Synthesis and Characterization of Bioplastic from Carrot Starch and Green Mussel Shell Chitosan

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ABSTRACT

Conventional plastics made from crude oil, which are difficult to decompose, have become an urgent global issue. Because of their nature, these conventional plastics pose a threat to ecosystems. To address this issue, bioplastics have been developed as an environmentally friendly alternative. Using renewable starch from carrots and chitosan from mussel shells as the main materials, the synthesized bioplastic can be degraded within a specified period. In this study, the optimal synthesis conditions for bioplastic were determined, and its plastic characteristics, such as mechanical and degradation properties, were tested. Functional group analysis using FTIR confirmed that the synthesized bioplastic had characteristic chitosan bands (OH, NH, amide I/II, C-O-C), and O-H broadening upon the addition of a plasticizer indicated the formation of hydrogen bonding within the polymer matrix. Based on test results for flexibility, tensile strength, and biodegradability, the bioplastic comprising 5% w/v starch, 2% w/v chitosan, and 1 mL of glycerol exhibited optimal properties. SEM analysis revealed a dense morphology, indicating favorable barrier and mechanical properties. The synthesized bioplastic has a tensile strength of 4.5529 MPa, which is within the range of commonly reported starch-chitosan bioplastics, and a biodegradability of 23.6%.

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1. Introduction

Plastic is defined as a polymer material and has evolved from an experimental material into one that dominates various industries. The rapid development of the plastic industry since the beginning of the 20th century has brought significant changes in human life [1]. The massive increase in plastic use has triggered a plastic waste crisis. Ineffective plastic waste management methods, such as landfilling and incineration, have only exacerbated the environmental problem. Recycling is another promising solution; however, this solution still deals with many technical and economic difficulties [2]. Aside from that, plastic recycling remains insufficient due to the material recovery still being less than 100% [3]. Outlawing plastic is not a viable option, as there are no suitable alternatives to replace it [4]. Due to its durability, plastic can persist for more than 450 years in the environment [5], contributing to a global environmental crisis in which an estimated 79% of plastic waste accumulates in landfills or rural areas [6].

As an environmentally persistent material, plastic is dangerous because it can break down into micro- or even nanoplastic particles that contaminate air, water, and soil [7]. Due to its tendency to break down into micro- or nanosized particles, plastic affects both terrestrial and aquatic ecosystems, causing entanglement, ingestion, and a range of health issues in living organisms. Moreover, due to the food chain system, humans face potential health issues, such as cardiovascular disease, chronic kidney disease, and cancers, as a result of plastic contamination [8]. To overcome these problems,

various approaches have been proposed. However, these steps have not yielded significant results; effective plastic waste management requires collaboration among all stakeholders and decision-makers to implement more sustainable strategies [9], such as using alternative materials, such as biodegradable bioplastics [10].

Bioplastics are generally made from natural materials that readily degrade over time, such as starch or vegetable oils. These environmentally friendly materials are derived from polysaccharides, proteins, and lipids, which shows their biodegradability and sustainability [11]. Bioplastics have shown potential to reduce waste accumulation, greenhouse gas emissions, and even the dependence on fossil-based fuels. However, scalability, cost-effectiveness, poor water resistance, weak mechanical strength, and end-of-life management remain challenges [12], [13]. Despite these difficulties, the transformation to bioplastics is crucial to overcome plastic pollution and advance environmental sustainability in the 21st century [14].

Natural materials such as starch are essential ingredients in bioplastic production because of their ability to degrade naturally with the help of microorganisms [15]. Starch is readily found in natural products such as potatoes, carrots, and sweet potatoes; thus, it has potential as a primary material for bioplastic production. Unlike cassava, potato, and sweet potato, carrot starch remains underexplored despite its potential. Based on previous research, the amylose content in carrot is approximately 20%; thus, it promotes strong intermolecular hydrogen bonding that increases the tensile strength of synthesized bioplastics [16]. Carrot is a starch source that is easily found throughout Indonesia; some of it is unused due to its appearance and susceptibility to rot [17]. However, starch from these natural products has poor mechanical properties, especially carrot starch. Therefore, adding other materials to improve the mechanical properties and thermal stability of the bioplastic material is necessary. One well-known material for this purpose is chitosan [18]. As a natural polymer, chitosan can strengthen and enhance the heat resistance of starch-based bioplastics. Moreover, chitosan has antimicrobial properties and reduces water sensitivity [19], [20]. Chitosan can be easily produced from crustaceans such as green mussel shells [21]. In Indonesia, the waste of green mussel shells remains un largely underutilize [22]. Therefore, utilizing green mussel shells as a source of chitin for chitosan production represents a sustainable strategy for reducing shell waste while adding value to this abundant marine by product [23].

Several research studies already utilize starch and chitosan as their materials for bioplastic synthesis [24]. However, no previous study has optimized the combination of carrot starch and chitosan from green mussel shell. Therefore, this study was conducted to synthesize bioplastic from carrot starch and green mussel shell chitosan under optimum conditions and to analyze its physical and mechanical properties. Thus, the synthesized bioplastic is expected to contribute to the development of an alternative to replace conventional plastic.

2. Research Methodology

2.1. Materials

Materials used in the research were NaOH, HCl, acetic acid, glycerol (Pro Analysis, Sigma-Aldrich), Carrot, green mussel shell, tapioca (Pak Tani), and distilled water.

2.2. Procedures

1) Isolation of starch from carrot

The carrot isolation method was modified from a previous method. The carrots were washed, 200 g were taken, and they were cut into small pieces (1-2 cm). Then, 100 mL of distilled water was added, and the mixture was homogenized using a blender for 2-3 minutes. The resulting slurry was filtered through a 250 μm sieve and left to stand for 3 hours to allow the starch to sediment and separate from the water. The supernatant was discarded, and the starch sediment was stored in a closed container for future use [16].

2) Isolation of chitin from green mussel shell

a) Deproteinization:

Cleaned green mussel shells were dried at 80°C for 6 hours and then ground into a powder. A total of 100 mL of 1 N NaOH was added to 10 g of green mussel shell powder, and the mixture was heated at 80-90°C with continuous stirring for 90 minutes. The mixture was then washed with distilled water

until a neutral pH was reached, as determined using a universal pH indicator. The mixture was left to stand until sedimentation occurred, after which the sediment was collected and dried in an oven at 80°C for 2 hours.

b) Demineralization:

A total of 80 mL of 1 N HCl was added to 8 g of dried material obtained from the deproteinization stage. The mixture was heated at 60-70°C for 1 hour under continuous stirring. Following the treatment, the mixture was filtered, and the residue was thoroughly washed with distilled water until a neutral pH was reached, as confirmed with a universal pH indicator. The washed residue was then allowed to settle, after which the sediment was collected and dried in an oven at 80°C for 2 hours. The resulting product was identified as chitin.

3) Chitosan synthesis from chitin

A total of 50 mL of 25% NaOH was added to 5 g of chitin, and the mixture was thoroughly mixed. The mixture was then heated at 80-90°C for 90 minutes under continuous stirring. Afterward, the mixture was filtered, and the resulting sediment was collected and dried in an oven at 80°C for 2 hours to obtain chitosan.

4) Bioplastic synthesis

To determine the optimal conditions for bioplastic synthesis, a series of optimization experiments was conducted by varying the concentrations of carrot starch and chitosan, as well as the volume of glycerol. Optimization was performed with three replicates for each condition. The optimum concentration of carrot starch was determined by varying its concentration to 1, 2, 3, 4, and 5% (w/v). For each formulation, 10 mL of 1% (w/v) chitosan prepared in 1% acetic acid was added to the carrot starch solution. The mixture was heated and continuously stirred on a hot plate at 70-80°C for 30 minutes until a homogeneous mixture was obtained. Subsequently, 3 g of tapioca starch was added, and the mixture was heated to 130°C and stirred until a gel formed. Then, 1 mL of glycerol was added, and the mixture was stirred for an additional 30 minutes. The resulting mixture was cast onto Petri dishes to ensure the entire surface was evenly covered. The films were dried in an oven at 60°C for 4 hours, cooled to room temperature, carefully removed from the mold, and stored in a desiccator until further analysis. The resulting bioplastic films were subsequently characterized to optimize **chitosan concentration.** The optimum chitosan concentration was determined by varying it at 1, 2, 3, 4, and 5% (w/v). For each formulation, 10 mL of 5% (w/v) carrot starch solution was added to the chitosan solution prepared in 1% acetic acid. The mixture was then heated and continuously stirred on a hotplate at 70-80°C for 30 minutes until homogeneous. Subsequently, 3g of tapioca starch was added, followed by heating at 130°C with continuous stirring until a gel formed. Then, 1 mL of glycerol was added, and the mixture was stirred for an additional 30 minutes. The mixture was then cast onto the surfaces of Petri dishes until the entire surface was covered, dried at 60°C for 4 hours, cooled to room temperature, removed from the mold, and stored in a desiccator until further analysis—optimization **of glycerol concentration.** The optimum glycerol concentration was determined by varying the volume of glycerol added to the bioplastic formulation. First, 10 mL of 5% (w/v) carrot starch solution was prepared, followed by the addition of 10 mL of 5% (w/v) chitosan solution prepared in 1% acetic acid. The mixture was then heated and continuously stirred on a hotplate at 70-80°C for 30 minutes until homogeneous. Subsequently, 3 g of tapioca was added, and the mixture was heated to 130°C and stirred until a gel formed. Then, 0.5 mL of glycerol was added, and the mixture was stirred for 30 minutes. The resulting mixture was cast onto Petri dishes until the entire surface was covered, dried at 60°C for 4 hours, cooled to room temperature, removed from the mold, and stored in a desiccator. The same procedure was repeated using 1, 1.5, 2, and 2.5 mL of glycerol. The resulting bioplastic films were subsequently characterized to determine the optimum glycerol concentration.

5) Characterization of bioplastic

The bioplastic samples were characterized using Attenuated Total Reflectance-Fourier-Transform Infrared Spectroscopy (ATR-FTIR) on a Shimadzu IR-Spirit A224155 to identify their functional groups and chemical composition. The spectra were recorded over a wavelength range of 4000-400 cm^{-1} with 99 scans at a spectral resolution of 16 cm^{-1}. The surface morphology of the synthesized bioplastic was examined using a Scanning Electron Microscope (SEM; JSM-IT200, JEOL Ltd., Japan). Before observation, the bioplastic sample was sputter-coated with a thin layer of Au using an auto fine coater (JEC-3000FC, JEOL Ltd., Japan) to improve electrical conductivity. SEM observations were conducted at an accelerating voltage of 5 kV. The tensile strength of the synthesized bioplastic was evaluated using a universal testing machine (UTM) in accordance with ASTM D638.

The bioplastic samples were prepared in a dog-bone-shaped form with an overall length of approximately 7 cm, consisting of two end sections measuring 1 cm in width and 1 cm in length, connected by a narrower central section measuring 3 cm in length and 0.5 cm in width. In addition, biodegradability was evaluated through a soil burial test. The bioplastic samples were buried in Regosol soil for 14 days under ambient conditions, after which their degradation was assessed.

3. Results and Discussion

3.1. Isolation of starch from carrot

The isolation process of starch from carrot was carried out using the method previously developed by Rocha et. al [16] as shown in Fig. 1.a to 1.c. The isolation process began by cutting carrot into small pieces, followed by blending and allowing the resulting suspension to stand until sedimentation occurred. The sediment was then separated from the liquid phase and collected as the isolated carrot starch. The carrot starch isolation process yielded 2.96 ± 0.04 g of dry starch from 200 g of fresh carrot, corresponding to a starch recovery yield of 1.479 ± 0.02% (w/w). The obtained starch yield was lower than that previously reported, ranging from 6.91% to 10.30% for Peruvian carrot [25]. The difference in starch yield may be attributed to variations in carrot variety, maturity, and extraction conditions.

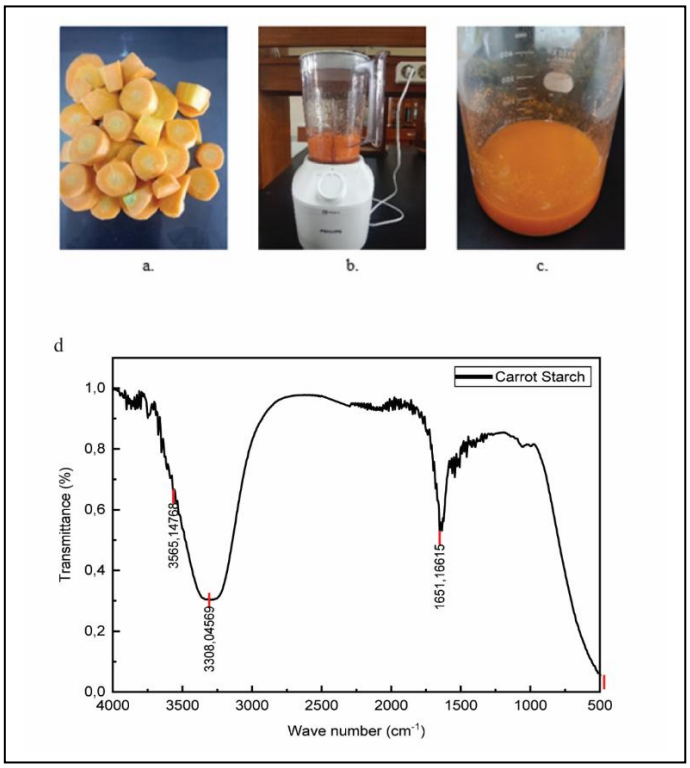

Fig. 1. Starch isolation process from carrot: (a) carrot slices, (b) carrot pureed with a blender, (c) blended carrot, and (d) FTIR data of starch from carrot.

The carrot starch sediment was subsequently characterized using ATR-FTIR, and the resulting spectrum is presented in Fig. 1.d. As shown in Fig. 1.d, the broad absorption band in the 3000-3600 cm^{-1} region was attributed to O-H stretching vibration of hydroxyl groups present in glucose units of starch. The absorption band around 2900 cm^{-1} was assigned to C-H stretching vibrations of the glucose units in the starch polymer. The absorption in the 1000-1200 cm^{-1} region is attributed mainly to C-O, C-C, and C-O-C stretching vibrations associated with the polysaccharide backbone and glycosidic linkages of starch [26]. The FTIR spectrum confirms the characteristic functional groups of starch, including the hydroxyl groups and glycosidic C-O-C linkages originating from its amylose and amylopectin components. Amylose and amylopectin are abundantly found in carrot starch, with a higher proportion of amylopectin [27]. Amylopectin is a natural polymer composed of α-1,4 and1,6-glycosidicc bonds, making it a suitable material for bioplastic synthesis. Additionally, amylopectin is easily biodegradable in soil, further supporting its potential in environmentally friendly applications

[28]. The α-glycosidic bond in starch enhances the mechanical properties of bioplastics by contributing to a rigid and sturdy structure [29].

3.2. Isolation of chitin from green mussel shell and chitosan synthesis

Green mussel shell, a type of natural crustacean waste, serves as a source of chitin for chitosan synthesis. Chitosan is a biocompatible and biodegradable material with antimicrobial activity. Additionally, it has the potential to act as an absorbent for heavy metals. The chitosan synthesis process is shown in Fig. 2.a-f. The process began with cleaning the green mussel shell, followed by drying and grinding it into a powder. NaOH was then added to remove protein from the shell powder. This was followed by the addition of HCl to remove the minerals, thereby extracting chitin. The chitin was subsequently treated with NaOH to produce chitosan. The resulting chitosan was washed and dried to yield a yellowish-white powder. The yield of chitosan obtained from the isolation process was 50 ± 0.82% (w/w). During the chitosan isolation, acetylation and deacetylation processes were performed to modify the degree of acetylation of the chitin-derived material. The degree of acetylation (DA) and degree of deacetylation (DD) were determined using the Brugnerotto method, based on the absorbance ratio at 1320 and 1420 cm^{-1} obtained from the FTIR spectra.

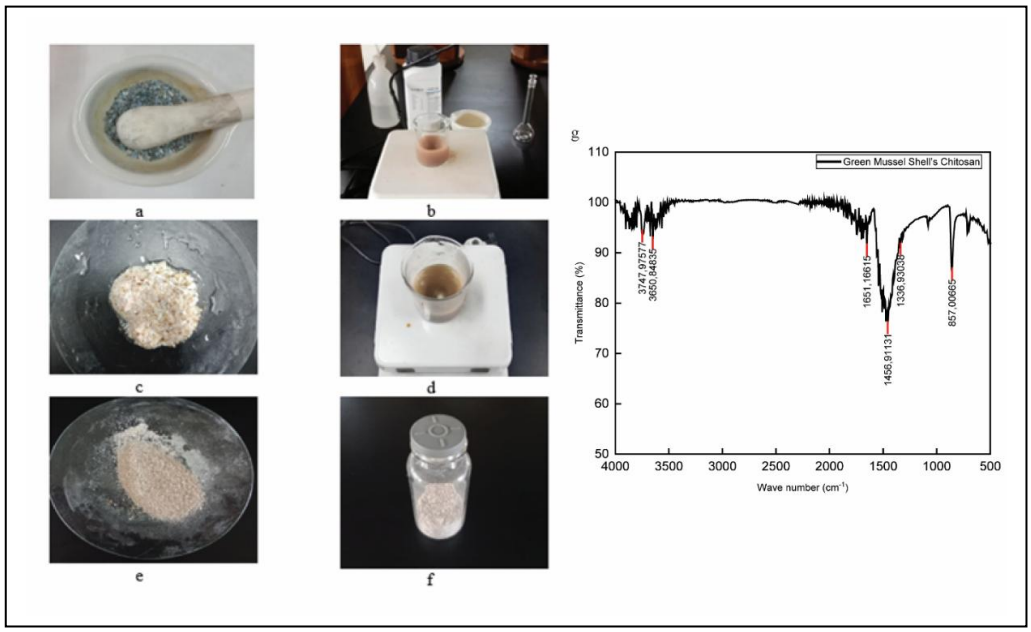

Fig. 2. The synthesis process of chitosan from the green mussel shell: (a) the ground green mussel shell, (b) deproteinization step, (c) demineralization step, (d) deacetylation step, (e) formation of chitin, (f) formation of chitosan, and (g) FTIR data of chitosan.

The FTIR analysis showed that the DA was 9.24 ± 2.49%, while the corresponding DD was 90.76 ± 2.49%. The relatively high DD value indicates that the deacetylation process was effective in removing acetyl groups from the chitin structure, resulting in chitosan with a high degree of deacetylation [30]. FTIR analysis was conducted to confirm the successful synthesis of chitosan. As shown in Fig. 2.g, the spectrum expresses the presence of amine (-NH_2) with characteristic absorptions around 3400 cm^{-1} and 1600 cm^{-1}, hydroxyl (-OH) with strong, broad absorption around 3400 cm^{-1}, C-H groups around 2900 cm^{-1}, amide (C=O) groups around 1650 cm^{-1}, C-H groups around 1405-1455 cm^{-1}, and C-O groups around 1000-1300 cm^{-1}. These absorption bands correspond to those typically found in chitosan [31].

3.3. Bioplastic synthesis

To determine the optimal conditions for bioplastic synthesis using carrot starch and chitosan from green mussel shells, a series of optimization steps were conducted. These steps included varying carrot starch concentration, chitosan concentration, and glycerol volume. The best conditions were identified based on the results of tensile strength and degradation tests.

1) Carrot starch concentration

Starch concentration influences the mechanical properties of bioplastic, including flexibility, durability, and biodegradability. Therefore, the optimal starch concentration should be determined. The optimization step was carried out by varying the starch concentration from 1 to 5% (w/v).

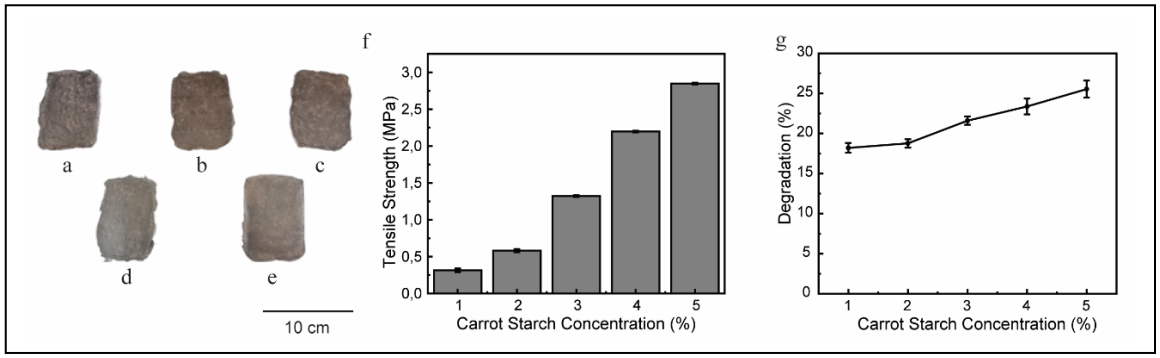

Fig. 3. The synthesis results and characteristics of bioplastic samples. Bioplastics synthesized with varying starch concentrations of (a) 1%, (b) 2%, (c) 3%, (d) 4%, (e) 5%, (f) tensile strength analysis of bioplastic with different carrot starch concentrations, and (g) degradation result of bioplastic with varying carrot starch concentration.

Based on the results, the transparency of the synthesized bioplastic decreases with increasing carrot starch concentration (Fig. 3.a-e). However, according to the mechanical test, a 5% (w/v) concentration of carrot starch yields the best result, due to the hydrophilic groups on the starch that attract water. Water plays an important role in the biodegradation process by assisting the degradation enzyme. Therefore, the higher the carrot starch concentration, the greater the biodegradability of the bioplastic [32].

Tensile strength is one of the parameters tested in bioplastic assessment. It indicates the strength of the synthesized bioplastic. Tensile test results for the synthesized bioplastic samples are shown in Fig. 3.f. The tensile strength of bioplastic increases with the concentration of carrot starch: 1% (0.32 ± 0.02 MPa), 2% (0.58 ± 0.02 MPa), 3% (1.32 ± 0.01 MPa), 4% (2.22 ± 0.01 MPa), and 5% (2.85 ± 0.01 MPa). Based on these data, bioplastics containing 3 to 5% carrot starch met the standard for moderate bioplastic properties, while the tensile strength ranged from 1 to 10 MPa [33]. The increase in tensile strength with higher carrot starch concentration is due to the stronger intermolecular forces between the starch biopolymer chains in the bioplastic [34].

The degradation test was conducted to assess the effectiveness of the bioplastic composition under degradation conditions. The test was conducted over 14 days by burying the synthesized bioplastic in soil, after which the mass reduction was measured. Fig. 3.g shows that the degree of bioplastic degradation increases with increasing carrot starch concentrations. This phenomenon occurred because the hydrophilicity of starch increased with increasing concentration. The hydrophilic structure absorbs water from soil, which provides a medium for bacteria and microbes to grow, thereby enhancing the degradation process of bioplastic [35]. Based on the data, a 5% carrot starch concentration is the most effective for bioplastic synthesis. However, tapioca starch was incorporated into the formulation to improve the mechanical strength and structural integrity of the bioplastic sample.

2) Chitosan concentration

Chitosan is a naturally abundant polymer that exhibits excellent biodegradability in various environmental conditions. The incorporation of a plasticizer, such as glycerol, enhances the mechanical properties of chitosan, thereby increasing its potential as a bioplastic material. To determine the optimal chitosan concentration for bioplastic synthesis, chitosan concentrations ranging from 1 to 5% (w/v) were evaluated.

Based on Fig. 4.a- e, increasing the chitosan concentration did not result in noticeable differences in the physical appearance of the bioplastic. However, variation in chitosan concentration significantly influenced its tensile strength. As shown in Fig. 4.f, the tensile strength was 2.82 ± 0.02 MPa at 1% chitosan, increasing to 4.56 ± 0.01 MPa at 2% chitosan. At 3%, strength decreased to 2.66 ± 0.04 MPa, then further decreased to 0.44 MPa and 0.04 MPa at 4% and 5% chitosan, respectively. The highest tensile strength was observed at a chitosan concentration of 2%. This phenomenon can be

attributed to the formation of additional intermolecular bonds as chitosan content increases, thereby enhancing the structural integrity of the bioplastic and making the sample stronger and stiffer [36]. However, excessive chitosan reduces elasticity and increases brittleness [37].

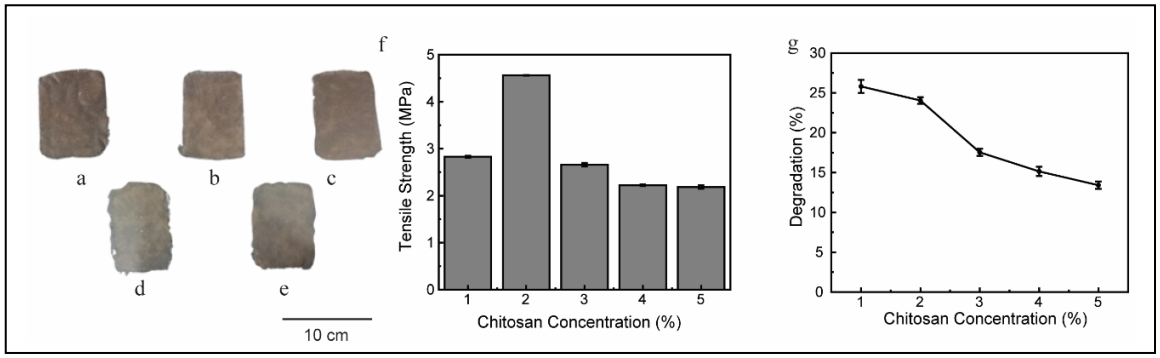

Fig. 4. Synthesis results and characteristics of bioplastic samples. Bioplastics were synthesized using varying chitosan concentrations: (a) 1%, (b) 2%, (c) 3%, (d) 4%, (e) 5%, (f) and (g) the tensile strength analysis and degradation behavior of bioplastics prepared with different chitosan concentrations, respectively.

The degradation test was conducted over 14 days by burying bioplastic samples in soil. Based on Fig. 4.g, the degree of degradation decreased with increasing chitosan concentration. This is due to the hydrophobic nature of chitosan, which limits water absorption and thereby inhibits the activity of bacteria and microbes involved in the degradation process of bioplastic [38].

3) Glycerol volume

Glycerol is an alcohol with three hydroxyl groups; it is a water-soluble and nontoxic material [39] was used as a plasticizer to enhance the flexibility of bioplastic. The effect of glycerol concentration was evaluated by varying its volume from 0.5 to 2.5 mL, with the mixture consisting of 10 mL of 5% carrot, 10 mL of 5% chitosan in 1% acetic acid, and 3 g of tapioca.

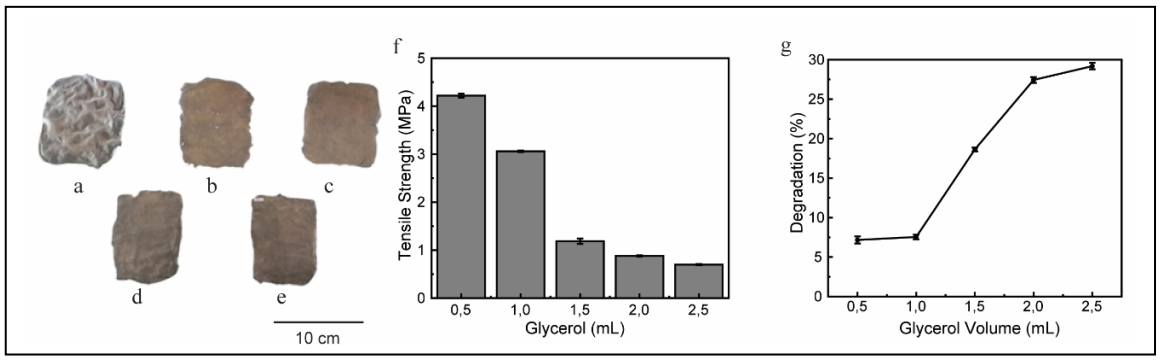

Fig. 5. Synthesis results and characteristics of bioplastic samples. Bioplastics were synthesized using varying glycerol volumes: (a) 0.5, (b) 1, (c) 1.5, (d) 2, and (e) 2.5 mL. (f) and (g) represent the tensile strength analysis and degradation behavior of bioplastic prepared with different glycerol volumes, respectively.

As shown in Fig. 5.a-e, higher glycerol content improved the physical appearance of the bioplastic. The addition of glycerol increased plasticity by enhancing air permeability, allowing air to pass through pores or gaps in the matrix. Glycerol also improved the bioplastic's wettability. However, excessive glycerol reduced the strength of the bioplastic [40]. The optimal glycerol volume for the best bioplastic was 1 mL. Fig. 5.f shows that the tensile strength of the bioplastic samples decreased with increasing glycerol volume. This reduction is attributed to decreased intermolecular interaction between polymer chains [41]. Based on the data obtained, bioplastics containing 0.5, 1, and 1.5 mL of glycerol complied with the moderate bioplastic properties, which are 1-10 MPa [33]. The degradation test (Fig. 5.g) showed that the mass reduction increased with higher glycerol content. This is attributed to the hydrophilic nature of glycerol, which promotes water absorption and enhances microbial activity in the degradation process of bioplastic [42].

3.4. The Characterization of Bioplastic

Functional group analysis of the synthesized bioplastic plays an important role in confirming the successful formation of the bioplastic matrix. FTIR analysis was conducted to identify functional groups in the bioplastic and to evaluate potential interactions among its constituent components. FTIR analyses were performed on the isolated carrot starch, synthesized green mussel shell chitosan, and resulting bioplastic. Fig. 6.a presents the FTIR spectra of carrot starch, green mussel shell chitosan, and the synthesized bioplastic. Several shifts in the absorption bands were observed in the bioplastic spectrum compared with those of the individual raw materials, indicating interactions among the components during bioplastic formation [43].

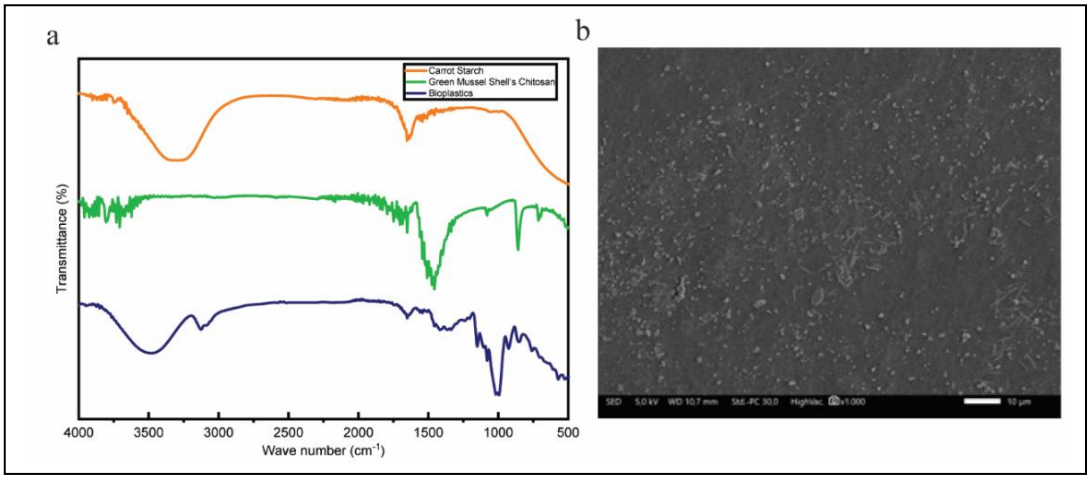

Fig. 6. Synthesis results and characteristics of bioplastic samples. (a) FTIR spectra of carrot starch, chitosan derived from green mussel shells, and the synthesized bioplastic, and (b) SEM of the surface morphology of the bioplastic.

In the bioplastic spectra, absorption at 2925.24 cm^{-1} corresponds to C-H stretching vibrations, which can be attributed to the carbohydrate structure of starch and the glycerol plasticizer. The broad absorption band at 3290.90 cm^{-1} corresponds to O-H stretching vibrations of the carboxylate group, suggesting a contribution from acetic acid. The presence of chitosan in the bioplastic is confirmed by absorption at 1416.91 cm^{-1}, attributed to C-H (alkyl) stretching, as well as absorption in the fingerprint region at 1016.98 cm^{-1}, which corresponds to the C-O stretching of C-O-C. Additionally, absorption at 1148.38 cm^{-1} indicates the presence of a C-O functional group in C-O-H, confirming the presence of starch functional groups. An absorption band in the range of 1640-1820 cm^{-1} corresponds to the C=O (ester) functional group, indicating the presence of glycerol [44]. The spectra from the 900-1000 cm^{-1} region are commonly associated with C-O and C-O-C stretching vibrations of polysaccharides, while chitosan shows characteristic amide I and II bands around 1600 cm^{-1} and 1500 cm^{-1}, respectively—the broadening of O-H with the addition of plasticizer, indicating hydrogen bonding with the matrix [45]. Changes in the position, intensity, and shape of these characteristic bands compared with the spectra of the individual components indicate intermolecular interactions among starch, chitosan, and glycerol. These interactions, particularly hydrogen bonding, contribute to the formation and integration of the polymer network. Overall, the FTIR results confirmed the presence of the characteristic functional groups of starch, chitosan, and glycerol in the synthesized bioplastic and indicated interactions among these components during film formation.

The surface morphology of the bioplastic (Fig. 6.b) was analyzed using Scanning Electron Microscopy (SEM). SEM employs a focused electron beam to generate high-resolution images of the bioplastic sample surface, enabling the morphological characteristics and surface homogeneity of the bioplastic to be evaluated [46]. The SEM image showed a relatively smooth surface with some irregularities and brittle regions. The morphological characteristics may be related to the distribution and interaction of the plasticizer within the polymer matrix [47]. However, the surface was not completely homogeneous, as evidenced by localized irregularities and aggregated regions. The occurrence of particle aggregation may be attributed to incomplete dispersion of the biopolymer components or insufficient compatibility among starch, chitosan, and the plasticizer. Such aggregation can lead to structural heterogeneity and may affect the mechanical barrier properties of the resulting bioplastic.

4. Conclusion

A biodegradable bioplastic was successfully synthesized using carrot starch and green mussel shell chitosan as renewable polymeric materials, with glycerol serving as a plasticizer. FTIR analysis confirmed the characteristic functional groups of starch and chitosan and indicated the formation of hydrogen-bonding interactions within the polymer matrix following plasticizer incorporation. Among the formulations investigated, the bioplastic containing 5% (w/v) carrot starch, 2% (w/v) chitosan, and 1 mL of glycerol exhibited optimal properties, with a tensile strength of 4.5529 MPa and a biodegradability of 23.6%. SEM analysis revealed a relatively dense, compact morphology, consistent with the formation of an integrated polymer matrix. These findings demonstrate that carrot starch and green mussel shell chitosan have potential as renewable raw materials for producing biodegradable bioplastics and may provide a more environmentally friendly alternative to conventional petroleum-based plastics.

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