Synthesis and characterization of edible plastic based on waste-derived durian seed starch with patchouli leaf extract as eco-friendly primary packaging

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Abstract. Plastic pollution from single-use food packaging remains a critical environmental challenge due to its persistence and non-biodegradability. This study aimed to synthesize and characterize edible bioplastics derived from durian seed starch enriched with patchouli leaf extract (*Pogostemon cablin*) as a bioactive agent. Starch was obtained through sedimentation and drying, while patchouli oil was extracted via the Soxhlet method. Bioplastic films were prepared using starch concentrations of 6%, 8%, and 10%, supplemented with 1% glycerol, 0.5 g CMC, and 1 mL patchouli extract through solvent casting. Increasing starch concentration enhanced film thickness (0.020–0.032 mm), tensile strength (up to 3.3913 MPa), and elongation (13.5801%). The films exhibited antimicrobial activity against *Escherichia coli* (<3.0 MPN/g) and achieved 65% biodegradation after 14 days. These results highlight the potential of durian seed starch enriched with patchouli extract as a sustainable bioplastic for primary food packaging applications.

1 Introduction

The extensive use of petrochemical-based plastics has led to serious environmental problems due to their resistance to natural degradation. Indonesia is recognized as one of the largest contributors to plastic waste in the world, with food packaging constituting a major source of this pollution [1]. To address this issue, increasing attention has been directed toward the development of biodegradable and edible plastics derived from renewable biopolymers that can safely decompose in the environment [2]. Durian seed waste is an underutilized by-product that contains a high starch content, approximately 31–43.6% carbohydrates, making it a promising raw material for the production of edible plastic [3].

Previous studies have demonstrated that starch-based films exhibit acceptable mechanical and barrier properties; however, their performance is strongly influenced by formulation variables such as starch concentration and plasticizer content [4, 5]. The incorporation of

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natural bioactive compounds, particularly plant-derived essential oils, has been widely reported to significantly enhance the antimicrobial functionality of biodegradable packaging materials [6, 7, 8]. Nevertheless, limited studies have investigated the combined utilization of waste-derived durian seed starch and patchouli (*Pogostemon cablin*) leaf extract in edible bioplastic systems for active primary food packaging applications. Therefore, this study aims to synthesize and characterize edible bioplastic films derived from durian seed starch incorporated with patchouli leaf extract, providing a sustainable approach that integrates waste valorization and bioactive packaging development.

2 Materials and methods

Durian seed waste (*Durio zibethinus*) was collected from local markets, while fresh patchouli leaves (*Pogostemon cablin*) were obtained from local farmers. The durian seeds were selected as the main polymer source because of their high starch content and suitability for edible plastic production [3]. Patchouli leaves were used as a source of natural antimicrobial compounds, particularly patchouli alcohol, which is known for its strong antibacterial activity [9]. The chemicals employed in this study included distilled water, n-hexane (analytical grade) as an extraction solvent, glycerol as a plasticizer, and carboxymethyl cellulose (CMC) as a stabilizing agent. All reagents were of analytical or food-grade quality.

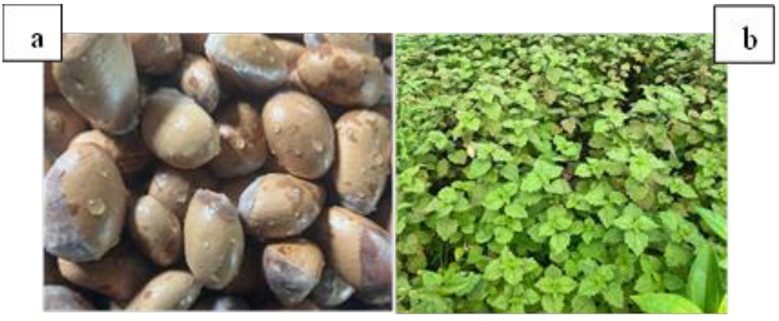

Fig. 1. Durian seed waste (a), Patchouli leaves (b).

2.1 Extraction of durian seed starch

The durian seeds were washed, peeled, sliced, and homogenized with distilled water at a ratio of 1:3 (w/v). The resulting slurry was filtered, and the filtrate was allowed to stand for 24 h to facilitate the sedimentation of starch granules. The precipitated starch was then washed, oven-dried at 50–60 °C, milled, and sieved to obtain a fine starch powder. This procedure followed commonly applied methods for starch isolation intended for edible plastic preparation [4, 10].

2.2 Extraction of patchouli leaf extract

Dried patchouli leaves were subjected to Soxhlet extraction using n-hexane as the solvent until the solvent became colorless. The extract was subsequently concentrated by evaporating the solvent and stored in dark glass bottles prior to use. The Soxhlet method is widely employed for the efficient extraction of bioactive compounds from plant materials, particularly essential oil constituents with antimicrobial properties [9].

2.3 Preparation of edible plastic

Durian seed starch at concentrations of 6, 8, and 10% (w/v) was dispersed in distilled water and heated to induce gelatinization. Glycerol was added as a plasticizer and CMC as a stabilizing agent, followed by the incorporation of patchouli leaf extract as a bioactive component. The resulting film-forming solution was poured onto flat glass plates and dried at 50 °C for 24 h using the solvent casting technique to obtain edible plastic sheets. This method is commonly used in the preparation of starch-based edible plastics [4, 11].

2.4 Characterization of edible plastic

2.4.1 Thickness

The thickness of the edible plastic was measured using a digital micrometer with an accuracy of 0.01 mm. Measurements were taken at five randomly selected points on each sample and the average value was calculated, following standard procedures for thin polymer materials [12]. Uniform thickness reflects homogeneous film formation and strongly influences mass transfer properties, including water vapor and gas permeability, which are critical for the protective role of edible plastic.

2.4.2 Tensile strength and elongation

Mechanical properties were determined using a Universal Testing Machine in accordance with ASTM D882-18. Tensile strength and elongation at break were calculated from the stress–strain curves obtained during the tensile test, as recommended for the evaluation of thin plastic sheets [6, 13]. These parameters describe the film's ability to withstand applied forces and its flexibility, which are key indicators of its suitability for handling, packaging, and distribution.

2.4.3 Antimicrobial activity

The antimicrobial activity of the edible plastic containing patchouli leaf extract against *Escherichia coli* was evaluated using standard microbiological methods. The reduction in bacterial growth indicated the inhibitory effect of the incorporated extract, in line with previous studies on the antimicrobial action of patchouli-derived compounds in active packaging systems [9, 14]. This result demonstrates the potential of the developed films to function as active packaging materials capable of limiting microbial growth and extending food shelf life.

2.4.4 Biodegradation behavior

Biodegradability was assessed using the soil burial test. The edible plastic samples were buried in moist soil and retrieved after predetermined periods to determine weight loss as an indicator of degradation. This method is widely applied to evaluate the environmental degradability of starch-based plastics and biodegradable polymer composites [7, 15]. This test simulates natural environmental conditions and verifies that the starch-based films can be readily decomposed by soil microorganisms, supporting their application as sustainable alternatives to conventional synthetic plastics.

3 Results and discussion

Edible plastic sheets were successfully formed at durian seed starch concentrations of 6%, 8%, and 10% (w/v). Increasing starch concentration produced smoother surfaces, higher transparency, and better structural integrity, indicating the formation of a more continuous and compact polymer network [4, 10].

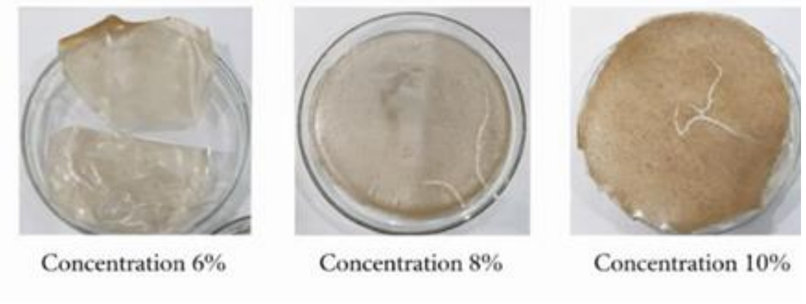

Fig. 2. Appearance of edible plastic.

3.1 Thickness

The thickness of the edible plastic increased with increasing starch concentration, with average values of 0.020 mm, 0.027 mm, and 0.032 mm for starch contents of 6%, 8%, and 10%, respectively.

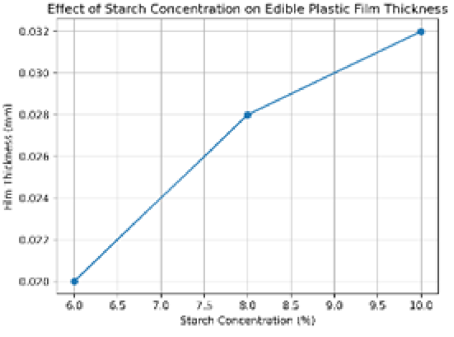

Fig. 3. Thickness Test.

This trend is attributed to the higher total solid content in the casting solution, which leads to greater material deposition per unit area and the formation of a denser matrix structure after drying [10, 12].

3.2 Tensile strength and elongation at break

Tensile strength increased significantly with starch concentration, whereas elongation at break decreased. This opposite trend indicates that higher starch levels enhance intermolecular hydrogen bonding and polymer chain entanglement, resulting in a more rigid network with reduced chain mobility. Similar trends have been reported in starch-based edible films, where increased matrix density enhances mechanical strength while reducing flexibility [11, 13].

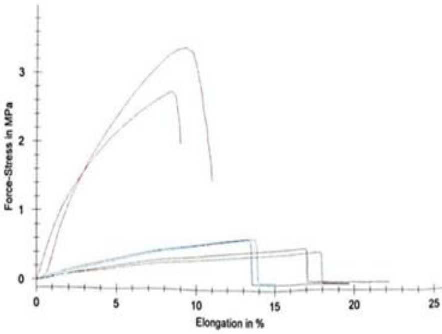

Fig. 4. Tensile strength and elongation.

3.3 Antimicrobial activity

All edible plastic samples containing patchouli leaf extract exhibited strong inhibitory activity against *Escherichia coli*, as indicated by bacterial counts below the detection limit (<3.0 MPN/g). The antimicrobial effect is mainly attributed to patchouli alcohol and other bioactive constituents in the extract, which can disrupt bacterial cell membranes and interfere with cellular metabolism [9].

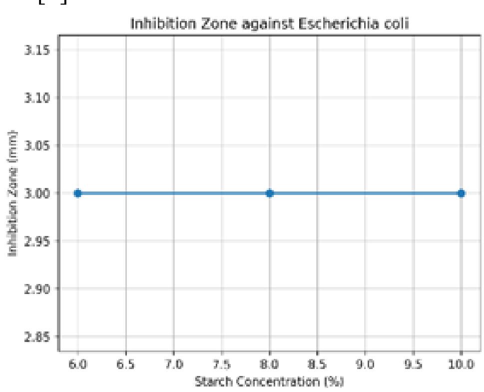

Fig. 5. Microbiological analysis (*Escherichia coli*).

The incorporation of plant-derived antimicrobial agents into biodegradable plastic matrices has been widely reported to enhance the functionality of active food packaging systems [9, 14]

3.4 Biodegradation behavior

The soil burial test demonstrated rapid biodegradation of the edible plastic films, with weight loss values of approximately 20–25% after 4 days, 40–45% after 7 days, and 60–65% after 14 days.

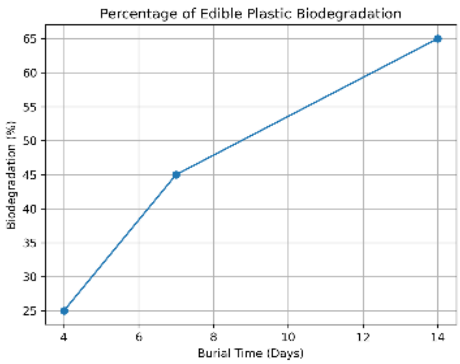

Fig. 6. Biodegradation test.

The hydrophilic nature of starch facilitates water absorption and microbial colonization, leading to enzymatic degradation of polymer chains. Comparable degradation behavior has been reported for other starch-based plastics and biodegradable polymer composites [7, 15].

4 Conclusion

Edible bioplastic films based on durian seed starch incorporated with patchouli leaf extract were successfully synthesized and characterized. Increasing starch concentration enhanced film thickness and tensile strength while reducing elongation due to the formation of a denser polymer network. The incorporation of patchouli leaf extract provided effective antimicrobial activity against *Escherichia coli*, demonstrating the potential of the films as active food packaging materials. In addition, the rapid biodegradation observed in soil burial tests confirms the environmental compatibility of the developed bioplastic. To the best of our knowledge, this study represents one of the limited investigations utilizing waste-derived durian seed starch combined with patchouli leaf extract as a bioactive agent in edible plastic systems. The formulation containing 8–10% starch exhibited the most balanced mechanical, antimicrobial, and biodegradation properties, indicating strong potential for sustainable primary food packaging applications. Further studies focusing on scalability, shelf-life evaluation, and barrier performance optimization are recommended to support industrial implementation.

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