International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

Innovative Bioplastic Production from Smooth Narra Leaves *(Pterocarpus indicus forma indicus)*: A Path Towards Sustainable Alternatives

Andre C. Clemenia, Dr. Lizamyl R. Laping
Falcatan, St., Tetuan, Zamboanga City, 7000
#1 Villa Teresa Subd., Lunzuran, Zamboanga City, 7000
Email address: andreclemenia9@gmail.com, Lizamyl.laping@wmsu.edu.ph

Abstract— *Exploring a path towards sustainable alternatives, this thesis aims to develop sustainable plastic by extracting starch coming from the leaves of the smooth narra (Pterocarpus indicus f. indicus). Three bioplastics were created with varying starch to glycerin Mixture (18 g-4 g, 15 g-5 g, 12 g-6 g), the three were then tested for their viability through mechanical properties (tensile strength, elongation), physical properties (density, water absorption, thickness), and biodegradability. The statistical analysis of the bioplastics shows that the mechanical properties have significant difference for tensile strength but none on elongation, all the physical properties are significantly different, and for biodegradability is also significantly different. Ultimately, the results are that Mixture 2 stands out as the most promising bioplastic as Mixture 2 could potentially become a sustainable alternative, given that it exhibited the best mechanical properties, with an average of 13.35 Pa in tensile strength and 10.34% in elongation due to a balanced starch- to-glycerol mixture. While starch increases mechanical strength, glycerol enhances elongation but may slightly reduce strength. Regarding physical properties, Mixture 3 had the lowest water absorption of 17.87% and density of 6.89 g/ml, making it suitable for food packaging. Mixture 2, with moderate water absorption at 19.48% and thickness of 2.54 mm, was deemed optimal for food packaging. Biodegradability testing revealed all mixtures degraded, with Mixture 3 showing the highest degradation rate of 53.93%, followed by Mixture 2 and Mixture 1. Overall, Mixture 2 was identified as the best formulation due to its balanced composition, closely competing with LDPE in thickness and elongation but surpassing it in biodegradability, suggesting potential as a sustainable alternative with further refinement.*

I. INTRODUCTION

Background of the Study

Solid waste shall refer to all discarded household, commercial waste, non- hazardous institutional and industrial waste, street sweepings, construction debris, agricultural waste, and other non-hazardous/non-toxic solid waste as per RA 9003 otherwise known as Ecological Solid Waste Management Act of 2000. More over according to DeVroom (2023), the materials included in solid waste are food waste, paper, plastics, and glass. Sludge from industrial plants and other abandoned materials from commercial, mining, industrial, and agricultural operations are considered solid waste.

Yard waste or also called green waste, this category of yard trimmings covers a broad swath of materials, including deciduous leaves, grass clippings, unused fruits and vegetables, shrubs, tree branches, garden vegetation, and other vegetative materials. The majority of yard waste is vegetative in nature, typically consisting of a variety of herbaceous and woody plant species. Yard waste is generally produced in an outdoor residential setting and consists of a fairly balanced mixture of moist green vegetation, dried brown vegetation, leaves, flowers, stalks, stems, branches, green wood, and other plant components. Compared to home garbage or commercial and industrial rubbish, yard waste is typically thought to be the cleanest kind of solid waste.

When yard waste is dumped in a landfill, it decomposes and releases acidity and methane. Not only is methane combustible and explosive, but it is also an unnoticeable greenhouse gas, if left unchecked, green waste can produce a lot of methane that leaks into the surrounding ground and buildings. Yard waste can contaminate lakes and waterways. Through the storm drain, leaves and other yard waste find their way to our lakes, rivers, streams, and creeks. The decomposition of leaves and other yard waste produces toxins and depletes oxygen, which can harm plants and marine organisms.

Due to the world's inability to handle the world's fast expanding output of disposable plastic products, plastic pollution has come to be as one of the most pressing environmental challenges, an estimated 2.7 million tons of plastic garbage are produced in the Philippines each year. A large amount of this garbage ends up in various waterways and landfills. Around twenty percent of this plastic garbage ends up in the ocean, where it devastates marine ecosystems and puts marine life at risk. According also to Ramos (2023), with an estimated 20 million people living below the poverty line in 2021, the widespread poverty in the nation forces people to look for the least expensive option. The government passed the Waste Management Act in 2001 in an effort to address the nation's mounting solid waste issue by implementing systematic waste segregation and outlawing open dumps for solid waste.

According to Lackner et al. (2023), bioplastic, also known as a biopolymer, is a macromolecule made up of "natural" or biobased building units, which are materials that are either partly biobased or degradable under specific circumstances. Bioplastics can be recycled in a variety of ways and are derived from renewable resources. They can also be (bio)degradable, which is a choice for the improperly handled portion and for certain uses that have a natural end of life (e.g., seed coatings

Andre C. Clemenia and Lizamyl R. Laping "Innovative Bioplastic Production from Smooth Narra Leaves (Pterocarpus indicus forma indicus): A Path Towards Sustainable Alternatives," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 8, Issue 4, pp. 61-76, 2025.

and tree bite protection). Like traditional plastics, bioplastics have different characteristics and can be utilized in composites.

Bioplastics are biodegradable materials that degrade naturally, and they can help lessen the amount of plastic waste that is polluting the environment and suffocating the planet. The utilization of bioplastics, which are made from natural polymers derived from cellulose, potato starch, and agricultural waste, is being encouraged. These are completely biodegradable, equally resilient, and adaptable; they are already utilized in the textile, medical, and agricultural industries, as well as in the container and packaging market.

One potential source for biopolymer for bioplastic would be from the yard waste more specifically dried leaves. Energy is needed by plants for defense, growth and reproduction. Plant tissue stores excess energy produced by photosynthesis as starch. Starch is a powdery, white material. It contains glucose, which is used as nourishment by plants. A leaf's starch content is a reliable indicator of photosynthesis. This is because photosynthesis is necessary for the creation of starch. According to Gomide 2022), leaves are composed of lignocellulose a chain of sugar molecules, that can be broken down to make bioplastic. Starch can accumulate to significant levels, and up to 25% of the leaves' dry biomass can be starch.

Statement of the Problem

Biodegradable waste dominates the percentage of solid waste in the northern Philippines standing in a 76.9% of the total solid waste here in the Philippines, which is the primary cause of pollution (Ngohayon and Tulagan 2022), if left open it will pollute the soil, air, and water. The main contributor of the accumulated biodegradable waste is yard waste, one solution that people opt to do with yard waste is by burning to lessen the biomass of yard waste but by burning waste cause even more problems risking human health and the environment. Yard waste contains starch which is a material for bioplastic making its disposal or burning of dried leaves a waste of valuable material.

Objectives of the Study

This study aims to explore the potential of innovative bioplastic using the leaves of smooth narra (*Pterocarpus indicus f. indicus)* as primary raw material in three different starch-to-glycerol mixtures. The mixtures are Mixture 1 (18 g:4 g), Mixture 2 (15 g:5 g), Mixture 3 (12 g:6 g)

1. Analyze the mechanical properties of dried leaves based bioplastic through:
    - Tensile Strength
    - Percent Elongation
2. Analyze the physical properties of dried leaves based bioplastic through:
    - Water absorption
    - Density
    - Thickness
3. Assess the biodegradability of the bioplastic by measuring its degradation rate
4. Determine the result of bioplastic under three different mixtures and which among the three is an ideal bioplastic.
5. Compare the performance of dried leaves based bioplastic with commercial plastic specifically, Low-Density Polyethylene food packaging plastic.

Significance of the Study

The use of smooth narra leaves in producing bioplastics if found effective may become a cost effective approach and beneficial to the environment by reducing the mass of yard waste and eliminating the cause of open burning in turn will provide healthier community by encouraging waste segregation. If the use of dried leaves as a valuable raw material for bioplastic production it can diversify the field of bioplastic and provide sustainable material solution by reducing use of petroleum based resources.

Scope and Limitation

This study evaluated the use of *Pterocarpus indicus f. indicus* leaves in creating bioplastic. The evaluation for bioplastic are done in a "DIY" manner this tests includes mechanical tests, physical tests, and biodegradability tests. The physical test includes a water absorption test, its density, and thickness, for the mechanical test tensile strength and elongation are included, the testing is performed without the use of any machineries, it was performed manually ten (10) times of each of the category to provide sufficient data for statistics. The findings are specific to the conditions and characteristics of the yard waste in Zamboanga City and may or may not apply to other areas.

II. Review of Related Literature

According to Lackner et al. (2023), bioplastics are biopolymers that can be renewable and/or degradable this is because there are 3 types of bioplastics which are based on renewable materials this once are sourced from various plants and biological materials, Biodegradable plastic are plastic that are not made entirely of plants or biological materials but are easily degradable intended for short-lived, disposable product, and the bioplastic that is both based on renewable material and biodegradable at the same time which functions similar way from the previous type as it is based on biological material and is degradable this is further illustrated on the Figure 2.1.

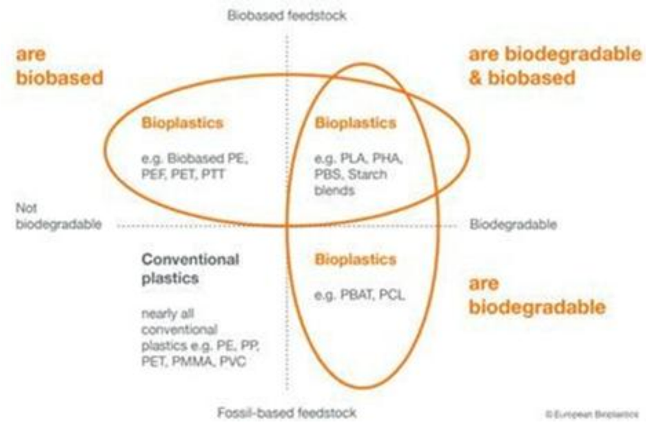

Figure 2.1. Types of Bioplastics, Both Biodegradable and Non-Biodegradable, and Examples.

Note: Figure 3 of What Are Bioplastic? Defining Renewability, Biosynthesis, Biodegradability, and Biocompatibility by Lackner et al. (2023).

Andre C. Clemenia and Lizamyl R. Laping "Innovative Bioplastic Production from Smooth Narra Leaves (Pterocarpus indicus forma indicus): A Path Towards Sustainable Alternatives," *International Journal of Multidisciplinary Research and Publications (IJMRAP*), Volume 8, Issue 4, pp. 61-76, 2025.

Bioplastics have become an increasingly viable proposition and being push to promote sustainability. More and more bioplastics are being made simply for the cost effective solution and abundance of renewable materials. Different biological materials and plants, such as softwoods and starchy veggies, can be used to make bioplastics. Sugar cane, maize, wheat, and potatoes are among the most frequently utilized crops for bioplastics. It's also possible to synthesize bioplastics from microorganisms and algae. Hardman (2022) states that bioplastic is advantageous because they are recyclable and compostable, made from renewable resources, non-toxic substance. Bioplastic break down by natural process which also means recycling makes lesser worry for disposal. It is stated that the sources for bioplastic are abundant as they are organic by nature which also means they are non-toxic as most ingredients used in producing bioplastic are organic as well.

Bioplastic adapts many form of ingredients they commonly consist a starch, a plasticizer, and an acid. The amount of ingredients used also varies depending on the type

of bioplastic will be made but a bioplastic typically consists of the following ingredients, such pattern can be observed from various researches like Devarayan et al. (2020), or Ding et al. (2025). One way to create a bioplastic combination is to heat a first aqueous mixture that contains at least one plasticizer and at least one other component. acidic; heating and mixing the second aqueous mixture to add at least one starch to the first aqueous mixture to create a second aqueous mixture; separate the precipitate from the leftover liquid of the second aqueous mixture to create a bioplastic composition.

Yard Waste

Yard waste is also known as green waste, yard waste comprises grass, grass clippings, bushes, shrubs, leaves, deciduous leaves, unused fruits and vegetables, tree branches, garden vegetation, aquatic plants, and other vegetative materials. Yard wasted does not include sand, soil, stones, and house wastes. Ngohayon and Tulagan (2022) Researchers of "Analysis and Characterization of Municipal Solid Wastes Generated in a Community in the Northern Philippines" Found out that biodegradable waste dominates the percentage of solid waste in the northern Philippines standing in a 76.9% rating, with such rating highlights that there is a growing concern of biodegradable waste present in the Philippines, the researcher's also stated that the biodegradable waste is mostly composed of yard waste.

Biodegradable waste in the city is lesser due to the five operating material recovery facilities (MRF) located in Sta. Cruz Market, Magay, San Roque, Lumbangan, and Salaan. According to the Zamboanga City Local Sustainable Sanitation Plan Team (2020-2030) Zamboanga city generates 42% biodegradable waste and 12% of it is coming from yard waste based on Figure 2.2

Open Burning

The thermal breakdown of trash by direct exposure to fire is known as open burning. Traditional, small-scale community sanitation or "siga" techniques will be covered by this definition. There is a republic act in the Philippines that prohibits the act of open burning, this act is called "The Ecological Solid Waste Management Act of 2000" or Republic Act 9003. The State's policy to implement a systematic, complete, and ecological solid waste management plan is known as RA 9003. Among other things, this program would guarantee the following: Through the formulation and implementation of rules, we must ensure the appropriate separation, collection, transportation, storage, treatment, and disposal of solid waste, as well as the protection of the environment and public health. the implementation of the finest environmental practices in ecological waste management, with the exception of incineration. Under Section 48, paragraph 3 states that all kinds of open burning are prohibited and are punishable by fines and penalties.

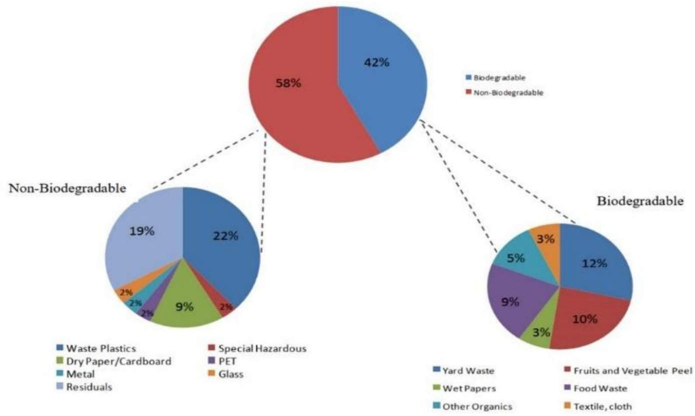

Figure 2.2. Zamboanga City Solid Waste Composition
Note: Figure 3-12 *Zamboanga City Solid Waste Management Plan (2020-2030)*

Open burning is prohibited as it poses risks to the environment and public health. Smoke pollutes the air we breathe. Ash pollutes our soil, groundwater, lakes, rivers and streams. Burning anything in the outdoors can cause a wildfire. Depending on the materials that are being burned could cause different effects to the environment. Burning plastics are creating and releasing some of the most dangerous chemicals such as dioxin. Dioxin is a byproduct of burning chlorine based plastics. Dioxin tend to cling to waxy surface leaves and enter the food chain this way. According to World Health Organization or WHO (2023), once dioxins enter the body, they last a long time because of their chemical stability and their ability to be absorbed by fat tissue, where they are then stored in the body. Their half-life in the body is estimated to be 7 to 11 years. Skin lesions, such chloracne and blotchy discoloration of the skin, as well as changes in liver function can result from short-term exposure of people to high amounts of dioxins. Impairment of the immune system, the developing neurological system, the endocrine system, and reproductive functions are all associated with prolonged exposure.

Any fire will create ash waste which are fine particles averaging in diameter size of 230 micrometers (Burns, 2019). While wood ash contains some nutrients required by plants for healthy growth, ash is harmful for our lakes, ponds and rivers. Ash contains phosphorous, potassium and trace amounts of micro-nutrients, such as iron, manganese, boron, copper and zinc, all of which can disrupt the delicate ecosystems of water bodies. For example, phosphorus is a powerful growth agent that stimulates algae growth in water bodies. As important as some algae is to the natural food chain, too much algae can result in the formation of scum, foul odors, low oxygen in the water and offensive views. People with heart or lung diseases, children, older adults, minority populations, and low socioeconomic status populations are the most likely to be affected by particle pollution exposure. Inhalation can worsen heart and lung conditions such as chronic obstructive pulmonary disease, asthma, emphysema, and chronic bronchitis exposure may also cause carbon monoxide poisoning, eye damage, and many more health risk (Santos, 2018).

Component of Leaves

A leaf, is the flattened green outgrowth from the stem of a vascular plant. It is the primary site for photosynthesis. Photosynthesis is the process that plants trap light energy with their leaves. Plants use the energy of the sun to change water and carbon dioxide into sugar called glucose. The glucose in these plants is used for energy and to make other substances like, cellulose and starch. Cellulose is the one responsible for building the cell walls, whereas the Starch stored in seeds and in other plant parts as a food source. The presence of starch in a leaf is reliable evidence of photosynthesis. That's because starch formation requires photosynthesis. According to Tereos (2019), Starch naturally occurs in most plants, starch is formed through the process of photosynthesis. It is mainly extracted from corn, wheat and potatoes, but it is also found in many other plants such as rice, barley, peas, cassava, and even bananas. Plants will form glucose in the leaves from photosynthesis, providing a high concentration of glucose, forcing some down into the roots. When the plant is storing energy, it will convert glucose in the roots into starch, allowing for the glucose to continue flowing into the roots to be stored. When the plant needs that energy it will break down the starch in the roots, creating a high concentration of glucose, forcing it up into the leaves to rebuild and fuel.

Smooth Narra

Combalicer et al. (2024), Narra comes in two varieties of species prickly narra and smooth narra, smooth nara prickly narra bears a pod that has thorns or pricks surrounding its pods while the smooth narra tree or the scientific name of *Pterocarpus forma indicus* is used for to extract seeds from. *Pterocarpus indicus f. indicus* (smooth narra) is a deciduous nitrogen-fixing tree species that grows best in open areas. Commonly found in from the Hindustani and Indochina-Indonesian Centers of diversity. defined its western limit to be Southern Burma. Its occurrence then extends eastward to Thailand and Vietnam, farther eastward with the limits at the Solomons in the Pacific passing through Sumatra, West Java, Borneo, the Philippines, Sunda Islands, the Moluccas, Papua New Guinea, and the Pacific (Ryukyu, Carolines). In the Philippines, it is widely used for reforestation. It can be propagated via seeds and cuttings; seedling stocks are mostly used for reforestation and rehabilitation of denuded lands. However, establishment trials in degraded forest areas have yielded varied results, with some failing. Thus, to understand how narra seedlings respond to multiple stresses typical of denuded lands. Smooth narra the tree is abundant in the school grounds of Western Mindanao State University which is utilized as a raw material for starch extraction.

Starch

Alcantara et al. (2020), It is found out that 1% narra leaves may contain soluble starch, together in bulk may produce higher scale of soluble starch making it a feasible material in creating bioplastic based on narra leaves as it offers not only a sustainable solution but it also offers environmental, economic, and functional benefits. Since it is abundant in the school grounds making bioplastic out of narra leaves will help reducing plastic waste and dependence on fossil fuels while lowering carbon emissions.

According to Smith (2024), Starch is present in almost any flora and fauna, Polysaccharides being the most abundant macromolecules in flora and fauna, it is one of the most suitable raw material for bioplastics, which is not only renewable and sustainable but is also plentiful and cheap. Starch is a biopolymer composed of glucose molecules linked together to form two distinct polysaccharides: amylose and amylopectin. Amylose is primarily a linear chain of glucose units connected by α-(1→4) glycosidic bonds, while amylopectin is a branched molecule featuring α-(1→4) linked glucose chains with branching points introduced by α-(1→6) glycosidic bonds. In natural starches, amylose typically constitutes about 10%–30% and amylopectin about 70%–90% of the starch content. found in various plant sources like corn, rice, potato, and wheat. It can undergo modifications and combinations with other polymers by using starch.

Bioplastic can be used to reduce the carbon footprint of traditional resins because they can replace petroleum-based polymers with natural ones. Furthermore, it is very biodegradable, which means it can be used in conjunction with a compostable polymer without affecting the decomposition process. Ding et al. (2025) who also stated that depending on what type of leaves are used different amount of starch can be extracted from leaves in Ding's case a rice seedling can accumulate 4-8% of starch while wheat and barley seedling can accumulate typically less than 2% dry weight. There are various methods in extracting starch, one of the method may follow Sakthivel et al. (2020), where it begins by cleaning the leaves through running tap water to remove attached dust particles. About 25g of leaves were then grinded by using mortar and pastel to make a paste along with sufficient quantity of distilled water and made the value as 1000 mL paste and boiled with a heating mantle.The boiled contents were allowed to cool and filtered through a typical kitchen filter to remove all debris. Then the extract was stored at a room temperature for 24 hours.

Vinegar

Helmenstine (2022), Vinegar is an acidic liquid produced through the fermentation of ethanol by acetic acid bacteria. It primarily consists of acetic acid (CH_3COOH) and water, with acetic acid concentrations typically ranging from 4% to 8% by volume. commonly added to starch-based bioplastics to facilitate starch gelatinization, improve homogeneity, and enhance mechanical properties. The acetic acid helps break down the semi-crystalline structure of starch, allowing it to form a more uniform and flexible bioplastic film. It also promotes better interaction between starch, glycerol, and other additives, resulting in more consistent mechanical characteristics (Moncel, 2023).

Vinegar found its usage in many applications in bioplastic making, such as the Production of Bioplastic Films from Wild Cocoyam Starch by Adeleke et al. (2024), Development and Characterization of Natural Sourced Bioplastic for Food Packaging Applications by Badrudduza et al. (2023), and many more starch based bioplastics utilizing vinegar. During the test of the said researches it was found out that by the effect of vinegar the plastic yielded more tensile strength and performs better by the help of the vinegar, this statement becomes more apparent as Mufrodi et al. (2019), test out effect of different vinegar to cassava starch as observed in the Table 2.1.

TABLE 2.1. Comparison of Tensile Strength and Breaking Elongation for Different Vinegar.

Parameter	Variable	Results
Tensile Strength, kg/cm^2	Acetic Acid 2%	105,34
	Apple Vinegar	105,98
	Rice Vinegar	93,09
Elongation At Break, %	Acetic Acid 2%	71,67
	Apple Vinegar	129,91
	Rice Vinegar	144,67

Note: Table 3 of Biodegradable Plastic from Cassava and Organic Acid as a Synthetic Plastic Replacement by Mufrodi et al. (2019).

Based on Table 2.1 it is concluded that apple vinegar yielded more tensile strength and acetic acid follows in close second, though lowering its score in elongation at break making rice vinegar with the highest result for elongation at breaking point.

Glycerol

Glycerol is a naturally occurring alcohol which typically obtained from plants like soybeans and palm. It is a naturally occurring substance that has a sweet flavor and is colorless, odorless, and thick like syrup. According to the pyrolysis book of organic molecules, propane-1,2,3-triol is the name for glycerol, the most basic of the alcohols. It is also referred to by its commercial names, which include glycerin, 1,2,3-propanotriol, trihydroxypropane, glyceritol, and glycidic alcohol. Glycerol is a liquid that dissolves in water due to its three hydrophilic hydroxyl groups, which also give it its hygroscopic properties. Used as a solvent, sweetener, and medication. Toothpaste, hair conditioners, cosmetics, and moisturisers all frequently include glycerol.

Athanassiou et al. (2024) stated that, cellulose films have garnered increasing attention in various industrial applications due to their biodegradability, renewability, recyclability, and inherent mechanical strength. Glycerol is a common plasticizer for hydrophilic polymers such as polysaccharides. In the case of starch, glycerol has been used to provide thermoplasticity to allow molding and shaping by extrusion, injection molding, and film casting. The incorporation of glycerol into starch matrices disrupts the intermolecular hydrogen bonding between the polymer chains, reduces crystalinity and renders a more flexible material. Pamungkas (2019) states that, glycerol as a plasticizer has the function of improving the ability of bioplastic to absorb water and as crystal forming agent. Cheung, et.al. (2024) also supports the statement base on the test results that higher amount of glycerol reduces tensile strength but enhances elongation and water absorption of the bioplastic.

Mechanical Properties

Bioplastics, derived from renewable biomass sources, exhibit mechanical properties that can vary widely based on their composition, processing methods, and any reinforcing agents used. Mechanical properties of bioplastics include tensile strength, and elongation at break. The greatest stress that a material can endure before breaking when pulled is measured by its tensile strength. For instance, starch-based bioplastics have demonstrated tensile strengths ranging from approximately 0.43 MPa to 28.04 MPa, depending on formulation and processing conditions Nasir and Othman (2021). Elongation at break indicates the extent to which a material can be stretched before it breaks, reflecting its flexibility. Variations in elongation at break are observed based on the bioplastic's composition and additives. A test commonly conducted to determine the tensile and percent elongation is ASTM D412 a common standard for determining the tensile properties of vulcanized rubber and thermoplastic elastomers. The test for ASTM D412 begins with the conditioning of the specimen in a standardized to ensure consistent result, next step is Placing the specimen in the grips of a universal testing machine (UTM), ensuring proper alignment to prevent bending stresses. Initiate the test by separating the tensile grips at a constant crosshead speed of 50 mm/min until the specimen fails. Throughout the test, record data such as the applied force and the corresponding elongation.

Physical Properties

Bioplastics are evaluated based on several physical properties, including water absorption, density, and thickness. These characteristics are influenced by the bioplastic's composition of starch, and glycerol along with the processing methods the results for each property will change. Water absorption measures how much moisture a bioplastic can uptake, which affects its durability and suitability for various applications. For instance, incorporating plasticizers like glycerol can reduce water absorption; films with 35% glycerol demonstrated the lowest water uptake at 141% (Elfaghi et al., 2022). A common test to determine the water absorption of a bioplastic is by conducting ASTM D570, the procedure for water absorption is done by weighing of the initial bioplastic, then put into a graduated cylinder filled with water. After 10 seconds, the bioplastic is removed and weighed. The procedure is repeated until the bioplastic weight is constant. Density reflects the mass per unit volume of bioplastic films and is influenced by material composition and additives Density can be tested in a similar manner as the water absorption but this time it requires a beaker filled to a certain amount (Ex. 25ml) the plastic film is then weighed and then placed inside the beaker, whatever the new volume of the beaker the density is then calculated by dividing mass over volume. In studies, silica-based bioplastics exhibited densities ranging from 1.62 to 1.69 g/cm^3, while water spinach stem-based bioplastics had densities between 1.266 to 1.516 $x10^{-5}$ g/mm^3 (Lazim et al. 2023). Thickness is a determining factor for the plastic's quality to preserve the quality and integrity of the content as it serves as an effective barrier against light, heat, and oxygen. Kaavessina et al. (2024), Bioplastic films using a blend of empty fruit bunch cellulose, chitosan, and starch. The films were produced through solution casting and drying processes, resulting in thicknesses ranging from 0.1 to 0.5 mm. Being able to accurately measure the thickness helps in determining irregularities of the plastic as consistent thickness is important for the material as this will aid in making the distribution of stress even, this is done by using a tool called caliper in order to measure the thickness of a bioplastic film. as well as distribution of strength, having irregular thickness will have weak points within the material thus posing risk of breaking.

Biodegradability

Bioplastics, derived from renewable resources, offer a promising alternative to conventional plastics. However, their degradation rates vary significantly depending on their chemical composition and environmental conditions. Composting provides controlled conditions such as elevated temperatures and specific microbial activity that can enhance the biodegradation of certain bioplastics. For instance, a study by Benali et al. (2021), simulating industrial composting conditions found that starch-based films degraded by 45% over 20 days during the thermophilic phase. Another study from Ali et al. (2023), observed that a starch-based bioplastic experienced a 96% weight reduction after 28 days of soil burial. Environmental conditions such as temperature, humidity, and microbial presence significantly impact the degradation rates of bioplastics. As such the testing that this thesis conducted in order to test the degradation rate of smooth narra leaves based bioplastic is a 7 days' burial test to see the level of degradation of the bioplastic.

III. METHODOLOGY

Methodology discusses the systematic approach towards the process of the thesis, the discussion includes data gathering methods which describes how the information's were gathered, the location of the experimental study describes where the experimentation and testing are conducted, research design explains the approach for the thesis project, materials used, and experimental procedures where it discusses the process and the creation of the bioplastic. Methodology also includes the testing conducted for the bioplastic product in order to test the accuracy, reliability and validity of the bioplastic.

Secondary Data Gathering

Secondary data and information are acquired through searching data and gathering related literatures from the internet. The data and information sources include but are not limited to Thesis samples, Google search, and Google Scholar.

Location of the Experimental Study

The experimental study was conducted on the researcher's residence in Barangay Tetuan, Zamboanga City, Zamboanga Del Sur, Philippines. It gave the researcher full control and access to supervise the experiment.

Research Design

The thesis takes an experimental approach as the thesis involves controlled testing to establish cause and effect relationship, this is done through recording data from experimentation and testing to be able to procure a viable bioplastic.

Experimental Procedure

The process begins by collecting yard waste from Western Mindanao State University. with the collected yard waste the researcher manually removed any debris that is not dried leaves to proceed in placing the dried leaves in a container of water with lid to be shaken manually, a strainer is used to get the clean leaves, placing the clean leaves in a cooking pot with distilled water leaving it to boil for 30 minutes once done, the contains of the pot is then poured through a strainer, the leaves is then blended till it was in paste form, the paste are then placed in cloth and be pulped to and have the liquid be extracted in a container, leaving the container to settle overnight which in turn separates the liquid on top and the starch on the bottom. Using the extracted starch, it was mixed in a mixing bowl together with the vinegar, distilled water, and glycerol The mixture was then placed in a frying pan mixing it until the mixture becomes thick and sticky, once sticky and thick it was placed on a baking pan making sure to spread evenly then placed into a pre-heated oven at 105°C for 60 minutes to produce the bioplastic. Figure 3.1 shows summarized version of the process.

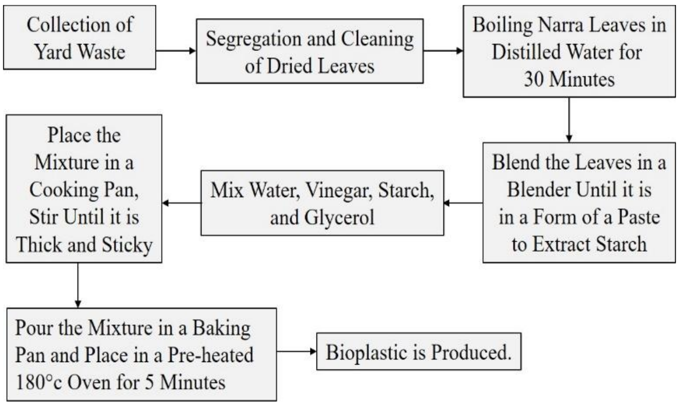

Figure 3.1. Experimental Procedure

Materials, Tools, and Equipment

The materials, tools, and equipment used in the study were purchased or collected from different establishments in Zamboanga City and online. Table 3.1 shows the list of materials that were used in the experimental set up.

TABLE 3.1. Materials, Tools, and Equipment

Quantity	Materials
1000 ml	Acetic Acid (vinegar)
1000ml	Glycerol
4L	Distilled water
12 kg	Dried Leaves
1 set	Measuring Cup
1 set	Measuring Spoon
1	Blender
1	Cooking pot
1	Mixing Bowl
2	Baking Pan
10 pcs	Wax Paper
1	Digital Caliper

1	Weighing Scale
3	Graduated Cylinder
3	Beaker
1	Oven
1	Stove top
2	1lb Dumbbell
1	Thermometer + Stirring Rod

Collection and Preparation of Yard Waste Supplies

The yard waste materials (dried leaves) were collected for 6 days collecting 6 sacks of yard waste from the Western Mindanao State University in Zamboanga City. The collected dried leaves were brought to the researcher's residence and manually removed unnecessary materials present in the waste such as plastic, rocks, bottles, etc. as shown on Figure 3.2. The segregated leaves were then placed in a container with enough water to submerge the leaves and the container was then shaken for 10 minutes, a strainer was used to extract the leaves out of the container resulting a clean dried leaves.

Figure 3.2. Segregated Leaves from One Batch of Collection

Figure 3.3. Boiling of Smooth Narra Leaves

Extraction of Starch

The materials, tools, and, equipment were ready, the experiment began by boiling one-kilogram batch of clean dried leaves in a cooking pot of distilled water just enough to submerge the leaves as observed on Figure 3.3. Once finished, the leaves were then extracted from the pot through a strainer and placed in a blender with the chop setting for 30 seconds resulting in a paste form. The said paste was then pulped manually and collecting the juice of the paste. The collected juice of the paste is left to settle for a night separating the solid and liquid material. The solid material is the starch as shown in Figure 3.4. This process was patterned after Sakthivel et al. (2020).

Figure 3.4. Starch Collection from One Batch of Smooth Narra Leaves

Producing Bioplastic

Three bioplastics were produced during the experiment each having a different starch-to-glycerol mixture to test the effectivity of the bioplastic. The mixture is patterned after Sakthivel et al. (2020), where they provided large scale proportions, replicating the mixture comes down as follows.

TABLE 3.2. Starch to Glycerol Mixture

Mixture	Starch	Glycerol
Mixture 1	18g	4g
Mixture 2	15g	5g
Mixture 3	12g	6g

Note: Each mixture will follow the same process of producing bioplastic

Presented on Figure 3.5, the 15 g starch was mixed in a mixing bowl together with 10 ml of vinegar and 5 g of glycerol and 100 ml water, once mixed it was then poured on a cooking pan to be mixed thoroughly on low heat until the mixture was thick and sticky. The mixture was then evenly spread on a baking pan which would look as displayed on Figure 3.6, with the use of a spatula. The mixture can also be left for a week to solidify into a bioplastic but in order to speed up the process, the pan can be placed in an oven of 180^{o}c for 5 minutes thus producing the bioplastic shown in Figure 3.7.

Figure 3.5. Mixture of Water, Vinegar, Starch, and Glycerol

Andre C. Clemenia and Lizamyl R. Laping "Innovative Bioplastic Production from Smooth Narra Leaves (Pterocarpus indicus forma indicus): A Path Towards Sustainable Alternatives," *International Journal of Multidisciplinary Research and Publications (IJMRAP*), Volume 8, Issue 4, pp. 61-76, 2025.

Figure 3.6. Biolplastic After Cooking

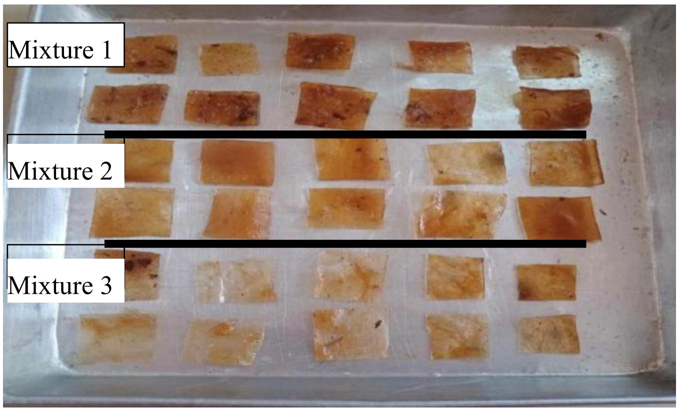

Figure 3.7. Mixtures 1, 2, and 3 Bioplastic Ready for Testing

Laboratory-scale Set-up Trial Run

Bioplastics went through multiple tests to provide data on its effectivity as a bioplastic. They were also compared to a conventional food packaging plastic specifically an LDPE "sando" bag as a control. The test that the bioplastic and the conventional plastic ran through are biodegradability test, physical test, and mechanical test. The testing was executed ten times to provide sufficient data on its effectivity.

Mechanical Analysis

The purpose of testing the mechanical properties of bioplastics was to get the value of tensile strength and percent elongation. The following are the parameter under mechanical properties.

- *Tensile Strength*

The tensile strength was carried out with the test object drawn from two directions so that the length increases and the diameter shrinks. The tensile properties of rubber and rubber-like materials, such as bioplastics, are ascertained using the ASTM D412 standard test method adjusted to fit a manual method. The amount load and length increase was recorded during the test. A test conducted from Michigan Technological University (2024) where it includes weights to conduct the tensile strength at home, the process proceeds as hanging the plastic sample from the top by the use of clippers and add weights on the other end of the plastic as shown on Figure 3.8. Before the test commence the samples must be cut down to 3x5cm shape to test the very center strength of the plastic. The results were calculated by the use of the formula shown:

$$TS = F/Wxt \text{ ....Equation 3.1}$$

Where:
TS (Pa) = Tensile Strength
F (N) = Force required to break
W (m) = Width of bioplastic
t (m) = Thickness of bioplastic

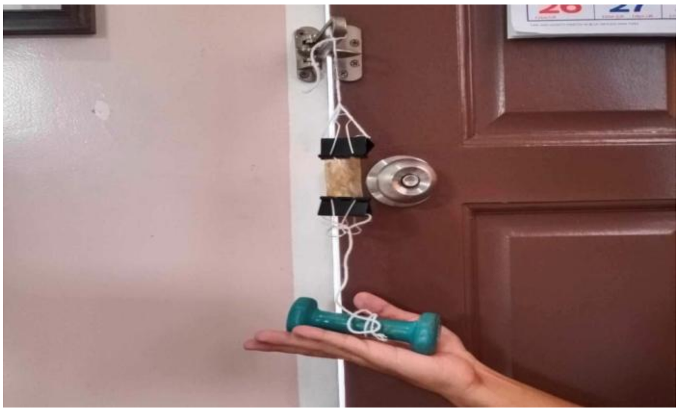

Figure 3.8. Tensile Strength and Elongation Test
Note: The weights will be released once the setup is ready.

- *Percent Elongation Test*

A standard method by ASTM D412 to calculate the percent elongation is by comparing the length of the film at break and length of the film before being pulled by the tensile strength elongation tested. The mathematical percent elongation can be calculated using the Elongation Formula:

$$(\%) = [(L_1 - L_0)/L_0] \text{ x } 100\% \text{ ....Equation 3.2}$$

Where:
% = Percent Elongation
L_1 (m) = Length of bioplastic after pulled
L_0 (m) = Length of bioplastic before pulled

Physical Analysis

Starch-based biodegradable plastics are water-sensitive, have high water vapor permeability and generally provide films with physical properties unsuitable for many applications, which has hindered the expansion of their use and justifies the need to make modifications to improve their properties.

- Water Absorption Test

ASTM D570 procedure for water absorption was done by weighing of the initial bioplastic, then put into a graduated cylinder filled with water displayed on Figure 3.9. After 10 seconds, the bioplastic is removed and weighed. The procedure was repeated until the bioplastic weight is constant. The water absorbed was calculated by:

$$\% = [(W_1 - W_0)/W_0] \text{x } 10 \text{ ...... Equation 3.3}$$

Where:
% = Percent of Water absorbed
W_1 (g) = Weight of bioplastic after soaking
W_0 (g) =Weight of bioplastic before soaking

Figure 3.9. Bioplastic Under Water Absorption Test

- Density Test

In this test, the method by Darni *et al.* (2018) is adapted. The mass (m) of bioplastic is weighed. Then the 25 ml of beaker is filled with up to 15 ml of distilled water, and the weighed bioplastic was placed into the beaker as shown on Figure 3.10. After 15 minutes, the new water volume (V) was recorded to calculate the actual bioplastic volume by finding the difference between the initial and final water volumes. In formula, it shows as:

$\rho =$ m/v Equation 3.4

Where:

ρ (g/ml) = Density of bioplastic

m (g) = Mass of Bioplastic

v (ml) = Difference between the initial and final volumes of water.

Figure 3.10. Bioplastic Under Density Test

- *Thickness*

A device called Vernier caliper was used to measure the bioplastic's thickness in all four sides ensuring accuracy as the type of caliper that was used is a digital caliper.

Biodegradability

The biodegradability of the smooth narra leaves based bioplastic was evaluated through a soil burial degradation test. Degradation testing serves to determine the extent of damage of bioplastics. The damage was seen from the mass reduction of respective specimens buried in the ground (Benali et al. 2021). The bioplastic samples were weighed, and measured its length to provide initial data. Three 10 cm holes as shown on Figure 3.11 was dug representing each mixture, with 10 samples for each hole. After one week, the samples were recovered as seen in Figure 3.12 and the weight loss of each sample were recorded to determine the degree of biodegradability of the bioplastics and to determine how effective the samples broke down in a natural environment.

Figure 3.11. Biodegradability Setup

Figure 3.12. Bioplastic After 7 days of Biodegradability Test

IV. Results And Discussion

This chapter discusses the results from the testing of smooth narra leaves based bioplastic. A series of test was conducted to investigate the physical, and mechanical properties, and biodegradability of the bioplastic. Smooth Narra based bioplastic comprises of 3 various mixtures namely Mixtures 1, 2, and 3, Each mixture included ten trials that assessed key properties such as tensile strength, percent elongation, density, water absorption, thickness, and biodegradability the following characteristics are significant in determining the viability of the smooth narra based bioplastic. In addition, the results of the bioplastic are compared to a commercial plastic which is a low-density polyethylene (LDPE) in a form of a "sando" bag. The LDPE undergo the same test of mechanical and physical properties.

Mechanical Properties

Mechanical properties define how a material responds to external forces this section discusses tensile strength which determines a material's durability and load-bearing capacity. and Elongation a key mechanical property, measures how much a material can stretch before breaking, indicating its ductility and flexibility.

- Tensile Strength

Nasir and Othman (2021) tensile strength is a critical mechanical property that indicates the maximum stress a material can withstand while being stretched or pulled before breaking. In the context of bioplastic films, it reflects the film's ability to endure tension without failure. This is an important characteristic for food packaging products as it is the factor on how much weight the material can yield before breaking. Low-density polyethylene has a tensile strength at breaking point ranging from 10-20Mpa while bioplastic typically have lower tensile strength.

Table 4.1 presents the results of tensile strength among each mixture of bioplastic, Mixture 2 displays consistent tensile strength having values that are ranging within each other from 11.41 to 16.481Pa Mixture 2 also has the highest means score among the three while the other Mixture 1 and 3 is inconsistent having displayed higher and lower results that are not within each other's range such as on Mixture 1, having the highest value of 16.48 Pa but also having the lowest value of 7.06 Pa. Mixture 3 has this pattern having the highest result of 14.13 Pa and the lowest value of 8.24 Pa. The reason for having a high tensile strength of the bioplastic has something to do with the amount of starch present in the bioplastic, having more starch enhances the tensile strength of the bioplastic as well as the elongation (Akinyele *et al.,* 2021). Additionally, the effect of glycerol on tensile strength is that the more glycerol is included in the mix will lower the tensile strength of the bioplastic. When Mixture 2 is compared to LDPE, LDPE undoubtedly presents superior tensile strength as the process, additives, and equipment used to engineer the LDPE plastic are of best quality in order to perform at its best.

TABLE 4.1. Tensile Strength for Bioplastic in Mixtures 1,2, 3, and LDPE

Tensile Strength, Pa				
Trial	**Mixture 1**	**Mixture 2**	**Mixture 3**	**LDPE**
1	7.063	11.866	12.360	573.9
2	15.344	16.481	10.595	404.7
3	12.360	12.360	8.240	739.1
4	8.240	12.898	8.725	529.7
5	12.360	15.892	11.410	469.5
6	16.480	11.410	10.595	501.1
7	10.595	11.866	9.270	792.19
8	15.892	13.484	9.888	807.2
9	13.905	15.344	11.410	508.9
10	12.898	11.866	14.126	802.6
mean	**13.22**	**13.35**	**10.66**	**612.89**
Standard Deviation	**2.51**	**1.88**	**1.77**	**155.45**

Under Shapiro Wilk Test results states that the data does belong to a normal distribution as the result states that 0.96456 is greater than 0.927 which is the reference value. Using Levene's test to test for homogeneity for Mixture 1,2, and 3 the p-value result is 0.1777 which are greater than 0.05 alpha value this means that the data are homogenous therefore ANOVA can be used. Table 4.2 shows that the p-value of 0.047284 is less than 0.05 meaning among the three groups there is a significant difference among them. To determine which group is different from the other group a Tukey's test is used.

TABLE 4.2. ANOVA Result from Tensile Strength

F-Static	p-Value	F Critical
3.424	0.047284	3.354131

Observed on Table 4.3 that Mixture 1 against Mixture 2 are insignificant meaning that there is no statistical difference between them, same goes for Mixture 1 against Mixture 3, but Mixture 2 against Mixture 3 states that $p<0.05$ meaning they have statistical difference between them this is likely to the reason that Mixture 2 have the highest mean close to the mean of Mixture 1 but Mixture 3 have the lowest among them. Proving that higher concentration of glycerol reduces the tensile strength of the bioplastic and having higher starch concentration increases the tensile strength (Akinyele *et al.,* 2021).

TABLE 4.3. Tukey Test Result for Tensile Strength

Treatment Pairs (Mixture)	Tukes HSD Q Statistics	Tukey HSD p-Value	Tukey HSD Interface
1 vs 2	1.1216	0.69751	Insignificant
1 vs 3	2.4934	0.20107	Insignificant
2 vs 3	3.6151	0.04228	P<0.05

- Percent Elongation

Percent elongation determines the maximum stretch of the material at break, Percent elongation also ties to tensile strength as lower percent elongation indicates lower tensile strength and vice versa, this means that low elongation poses high risk of breaking under stress which means higher percent elongation is desirable. This makes percent elongation a necessary test for bioplastic to be able to determine the dependability and quality of the bioplastic (Elhabishi et al., 2018).

Presented on Table 4.4 are the elongation at breaking point, Among the three mixtures, Mixture 2 has the highest average of 10.34% while Mixture 3 follows with a mean score of 9.61% and Mixture 1 displayed the lowest elongation yielding a mean of 8.74%. The presence of starch in a bioplastic greatly enhances the elongation of the bioplastic with the addition of glycerol improves the effect of elongation (Cheung et al. (2024). Since Mixture 2 has the highest elongation among the three bioplastic, it was compared to LDPE. Mixture 2 is close to the elongation of LDPE which is 14.05%, providing a difference of 3.71%.

TABLE 4.4. Percentage Elongation for Bioplastic in Mixtures 1,2, 3 and LDPE

Elongation at Break, %				
Trial	**Mixture 1**	**Mixture 2**	**Mixture 3**	**LDPE**
1	9.84	9.65	8.86	13.06
2	6.70	10.83	9.84	14.43
3	7.48	8.66	10.83	12.84
4	11.81	8.86	10.43	13.86
5	7.10	12.01	8.10	14.66
6	8.26	11.61	8.26	15.10
7	14.57	11.02	12.01	13.45
8	6.67	9.06	9.25	13.20
9	6.34	12.20	7.28	15.25
10	8.66	9.45	11.22	14.70
Mean	**8.74**	**10.34**	**9.61**	**14.05**
Standard Deviation	**2.653**	**1.35**	**1.52**	**0.88**

Under Shapiro Wilk Test, results state that the data do

Andre C. Clemenia and Lizamyl R. Laping "Innovative Bioplastic Production from Smooth Narra Leaves (Pterocarpus indicus forma indicus): A Path Towards Sustainable Alternatives," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 8, Issue 4, pp. 61-76, 2025.

belong to a normal distribution as the result is 0.96996 is greater than 0.927 which is the reference value. Using Levene's test to test for homogeneity for Mixtures 1, 2, and 3, the p-value results is 0.1932 which is greater than 0.05 alpha value this means that the data are homogenous therefor we can now proceed to using ANOVA test. Table 4.5 shows that the p-value of 0.200848 is greater than 0.05 meaning among the three groups there are no significant difference among them.

TABLE 4.5. ANOVA Results from Percent Elongation

F-Static	p-Value	F Critical
1.704538	0.200848	3.354131

Physical Properties

The physical properties of a bioplastic affect their viability. The physical properties that are included in the test are water absorption, density, and thickness. Throughout the discussion the relationship of starch and glycerol became relevant as to why the result is presented as is.

- Water Absorption

Water absorption levels are crucial, as it directly impacts their performance and suitability for specific applications. High water absorption is suitable for agricultural applications as it is usually designed for soil integration, while low water absorption is suitable for food packaging products and durable goods such as utensils, this is because they prevent moisture from compromising the products integrity (Aswath, 2023). Nasir and Othman (2021), Starch-based bioplastics tend to absorb

more moisture because starch molecules naturally attract water. Increasing the starch content in bioplastics generally leads to higher moisture and water absorption rates. This heightened absorption is attributed to the hydrophilic nature of starch, which readily interacts with water molecules. In addition, Glycerol, commonly used as a plasticizer in bioplastics, also affects water absorption as Elevating glycerol levels can enhance water absorption. For instance, bioplastics with 40% glycerol concentration exhibits higher water absorption compared to those with 20%

The tested LDPE yielded 0% water absorption as it is designed to be a very suitable food packaging plastic and this is supported by Boaventura et al. (2020), stating that pure LDPE, yielded almost no water absorption. Table 4.6 showcases water absorption of Mixture 1 with an average of 29.06% which is notably higher and undesirable for bioplastic, as it indicates poor resistance to water. In comparison, Mixtures 2 and 3 demonstrates much lower water absorption rate at 19.48% and 17.87%, respectively, making them more suitable for bioplastic application where lower water uptake is generally preferred for better performance and durability. To put it into perspective, LDPE has a water absorption rate of 0% which is the most desirable for food packaging.

Under Shapiro Wilk Test, results state that the data do belong to a normal distribution as the result is 0.96057 is greater than 0.927 which is the reference value. Using Levene's test to test for homogeneity for Mixtures 1,2, and 3 the p-value results is 0.0079 which is less than 0.05 this means that the data are not homogenous therefor Kruskal-Wallis test can be used. Table 4.7 shows that the p-value of 0.00112 is less than 0.05 meaning among the three groups there are significant difference among them. To determine which group is different from the other group a Tukey's test is used.

TABLE 4.6. Water Absorption for Bioplastics 1, 2, 3 and LDPE

Water Absorption, %				
Trial	Mixture 1	Mixture 2	Mixture 3	LDPE
1	25	22.22	11.25	0
2	30	30	13.75	0
3	29.41	16	8.89	0
4	35.71	17.5	10	0
5	35	13	23.33	0
6	28.89	18	26.67	0
7	30.43	22.5	20	0
8	22.5	17.78	25	0
9	25.45	15.56	28.57	0
10	28.21	22.22	11.25	0
mean	**29.06**	**19.48**	**17.87**	**0**
Standard Deviation	**4.16**	**4.87**	**7.63**	**0**

TABLE 4.7. Kruskal-Wallis Results for Water Absorption

K	H	H Critical	p-Value
3	13.5951	5.991464547	0.00112

Observed on Table 4.8 that Mixture 1 against Mixture 2 are significant as well as Mixture 1 against Mixture 3 meaning there are statistical difference between them the reason is likely because Mixture 1 have a very high mean because of the starch concentration present on Mixture since the higher concentration of starch increases water absorption. Meanwhile, Mixture 2 against Mixture 3 states that it is insignificant meaning there are no statistical difference between them.

TABLE 4.8. Dunn Test Results for Water Absorption

Treatment Pairs (Mixture)	Dunn p-Value	Dunn Interface
1 vs 2	0.0024	$p<0.05$
1 vs 3	0.0008	$p<0.05$
2 vs 3	0.7701	Insignificant

- Density

Density results vary depending on the compositions used to create the plastic or bioplastic, LDPE polymer have densities ranging from 0.915 g/cm^3 to 0.935 g/cm^3 or9.15x10^{-7} g/ml to 9.35x10^{-7} g/ml. Akinyele et al. (2021), Depending on the starch concentration it increases the density or lowers the density proportionally (Abdullah, et al., 2019). While the addition of glycerol lowers the density the more glycerol is added the lower the density this is relevant as lower density is more desirable because it makes the bioplastic light weight making it suitable for food packaging as it does not increase the overall weight of the food and the packaging.

Table 4.9 is a data of the results for density of bioplastic and LDPE. Mixture 1 resulted with the highest density mean of 7.78 g/ml which is not the most desirable for food packaging as it means it will be heavier. Mixture 2 and 3 yielding the least density having the mean of 6.96 g/ml and 6.89 g/ml respectively, which are the desirable options for food packaging.

Under Shapiro Wilk Test the result states that the sample does not belong to a normal distribution as the result states that 0.9159 is less than 0.927 which is the reference value. Since the data is not normally distributed, Kruskal Wallis test was used to compare the medians of the three Mixture. Table 4.10 shows that the p-value of 0.010158 is less than 0.05 meaning among the three groups there are significant difference among them. To determine which group is different from the other group a Dunn's test is used.

TABLE 4.9. Density for Bioplastics 1, 2, 3, and LDP

Density, g/ml				
Trial	Mixture 1	Mixture 2	Mixture 3	LDPE
1	7.3	7	6.7	0
2	7.8	6.7	6.4	0
3	7.8	6.4	6.7	0
4	7.8	7.8	6.3	0
5	6.7	6.4	6.7	0
6	8.2	6.7	7.8	0
7	8	8.9	7.8	0
8	8.9	7	6.7	0
9	7.8	6.7	7.5	0
10	7.5	6	6.3	0
mean	**7.78**	**6.96**	**6.89**	**0**
Standard Deviation	**0.57**	**0.83**	**0.59**	**0**

TABLE 4.10. Kruskal-Wallis Results for Density

K	H	H Critical	p-Value
3	9.178997	5.991464547	0.010158

Observed on Table 4.11 that Mixture 1 against Mixture 2 are significant as well as Mixture 1 against Mixture 3 meaning there are statistical difference between them the reason is likely because Mixture 1 have a very high mean because of the starch concentration present on the Mixture since the higher concentration of starch increases density. Meanwhile, Mixture 2 against Mixture 3 states that it is insignificant meaning there are no statistical difference between them.

TABLE 4.11. Dunn Test Results for Density

Treatment Pairs (Mixture)	Dunn p-Value	Dunn Interface
1 vs 2	0.01269	$p<0.05$
1 vs 3	0.00618	$p<0.05$
2 vs 3	0.80617	Insignificant

- Thickness

Measurement of the thickness helps in determining irregularities of the plastic as consistent thickness is important for the material as this will aid in making the distribution of stress even as well as distribution of strength. Having irregular thickness will have weak points within the material thus, posing risk of breaking but ultimately thickness aids in plastic's quality to preserve the quality and integrity of the content as it serves as an effective barrier against light, heat, and oxygen. Baryla et al. (2021) states that the thickness of LDPE is usually between between 0.15 and 0.7 mm.

Among the three bioplastic Mixture 2 scored the highest as it has the thickest among the three mean of 2.54 mm. Mixture 1 follows with a mean thickness of 2.4 mm, and Mixture 3 is the thinnest among the three bioplastic with a mean score of 1.53 mm. LDPE is very thin ranging from only 0.1mm and 0.11mm with an average of 0.11 mm.

Under Shapiro Wilk Test results states that the data do belong to a normal distribution as the result is 0.934623 is greater than 0.927 which is the reference value. Using Levene's test to test for homogeneity for Mixture 1, 2, and 3 the p-value results is 0.0674 which are greater than 0.05 alpha value this means that the data are homogenous therefor ANOVA test can be used. The result shows that the p-Value of 0.0000023 is far less than 0.05 meaning among the three groups there is a significant difference among them. To determine which group is different from the other group a Tukey's test is used.

TABLE 4.12. Thickness for Bioplastics 1, 2, 3, and LDPE

Thickness, mm				
Trial	Mixture 1	Mixture 2	Mixture 3	LDPE
1	2.1	2.5	1.2	0.1
2	2.9	2.7	1.4	0.1
3	2.4	2.4	1.8	0.11
4	1.8	2.3	1.7	0.11
5	2.4	2.8	1.3	0.11
6	2.7	2.6	1.4	0.11
7	1.4	2.5	1.6	0.11
8	2.8	2.2	1.5	10
9	3.2	2.9	1.3	10
10	2.3	2.5	2.1	11
mean	**2.4**	**2.54**	**1.53**	**0.11**
Standard Deviation	**0.54**	**0.21**	**0.28**	**0.01**

TABLE 4.13. ANOVA Results from Thickness

F-Static	p-Value	F Critical
21.82105	0.0000023	3.354131

Observed on Table 4.14 that Mixture 1 against Mixture 2 are insignificant meaning there are no statistical difference between them but when Mixture 1 and Mixture 2 is being compared to Mixture 3 the result becomes significant meaning that there is significant difference between them. This is because Mixture 3 is very thin compared to the 2 Mixture because the addition of starch contributes to the bulk of the output bioplastic. According to Nasir and Othman (2021), increasing the starch concentration in bioplastic formulations generally leads to an increase in the thickness of the resulting bioplastic films. This is because higher starch content contributes more solid material to the film matrix, resulting in thicker films upon drying.

TABLE 4.14. *Tukey Test Result for Thickness*

Treatment Pairs (Mixture)	Tukey HSD Q Statistic	Tukey HSD p-Value	Tukey HSD Interface
1 vs 2	1.1951	0.66785	Insignificant
1 vs 3	7.4269	0.00101	$p<0.01$
2 vs 3	8.6220	0.00101	$p<0.01$

- Biodegradability

The biodegradation of bioplastics depends on their physicochemical properties as well as environmental factors, such as the soil and its essential microbial diversity. Studies have shown that regardless of the source and type of bioplastic, soil enrichment significantly enhances the rate of biodegradation (Chakraborty et al., 2023). Furthermore, the biodegradation of bioplastics is significantly influenced by variables like temperature and humidity. Biodegradation can be performed in numerous ways, one of which is burial degradation or burying the material to degrade this is the method used to test the biodegradability of the bioplastic, while LDPE is least favorable for such quality as it is not made to degrade easily (Flury and Narayan, 2021).

Table 4.14 shows the results of how much the bioplastic have degrade after experiencing burial test with all the Mixture showed significant changes while LDPE did not undergo burial test but it is given that it will not degrade under such condition.

TABLE 4.15. Biodegradability for Bioplastic in Mixtures 1,2, 3 and LDPE

Biodegradability, %				
Trial	**Mixture 1**	**Mixture 2**	**Mixture 3**	**LDPE**
1	37.5	25	57.14	0
2	40	40.91	42.86	0
3	33.33	62.5	62.5	0
4	50	43.28	50	0
5	44.44	60.0	71.43	0
6	40	36.84	42.86	0
7	25	42.11	62.5	0
8	55.55	48.57	50	0
9	45.45	40	57.14	0
10	33.33	55.56	42.86	0
mean	**40.46**	**45.48**	**53.93**	**0**
Standard Deviation	**8.88**	**11.42**	**9.84**	**0**

Under Shapiro Wilk Test it is found out that the sample do not belong to a normal distribution as the result states that 0.190785 is lower than 0.927 which is the reference value. Since the data is not normally distributed, Kruskal Wallis Test will be used to compare the medians of the three Mixture. Table 4.16 shows the result that the p-value of 0.020215 is less than 0.05 meaning among the three groups there are significant difference among them. To determine which group is different from the other group a Dunn's test is used.

TABLE 4.16. Kruskal-Wallis Results for Biodegradability

K	H	H Critical	p-Value
3	7.802659	5.991464547	0.020215

Observed on Table 4.17 that Mixture 1 against Mixture 2 are insignificant as well as Mixture 2 against Mixture 3 meaning there are no statistical difference between them the reason is likely because Mixture 2 strikes a middle ground between the two but when Mixture 1 and Mixture 3 is being compared they have significant differences as Mixture 3 have a high degradation rate as Mixture 1 have a lower degradation rate.

TABLE 4.17. Dunn Test Results for Biodegradability

Treatment Pairs (Mixture)	Dunn p-Value	Dunn Interface
1 vs 2	0.30860	Insignificant
1 vs 3	0.00575	$p<0.05$
2 vs 3	0.08123	Insignificant

- Comparison of Bioplastic and LDPE

Throughout the testing, bioplastic and low-density polyethylene showed significant differences. These differences were due to the different materials used, process, equipment, and methods used to derive such plastic. Bioplastic yielded the least desirable result for reasons such as the materials used, equipment, and the process used to make the bioplastic as most of the processes are done manually, while LDPE certainly showed superior results as it is made to be able to perform its functions as a food packaging. Under the right conditions the bioplastic might show a promising result given the proper equipment and process. Despite bioplastic showing less desirable results it is superior in terms of it biodegradability which the LDPE could not compete. Such quality is beneficial for the environment as it helps in reducing total biomass and plastic waste.

Presented on Table 4.17 are the scores of the bioplastic and the LDPE based from the results from the mechanical test, physical test, and biodegradability test. Among the bioplastics, Mixture 2 scored the highest while Mixture 3 closely follows, and Mixture 1 scored the lowest, LDPE undoubtedly scored the highest.

TABLE 4.18. Scoring of Bioplastics and LDPE

Properties	Mixture 1	Mixture 2	Mixture 3	LDPE
Tensile Strength	2	3	1	4
Elongation	2	3	1	4
Water Absorption	1	2	3	4
Density	1	2	3	4
Thickness	3	4	2	1
Biodegradability	2	3	4	1
Total:	**11**	**17**	**14**	**18**

Note: Score of 1 indicates least performance, and score of 4 indicates high performance on specific test.

Table 4.18 shows the score and description according to the summation of scores of each bioplastic. Based on Table 4.18, the total score for LDPE is 18 which classifies as a very satisfactory plastic. The highest result for the Smooth Narra-based bioplastic is Mixture 2 yielding a total score of 17 which is a very satisfactory bioplastic. Mixture 3 score is 14 which is also satisfactory and lastly Mixture 1 yielded the lowest score of 11 which is unsatisfactory scale of a bioplastic. The basis of assessing the bioplastic scale is Table 4.19.

TABLE 4.19. Score Scale and Description

Classification	Description
Poor	It suggests a poor summation with a range of 0-6
Unsatisfactory	It suggests an unsatisfactory summation with a range of 7-11
Satisfactory	It suggests a satisfactory summation with a range of 12-16
Very Satisfactory	It suggests a very satisfactory summation with a range of 17-21

Note: Adapted from Table 4.18 Biodegradable Plastic from Taro *(Colocasia)* and Potato *(Solanum tuberosum)* Peels with Tomato *(Solanum lycopersicum)* Seeds. Intong, (2024).

V. Conclusion and Recommendation

The objective of this thesis project is to be able to come up with viable sustainable plastic that can potentially be viable for convenient usage, in order to achieve this goal, the bioplastic the must undergo testing such as mechanical properties, physical properties, and biodegradability. The bioplastic has varying mixtures of starch to glycerol namely; Mixture 1, Mixture 2, and Mixture 3 This chapter summarizes the key findings throughout this thesis project, explaining their significance towards the goal of the thesis project. This chapter also includes recommendation for further improvement of the viability of the bioplastic.

Conclusion

The goal of this study is to come up with an alternative for plastic that is both innovative and sustainable, the goals are close to being desirable if certain conditions are met, and certain characteristics are improve the following reasons are found on the study:

Mechanical properties include tensile strength and percent elongation, among the three bioplastic, Mixture 2 scored the highest with a score of 3 which also scored 3 in percent elongation. The reasoning for the result is that higher concentration of starch heightens the mechanical properties of the bioplastic while higher concentration of glycerol lowers the mechanical properties but it still aids in the overall performance of the bioplastic which is why a good balance of starch to glycerol Mixture results into a desirable outcome.

Water absorption, density, and thickness are part of the physical properties of a bioplastic. The results came out to be as is due to the relationship of starch and glycerol towards the water absorption and density of the bioplastic, as having higher starch concentration enhances water absorption and lowering the amount of starch lowers water absorption meanwhile the addition of glycerol enhances the effect but may also lower the water absorption to some degree which is why a good balance of starch to glycerol Mixture is necessary to create a balanced bioplastic. Throughout the testing, the results came out to be that Mixture 3 scored highest in both water absorption and density with a score of 3 while Mixture 2 came in second with a score of 2 and Mixture 1 scored lowest of 1. For thickness Mixture 2 scored highest of 4, Mixture 1 follows with a score of 3 and Mixture 3 with a score of 2. Depending on the usage lower water absorption and density is more preferable for the goal of making a food packaging bioplastic as lower means the contents of the food packaging will be less likely to diminish in quality as there is less moisture content present in the packaging. Meanwhile, Mixture 1 scored lowest for having high water absorption and density but having higher water absorption and density means it is preferable for agricultural purposes but this is not the goal of the thesis project which is why Mixture 1 scored the lowest. Mixture 2 scored highest for thickness since it a thick bioplastic which is beneficial for preserving the quality and integrity of the content it also protects the content from light, heat, and oxygen. Mixture 1 followed closely for having the same reason.

The biodegradability of smooth narra leaves based bioplastic displayed significant changes when it comes to its biodegradability as all of the Three-Mixture suffered weight losses which means that the bioplastic is indeed biodegradable. Mixture 3 having the highest score of 4 as the mean degradation rate is 53.93%, Mixture 2 follows with a score of 3 a mean score of 45.48% and mixture 1 with a degradation rate of 40.46 yielding a score of 2.

Among the 3 bioplastic that have been created, Mixture 2 scored the highest amongst the three because of having a balance Mixture as stated multiple time throughout this thesis that starch and glycerol work hand in hand balancing the different aspects of the bioplastic from tensile strength is being enhanced by starch while being lowered by glycerol but glycerol also enhances elongation same goes for physical aspects of the bioplastic that more starch means more water absorption but more glycerol lowers the water absorption but is still necessary for the bioplastic's density thus Mixture 2 striking a good balance of starch to glycerol Mixture.

To compare the results for the best bioplastic which is Mixture 2 against LDPE, LDPE is still superior in terms of functionality and quality as it is industrially made to withstand various purposes and not easily break. With careful consideration Mixture 2 could potentially contend with LDPE as Mixture 2 is able to degrade easily which LDPE could not, Mixture 2 also have qualities that are near the optimal level, such as thickness and elongation. In conclusion Mixture 2 scored highest among the three bioplastic Mixture gaining a score of 17 closing in with the score of 18 by the LDPE, if given proper procedure and treatment the Mixture 2 smooth narra based bioplastic could become a viable sustainable solution.

Recommendations

The following are recommendation based on the work accomplished during this project and on the conclusions given above. The researcher recommends:

1. Experimenting on a better starch to glycerol mixture to enhance the quality of the bioplastic or even adding other ingredients that could enhance the tensile strength, and lower the water absorption to make the bioplastic ideal for practical use.
2. Consider using machinery and equipment for starch extraction and grinding, as manual methods can be time-consuming and require significant effort.
3. To improve the mold design by having ventilation to allow trapped air escape during curing to prevent bubble pores in the bioplastic.

REFERENCES

[1]. Aasen Helga, Baumann Philipp, Frey Lea Antonia, Kolliker Roland, and Studer Bruno (2020). *A Non-Destructive Method to Quantify Leaf Starch Content in Red Clover*. Date retrieved December 15, 2024. Retrieved from https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2020.569948/full

[2]. Abdullah Akbar Hanif Dawam, Putri Oceu Dwi, and Sugandi Winda Windi (2019) *Effects of Starch-Glycerol Concentration Ratio On Mechanical and Thermal Properties of Cassava Starch-Based Bioplastics*. Date retrieved March 16, 2025. Retrieved from https://core.ac.uk/download/pdf/270302181.pdf

[3]. Adams M.R (2014). *Vinegar*. Date retrieved October 25, 2024. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/B9780123847300003487

[4]. Akinyele Bolaji, Mohallem Nelcy, Olusegun Sunday, Oluwasina Olayinka, and Oluwasina Olugbenga (2021). *Evaluation of the effects of additives on the properties of starch-based bioplastic film*. Date retrieved March 26, 2025. Retrieved from https://doi.org/10.1007/s42452-021-04433-7

[5]. Ali Shakir, Chang Young-Cheol, and Isha (2023). *Ecotoxicological Impact of Bioplastics Biodegradation: A Comprehensive Review*. Date retrieved March 27, 2025. Retrieved from https://www.mdpi.com/2227-9717/11/12/3445

[6]. Alcantara Virgie, Atole Liezel, Isagan Margareth, Parcon Raymond, Simbahan Jessica, and Zarate Jocelyn (2020). *Variations in enzymatic activity and response to abiotic factors of endophytic bacteria isolated from Narra Pterocarpus indicus growing in a forest environment and urban arboretum Badrudduza*. Date retrieved January 17, 2025. Retrieved from http://scienggj.org/2020/2020%20Special%20Issue/12/PSL%202020%20Special%20Issue%20120-126-Atole%20et%20al.pdf

[7]. Alonso Joji (2023). *Law vs Burning Dried Leaves*. Date retrieved October 7, 2024. Retrieved from https://tribune.net.ph/2023/10/17/law-vs-burning-dried-leaves#

[8]. Aswath Rajesh (2023). *Ecofriendly Polymeric Material: Paving The Way for Circular Bio-Economy. The Effect of Chitosan on Biodegradability and Water Resistance of Starch based Bioplastic*. Date retrieved March

Andre C. Clemenia and Lizamyl R. Laping "Innovative Bioplastic Production from Smooth Narra Leaves (Pterocarpus indicus forma indicus): A Path Towards Sustainable Alternatives," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 8, Issue 4, pp. 61-76, 2025.

16, 2025. Retrieved from. https://sspcdn.blob.core.windows.net/files/Documents/SEP/JIC/2023/Posters/2023JIC_Rajesh.Aswath.Poster.pdf

[9]. Athanassiou Athanassia, Benitez Jose, Florido-Morino Pedro, Heredia-Guerrero Jose, Giacomo Tedeschi, Guzman-Puyol Susana, and Porras-Vazquez Jose (2024). *Transparent, plasticized cellulose-glycerol bioplastics for food packaging applications*. Date retrieved April 30, 2025. Retrieved from https://www.sciencedirect.com/science/article/pii/S0141813024037619

[10]. Badrudduza M.D., Chowdhury Mohammad Asaduzzaman, Hossain Nayem, and Rana Masud. (2023). *Development and Characterization of Natural Sourced Bioplastic for Food Packaging Application*. Date retrieved November 13, 2024. Retrieved from https://www.sciencedirect.com/science/article/pii/S2405844023007454

[11]. Baryla Anna, Dobrev-Witkowska Joanna, Dohojda, Marek, and Szlachetka Olga (2021). *Low-density polyethylene (LDPE) building films – Tensile Properties and Surface Morphology*. Date retrieved April 13, 2025. Retrieved from https://www.sciencedirect.com/science/article/pii/S2352710221012444#:~:text=The%20applied%20granulate%20is%20usually,water%2Dtightness%20over%20the%20years

[12]. Benali Samira, Carretti Emiliano, Gori Riccardo, Lubello Claudio, Onderwarter Rob, Raquez Jean-Marie, Roosa Stephanie, and Wattiez Ruddy (2021). *Degradation of Film and Rigid Bioplastics During the Thermophilic Phase and the Maturation Phase of Simulated Composting*. Date retrieved March 27, 2025. Retrieved from https://link.springer.com/article/10.1007/s10924-021-02098-2?

[13]. Bejena Baru Debtera (2019). *Synthesis and Experimental Study of Production of Bioplastic from Banana Peels*. Date retrieved Septer 11, 2024. Retrieved from https://www.academia.edu/78483665/Synthesis_and_Experimental_Study_of_Production_Bio_plastic_from_Banana_Peels

[14]. Bevans Rebecca (2020). *One Way ANOVA, When and How to Use it*. Date retrieved November 13, 2024. Retrieved from https://www.scribbr.com/statistics/one-way-anova/

[15]. Bogers Loes (2020). *Vinegar in Bioplastic*. Date retrieved October 13, 2024. Retrieved from https://class.textile-academy.org/2020/loes.bogers/files/recipes/biorubber/

[16]. Burns Colin, Fusade Lucie, Viles H.A., and Wood Chris (2019). *The Effect of Wood Ash on the Properties and Durability of Lime Mortar for Repointing Damp Historic Buildings*. Date retrieved December 15, 2024. Retrieved from https://www.researchgate.net/figure/Particle-Size-distribution-of-wood-ash-from-0389-to-2000-mm-showing-a-bimodal_fig1_332269251#:~:text=The%20particles%20of%20the%20wood,dominate%20the%20particle%20size%20distribution

[17]. Carandang Wilfredo (2004). *Pterocarpus Indicus Willd*. Date retrieved January 7, 2025. Retrieved from https://www.apforgen.org/fileadmin/user_upload/publications/Priority_Species/InfoSheet_P_indicus_.pdf

[18]. Chakraborty Ishita, Mazumder Nirmal, Pooja Nag, and Rahman Hafizur (2023). *An Insight on Sources and Biodegradation of Bioplastic: A review*. Date retrieved March 16, 2025. Retrieved from https://pmc.ncbi.nlm.nih.gov/articles/PMC10230146/

[19]. Cheung Ka Man, Harte Lorraine, Ip Tammi, Kwan Clement, Lam Queenie, Lee Hannah (2024). *The Effect of Plasticizers on the Mechanical Properties and Chemical Properties of a Gelatin Bioplymer*. Date retrieved March 8, 2024. Retrieved from https://emerginginvestigators.org/articles/23-139

[20]. Combalicer Marilyn Sabalvaro, Hernandez Jonathan Ogayon, Maldia Lerma San Jose, and Umali Arthur Glenn Agojo (2024). *Effects of Decapitation, Water-Deficit Stress, and Pot Size on Morpho-Anatomy and Physiology of Pterocarpus Indicus*. Date retrieved. March 26, 2025. Retrieved from https://doi.org/10.23960/jsl.v12i1.821

[21]. Darni Y., Hanif M., Lesmana D., Lismeri L., and Sumartini S. (2018). *Bioplastics Synthesis Based on Sorghum–Eucheuma Spinosum Modified with Sorghum Stalk Powder*. Date retrieved March 8, 2024. Retrieved from https://iopscience.iop.org/article/10.1088/1742-6596/1376/1/012042/pdf

[22]. Das Abhijit, Gadekar Pradeep, Gadhave Ravindra, and Mahanwar Prakash (2018). *Starch Based Bio-Plastics: The Future of Sustainable Packaging*. Date retrieved March 8, 2024. Retrieved from https://www.scirp.org/journal/paperinformation?paperid=84926

[23]. Devarayan Kesavan, Kandasamy Gajendiran, Kandasamy Sabariswaran, Natarajan Devarajan, Sakthivel Gnanavel, Sukumaran Monikandon, Umadevi Ganapathi, and Vijayan Selvaraj (2020). D*evelopment of Ecofriendly Bio-Plastics from the Leaf Extract of Manihot Esculenta*. Date retrieved December 15, 2024. Retrieved from https://chesci.com/wp-content/uploads/2021/01/16_CS205111245_p978-985-1.pdf

[24]. DeVroom Dawn (2023). *What is Solid Waste?* Date retrieved September 9, 2024. Retrieved from https://blog.idrenvironmental.com/what-is-solid-waste

[25]. Ding Zhen, Gilbert Robert, Huang Lichun, Li Changfeng, Li Enpeng, Lv Chao, Xu Rugen, and Zhang Changquan (2025). *The molecular structure of leaf starch from three cereal crops*. Date retrieved March 26, 2025. Retrieved from. Science Direct. https://www.sciencedirect.com/science/article/pii/S0144861724013250

[26]. Dole Bhushan, Khare Sunil, Naik Satya, and Saxena Devesh (2018). *Potential and Perspective of Castor Biorefinery*. Date retrieved November 30, 2024. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/B9780444639929000215

[27]. Elfaghi Abdulhafid, Hasan Zaimah, Ilyas R.A., Khattak MA., Mohamed Abdulrahman, Omran Abdoulhdi, and Sapuan S.M. (2022). *Effect of Various Plasticizers in Different Concentrations on Physical, Thermal, Mechanical, and Structural Properties of Wheat Starch-Based Films*. Date retrieved March 27, 2025. Retrieved from National Library of Medicine. https://pmc.ncbi.nlm.nih.gov/articles/PMC9823313/

[28]. Elhabishi Rabea, Elhari Wael, Klash Abdalah, and Shehani Anour (2018). *Mechanical Properties of HDPE, LDPE and their Blends*. Date retrieved January 3, 2025. Retrieved from https://www.researchgate.net/figure/Mechanical-properties-of-the-HDPE-LDPE-and-their-blends_tbl2_327417672

[29]. Flury Markus and Narayan Ramani (2021). *Biodegradable Plastic as an Integral Part of the Solution to Plastic Waste Pollution of the Environment*. Date retrieved September 23, 2024. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S2452223621000468

[30]. Gomide Felipe Tadeu Fiorini (2022). *Making Bioplastic from a Leaf Viable*. Date retrieved October 8, 2024. Retrieved from https://www.linkedin.com/pulse/making-bioplastic-from-leaf-viable-felipe-tadeu-fiorini-gomide

[31]. Hardman Ben (2022). *Bioplastic: Pros & Cons and Are they the Future?* Date retrieved September 23, 2024. Retrieved from https://www.greenlivingblog.org.uk/advantages-and-disadvantages-of-bioplastics/

[32]. Helmenstine Anne Marie (2022). *What Is the Chemical Composition of Vinegar?* Date retrieved May 7, 2025. Retrieved from https://www.thoughtco.com/chemical-composition-of-vinegar-604002

[33]. Hill Ansley (2018). *White Vinegar: Ingredients, Uses, and Benefits*. Date retrieved October 25, 2024. Retrieved from https://www.healthline.com/nutrition/white-vinegar

[34]. Intong Lynn (2024). Date retrieved March 7, 2025. Retrieved from *Biodegradable Plastic from Taro (Colocasia) and Potato (Solanum tuberosum) Peels with Tomato (Solanum lycopersicum) Seeds*.

[35]. Karkalas John, Tester Richard, and Qi Xin (2004). *Starch-Composition, Fine Structure and Architecture*. Date retrieved October 20, 2024. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0733521003001139#:~:text=Starch%20granules%20are%20composed%20of,botanical%20origin%20of%20the%20starch.

[36]. Kaavessina Mujtahid, Purba Ibnu Tryansar, and Waluyo Joko (2024). *Bioplastic from empty fruit bunch cellulose/chitosan/starch: Optimization through box-Behnken design to enhance the mechanical properties*. Date retrieved March 27, 2025. Retrieved from. https://journals.sagepub.com/doi/abs/10.1177/87560879231226442

[37]. Lackner Maximilian, Martin Koller, and Mukherjee Anindya (2023). *What are Bioplastic? Defining Renewability, Biosynthesis, Biodegradability, and Biocompatibility*. Date retrieved September 26, 2024. Retrieved from https://www.mdpi.com/2073-4360/15/24/4695

[38]. Lazim A.M., Wong Freddawati Rashiddy, Yong Soon Kong, and Zulkifli Nor Ainin Sofia Ahmad (2023). *Wettability, Water Absorption, Mechanical and Chemical Properties of Water Spinach Bioplastic*. Date retrieved March 27, 2025. Retrieved from. https://doi.org/10.55373/mjchem.v25i3.342

[39]. Matovanni Maudy Pratiwi Novia and Pamungkas Damar Jati (2019).

Effects of Glycerol Concentration of Biodegradable Plastic. Date retrieved October 28, 2024. Retrieved from https://pubs.aip.org/aip/acp/article-abstract/2097/1/030110/818544/Effect-of-glycerol-concentration-on-mechanical?redirectedFrom=PDF

[40]. McPhee Colin, Reed Jules, and Zubizarreta Izaskun (2015). *Geomechanics Test*. Date retrieved November 29, 2024. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/B9780444635334000123

[41]. Moncel Bethany (2023) *What is vinegar?* Date retrieved may 7, 2025. Retrieved from. https://www.thespruceeats.com/what-is-vinegar-1328647

[42]. Mufrodi Zahrul, Pangestu Aji Ridho, and Shara Raifa Tryas (2019). *Biodegradable Plastic from Cassava and Organic Acid as a Synthetic Plastic Replacement*. Date retrieved November 22, 2024. Retrieved from https://scispace.com/pdf/biodegradable-plastic-from-cassava-and-organic-acid-as-a-40posarao1.pdf

[43]. Nasir, Nur Nadia and Othman, Sitti Amira (2021). *The physical and mechanical properties of corn-based bioplastic films with different starch and glycerol content*. Date retrieved March 17, 2025. Retrieved from. https://jps.usm.my/wp-content/uploads/2021/11/JPS-323_Art7.pdf

[44]. Ngohayon, J.M., and Tulagan, J. (2022). *Analysis and Characterization of Municipal Solid Wastes Generated in a Community in the Northern Philippines*. Date retrieved September 26, 2024. Retrieved from https://neptjournal.com/upload-images/(24)D-1389.pdf

[45]. Parker, Laura (2024). *The World's Plastic Pollution Crisis Explained*. Date retrieved September 11, 2024. Retrieved from https://www.nationalgeographic.com/environment/article/plastic-pollution

[46]. Ramos, Denise (2023). *How did the Philippines become the World's Biggest Ocean Plastic Polluter?* Date retrieved September 11, 2024. Retrieved https://earth.org/philippines-plastic/

[47]. Rodriguez, Ferdinand. (2024). *Plastic*. Date retrieved September 11, 2024. Retrieved from https://www.britannica.com/science/plastic

[48]. Rynk, Robert and Schwarz, Mary (2022). *Yard Wastes*. Date retrieved September 26, 2024. Retrieved from https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/yard-wastes

[49]. Santos-Longhurst, Adrienne (2018). W*hat to Do When You or Someone You Know May Breathed in Too Much Smoke*. Date retrieved October 16, 2024. Retrieved from https://www.healthline.com/health/smoke-inhalation

[50]. Sin Lee Tin and Tueen Bee Soo (2023). *Eco-Profiles of Plastics*. Date retrieved December 3, 2024. Retrieved from https://www.sciencedirect.com /science/article/abs/pii/B9780128244890000106

[51]. Smith (2024). Date retrieved March 25, 2025. Retrieved from: *Map: Organic Chemistry*.

[52]. Tereos (2019). *10 things you didn't know about starch*. Date retrieved March 26, 2025. Retrieved from https://tereos.com/en/news/10-things-you-didnt-know-about-starch/

[53]. World Health Organization (2023). Dioxins. Date retrieved November 15, 2024. Retrieved from https://www.who.int/news-room/fact-sheets/detail/dioxins-and-their-effects-on-human-health

[54]. Zamboanga City Local Sustainable Sanitation Plan Team. (2021). Local Sustainable Sanitation Plan of Zamboanga City. Date retrieved September 13, 2024. Retrieved from https://zcwd.gov.ph/wpcontent/uploads/2022/06/Final%20Report%20LSSP%20Zamboanga.pdf