Utilization of Indigenous Plants as an Additive for the Manufacture of Biodegradable Plastics

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Abstract: Plastic is the major toxic pollutants that threaten the environment. This study examines some of the indigenous plants such as the potato tuber, cassava tuber, and *gabi* tuber as a biodegradable plastic. The effect of glycerine (plasticizer) to the density and tensile strength of the finished product was investigated, and the formation of the layers becomes visible. The bioplastics made from cassava, taro, and potato were glossy and translucent. The products resemble the Elastomers Silicone and the Polyvinyl Chloride (PVC) type of plastic which is commonly used for packaging. The density and flexibility were both affected directly by the type of starch used. The bioplastic made from pure cassava has the highest moisture content of 70.800%, this means that this plastic shows signs of high electrical properties while bioplastic made from pure taro shows the lowest percentage of water absorbed, this signifies that among the six samples presented, bioplastic from pure taro is the most dielectric. There are no apparent changes in the dimensions of the six samples after one week by exposing to open air. The results indicate that the physical appearances of the bioplastics were not greatly affected by the atmospheric temperature and pressure. The samples were disintegrated after two weeks embedded in the soil and lost some mass that was presumably had been degraded to the soil.

Keywords: Indigenous plant biodegradable plastic; *Elastomers Silicone*; *Polyvinyle Chloride*; starch

1. INTRODUCTION

Plastic is the major threat of the environment (Needhidasan, 2014; Derraik, 2002). It remains on the ground, generates heat, and proves to be detrimental to the environment. Discarded plastic carry bags thrown all over the places have become a common sight, especially in cities and rural areas. Also, plastics affects the fertility of the soil (Jalil, Mian, & Rahman, 2013).

Conversion of municipal garbage wastes to useful manure through disposal by landfilling gas has also become difficult due to the presence of non-biodegradable plastic bags mixed in the garbage due to lack of proper sorting facilities at source (Atalia, Buha, Bhavsar, & Shah, 2015). The general objective of this study is to be able to produce biodegradable plastics using indigenous plants as an additive. To reduce the solid wastes generated from the process of non-biodegradable plastics and to determine whether the production of biodegradable plastics using starch materials from indigenous plants as an additive is possible.

Biodegradable plastics are those that can be completely degraded in landfills, composters or sewage treatment plants by the action of naturally occurring microorganisms (Reddy, Reddy, & Gupta 2013; Adhikari et al., 2016). Truly biodegradable plastics leave no toxic, visible or distinguishable residues following degradation. Plastics based on natural plant polymers derived from wheat or starch has molecules that are readily attacked and broken down by microbes (Ezeoha & Ezenwanne, 2013).

Starch is a natural polymer. It is a white, granular carbohydrate produced by plants during photosynthesis and it serves as the plant's energy store (Lu, Xiao, & Xu, 2009). Cereal plants and tubers normally contain starch in large proportions. Starch can be processed directly into a biodegradable plastic. It is poised to grab a bigger share of the plastic market as concerned about the environment. But, because starch is soluble in water, materials made from starch will swell and deform when exposed to moisture, limiting its use. The main thrust of this research is the development of starch-based biodegradable polymer from indigenous plants that will produce a biodegradable plastic, taking into consideration their in-use performance such as greater water resistant, mechanical properties, and greater process ability. It is also important that biodegradability or compostability is maintained so this must be taken into account during the selection of the type of processing and materials. The research will also attempt to select the perfect indigenous plant with a starch content ideal for producing biodegradable plastics.

1.1 Review of the Related Literature

Plastic bags have been introduced in the 1970's it is commonly used everywhere (Riyad, Maher, & Al, 2014). It is assessed that around 500 billion plastic sacks are utilized each year around the world (Riyad, Maher, & Al, 2014; Gogte, 2009). Plastics being made from oil may not be the most sustainable solution. They are harmful to wildlife and can take 1000's of years to decompose (Andrews, 2012). As a 'greener' solution, biodegradable plastics have been manufactured from a variety of materials, including starch-based polymers (potato, corn, wheat or tapioca starch), polyester (still made from oil products), water-soluble polymers, polymers that degrade with light or oxygen, or a blend of these (Reddy, Reddy, & Gupta 2013)

Most of the plastics, due to poor management, are discarded in unauthorized dumping sites or burned uncontrollably in the fields (Nkwachukwu, Chima, Ikenna, & Albert, 2013). Different urban areas in the Philippines have begun to disallow the utilization of plastic sacks and packaging materials in favor of paper products for waste disposal and management reasons (Biona, Gonzaga, & Ubando, 2015; Barachina, Bicongco, Garcia, & Anyayahan, 2015). Plastic shopping bags are progressively observed as environmental hazards that undermine human and animal welfare, as opposed to amiable present-day comforts (Clapp & Swanston, 2009). The solution is to develop a plastic material that biodegrades. The term biodegradable is poorly understood. Plastics that are petroleum-based do not biodegrade in the sense that they break down due to the action of moisture or microorganisms. The better term is compostable. This means that the material decomposes by 90 percent or better within six months in a landfill or dump without producing any toxic substance. This is the definition and standard in Japan, the US, and Europe.

Much attention has been focused on research to replace petroleum-based commodity plastics, in a cost-effective manner, with biodegradable materials offering competitive mechanical properties (Adhikari et al., 2016). There are three types of bioplastics that decompose according to this protocol. They are all made of starch, sometimes in combination with vegetable oil or animal fat to substitute for the polymers made from petroleum (Song, Murphy, Narayan, & Davies, 2009). Polymer materials which are degradable and additionally biodegradable have been paid to an ever-increasing extent consideration since the 1970s. Among the characteristic polymers, starch is of intrigue. It is recovered from carbon dioxide and water by photosynthesis in plants (Lu, Xiao, & Xu, 2009).

What is commercial now is polylactic acid or PLA, a starch-based bioplastic. It's made by NatureWorks, a joint venture between the US agribusiness giant, Cargill, and Teijin, a Japanese chemical company. PLA can be used to make packages for fresh foods and juices as well as a protective film for fruits, vegetables, and flowers. Using the same manufacturing process, PLA can be the intermediate material for rigid items like disposable spoons, forks, and knives or the casing of cellphones and laptops. Other applications are for textiles, diapers, sanitary napkins and filters. Products made from PLA are compostable; they break down when exposed to moisture, microorganisms, and high temperatures. (Jamshidian, Tehrany, Imran, & Jacquot, 2010).

The enthusiasm for bioplastics is developing for advertising specialties, such as in packaging and agriculture (Aranda, Gonzalez-Nuñez, Jasso-Gastinel, & Mendizabal, 2015). Starch is an efficient biopolymer that is contained in numerous natural products; it is attractive as a source to make biodegradable plastics (Aranda, Gonzalez-Nuñez, Jasso-Gastinel, & Mendizabal,2015; Vieira, da Silva, & de los Santos, 2011). Increasing public concern over environmental hazard caused by plastic, many countries are conducting various solid waste management programs including plastic waste reduction by the development of biodegradable plastic material.

There is intense research for making the biodegradable plastic (Abdullah, Sam, Zulkepli, & Ruzaidi, 2014). A plastic is biodegradable when the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae. Biodegradability is the ability of a material to be utilized as a carbon source by microorganisms and converted safely into carbon dioxide, biomass, and water.

Two very common types of biodegradable plastics are oxo-biodegradable and hydro biodegradable (Patel et al., 2011). Oxo-biodegradable plastics are usually still made from an oil by-product but contain an additive, allowing them to break down in the presence of oxygen to be consumed by microorganisms. Hydro-biodegradable plastics are starch-based plastics (sometimes a blend with oil-based material) that degrade with moisture. Bags made of 100% cornstarch can break down very quickly in the right conditions. The more starch in the blend, the faster it will degrade.

2. METHODOLOGY

To attain the objectives of this study, production of bioplastics was done in laboratory scale. Commercially available potato tubers, taro tubers, cassava tubers, cornstarch, and coconut vinegar were used in the study.

The components of the different indigenous plants; potato tubers, taro tubers, and cassava tubers, were gathered, ground and squeezed to extract the starch. Starches of these local plants are weighed individually. The treatments also consist of distilled water, corn starch, acetic acid, and glycerol. The components in every treatment were mixed, stirred and then poured in a collecting bottle and were heated until the solution becomes sticky and without bubbles. Testing of the plastic proceeds and the results are evaluated.

In materials preparation, 1000 grams of mature potato tubers, taro tubers, and cassava tubers were obtained in the local markets. The selected mature tubers weighed individually. Other ingredients that were used were: distilled water, corn starch, acetic acid, and glycerol. The apparatus and materials that are needed in the production of plastics were: grinder, cheese cloth, beaker or flask or collecting bottle, stainless steel hot plate, and burner.

The selected mature tubers of root crops were washed and peeled before shredding with the use of a grinder. 50 ml of water was added for every 59 grams of shredded tubers. The mixture was squeezed using cheese cloth. The extract was left to stand in a collecting bottle for about 24 hours. The white substance that was settled down was collected.

The amount of distilled water and starch was measured and mixed shown in Figure 1. Acetic acid and glycerol were added to the mixture. The mixture was then heated using burner until a sticky paste, free from bubbles is formed. The sticky paste was removed from the hot plate, transferred in a Petri dish and dried for at least a week. For other treatment, 5 grams of cornstarch was added.

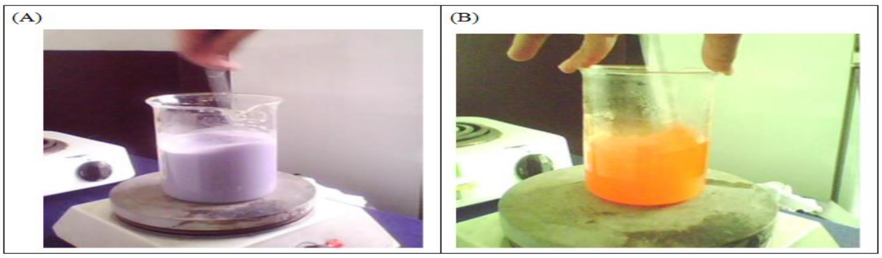

Fig. 1. Sample Pictures for A) Cooking of Bioplastics from Indigenous Plants and B) Cooked Starch Solution Ready for Molding

Six samples of plastics of equal sizes from each selected mature tuber were formed using the following proportions: 10 grams of starch from each mature tubers, 5ml acetic acid, 60ml distilled water and 5 ml glycerol. For other treatment, 5grams of corn starch was added to every 5 grams of starch from each tuber which will act as a flour catalyst. The samples were cut into strips about 3 cm by 6 cm dimension for testing.

The components, description, and concentrations of the starch solution were tabulated in the Table 1. Food colors were added for identification and aesthetic reason. Starch solutions were then cooked at around 250 degree Celsius for a few minutes until the solutions thickened. Cooked starch solutions were poured into a pan and dried/cured.

Table I. Components of Bioplastic from different Starchy Plants

Materials	Description	Pure			Corn Flour Mixed With:		
		Cassave	Taro	Potato	Cassava	Taro	Potato
Starch	Backbone polymer	10 g	10 g	10 g	5 g	5 g	5 g
Vinegar/ Acetic Acid	Binder	5 ml	5 ml	5 ml	5 ml	5 ml	5 ml
Glycerine	Pasticizer	5 ml	5 ml	5 ml	5 ml	5 ml	5 ml
Water	Solvent	60 ml	60 ml	60 ml	60 ml	60 ml	60 ml
Food Coloring	Colorant	Violet	Green	Yellow	Black	Red	Orange
Corn Flour	Flour Catalyst	0 g	0 g	0 g	5 g	5 g	5 g

The experimental research method was used to accomplish the purpose of this study. This method was chosen because of its appropriateness to the problem. The data that's gathered was analyzed, and several types of scientific study and experiments were conducted. Laboratory tests such as tensile stress, strong and weak acid test, strong base test, water absorption test, flammability test, organic solvent test, air test, and biodegradability test were prepared to examine the affectivity and efficiency of the samples.

For this research, the experimental method will seek to determine whether it is possible to produce biodegradable plastic from local plants and which among the plants will generate good texture, clarity, and mechanical property.

To check on the quality of the plastic that must be created in this experiment, testing was conducted as shown in Figure II. Some examples of the test made to validate the strength and stiffness distribution parameters of the plastics and how they vary with changes in raw material properties, processing variables, long-term load, and environmental exposure must be the basis to check the quality of plastic that must be produced.

The first part is the Biodegradability test: The products will be cut into strips of 6cm by 3 cm dimension, weighed and then stapled to a piece of cardboard and eventually buried in a can of soil. The six samples will be unearthed after a week, and the visual appearance was observed and recorded for some traces of biodegradation. The products were observed visually regarding change in color, appearance, texture, and weight.

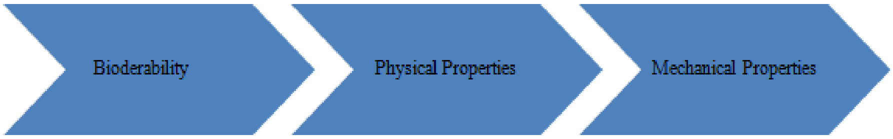

Fig. 2. Testing Procedure

Second is the Physical Properties test: The physical properties of the specimen that was tested were: mechanical properties, (percent elongation and tensile stress), thickness, transparency, and density.

The third is the Mechanical Properties test: Some important mechanical properties of bioplastics such as tensile and percentage elongation was tested using ASTM D412. The plastic samples are either machined from stock shapes or injection molded. The tensile testing machines pull the sample from both ends and measures the force required to pull the specimen material and how much the sample stretches before breaking.

All materials and products covered by these test methods must withstand tensile forces for adequate performance in certain applications. These test methods allow for the measurement of such tensile properties. However, tensile properties alone may not directly relate to the total end-use performance of the product because of the wide range of potential performance requirements in actual use.

Tensile properties depend both on the material and the conditions of the test (extension rate, temperature, humidity, specimen geometry, pretest conditioning, etc.); therefore, materials should be compared only when tested under the same conditions.

Temperature and rate of extension may have substantial effects on tensile properties and therefore should be controlled. These effects will vary depending on the type of material being tested.

The tensile set represents the residual deformation, which is partly permanent and partly recoverable after stretching and retraction. For this reason, the periods of extension and recovery (and other conditions of the test) must be controlled to obtain comparable results.

At least ten replicates were done for each treatment. The testing of the mechanical properties such as percent elongation and tensile strength of the specimen was conducted in the Standard Testing Division (STD) of Industrial Technology Development Institute. The percent elongation was then compared to the percent elongation of some common plastics for the identification of application of the products. The thickness of each sample was measured using Vernier caliper. Transparency will be observed visually. Opaque if the substance will not allow the light to pass through the sample, translucent if some of the light will pass through the sample and transparent allows all the light to pass through it.

The finished products were weighed, and their volume was measured by the displacement method. The density was calculated by dividing the mass of the bioplastic by its volume. The density was then compared to the density of some common plastics for the identification of application of the products.

3. RESULTS AND DISCUSSION

The statistical treatment method that was used in this study to determine if there is a significant difference in the tensile strength of the plastic concerning the different sources of starch materials that were being added as one of the major components in the production of biodegradable plastics is the Chi-Square. The researchers used a 0.05 level of significance to determine if there's a significant difference in the tensile strength. The computed chi-square was 0.4793 while the tabulated chi-square with a degree of freedom of 4 was 9.488. Since the tabulated value is greater than the computed value, the researcher concluded that there is no significant difference concerning the tensile strengths of the different sources of starch material.

The physical and chemical properties of the finished product were presented relating to its possible application or uses.

The bioplastics produced were translucent and glossy. Some of the finished products have bubbles, and the formation of the layers becomes visible. This may be due to some uncontrolled parameters that affect the appearance of the plastics.

Bioplastics made from the starch of cassava show the thinnest among the bioplastics that were made, (1.69 mm). It was also observed that this plastic was the slowest to dry of about three weeks. Figure III shows that among the six samples, bioplastic from taro was the thickest (2.76 mm). The average thicknesses of bioplastics made from potato, cassava with corn, taro with corn, and potato with corn, respectively are as follows: 1.91mm, 2.01 mm, 2.21mm, and 2.00mm. These bioplastics dried in 2 weeks.

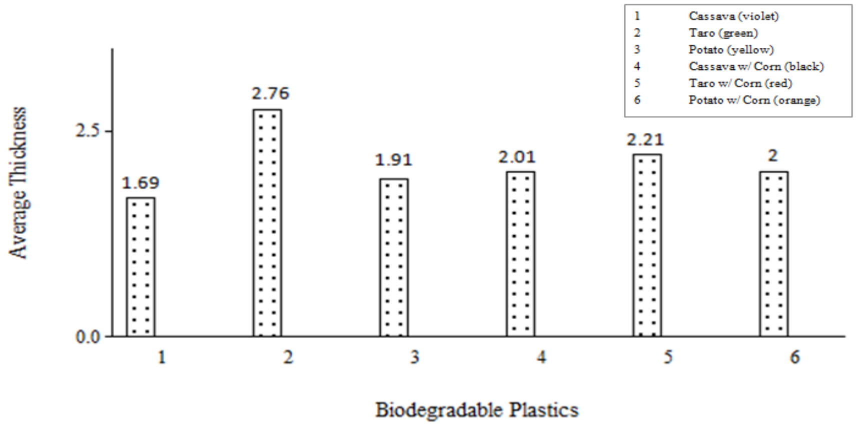

Fig. 3. Appearance and Thickness of Bioplastics

One of the easiest ways of classifying plastics is by their densities. Density is the amount of mass of the substance per unit volume. Each type of plastic has a specific density range, and this can be used to identify the plastic types. Identifying the density range of plastics is also used to sort plastics during the recycling process.

The density of the bioplastics as shown in Table II indicate that the bioplastics made from cassava starch are 1.25 g/ml while taro starch is 1.13 g/ml, potato starch is 1.26 g/ml, hence, the density of bioplastic from cassava with corn is 1.026g/ml, whereas, taro with corn is 1.29 g/ml. Bioplastic from cassava, potato, and taro with corn has densities that are within the range of those for polyvinyl chloride (PVC) which is 1.16 g/mL - 1.35 g/ml. This type of plastic is usually used for detergent bottles, shampoo bottles, and pipes.

Table II. Density of the Bioplastics from Starch of Indigenous Plants compared to the Density of Common Non-biodegradable Plastics

Bioplastics from Starch of Indigenous Plants		Common non biodegradable Plastics	
Type of Starch	Average density g/ml	Type	Density range
Cassava (violet)	1.25	Polyvinyl Chloride Elastomers silicone	1.16-1.35 1.10-1.60
Taro (green)	1.13	Elastomers silicone	1.10-1.60
Potato (yellow)	1.26	Polyvinyl Chloride Elastomers silicone	1.16-1.35 1.10-1.60
Cassava with Corn (black)	1.04	Polyetheretherketone	1.04-1.46
Taro with corn (red)	1.29	Polyvinyl Chloride Elastomers silicone	1.16-1.35 1.10-1.60

One of the important properties of plastics is their durability. The ability of plastics to resist breaking under tensile stress is one of the important and widely measured properties. Another important mechanical property of plastic is the ultimate elongation of engineering material. It is the percentage increase in length that occurs before plastic breaks under tension. Ultimate elongation values of several hundred percents are common for elastomers and film/packaging polyolefins. Rigid plastics, especially fiber reinforced ones, often exhibit values under 5%. The combination of high ultimate tensile strength and high elongation leads to materials of high toughness.). Table III shows the mechanical properties of Bioplastics.

Table III. Mechanical Properties of Bioplastics

Biodegradable Plastic	Mean Load at Break, N	Mean Area mm2	Tensile Strength MPa	% Elongation
Cassava (violet)	5.12	49.86	0.103	20.00
Taro (green)	56.2	82.52	0.681	8.57
Potato (yellow)	23.1	66.85	0.346	8.33
Cassava w/ Corn (Black)	34.5	59.7	0.578	10.00
Taro with corn (red)	42.7	72.27	0.591	5.71

Bioplastic from cassava exhibited the lowest tensile strength of 0.103MPa but shows the highest percent elongation of 20%, this demonstrates that bioplastic from cassava breaks easily under tensile stress, but it also shows that this sample is the most flexible among the samples that were treated. The average tensile strength of bioplastic taro is 0.681 MPa which exhibits the highest tensile strength among the six samples which means it is the hardest to break. However it only has 8.57 percent elongation. Bioplastic potato has an average tensile strength of 0.346 MPa and has 8.33 percent elongation. The average tensile strength of Cassava and taro, with cornstarch, are 0.578 MPa, 0.591 MPa and respectively. Bioplastic made from taro with corn exhibits the lowest percent elongation of about 5.71% this means that this plastic is the most rigid among the six samples.

Plastic materials absorb varying amounts of water, and the presence of absorbed water may affect the plastic materials in different ways.

The electrical properties are reduced with moisture absorption. Plastic materials with very low moisture absorption characteristics are highly favored as dielectric materials because these materials exhibit negligible effects of moisture in their properties.

Table IV. Chemical Property Test Water Absorption

Biodegradable Plastic	Initial Weight (g)	Final Weight (g)	Percentage Gained (%)
Cassava (violet)	3.678	6.282	70.8
Taro (green)	4.753	5.341	12.371
Potato (yellow)	6.231	8.112	30.188
Cassava with Corn (black)	5.104	7.697	50.8
Taro w/ corn (red)	7.049	10.476	48.617

It can be gleaned from Table IV that the bioplastic made from pure cassava has the highest moisture content of 70.800%, this means that this plastic shows signs of high electrical properties. Bioplastic made from pure taro shows the lowest percentage of water absorbed, these signify that among the six samples presented, bioplastic from pure taro is the most dielectric.

The plastic strips were embedded in the soil, and after ten days the six samples were unearthed. The observation was shown in Figure IV.

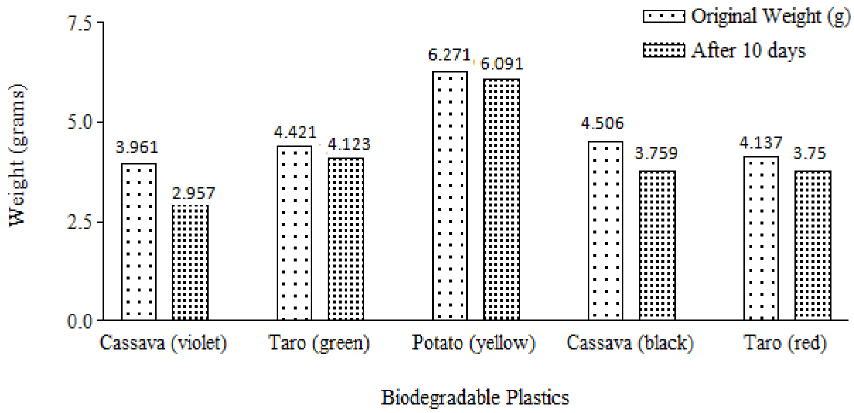

Fig. 4. Biodegradability

There were no standard methods used in testing the biodegradability of the samples. The finished products were embedded in the soil found at the backyard of the researcher. It was observed that after ten days, bioplastics have disintegrated or torn apart

Some parts of bioplastics cannot be found anymore. The collected remains of bioplastics were weighed again. The collected bioplastic cassava weighs 2.957 g from 3.961 g. There was a 25 percent difference in weight from the time it was embedded in the time it was dug up. Though there was great weigh lose in the said sample, it cannot be accounted that this were all degraded. There might be some parts that after this sample has torn apart, they might have been misplaced due to some uncontrollable conditions in the environment. There were also changes in the mass of bioplastic taro, potato, cassava with corn, taro with corn, and potato with corn after ten days. Bioplastic taro, potato, cassava with corn, taro with corn, and potato with corn were also disintegrated. Unlike bioplastic cassava, fragments of bioplastic taro, potato, cassava with corn, taro with corn, and potato with corn were just within the vicinity where they were embedded. Hence, there were more plastics found and weighed.

4. CONCLUSION

Based on the results of the experiments, the following are the salient findings that led to the conclusion that bioplastic can be produced from cassava, taro, and potato starch. Thus, the objectives set was met.

The following are recommendations based on the preceding results and discussion of the study.

The best-operating conditions in producing bioplastic from cassava starch, taro starch, and potato starch must be identified to improve the quality of the product and to get rid of the presence of bubbles and formation of visible layers in some finished products.

There is a need to determine the best or proper way of molding the product in such a way that it will lessen the time of curing but giving the best quality of the product and to study the effects of adding a catalyst to increase the rate of curing/drying and quality of bioplastic from cassava starch, taro starch, and potato starch.

Another is to determine some other important properties of bioplastics from cassava starch, taro starch, and potato starch such as brittleness, compressive strength, copper wire test, glass transitions temperature, and biodegradability, and compare them with the existing bioplastics in the market or petroleum-based bioplastics. It can also be recommended to study some other ways or processes in making bioplastics from cassava starch, taro starch, and potato starch such as polylactic acid fermentation.

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