\frac{\text{Colenies} \times \text{Dilution Factor}}{\text{Volume plated in mL}} \right) \times 100 . \quad (2)$$

After incubation, the colonies within the range of 30 to 300 CFUs were counted. The equation (2) was used. A total of 10 agar plates were used for this setup, based on two film types, two dilution levels per sample, and double replicates for each dilution.

2.3.3 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) was carried out using Agilent Technologies. The FTIR spectrum was used to determine the presence of functional groups in edible films. In this procedure, thin films were applied directly onto the Attenuated Total Reflection cell (ATR). The FTIR spectra of the film were recorded at a resolution of 8 cm^{-1} and range from 4000 to 650 cm^{-1}.

2.3.4 Tensile Strength

The universal testing machine, Lloyd Instruments (LR 300K) with a 100 N load cell and a crosshead speed of 50 mm /min, measured the TS of composite seaweed-based edible films. The two film specimens were cut into (20 x 70) mm for the measurement. The maximum force (N) and extension of film (mm) were recorded to calculate tensile strength (TS) and per cent elongation at break (%E) of the films using a tensile test. Each trial per film was taken in three replicate measurements, and the results of tensile and elongation tests were expressed in MPa and percentage (%), respectively.

3. Results and Discussions

3.1 Solubility, pH and Microbial Stability

The solubility, pH value, and microbial stability of the seaweed-based edible film are shown in Fig. 2. The solubility of the edible film is the ability to dissolve in water. The solubility of Sample A is high and Sample B is low. The solubility increased with the increase in the concentration of sage. The pH value of Sample A is higher than Sample B. The average pH value of the sample is slightly acidic, around pH 5.57. The average microbial stability of Sample A without sage is higher than Sample B with sage. The film with sage present shows less growth than the film without sage.

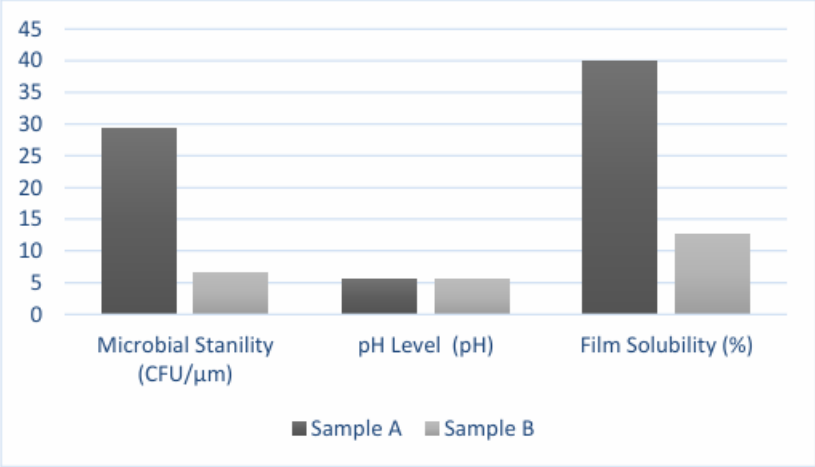

Fig. 2 *Comparison between solubility, pH level and microbial stability of seaweed-based edible film*

3.2 Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectra of edible film Sample B, which contains sage and a low concentration of glycerin, is shown in Fig. 3. The absorption peak at 3412 cm^{-1} showed –OH stretching vibration, which enhanced the film's ability to act as a moisture barrier, critical for preventing food dehydration or microbial growth caused by excess humidity. The C–H stretching band is at around 2889-2992 cm^{-1} in the film, contributing to its mechanical integrity. The low glycerol concentration in the film balanced flexibility and rigidity, preventing brittleness while maintaining structural stability during handling and storage. The bending of C=O stretching (amide I) and NH bending (amide II) were detected at 1644 cm^{-1} and 1543 cm^{-1}, respectively, which enhances tensile strength and durability. Additionally, the bands at 938, 1032, 1238 and 1268 cm^{-1} are attributed to C–O stretching vibrations. The result of the FTIR spectra of the blend film shows that the interactions between the hydroxyl groups and the amino groups of seaweed, gelatine, glycerol, and sage contribute to robust moisture resistance, mechanical durability, and potential active functionality, aligning with the requirements for sustainable, high-performance food packaging.

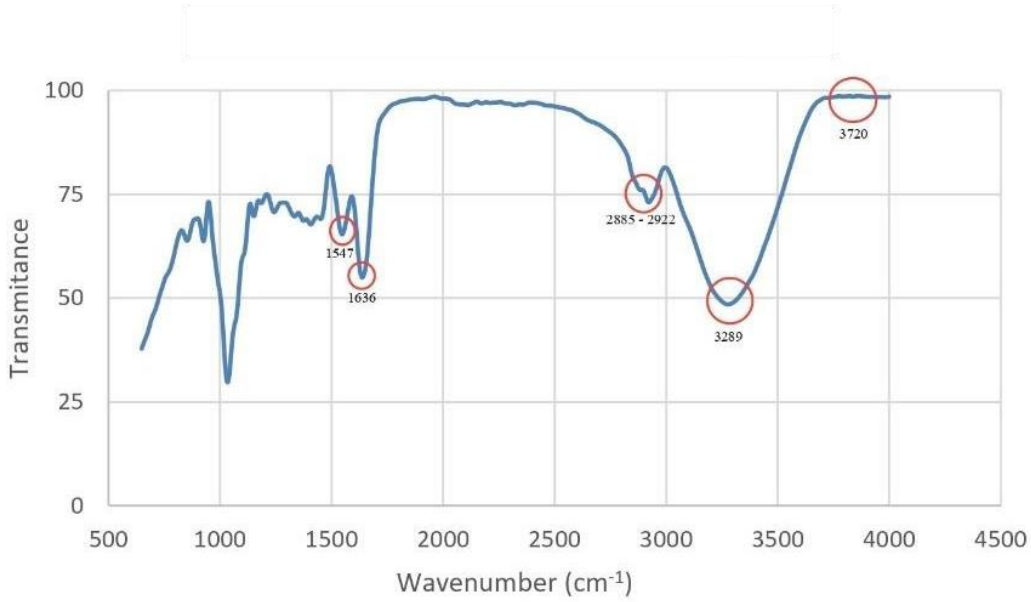

Fig. 3 *FTIR Spectra of seaweed-based edible film*

3.3 Tensile Strength

The tensile strength (TS) of the edible seaweed-based film is shown in Table 1. Tensile strength was high in Sample B and low in Sample A. The tensile strength was high due to the high amount of sage in the film. Elongation at break (E%) was found to be high in Sample A, which could be due to the high flexibility of the film

because it contains a low amount of glycerol. The results indicate that Sample B possesses strong tensile strength (MPa) and a low elongation at break (%E), making it less stretchable and ideal for food packaging applications.

Table 1 *Tensile strength and elongation at break of seaweed-based edible film*

Sample	Tensile Strength (MPa)	Elongation at Break (E%)	Thickness (mm)	Maximum Load
A	16.20	10.82	0.05	25.90
B	35.40	4.29	0.08	35.45

Overall, Sample B demonstrated statistically significant improvements in tensile strength, solubility resistance, and microbial inhibition compared to Sample A. These results confirm that modifying the film formulation specifically by reducing glycerin and incorporating sage powder enhances the film's suitability for biodegradable food packaging. The findings also highlight the critical role of formulation parameters in determining film performance, providing valuable insights for the development of plant-based packaging alternatives.

4. Conclusion

In the study of the developed seaweed-based edible film from Sample B, the results directly align with the objectives of this study. The successful formulation of edible film with 1.0 g agar powder, 0.5 g sage powder, 5.0 g gelatine and 1.0 mL food-grade glycerin, which demonstrated favorable characteristics such as improved solubility, balanced pH levels, enhanced microbial stability, and clear functional group interactions in the FTIR spectra, fulfils the first objective of formulating a seaweed-based edible film for food packaging. Furthermore, the tensile strength, microbial stability and solubility, influenced by the sage product, contribute to the second objective by providing insights into the physical and chemical properties of the film. These results also support the significance of the study by showing that a biodegradable, safe, and locally viable food packaging material can be developed using natural ingredients.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Thasmita Dev Jegan, Nur Aina Hakim Mohd Yazid, Muhammad Nur Azri Jasmi, Rozainita Rosley;* ***data collection:*** *Thasmita Dev Jegan, Nur Aina Hakim Mohd Yazid, Muhammad Nur Azri Jasmi, Rozainita Rosley;* ***analysis and interpretation of results:*** *Thasmita Dev Jegan, Nur Aina Hakim Mohd Yazid, Muhammad Nur Azri Jasmi, Rozainita Binti Rosley;* ***draft manuscript preparation:*** *Thasmita Dev Jegan, Nur Aina Hakim Mohd Yazid, Muhammad Nur Azri Jasmi, Rozainita Rosley. All authors reviewed the results and approved the final version of the manuscript.*

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