



Enhancing Mechanical and Physical Properties of Bioplastics: Impact of Starch/Chitosan Mass Ratio and Corn Stem Cellulose Nanofiber Filler

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Abstract. The utilization of traditional polymers has resulted in various environmental problems due to their extended decomposition period, compounded by the finite nature of petroleum-derived raw materials. Thus, alternative materials are needed as raw materials for making plastics that are more environmentally friendly, easily decomposed, and have an abundant supply of raw materials. This study aims to extract nanometer-sized cellulose fibers from corn stalks, determine the mass ratio of starch:chitosan effect and fillers on the properties of bioplastics, and to obtain bioplastics that have mechanical and physical properties that comparable to conventional LDPE (low density polyethylene) plastics. In this study variations in the starch: chitosan mass ratio used were 9:1, 8:2, and 7:3 (gram/gram) and variations of cellulose fiber fillers derived from corn stalks were 0.1, 0.2, and 0.3 grams. The analysis carried out was the analysis of mechanical properties, analysis of physical properties (water absorption and density test), and analysis of SEM. The resulting cellulose fibers exhibited a micro-sized diameter ranging from 0.289 μm to 2.086 μm . The study revealed that the bioplastic formulation closest to LDPE characteristics comprised a starch:chitosan mass ratio of 9:1 with 0.2 grams of filler. This bioplastic has a tensile strength of 8.258 MPa, elongation of 2.472%, Young's modulus of 334.065 MPa, water absorption of 87.500%, and density of 0.762 gram/ml.

Keywords: Bioplastic, renewable material, fillers, mechanical strengths.

1 Introduction

Technological and industrial developments have triggered an increase in people's consumption of plastic-based packaging. Excessive use of plastic causes various environmental problems. Plastics around us are petrochemical plastics based on petroleum or characteristic gas, posturing a danger to human presence on Earth [1]. Its chemical structure which could be a tall atomic weight and includes a solid holding chain, makes this plastic take an awfully long time to break down in nature and gotten to be an natural issue such as avalanches and floods [2]. Accumulation of plastic waste is inevitable because it is very difficult to decompose in nature. To overcome this, alternative materials are needed to replace conventional plastic. One thing that can be used is biodegradable plastic or bioplastic.

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Biodegradable plastic or bioplastic is plastic composed of natural polymers which are capable of being degraded by both microorganisms and weather [3]. Biodegradability is one of the most properties of the edible bioplastic, that can be biodegraded by chemicals activity of the living being, such as organisms, microbes, and yeast [4]. Bioplastics could be made from renewable biomass sources such as starch[3]. Starch may be a promising crude fabric for bioplastic generation because it is 100% biodegradable, has consistent mechanical properties, and is renewable [1]. Undoubtedly, starch, an abundant naturally occurring biopolymer, is the focal point of this campaign. Starch is mostly composed of two types of glucose polymers, namely amylose and amylopectin [5]. The amylose/amylopectin ratio, which may vary depending on the source of starch, is crucial since it affects several physicochemical aspects of starch that ultimately determine its utility and potential applications [5]. Indonesia cultivates a diverse range of starch-producing plants, such as sorghum, cassava, rice, corn, sweet potatoes, taro tubers, potatoes, bananas and other varieties.

Sorghum (*Sorghum bicolor* L. Moench) emerges as a promising source of starch in Indonesia. As a cereal crop, sorghum exhibits wide adaptability, making it conducive to cultivation across diverse regions [6]. Notably, sorghum boasts a high starch content, ranging start 56% up to 73%, with an average 69.5%. The composition of sorghum starch comprises amylose (20-30%) and amylopectin (70-80%), subject to genetic and environmental factors [7]. Given its abundant starch content and widespread availability, sorghum holds significant potential as a raw material for biodegradable plastic (bioplastic) production.

However, starch-based bioplastics suffer from inherent drawbacks, particularly in terms of mechanical and physical properties compared to conventional petroleum-derived plastics. Therefore, the incorporation of fillers and plasticizers is essential in sorghum starch-based bioplastic production. Among the available filler options, cellulose derived from plants stands out due to its abundant availability, accessible as long as the plant contains lignocellulose. Corn stalks present a viable material option, boasting a cellulose content of 42.6%, hemicellulose content of 21.3%, and lignin content of 8.2% [8].

Cellulose derived from Corn corn stalk cellulose can be used as a filler material to fill empty cavities in bioplastics. Fillers can has function as agents that make the biopolymer chains in bioplastics more orderly, resulting in better mechanical properties and structure in bioplastics [9]. However, cellulose has several disadvantages, including interaction with the matrix, poor water resistance and low durability. These shortcomings can be overcome by modifying it into nanocellulose. The dispersion of nanocellulose throughout the bio-plastic is anticipated to be uniform and even, allowing it to occupy vacant spaces and enhance the mechanical characteristics of the bioplastic.

What is desired for bioplastics is to have strong and elastic properties. This property can be obtained by adding chitosan and glycerol. Chitosan has reactive component properties, binding, chelating, absorbing, stabilizing, film forming and clarifying [10]. In addition, chitosan functions as a reinforcement biodegradable plastic [11]. Glycerol is a type of plasticizer that is commonly used because it is effective in reducing internal hydrogen bonds so that it can increase the intermolecular distance [12].

This research was carried out using a combination of sorghum starch-chitosan with filler material in the form of nanocellulose obtained from corn stalks with glycerol plasticizer. In this research, the method used to obtain nanocellulose from corn stalks was the method used by Wicaksono (2013), namely alkali + bleaching + acid + mechanical hydrolysis. By using the method used by Wicaksono (2013), it is hoped that the cellulose fibers from the corn stalks produced will be nano-sized. The use of nanocellulose from corn stalks as a filler is expected to improve the mechanical (tensile strength and Young's modulus) and physical (water absorption and density) properties of bioplastics.

The aim of this research is to obtain nanometer-sized cellulose fibers from corn stalks, determine the effect of the mass ratio of starch: chitosan and fillers on the mechanical and physical properties of bioplastics, and to obtain bioplastics that have mechanical and physical properties that match conventional LDPE plastics.

2 Methodology

2.1 Material and Tools

The materials used in this research were corn stalk powder derived from Mranggi Jaya, Central Lampung, sulfuric acid (H_2SO_4) 6.5 M, potassium hydroxide (KOH) 4%, peroxide (H_2O_2) 6%, distilled water, sorghum starch derived from Yukum Jaya, Central Lampung, corn stalk cellulose, chitosan, glycerol 10% and acetic acid. PSA analysis equipment or instruments to determine the particle size of corn stem cellulose using the Horiba SZ-100, mechanical properties analysis using an Universal Testing Machines (UTM), Fourier Transform Infra Red (FTIR) analysis to determine functional groups using the Varian 2000 FT-IR, and Scanning Electron Microscopy (SEM) analysis To determine the morphology of bioplastics using ZEISS EVO MA 10.

2.2 Corn Stem Cellulose Fiber Extraction

The research began by processing corn stalks. The corn stalks were cut into smaller sizes, dried, and then ground before being sifted using a 200-mesh sieve. The corn stalk powder that passed through the sieve was stored in a zip bag lock.

Further, about 10 grams of corn stalk powder was weighed and then placed into a 500 mL volume beaker glass. After that, the corn stalk powder was mixed with a 4% KOH solution. The ratio of the solid corn stalk powder to the added KOH solution was maintained at 1:10 (weight/volume). The extraction process was carried out using a hotplate at the temperature of 80°C for 1 hour. After a one-hour cooking process and extraction, the material was filtered using a filter cloth. The filtered material was washed with distilled water until a pH of 11 is reached.

Following the washing process, the remaining material (residue) underwent bleaching twice using 6% H₂O₂ at 70°C for 1 hour each, with stirring. For each bleaching treatment, the ratio of the residue to the 6% H₂O₂ solution added was 1:10 (weight/volume). After the bleaching process, the washed material was then mixed again with a 4% KOH solution. This treatment was carried out at 80°C for 1 hour with stirring. Following the alkali treatment, the material underwent acid treatment using 6.5 M H₂SO₄. The fibers that have undergone alkali treatment are then dispersed in 200 ml of 6.5 M H₂SO₄ solution in a glass beaker and stirred. The hydrolysis process was carried out at 60°C with stirring for 1 hour. The mixture was then washed with distilled water until a neutral pH of 6-7 was reached. After that, the resulting suspension was centrifuged at 6000 rpm in 10 minutes to obtain pulp sediment. Then, 5 grams of pulp precipitate were suspended in 300 ml of distilled water and continued with mechanical treatment using an ultrasonic bath. It was then dried and ground using a powder grinder at a speed of 25,000 rpm.

2.3 Preparation of Sorghum Starch

Sorghum grains is cleaned of impurities and dried in the sun until its weight remains constant. After that, the sorghum is ground with a grain grinder until smooth to obtain sorghum flour. Then the fine sorghum flour is sifted using a 200 mesh sieve. The sorghum flour is then stored in a closed jar to avoid mold or lice.

2.4 Synthesis of Bioplastic

The synthesis of bioplastic initiates with the precise measurement of sorghum starch, chitosan, and corn stalk fiber cellulose according to the designated variables. Glycerol, acetic acid, and distilled water are proportioned based on their respective volumes. This study explores various ratios of starch to chitosan (9:1, 8:2, and 7:3) and filler ingredient variations (0.1 grams, 0.2 grams, and 0.3 grams).

To prepare the starch solution, 9 grams of starch is mixed with 194.21 ml of distilled water in a 500 ml beaker. Simultaneously, 1 gram of chitosan is dissolved in acetic acid and stirred until homogenized in a petri dish. The chitosan solution is then added to the starch solution in the beaker. Subsequently, 0.8 ml of 10% glycerol solution by weight and the specified amount of corn stalk filler (0.1 grams) are introduced into the beaker. The mixture, constituting starch, chitosan, glycerol, and filler (bioplastic solution), is thoroughly blended.

The bioplastic solution is transferred to a hot plate and stirred at 375 rpm under a temperature of 95°C for 35 minutes. After stirring, the solution is briefly cooled to room temperature. Portions of 100 ml of the bioplastic solution are poured into molds, taken after by arrangement in an oven set at 60°C for 10 hours. Once the allotted time has elapsed, the bioplastic samples are removed from the molds, labeled with pertinent information, and stored in zip lock bags before being placed in a desiccator for further analysis. The initial phase of experimentation involves stirring the solution at 375 rpm, maintaining a starch-to-chitosan ratio of 9:1, and incorporating filler ingredients in quantities of 0.1 grams, 0.2 grams, and 0.3 grams. The next step is at the same speed with a starch-chitosan concentration ratio of 8:2 and 7:3 and also adding fillers of 0.1 grams, 0.2 grams and 0.3 grams.

2.5 Analysis of Bioplastic Films

2.5.1 Mechanical Properties Analysis

Mechanical properties are critical in arrange to foresee how the materials carry on beneath loads when they are subjected to different fabricating operations [14]. In this research, the mechanical properties of materials are decided by the tensile strength (ultimate tensile strength), percent elongation (elongation at break) and elasticity (Young's modulus). Bioplastic film samples were analyzed using an universal testing machines (UTM).

a. Tensile Strength

Tensile strength (stress) or maximum tensile strength (ultimate tensile strength) is the ratio between the maximum load (F_{max}) and the initial cross-sectional area of the test object ($A = \text{width} \times \text{thickness of the initial sample}$). Tensile strength can be calculated by the formula [15]:

$$\sigma = \frac{F_{max}}{A} \quad (1)$$

Details:

σ = Tensile Strength (MPa)

F_{max} = Maximum Load (N)

A = Cross-Sectional Area (m^2)

b. Percent Elongation

Percent elongation is one way to measure the ductility of a material obtained from a tensile test. This measurement is obtained after the break or engineering strain at break (ϵ). The percent elongation value is usually expressed in percentage form. Percent elongation can be calculated by the formula [15]:

$$\epsilon = \frac{L_1 - L_0}{L_0} \times 100\% \quad (2)$$

Details:

ϵ = Percent Elongation (%)

L_0 = Initial length of Specimen (m)

L_1 = The length of the specimen when the maximum tensile force is applied (m)

c. Young's Modulus

Young's modulus (elasticity) are a degree of the solidness of a material. Young's modulus (elasticity) are the ratio between ultimate tensile strength and percent elongation (elongation at break). The greater the elastic modulus, the smaller the elastic strain

resulting from applying stress. Elasticity (Young's Modulus) can be calculated by the formula [15]:

$$E = \frac{\sigma}{\varepsilon} \quad (3)$$

Details:

E = Young's Modulus (MPa)

σ = Tensile Strength (MPa)

ε = Percent Elongation (%)

2.5.2 Physical Properties Analysis

a. Water Absorption Analysis

The water absorption test is basic to decide the amount of water retained by a fabric as well as the impacts that the water ingested may have on the appearance of the composites [14]. This analysis was carried out by cutting the sample to a length of 2 cm and a width of 2 cm, at that point weighing the beginning weight of the sample (W_0) employing a digital balance. After that, the sample was put into a beaker containing 5 ml of distilled water. After 15 minutes, the sample was removed from the beaker and the water attached to the surface of the sample was removed by hand [16]. Following, the ultimate weight of the sample (W) is weighed employing a digital balance and the percent of water absorbed by the sample is calculated. The water absorption test can be calculated by the formula [16]:

$$\frac{W - W_0}{W_0} \times 100\% \quad (4)$$

Details:

W_0 = Initial Weight of Sample (gram)

W = Sample Weight after standing in water (gram)

b. Density Analysis

Density analysis was carried out by cutting the sample to a length of 2 cm and a width of 2 cm, at that point weighing the introductory weight of the sample (m) employing a digital balance. After that, measure the thickness of the sample using a caliper and calculate the volume of the sample. Sample volume and density can be calculated by the formula [16]:

$$V = p \times l \times t \quad (5)$$

$$\rho = \frac{m}{V} \quad (6)$$

Details:

ρ = Density (gram/ml)

m = Mass of Sample (gram)

V = Volume (ml)

p = Length of Sample (cm)

l = Wide of Sample (cm)

t = Thick of Sample (cm)

2.5.3 FTIR Analysis

Functional group analysis with FTIR is carried out using the IR method or structure elucidation method to find out what functional groups are present in a sample. The sample, in the form of a film, is placed into the seat holder, then the appropriate spectrum is searched for. The comes about gotten are within the shape of a spectrogram of the number relationship between waves and intensity. FTIR spectrum was recorded employing a spectrometer at room temperature.

2.5.4 Scanning Electron Microscopy (SEM) Analysis

SEM is an instrument that produces an electron beam on the surface of a target specimen and displays and collects the signals given by the target material. SEM tests are carried out to observe the microstructure, topography, morphology, fractography solid samples from metal, polymer or ceramic materials [16]. Scanning Electron Microscopy (SEM) analysis was carried out to determine the morphological structure of the bioplastic produced. In principle, SEM consists of an electron column, sample chamber and vacuum system.

3. Results and Discussion

3.1 Cellulose Fiber Properties

Table 1. Lignocellulose Composition of Corn Stems Raw Material and After Treatment.

Sample	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Raw material	34.00	23.71	9.29
After Treatment	49.70	16.62	6.58

Based on Table 1, notable differences are observed in the composition of corn stalks before and after undergoing chemical and mechanical treatments. Specifically, there is

an increase in cellulose levels and a corresponding decrease in hemicellulose and lignin levels. This indicates that the chemical treatment applied to the corn stalks has led to an enhancement in cellulose content.

3.2 Mechanical Properties Analysis

3.2.1 Tensile Strength

The results of the tensile strength analysis of bioplastics from a mixture of sorghum-chitosan, cellulose filler and glycerol plasticizer can be seen in Fig. 1.

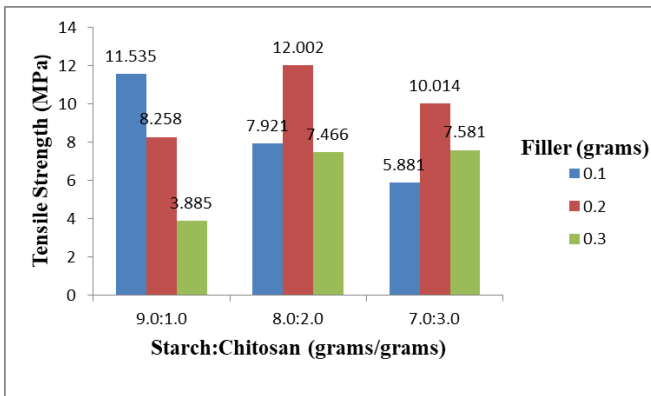


Fig. 1. Effect of Starch-Chitosan Formulation and Cellulose Filler on Tensile Strength of Bioplastics.

Fig. 1 shows the effect of starch-chitosan formulation and cellulose filler on the tensile strength of bioplastics. Based on Fig. 1, it can be seen that the addition of cellulose filler to bioplastics tends to increase the tensile strength value, but along with increasing the amount of cellulose filler, the tensile strength value decreases. Likewise with the composition of starch: chitosan where the addition of chitosan aims to increase the tensile strength value, but along with increasing the amount of chitosan in the bioplastic, the tensile strength value of the bioplastic decreases. This proves that there is an optimal composition in bioplastic formulations because the continuous addition of certain ingredients does not necessarily improve the tensile strength value[15].

In this research, the composition that produced the highest tensile strength value was 8:2 starch:chitosan with 0.2 grams of cellulose filler, which was 12.002 MPa. This bioplastic is intended to replace LDPE which has a standard tensile strength between 8-31.4 MPa, so it can be concluded that the tensile strength of this bioplastic can already match LDPE plastic.

3.2.2 Percent Elongation

The results of the analysis of percent elongation (elongation to break) in bioplastics from a mixture of sorghum-chitosan, cellulose filler and glycerol plasticizer can be seen in Fig. 2.

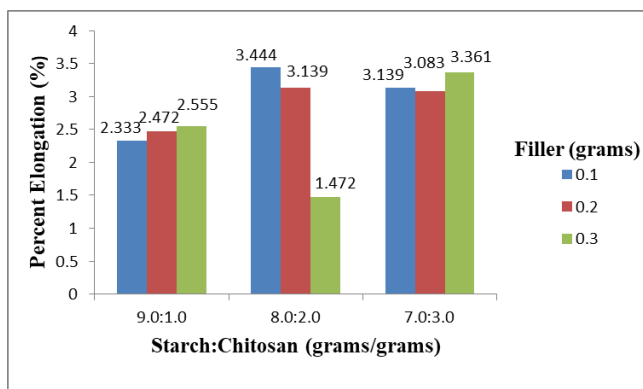


Fig. 2. Effect of Starch-Chitosan Formulation and Cellulose Filler on Percent Elongation of Bioplastics.

Fig. 2 shows the effect of starch-chitosan formulation and cellulose filler on the percent elongation (elongation to break) of bioplastics. Based on Fig. 2, it can be seen that there was an increase in elongation when cellulose was added. However, the elongation decreased again when cellulose was added starch:chitosan mass ratios of 8:2 and 7:3, this shows that there is a saturation point for the formation of hydrogen bonds so that cellulose is difficult to spread (disperse) [17]. Additionally, the reduction in elongation rate was influenced by the amount of chitosan added. The addition of chitosan can reduce the elongation value of bioplastics, this indicates that the amount of chitosan added can reduce the bond distance between molecules. This decrease in the distance is caused by the increase in the number of hydrogen bonds formed between chitosan-amylose-amylopectin molecules [18].

From the manufacture of bioplastics that have been carried out, the highest percent elongation value is obtained in the starch:chitosan mass ratio of 8: 2 filler 0.1 gram, which is 3.444%. The value of percent elongation produced has not met the standard value of percent elongation of LDPE which is 100-1000%.

3.2.3 Young's Modulus

The results of Young's modulus analysis of bioplastics from a mixture of sorghum-chitosan, cellulose filler and glycerol plasticizer can be seen in Fig. 3.

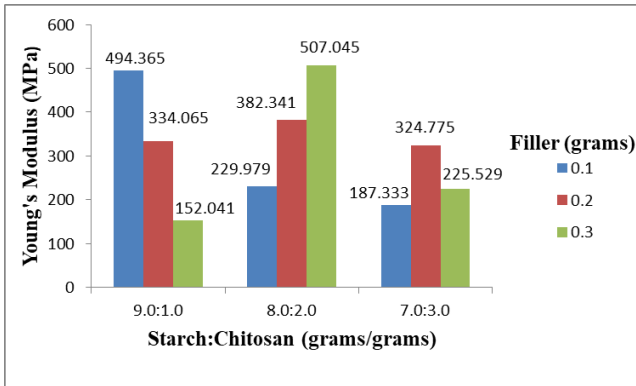


Fig. 3. Effect of Starch-Chitosan Formulation and Cellulose Fillers on the Young's Modulus of Bioplastics.

Fig. 3 shows the effect of starch-chitosan formulation and cellulose filler on the Young's modulus of bioplastics. Based on Fig. 3, it can be seen that the Young's modulus value at a starch: chitosan mass ratio of 8:2 increases, this is in accordance with what was explained by [19] and [10], that the Young's modulus value increases with increasing cellulose and chitosan fillers. However, at starch:chitosan mass ratios of 9:1 and 7:3, the Young's modulus value tends to decrease, this is inversely proportional to what was explained by [19] and [10]. As explained in the tensile strength analysis, that The inhomogeneity of the cellulose and chitosan fillers in bioplastics causes a decrease in the tensile strength value, so that the addition of cellulose and chitosan fillers which should increase the tensile strength and stiffness actually reduces the tensile strength and results in a decrease in the Young's modulus value.

Bioplastics with Young's modulus values that meet LDPE standards are bioplastics with a mass ratio of starch: chitosan 9: 1 filler 0.1 and 0.2 grams, namely 494.362 MPa and 334.065 MPa, a mass ratio of starch chitosan 8: 2 filler 0.1 and 0.2 grams are 229.979 MPa and 382.341 MPa, and the mass ratio of starch:chitosan 7:3 filler 0.1, 0.2 and 0.3 grams are 187.333 MPa, 324.775 MPa and 225.529 MPa. Where the amount of Young's modulus for LDPE plastic is between 170-500 MPa.

3.3 Physical Properties Analysis

3.3.1 Water Absorption Analysis

The results of the analysis of water absorption in bioplastics from a mixture of sorghum-chitosan, cellulose filler and glycerol plasticizer can be seen in Fig. 4.

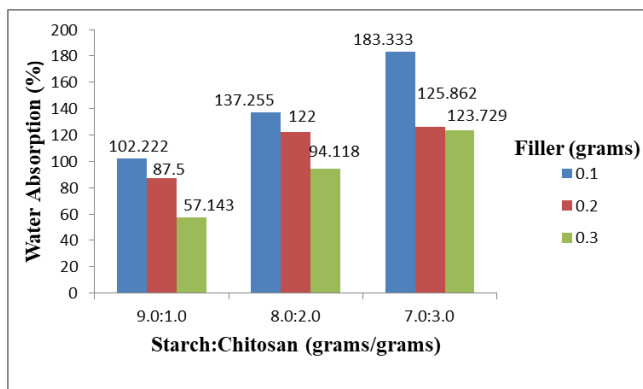


Fig. 4. Effect of Starch-Chitosan Formulation and Cellulose Fillers on Water Absorption of Bioplastics

Fig. 4. shows the effect of starch-chitosan formulation and cellulose filler on the water absorption of bioplastics. Based on Fig. 4, it can be seen that the water absorption value of bioplastics decreases as the amount of cellulose filler increases. This is because cellulose can reduce water absorption capacity. In terms of chemical structure, cellulose has strong hydrogen bonds making it difficult to combine with water [20]. However, water absorption in bioplastics increases as the amount of chitosan added increases. This is because the addition of chitosan can cause an increase in water content due to the nature of chitosan which is able to absorb water (hygroscopic), a bond occurs between chitosan polycations (NH_2^+) and water (H_2O) to become NH_3^+ and OH^- [21].

In this study, the lowest bioplastic water absorption value was obtained in bioplastics with a mass ratio of starch: chitosan 9: 1 and cellulose filler 0.3 grams, namely 57.143%. While the highest water absorption was obtained at a mass ratio of starch: chitosan 7: 3 and cellulose filler 0.1 gram, namely 183.333%. The LDPE standard for water absorption is 0.005-0.01%, so the resulting water absorption value does not meet the LDPE standard.

3.3.2 Density Analysis

The results of density analysis of bioplastics from a mixture of sorghum-chitosan, cellulose filler and glycerol plasticizer can be seen in Fig. 5.

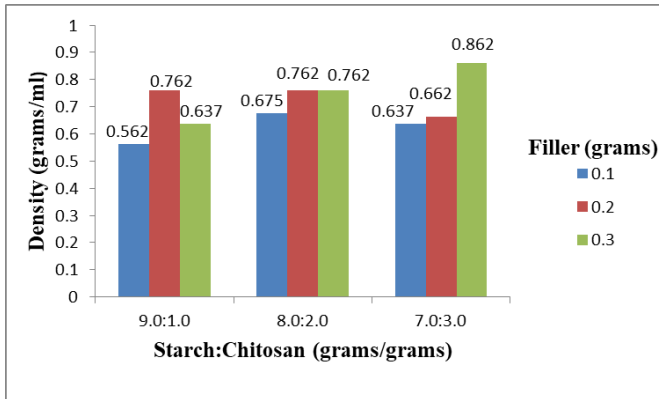


Fig. 5. Effect of Starch-Chitosan Formulation and Cellulose Fillers on Bioplastic Density.

Fig. 5 shows the effect of starch-chitosan formulation and cellulose filler on bioplastic density. Based on Fig. 5, it can be seen that the density value generally tends to increase with the addition of cellulose filler, only for one type of starch: chitosan mass ratio of 9: 1, filler is 0,3 grams, reduced density value. Then, when chitosan is added, the density value also tends to increase, only at a starch:chitosan mass ratio of 7:3, fillers of 0.1 and 0.2 grams, the density value decreases. The tendency to increase the density of bioplastics with the addition of cellulose and chitosan fillers is because with the addition of cellulose and chitosan fillers, the number of pores or cavities in the bioplastics will decrease because they are filled with cellulose or chitosan fillers so that the resulting bioplastics are denser or have a greater density [17].

The highest density value was obtained in bioplastics with a starch: chitosan mass ratio of 7:3 0.3 grams filler, namely 0.862 grams/ml. This density value does not meet the standard LDPE density value of 0.91 grams/ml - 0.93 grams/ml.

3.4 Fourier Transform Infra Red (FTIR) Analysis

Functional group analysis aims to determine the functional groups contained in a compound/sample [23]. The results of FTIR analysis of sorghum starch, corn stalk cellulose filler, chitosan, and bioplastics can be seen in Fig. 6 below.

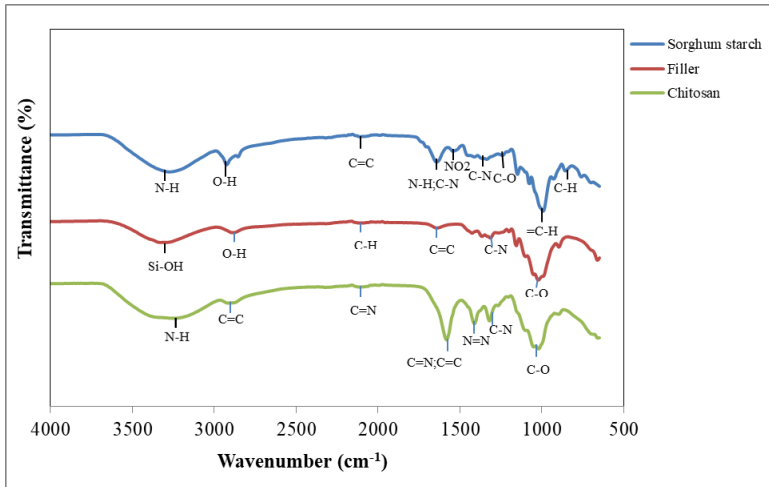


Fig. 6. The FTIR Spectrograms of Sorghum Starch, Filler, and Chitosan.

Based on Fig. 6, the results of the analysis of sorghum starch functional groups are obtained, namely the N–H functional group is shown at a wave number of 3280.1 cm^{-1} , O–H at 2922.2 cm^{-1} , C=C at 2109.7 cm^{-1} and 1640.0 cm^{-1} , combination of N–H and C–N at 1543.1 cm^{-1} , NO_2 at 1341.8 cm^{-1} , C–N at 1244.9 cm^{-1} , C–O at 1148.0 cm^{-1} , =C–H at 998.9 cm^{-1} , and C–H at 857.3 cm^{-1} . The results of the functional group analysis of the corn stalk cellulose filler, namely the Si–OH functional group, are shown at a wave number of 3332.2 cm^{-1} , O–H at 2892.4 cm^{-1} , C–H at 2892.4 cm^{-1} , C=C at 2117.1 cm^{-1} , 1640.0 cm^{-1} , and 1431.3 cm^{-1} , C–N at 1312.0 cm^{-1} , and C–O at 1021.3 cm^{-1} . The results of the analysis of chitosan functional groups, namely the N–H functional group, are shown at a wave number of 3250.2 cm^{-1} , C=C at 2117.1 cm^{-1} , a combination of C=N and C=C at 1580.4 cm^{-1} , N=N at 1416.4 cm^{-1} , C–N at 1319.5 cm^{-1} , and C–O at 1021.3 cm^{-1} [22].

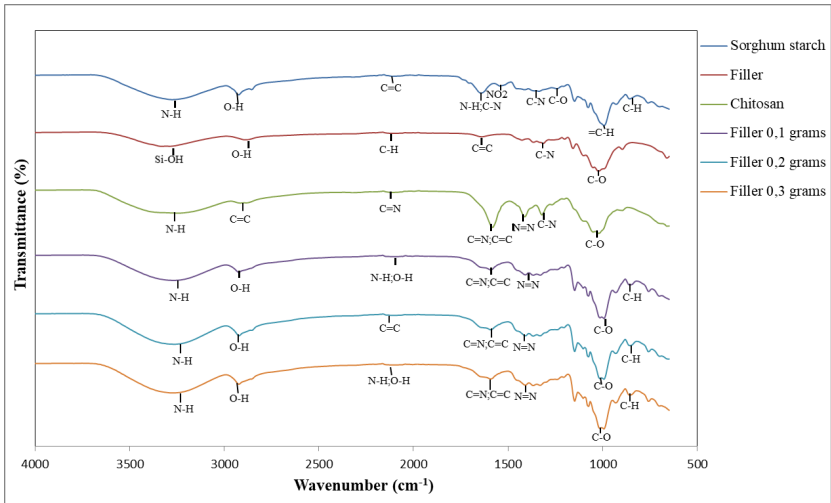


Fig. 7. The FTIR Spectrograms of Bioplastics with Starch: Chitosan 9:1 and Filler 0.1; 0.2; 0.3 grams

Based on Fig. 7, the results of analysis of bioplastic samples with a starch:chitosan mass ratio of 9:1 and 0.1 gram filler, namely the N–H functional group, are shown at a wave number of 3265.1 cm^{-1} , O–H at 2922.2 cm^{-1} , combination of N–H and O–H at 2087.3 cm^{-1} , combination of C=N and C=C at 1595.3 cm^{-1} , N=N at 1408.9 cm^{-1} , C–O at 1148.0 cm^{-1} and 1013.8 cm^{-1} , C–H at 857.3 cm^{-1} [22].

The results of the analysis of bioplastic samples with a starch:chitosan mass ratio of 9:1 and 0.2 gram filler, namely the N–H functional group, are shown at a wave number of 3265.1 cm^{-1} , O–H at 2922.2 cm^{-1} , C=C at 2117.1 cm^{-1} , the combination of C=N and C=C at 1595.3 cm^{-1} , N=N at 1408.9 cm^{-1} , C–O at 1148.0 cm^{-1} and 1013.8 cm^{-1} , C–H at 857.3 cm^{-1} [22].

The results of the analysis of bioplastic samples with a starch:chitosan mass ratio of 9:1 and a filler of 0.3 grams, namely the N–H functional group, are shown at a wave number of 3265.1 cm^{-1} , O–H at 2922.2 cm^{-1} , a combination of N–H and O–H at 2087.3 cm^{-1} , combination of C=N and C=C at 1595.3 cm^{-1} , N=N at 1408.9 cm^{-1} , C–O at 1148.0 cm^{-1} and 1013.8 cm^{-1} , C–H at 857.3 cm^{-1} [22].

The following is as Fig. 8 which shows the results of FTIR analysis of bioplastics with starch: chitosan 8:2 and the filler 0.1; 0.2; 0.3 grams.

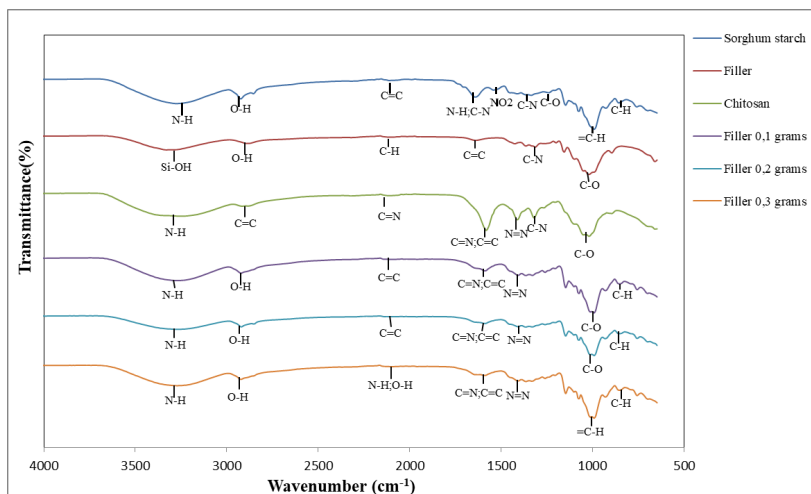


Fig. 8. The FTIR Spectrograms of Bioplastics with Starch: Chitosan 8:2 and Filler 0.1; 0.2; 0.3 grams.

Based on Fig. 8, the results of analysis of bioplastic samples with a starch:chitosan mass ratio of 8:2 and 0.1 gram filler, namely the N–H functional group, are shown at a wave number of 3272.6 cm^{-1} , O–H at 2922.2 cm^{-1} , C=C at 2102.2 cm^{-1} , combination of C=N and C=C at 1587.8 cm^{-1} , N=N at 1408.9 cm^{-1} , C–O at 1148.0 cm^{-1} and 1013.8 cm^{-1} , C–H at 857.3 cm^{-1} [22].

The results of the analysis of bioplastic samples with a starch:chitosan mass ratio of 8:2 and a filler of 0.2 grams, namely the N–H functional group, are shown at a wave number of 3265.1 cm^{-1} , O–H at 2922.2 cm^{-1} , C=C at 2102.2 cm^{-1} , the combination of C=N and C=C at 1595.3 cm^{-1} , N=N at 1408.9 cm^{-1} , C–O at 1148.0 cm^{-1} and 1013.8 cm^{-1} , C–H at 857.3 cm^{-1} [22].

The results of the analysis of bioplastic samples with a starch:chitosan mass ratio of 8:2 and 0.2 gram filler, namely the N–H functional group, are shown at a wave number of 3265.1 cm^{-1} , O–H at 2922.2 cm^{-1} , a combination of N–H and O–H at 2094.8 cm^{-1} , combination of C=N and C=C at 1595.3 cm^{-1} , N=N at 1408.9 cm^{-1} , C–O at 1148.0 cm^{-1} , =C–H at 998.9 cm^{-1} , C–H at 857.3 cm^{-1} [22].

The following is as Fig. 9 which shows the results of FTIR analysis of bioplastics with starch:chitosan 7:3 and the filler 0.1; 0.2; 0.3 grams.

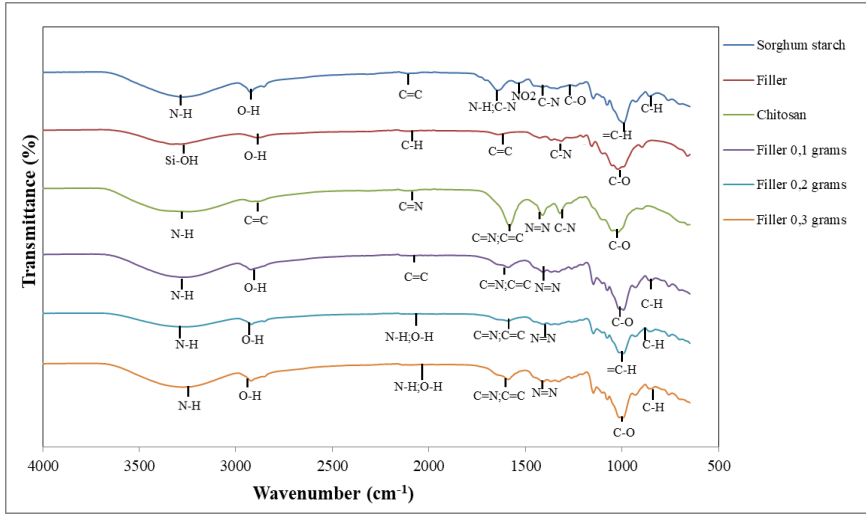


Fig. 9. The FTIR Spectrograms of Bioplastics with Starch: Chitosan 7:3 and Filler 0.1; 0.2; 0.3 grams.

Based on Fig. 9, the results of analysis of bioplastic samples with a starch:chitosan mass ratio of 7:3 and 0.1 gram filler, namely the N–H functional group, are shown at a wave number of 3265.1 cm^{-1} , O–H at 2922.2 cm^{-1} , C=C at 2102.2 cm^{-1} , combination of C=N and C=C at 1595.3 cm^{-1} , N=N at 1408.9 cm^{-1} , C–O at 1148.0 cm^{-1} and 1013.8 cm^{-1} , C–H at 857.3 cm^{-1} [22].

The results of the analysis of bioplastic samples with a starch:chitosan mass ratio of 7:3 and a filler of 0.2 grams, namely the N–H functional group, are shown at a wave number of 3280.1 cm^{-1} , O–H at 2922.2 cm^{-1} , a combination of N–H and O–H at 2087.3 cm^{-1} , combination of C=N and C=C at 1595.3 cm^{-1} , N=N at 1326.9 cm^{-1} , C–O at 1148.0 cm^{-1} , =C–H at 998.9 cm^{-1} , C–H at 857.3 cm^{-1} [22].

The results of analysis of bioplastic samples with a starch:chitosan mass ratio of 7:3 and 0.2 gram filler, namely the N–H functional group, are shown at a wave number of 3272.6 cm^{-1} , O–H at 2922.2 cm^{-1} , a combination of N–H and O–H at 2094.8 cm^{-1} , combination of C=N and C=C at 1595.3 cm^{-1} , N=N at 1408.9 cm^{-1} , C–O at 1148.0 cm^{-1} and 1013.8 cm^{-1} , C–H at 857.3 cm^{-1} [22].

Based on Fig. 7 to Fig. 9, the results of functional group identification at mass ratios of starch: chitosan 9:1, 8:2, and 7:3 show the presence of functional groups N–H, O–H, C=C, combination of N–H and O–H, combinations of C=N and C=C, N=N, C–O, =C–H and C–H. From the results of the analysis of the functional groups of bioplastics, when compared with the functional groups in the constituent materials (starch, cellulose, chitosan), it can be seen that the results of the functional groups contained in the analysis results of bioplastic samples are a combination of the functional groups contained in the constituent materials (starch, cellulose, chitosan). This observation indicates that the bioplastic was produced through a physical blending process, as no new

functional groups were detected. Consequently, the bioplastic film retains its inherent hydrophilic properties, similar to those of its constituent materials, allowing it to absorb significant amounts of water [23].

3.5 Scanning Electron Microscopy (SEM) Analysis

SEM (Scanning Electron Microscopy) analysis was carried out to determine the morphological structure of the resulting bioplastic. The cross-sectional structure of LDPE plastic and bioplastic is shown in Fig. 6 and Fig. 7 with a magnification of 2,500 \times .

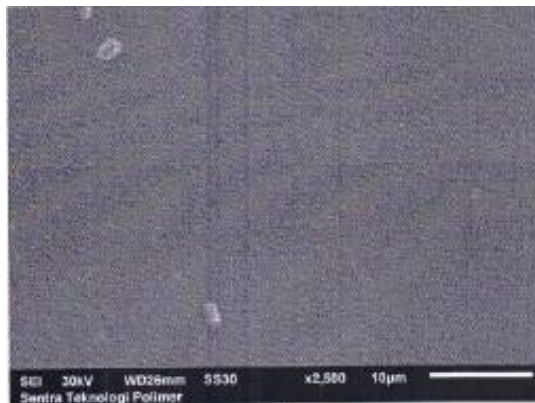


Fig. 10. LDPE (Source: [24]).

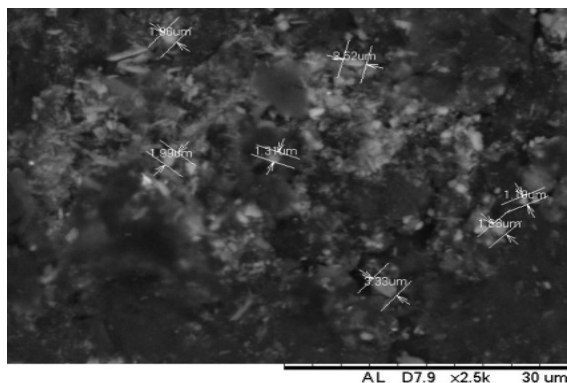


Fig. 11. SEM Analysis of Bioplastics on Starch:Chitosan 9:1 g/g and Filler 0.2 grams.

Fig. 10 and Fig. 11 present the SEM analysis results of LDPE plastic and bioplastic, respectively, with a magnification of 2,500 \times . Upon examination of Fig. 10 and Fig. 11, it is evident that the morphology of LDPE plastic exhibits a more uniform structure compared to the bioplastic sample with a starch-to-chitosan mass ratio of 9:1 and a filler content of 0.2 grams. This discrepancy can be attributed to the less homogeneous nature

of the bioplastic solution [23]. Furthermore, the surface of the bioplastic displays granules or clusters that remain undissolved within the material. These granules are likely attributable to unmixed chitosan and agglomerated cellulose, resulting in an uneven surface structure of the bioplastic. Moreover, the presence of cellulose fillers of varying sizes contributes to the irregularity observed in the surface structure of the bioplastic [23].

4 Conclusions

This study explored the feasibility of utilizing sorghum starch and corn stalk cellulose fibers as raw materials for producing bioplastics. The chemical and mechanical treatments applied to the corn stalks resulted in an increase in cellulose content, which is essential for enhancing the properties of bioplastics. The synthesis process involved blending sorghum starch, chitosan, and corn stalk cellulose fibers, along with glycerol, acetic acid, and distilled water in various ratios. The resulting bioplastic samples exhibited hydrophilic properties due to the physical blending process, as evidenced by SEM analysis. However, SEM analysis also revealed uneven surface structures in the bioplastic samples, likely due to the presence of unmixed chitosan and agglomerated cellulose fillers. Furthermore, variations in cellulose filler sizes contributed to the irregularities observed. Despite these challenges, the bioplastic samples demonstrated potential as environmentally friendly alternatives to conventional plastics. Future research efforts could focus on optimizing the blending process to achieve more uniform and homogeneous bioplastic samples with improved mechanical and physical properties. Overall, this study contributes valuable insights into the development of bioplastics using agricultural waste materials, paving the way for sustainable and eco-friendly plastic alternatives.

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