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RESEARCH ARTICLE

The Addition of Calcium Carbonate ($CaCO_3$) from *Anadara granosa* and Glycerol on The Quality of Bioplastic

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ABSTRACT

Bioplastic material is derived from natural materials that microorganisms can break down producing water and carbon dioxide. With the expansion of chitosan, $CaCO_3$ from *Anadara granosa* and glycerol, the structure of the materials utilized to create bioplastics from custard squander. The technique utilized was a trial, which started with producing chitosan and $CaCO_3$ from *Andara granosa*. The production of bioplastics was completed with custard squander composites blended in with *Anadara granosa* with an organization of 80% : 20% with the expansion of $CaCO_3$ and glycerol. The ratio of $CaCO_3$ and glycerol differed into four creation proportions 0.3 g : 10 mL; 0.3 g : 15 mL; 0.4 g : 10mL; 0.4 g : 15 mL. Tensile strength upsides of tests 1 10.98 MPa. The elongation test values are sample 1 23.79%, sample 2 22.00%, sample 3 19.16%, and sample 4 23.80%. In the after effects of biodegradation tests with soil media, the worth is near sample 2 which can be evaluated by 51.5% with an ideal structure of the proportion of $CaCO_3$ and glycerol 0.3 g : 15 mL.

Introduction

Single-use plastics are commonly used in daily life. Approximately one trillion plastics are used worldwide each year. The degradation characteristics of conventional plastics manufactured from petroleum were low. The decomposition of plastic bags can take 500 to 1,000 years, making plastic a major source of global waste and environmental damage [1]. Owing to their chemical and physical characteristics, these plastics have a high resistance against microorganisms and other degradation forces. This has led to problems in waste management in terms of environment and land scarcity [2]. To reduce the ecological effects, biodegradable plastics from sustainable assets coherently address the best chance. Bioplastics appear to be alluring eco-friendly elective plastics because they can handily corrupt them [3].

Another drawback is their resistance to natural degradation, which leads to plastic waste accumulation and pollution. Natural resources, such as starch, cellulose, collagen, proteins, and lipids from animals, are used to develop environmentally friendly plastics. These plastics are easily biodegraded by microbial decomposers and are known as biodegradable plastics. As an alternative, the development of biodegradable plastics has become a focus in food packaging. Biodegradable plastics are expected to decompose quickly in the environment because of their moisture and microorganisms [4]. In the production of bioplastics, raw materials are derived from natural or solid wastes from plants and animals. Bioplastics have the potential to decrease dependence on oil by reducing greenhouse gas emissions [5].

Some studies by Sari et al. [6] and Udyani [7] have used cassava and sweet potato as raw materials for bioplastic production. According to Rahim and Musta [8], starch serves as a food source for microorganisms involved in biodegradation. However, the use of single materials, such as starch, still has drawbacks, such as brittleness and rigidity. Therefore, it is important to add specific substances to improve the quality and mechanical properties of bioplastics. Chitosan is added to the process of making bioplastics to improve their mechanical properties. Plasticizers are added to chitosan to improve the versatility of biopolymer plastics.

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Plasticizers, such as glycerol, glycerin, and sorbitol, can be used [9]. Plasticizers are generally utilized as additives during the preparation of bioplastics. Plasticizers are non-unusual compounds with low subnuclear weights. The polymer chain is capable of adaptation and break-resistance and has a high dielectric consistency. The thickness, elasticity, hardness, and electric charge of the polymer are reduced. Glycerol is a widely used plasticizer, mostly in the plastics industry [10]. $CaCO_3$ can be used to improve the properties of composite materials. The nanometer-sized calcium carbonate particles caused polypropylene to have greater tensile and flexural strengths. The nanocomposite module increases by 85% with the added of calcium carbonate. However, there was not much change in the ultimate stress and strain, yield pressure, or strain [11].

Research conducted by Udyani [7] resulted in plastics with favorable characteristics, namely transparency, absence of bubbles, and hardness, with a starch: chitosan: glycerol: poly lactic acid (PLA) ratio of 10: 2: 2: 4 at starch concentrations of 10% and 20%. The water absorption capability was 2.71%. Widyastuti et al. [12] stated that the optimal composition on bioplastic production was a banana peels: tapioca flour: glycerol of 1: 13: 11.25 g in terms of tensile strength and elongation of 10.9 MPa and 29%, respectively. The biodegradation rate was 58%. In the Fourier Transform Infra-Red (FTIR) analysis, the OH, CH, C = O, C = C, CO, and =CH functional groups were detected in the biopest composition. In a study by Widyastuti et al. [13], the ideal bioplastic organization was accomplished utilizing custard flour as the base material, with the expansion of chitosan and glycerol in a proportion of 70%: 30%: 5 mL, resulting in a biodegradation rate of 43%.

Bioplastic produced using custard flour with chitosan and glycerol had rigidity upsides of 0.75 MPa for sample 1, 0.54 MPa for sample 2, and 0.34 MPa for sample 3. The stretching values at break were 23.68% and 15.33% for sample 2, and 12.12% for Samples 1, 2, and 3, respectively. Functional groups (C=C), CO, CH, OH, C=C, and CH_{2n}) were found in the chemical composition of bioplastics made from tapioca flour by adding chitosan and glycerol. This research was conducted in Sari et al. [6] used $CaCO_3$ as a filler for bioplastic production. The results indicated that a $CaCO_3$ 3% composition of 3% represents the optimal concentration, resulting in the highest mechanical properties, including a tensile strength of 7.5522 MPa, elongation of 9.64%, and Young's modulus of 0.7834 MPa. The compositions used in bioplastic production have varied across several studies, resulting in diverse bioplastic qualities. The objective of this study is to ascertain the quality of bioplastic with an optimal composition involving the addition of $CaCO_3$ and the volume of glycerol.

Materials and Methods

The raw materials for this research consisted of tapioca waste obtained from the cassava squeezing process, which was finely ground and dried in the form of chitosan powder that passed through a 200-mesh sieve and was derived from blood cockle shells, $CaCO_3$ from blood cockle shells, glycerol, ethanol, acetic acid, NaOH, and distilled water. The equipment included glass molds, a digital scale, a water bath, measuring cups, beakers, stirrers, mortar and pestle, a blender, and a 200-mesh sieve.

The Proses of Chitosan Production

Chitosan in the form of powder derived from blood cockle shells was produced through the following process [7]: 1) Protein separation (deproteinization). The sieved (200-mesh) blood cockle shell powder was placed into a glass beaker, and a 3.5% NaOH solution was added to it at a ratio of 1 : 10 (w/v) between the shell powder and the NaOH solution. At 65 °C, the process lasted two hours and consisted of stirring. A filter paper was then used to filter the solution to obtain this residue. The next step involved washing the residue with distilled water until a neutral pH was achieved. The washed residue was then dried in an oven at 100 °C until it was completely dry, resulting in what is referred to as crude chitin. 2) Mineral separation (demineralization). Demineralization was performed by placing the crude chitin in a glass beaker and adding 1 NHCl solution at a ratio of 1 : 10 (w/v) between the crude chitin and HCl solution.

This procedure was performed at room temperature with stirring for 30 min. To obtain the residual, the resulting mixture was filtered using filter paper. The residue was subsequently washed with deionized water until a neutral pH was achieved and then dried in an oven at 100 °C until it was completely dry, resulting in a powder known as chitin. 3) Deacetylation, this stage involves the transformation of chitin into chitosan. The chitin powder was placed in a three-necked flask, and a 50% NaOH solution was added at a ratio of 1 : 10 (w/v) between the chitin powder and the NaOH solution. The mixture was then strained for 5 h with stirring at 100 °C. A filter paper was used to filter the resulting mixture to obtain the residue. Distilled water was used to wash the residues until they had reached neutral pH and then dried in an oven at 100 °C for a maximum of 15 minutes.

Production Process of $CaCO_3$ from Cockle Shells

First, the cockle shells were washed with water to remove impurities. Subsequently, they were soaked in 10% NaOH alkaline solution for 4 h. After soaking, the cockle shells were rinsed with distilled water to neutralize them from the NaOH solution. To reduce the moisture content within the cockles, they were subjected to 24 h of air drying at room temperature, followed by an additional 10 min in a 100 °C oven. The cockle shells were crushed using a mortar and pestle until they broke into pieces, and then finely ground using an electric blender until they became a powder. The powder was passed through a 200-mesh sieve to obtain the desired particle size.

Experimental Design

This research was conducted experimentally at the Environmental Engineering Laboratory of the Universitas PGRI Adi Buana Surabaya. The study consisted of four variables, with a composition of 80% tapioca waste and 20% chitosan in a total mass of 20 g. The ratios of adding $CaCO_3$ and glycerol are provided in Table 1. The control group in this study consisted of one composition using tapioca waste as the raw material without the addition of chitosan, $CaCO_3$ from blood cockle shells, or glycerol.

Table 1. Comparison of $CaCO_3$ and glycerol.

Sample code	Variation $CaCO_3$: Glycerol
Sample 1	0.3 g : 10 mL
Sample 2	0.3 g : 15 mL
Sample 3	0.4 g : 10 mL
Sample 4	0.4 g : 15 mL

The process of bioplastic production involved mixing all raw materials, including tapioca waste, chitosan, $CaCO_3$, and glycerol, according to predetermined variable ratios. Deionized water and 1% acetic acid were then added before heating on a hotplate at 80 °C for 30 min. The homogeneous mixture was then molded into a mold. The mold solution was dried at 60 °C for three hours and cooled to room temperature for six hours. Another component is the centralization of the plasticizer. The grouping of plasticizers should be enhanced to create starch-based bioplastics that are precisely sturdy and adaptable. The most advanced convergence of plasticizers was in the range of 20 to 40%. The water ingestion of starch-based films has been expanded with a higher substance of glycerol and is bringing about a diminished unbending nature because of the accumulation of glycerol over 35% [14].

In accordance with the American Standard Testing and Material (ASTM) methods or in a laboratory that has adopted ISO/IEC 17025 standards, the quality of bioplastics should be measured according to parameters such as tensile strength and elongation at break FTIR analysis will be conducted using infrared wavelength to determine the chemical compounds present in the bioplastic. The thermoplastic should meet the prerequisites for a weighty metal substance, which should be less than 0.5 ppm for Cd, less than 50 ppm for Pb, less than 0.5 ppm for Hg, and less than 50 ppm for Cr^{6+}. Biodegradation testing involved the preparation of 2 × 6 cm samples, weighing them, burying them at a depth of 10 cm for one week, and then drying and reweighing the samples to determine their constant weight. The minimum requirement for biodegradation testing is a degradation rate of 30%.

Results and Discussion

Tensile Strength and Elongation at Break Test Results in Bioplastics

As shown in Table 2, the highest tensile strength test result for bioplastic was 10.98 MPa in sample 1 with the addition of 0.3 g of $CaCO_3$ and 10 mL of glycerol. The lowest elongation at break was 19.16% in sample 3. Figures 1 and Figure 2 present the aftereffects of elasticity and extension-at-break tests on bioplastics. The highest obtained value was 10.98 MPa for sample 1, which had a $CaCO_3$: glycerol ratio of 0.3 g: 10 mL. In the elongation at break test results, the lowest value was 19.16% in sample 3, which had a $CaCO_3$: glycerol ratio of 0.4 g: 10 mL.

If stronger plastics are produced and chitosan is added to them, adding more glycerol increases the tensile strength until this maximum point has been reached because the manufactured plastic is less strong. Bioplastics possess tensile strength that is derived from the tension at which they break down, as well as their strain [15]. This is due to the hygroscopic nature of glycerol, which makes it easy for a biopharmaceutical film to absorb and retain moisture, resulting in an approximate increase in the break time. Glycerol is a plasticizer that increases the flexibility of the cellulose rim and leads to slightly longer break lengths [16]. A lower tensile strength indicates that the material can easily deform with plastic behavior. Because of the smaller size of the sample, there was an increased degree of homogeneity compared to larger sizes, which led to a consistent distribution of bioplastic constituent molecules. In contrast, larger dimensions have a reduced degree of homogeneity, which makes it difficult for bioplastic constituents to be uniformly distributed [17].

Table 2. Test data result tensile strenght and elongation at break.

Sample code	Tensile strenght test (MPa)	Elongation at break test (%)
Sample 1	10.98	23.79
Sample 2	1.81	22.00
Sample 3	2.04	19.16
Sample 4	3.83	23.80

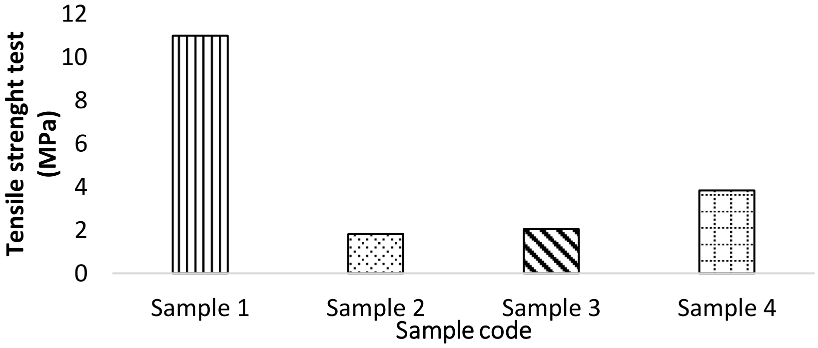

Figure 1. Data results tensile strength.

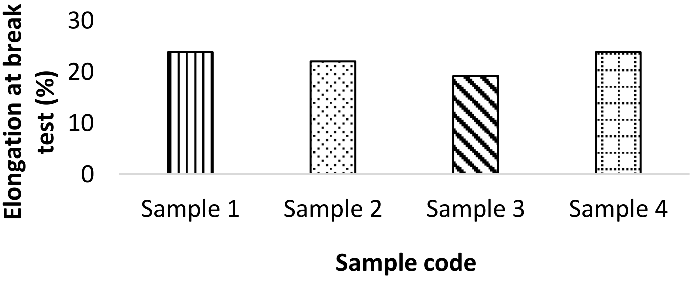

Figure 2. Data results elongation at break.

In the research conducted by Sari et al. [6] on the creation of bioplastics from cassava tubers, the ideal grouping of chitosan has been viewed as 6%, resulting in an elasticity of 8.75 MPa, prolongation of 11.83%, and Young's modulus of 0.7482 MPa. The ideal focus is 3% $CaCO_3$, with the best mechanical properties, an elastic coefficient of 7.5522 MPa, a lengthening variable of 9.64%, and a Young modulus of 0.7834 MPa. In this study, 4 g of chitosan being used out of a total mass of 20 g. Additionally, 0.4 g of $CaCO_3$ from the blood cockle shells was added. In this study, the elongation at break rate was above the permissible limit of 5% for the bioplastic samples. According to Widodo et al. [18], the elongation increases with the addition of glycerol. This is because the increased glycerol content leads to greater intermolecular matrix structure stretching in the edible films, making the resulting edible film more flexible. Based on this, it is assumed that the composition of chitosan with the addition of $CaCO_3$ and glycerol in this study was unbalanced. During the production of bioplastics, the addition of raw materials significantly influences the resulting quality. According to Hidayat et al. [4], the tensile strength of bioplastics may be reduced by the addition of chitosan, which in turn makes them more brittle. In addition, by reducing the water content of the bioplastics, thereby promoting a denser and more homogeneous molecular structure, which can increase the tensile strength, heating also affects the tensile strength of bioplastics. In addition, an increase in the proportion of biodegradable plastic was linked to increased levels of glycerol.

The highest stress a film can withstand before breaking is the tensile strength. Because glycerol weakens the molecular bonding power of cellulose and improves its flexibility, its application to cellulose derived from bioplastics impacts the tensile strength [19]. The expansion of more calcium carbonates decreased the tensile strength of the bio-plastic with calcium carbonate. The structure of the bioplastics was shown to be different. The construction of an unseen atom has some branches, but there is no firm organization, so the distance between particles is high, and their connections are weak. The lack of a nuclear bond in bio-plastics causes the power to separate plastics from each other to be relatively weak [20]. As the glycerol content increased, the Young's modulus decreased. This is because the expansion of glycerol can reduce the intermolecular power and increase the versatility of the biopolymer chain, resulting in this way bringing about a milder and stretchable film, which is reasonable for e-skin applications [21].

Biodegradation Test Results on Bioplastics

Data from the biodegradation tests conducted at the Laboratory of Engineering, Universitas PGRI Adi Buana Surabaya, are presented in Table 3 and Table 4. The results of the biodegradation tests on the bioplastic are quite significant (Table 3 and Table 4). The highest biodegradation value was observed in sample 4, 50.7% (Figure 3). Right when glycerol was incorporated into the custard waste chitosan bioplastics, the degradability of bioplastics film was similarly extended. Glycerol reduces the intermolecular force of starch and chitosan, provoking a basic diminishing in film strength. The strength of tapioca waste chitosan composites is decreased by the plasticizer-acting glycerol additives [22]. The above figure shows the results from biodegradability testing for bioplastics.

Table 3. Bioplastic biodegradation data results.

Sample code	Initial weight (g)	Final weight (g)
Sample 1	0.115	0.169
Sample 2	0.130	0.063
Sample 3	0.067	0.187
Sample 4	0.126	0.170

Table 4. Bioplastic biodegradation test calculation results.

Sample code	Biodegradation value (%)
Sample 1	35.5
Sample 2	51.5
Sample 3	47.8
Sample 4	50.7

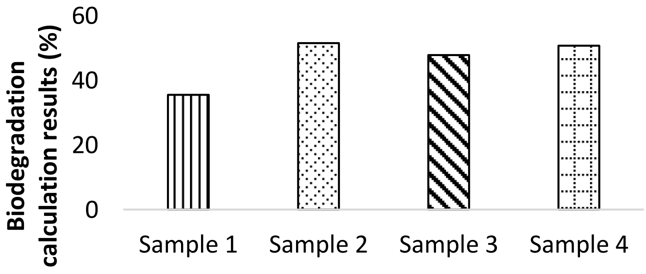

Figure 3. Bioplastic biodegradation calculation results.

The biodegradation analysis of the bioplastic indicates that samples with a composition of 80% cassava starch waste and 20% chitosan, with the addition of $CaCO_3$ and glycerol in the following ratios; sample 1 (0.3 g : 10 mL), sample 2 (0.3 g : 15 mL), sample 3 (0.4 g : 10 mL), and sample 4 (0.4 g : 15 mL), can degrade well in soil media for 7 days. The ability to degrade in the soil is demonstrated by the reduction in plastic weight. The biodegradation test results for sample 1 (35.5%), sample 2 (51.5%), sample 3 (47.8%), and sample 4 (58.7%), respectively. Research conducted by Widyastuti et al. [12], indicates that the biodegradation values for banana peels A and B were 66.7% and 85.3%, as the case may be. The biodegradability values are 58% and 79% for samples C and D, which contain rice waste. Compared to samples A and C, both biodegradation values in the sample B and D used cassava starch and glycerol amounts of 13 g and 11.25 g have been found to be higher.

The production of these bioplastics has been based on chitosan, which allows microorganisms to penetrate polymer chains in a very effective manner into the plastic itself [23]. The expansion of filler ($CaCO_3$) was seen to diminish the ability to biodegrade of the examples, as expanding how much filler decreased the biodegradation capacities of the examples. The expansion of plasticizer (glycerol) expanding the biodegradability of the examples can be attributed to more prominent water take-up also, dissolvability of the examples, which is because of the hydrophilicity of plasticizers [24]. The higher degree of glycerol in bioplastics, which makes it easier for bacteria to break down plastic examples on the grounds that glycerol is hydrophilic and accelerates water uptake, leads to high retention of water by bioplastics [25]. Adding glycerol improved bioplastic properties, including expanding, degradation, dissolvability, and water seethe transmission rate, yet diminished adaptability and straightforwardness [26].

According to Sari et al. [6], the bioplastics obtained from cassava tuber starch are influenced by added chitosan and $CaCO_3$ fillers. Water resistance is directly correlated with the concentration of chitosan and $CaCO_3$, whereas bioplastic degradation capacity is inversely correlated. This assertion is predictable with discoveries from this study where the expansion of chitosan and $CaCO_3$, at satisfactory focuses, altogether affects biomass biodegradation. In the meantime, a biodegradation value of 1.1% is observed in the control sample, which is a control variable with a composition of cassava starch that does not contain chitosan, $CaCO_3$ or glycerol. It follows from this that the hygroscopic properties of these plasticizers such as glycerol, which allow them to readily consume water and quickly decompose in the environment, necessitate their addition. In this study, sample 2 achieved a degradation rate of 51.5% with $CaCO_3$ and glycerol ratios of 0.3 g : 15 ml, an optimal composition for bioplastics. Debasement rates have been delayed in the initial three days, as soil bacterial biota has adjusted to another climate and is expanding again following four days. Carbon sources needed to grow and multiply microbes are found in the constituents like starch, pectin or cellulose. Extracellular hydrolysing enzymes are produced by soil organisms. In order to initiate bacterial biodegradation of the film enzymes, such as pectinases, cellulases and hemicellulases bind together with materials containing pectin, cellulose or heliliculosic content [27].

Data Analysis and Discussion of FTIR Test Results

The FTIR test data consists of peak values representing the functional groups composing the bioplastic at specific absorbances (Table 5). In this study, a total of eight compounds have been identified which are differentiated by their peak values. The absorbance range of 662.56 to 3,443.96 is observed for bioplastic samples in this study. The formation of hydrogen bonds due to interactions between hydrogen atoms and electronegative oxygen atoms is indicated by the presence of hydroxyl groups OH in bioplastics. FTIR analysis results from previous research by Widyastuti et al. [12] uncovered 11 distinct mixtures with differing top qualities, containing dextrose monohydrate powder, which is a white, dull powder. Hydroxy-propyl-beta-butyl-cyclodextrin is a compound with low dissolvability in water. With respect to bioplastic substances in all medicines, top qualities are somewhere in the range of 400 and 500 which demonstrates that they promptly break down into water because of their more significant levels of value than the guidelines on bioplastics. Notwithstanding these mixtures, the bioplastic likewise contains allyl liquor, 2-butene-1, 4-diol, glucose, methyl liquor 13c, propargyl liquor, maltose close to 100%, alpha-cyclodextrin hydrate, maltrotriose hydrate, and cyclodextrin hydrate. As affirmed by FTIR spectroscopy, the utilitarian gatherings Gracious, CH, C=O, C=C, CO, and =CH in all medicines show the arrangement of bioplastics from banana strip and rice squander.

According to Maneking et al. [28], intermolecular hydrogen bonds between hydroxyl groups of starch and hydroxyl groups of carboxyl groups of cellulose result in a denser and more homogeneous surface for bioplastics. The presence of C-O ester (COOH) groups in the tested bioplastic material using FTIR spectroscopy indicates that this bioplastic material is degradable. This statement aligns with the findings of Maneking et al. [28], indicating that bioplastics with the addition of alcohol have a smooth and non-porous surface structure. The FTIR analysis results show the presence of C-O Ester groups, categorizing the plastic as degradable. The FTIR analysis results in the production of bioplastics in this research do not indicate the presence of heavy metals in the bioplastic, with Cd < 100 ppm, Pb < 1,000 ppm, Hg < 1,000 ppm, Cr^{6+} < 1,000 ppm [29]. Additionally, bioplastics do not contain azo colorants. The bioplastics produced in this research are in the form of sheets with a smooth surface and minimal bubbles.

The presence of hydroxyl bunch O-H shows the development of a hydrogen bond as hydrogen molecules interface with an electronegative iota of one or the other oxygen, fluorine or nitrogen. Hydrogen iotas are given a halfway certain charge, although an oxygen particle has a fractional negative charge to which it can join itself, forming a hydrogen bond. As hydroxyl bunches have a hygoscopic nature, which empowers them to frame hydrogen bonds, this increases the water dissolvability of the example. Hence, bioplastics from cassava strips can retain a specific amount of water because of their elevated degrees of hydroxyl bunches, which make them more solvent in water. Likewise, the hydrocarbon chain (C-H) was viewed as present in cassava and glycerol, whereas alkene (C=C) was available in $CaCO_3$. The hydrocarbon chain is a fundamental unit in the development of plastics, wherein the carbon particles in the hydrocarbon chain are probably the groundwork of every single regular material in the polymer, while the alkene bundle is responsive and is widely used in the gathering of polymers or plastics, such as polyethene, which is made by polymerizing the most un-troublesome alkene, ethane (C_2H_4) [30].

Table 5. Bioplastic FTIR test results.

Sample code	Peak	Compounds	Sample code	Peak	Compounds
Sample 1	3,289.22	Hydroxyl group (O-H)	Sample 2	3,286.18	Hydroxyl group (O-H)
	2,919.22	Alkane (C-H)		2,921.60	Alkane (C-H)
	1,591.55	Simple aromatic compounds		1,642.66	Simple aromatic compounds
	1,412.91	Simple aromatic compounds		1,363.80	Simple aromatic compounds
	1,325.53	Simple aromatic compounds		1,148.48	Carboxyl (C-O)
	1,149.29	Carboxyl (C-O)		1,076.91	Carboxyl (C-O)
	1,102.46	Carboxyl (C-O)		1,009.72	Carboxyl (C-O)
	1,076.74	Carboxyl (C-O)		932,55	Alkenes (C=C)
	1,017.66	Carboxyl (C-O)		848,04	Alkenes (C=C)
	996,64	Alkenes (C=C)		758,25	Alkenes (C=C)
	935,61	Alkenes (C=C)		571,37	Hydrocarbons $(CH_2)n$
	757,79	Alkenes (C=C)		3,286.18	Hydroxyl group (O-H)
	571,49	Hydrocarbons $(CH_2)n$		2,921.60	Alkane (C-H)
Sample 3	3,280.76	Hydroxyl group (O-H)	Sample 4	3,284.17	Hydroxyl group (O-H)
	1,588.75	Simple aromatic compounds		1,591.88	Simple aromatic compounds
	1,374.32	Simple aromatic compounds		1,368.40	Simple aromatic compounds
	1,014.79	Carboxyl (C-O)		1,013.64	Carboxyl (C-O)

Product Bioplastic

The bioplastic produced from *Anadara granosa*, $CaCO_3$, and glycerol in this research are shown in Figure 4. Production of bioplastics was in the form of sheets. The bioplastics in samples 1, 2, 3, and 4 had a transparent brownish color, smooth surfaces, and few bubbles. The bioplastic in the control sample had a clear transparent color, smooth surface, and no elasticity.

Figure 4. Bioplastic product in sample 1 to sample 4.

Conclusion

The raw material composition of the cassava starch and chitosan, as well as addition of $CaCO_3$ and a Glycerol ratio has not yet reached optimal status according to these studies. In the biodegradation test results, the example that moves toward the quality principles most intently is sample 2, which accomplishes a debasement pace of 51.5% with the ideal creation of $CaCO_3$ and glycerol in a proportion of 0.3 g : 15 mL. The substance piece of the bioplastic produced using cassava starch with the expansion of chitosan and glycerol incorporated useful gatherings, for example, (C=C), (C-O) O, (C-H), (O-H), (C=C), and $(CH_2)_n$. The results of the FTIR test did not indicate that the bioplastics contained heavy metals. Optimizing the composition of the raw materials for bioplastic production and experimenting with the addition of $CaCO_3$ or various fillers are two examples of suggestions for future development and research.

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