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CHARACTERIZATION OF BIO-PLASTIC PRODUCED FROM CORN STARCH

Daida Sharath [1], Gizachew Balcha Asesse [2]

[1] Process Chemical Engineer, BioAtlantis, Tralee, Ireland
[2] Student, Department of Chemical Engineering, Wolkite University, Ethiopia

Abstract: This thesis aims to develop a bioplastic derived from corn starch as a sustainable alternative to petroleum-based plastics. The motivation for this research stems from the limited availability of petroleum resources in Ethiopia, as petroleum is a non-renewable material that must be imported, often at high costs. Furthermore, petroleum-based plastics are non-biodegradable and have been linked to environmental pollution and potential health hazards, including carcinogenic risks. In contrast, the proposed bioplastic offers a renewable, biodegradable, and environmentally friendly solution by utilizing locally available agricultural resources, specifically corn.

To ensure the economic viability of the project and to avoid competition with food resources, the study proposes integrating bioplastic production with existing corn oil industries in Ethiopia. Corn oil producers typically extract oil from the germ of the corn kernel, while the remaining components—often discarded as waste or used as low-value animal feed (despite concerns over SO_3-induced acidification during steeping)—could be repurposed as a raw material for starch extraction. Experimental work was conducted at the Chemical Engineering Laboratory of Wolkite University. The study investigated the effects of key process parameters—including temperature, residence time, and glycerin concentration—on the properties of the bioplastic. The resulting bioplastic was characterized through tensile strength testing, water absorption measurements, and biodegradability assessments.

The results demonstrated that tensile strength increased with processing temperature, while water absorption decreased under the same conditions, indicating improved material performance at higher temperatures. The biodegradability tests confirmed the environmentally friendly nature of the material. An economic analysis of the process showed that the proposed bioplastic production is financially feasible, with a calculated payback period of 1.33 years.

Overall, this research presents a viable pathway for replacing petroleum-based plastics in Ethiopia with locally produced, biodegradable bioplastics, contributing to environmental sustainability and economic self-reliance.

Keyword:- *Corn Starch, Plastic, Bio-plastic, Petroleum products*

1. INTRODUCTION

1.1 Background

Bioplastics are a class of materials derived from renewable biomass sources such as vegetable fats and oils, starches, and microbial-derived polymers. In contrast to conventional plastics produced from non-renewable petroleum resources, bioplastics offer the potential for reduced dependence on fossil fuels and lower greenhouse gas emissions. While not all bioplastics are inherently biodegradable, many are specifically engineered to degrade under controlled anaerobic or aerobic conditions, depending on their chemical composition and manufacturing processes.The feedstocks for bioplastics are diverse, with materials including starch, cellulose, and other biopolymers serving as the primary building blocks. Bioplastics have found applications across various industries, with common uses including packaging materials, disposable dining utensils, food containers, and insulation products.

Among the various types of bioplastics, polylactic acid (PLA) has emerged as one of the most commercially significant, ranking as the second most widely consumed bioplastic globally by volume. PLA is a transparent thermoplastic polymer produced through the fermentation of plant-based sugars, typically derived from corn or dextrose. It closely resembles conventional petroleum-based plastics in terms of mechanical and optical properties, making it a viable substitute in many applications. A key advantage of PLA lies in its compatibility with existing plastic processing infrastructure, allowing it to be manufactured using standard extrusion, injection molding, and thermoforming equipment commonly used for petrochemical-based polymers. PLA is predominantly supplied in the form of granulates with varying physical properties, enabling its use in the production of films, fibers, containers, cups, and bottles. Its versatility and ease of processing have facilitated widespread adoption in the packaging industry and beyond.

As global awareness of plastic pollution intensifies, with regulatory measures such as plastic bag bans enacted in countries like China, Ireland, South Africa, Uganda, and cities such as San Francisco, PLA has gained prominence as an environmentally preferable alternative. Its biodegradability and ability to reduce the environmental footprint of traditional plastics position PLA as a key material in the transition toward sustainable, bio-based economies.

1.1.1 Plastic production from Starch:

Thermal Processing of Starch-Based Polymers: Phase Transitions, Processing Techniques, and Functional Properties

Starch-based polymers are of growing interest in the field of sustainable materials due to their biodegradability and versatility. These polymers can undergo a variety of thermal processing techniques, including extrusion, injection molding, compression molding, and film casting. Liu et al. have extensively studied the processing methods applicable to starch-based materials, with a particular focus on the phase transitions that occur during thermal treatment. Their research highlighted the significant influence of processing conditions—such as temperature, moisture content, and the presence of plasticizers like water, glycerol, citric acid, and other additives—on the mechanical properties of the final material. Notably, their findings indicate that thermal processing often leads to a reduction in mechanical performance, primarily attributed to temperature-induced phase changes and moisture variations across different processing stages. Moisture control, in particular, emerged as a critical factor, as elevated moisture levels during processing were shown to significantly compromise the mechanical integrity of the final product.

Several other studies have corroborated these challenges, emphasizing that the effective processing of starch-based polymers is hindered by the complex interplay of heat and moisture management, as well as difficulties in achieving precise phase control. Thermal processing of starch-based materials involves a series of concurrent chemical and physical transformations, including water diffusion, granule swelling and extension, gelatinization, decomposition, melting, and crystallization. Among these, gelatinization plays a pivotal role, as it serves as the foundational mechanism for converting native starch into a thermoplastic form. Gelatinization is characterized by the irreversible disruption of the starch granules' crystalline structure, a process that encompasses granular swelling, loss of birefringence (native crystalline melting), and molecular solubilization. Differential scanning calorimetry (DSC) has been widely employed to detect and characterize these multistage transitions. It is noteworthy that the decomposition temperature of starch typically exceeds its melting point prior to gelatinization, underscoring the importance of careful thermal management during processing.

Beyond their processing challenges, starch-based polymers offer significant advantages, particularly as low-cost, biodegradable alternatives to synthetic polymers in applications where long-term durability is not required. Starch has long been utilized in non-food sectors, including paper production, cardboard manufacturing, textile sizing, and adhesives. More recently, its use has expanded into thermoplastic applications, with starch serving as a primary component in biodegradable utensils and films. These developments highlight starch's potential as a sustainable material platform for applications where rapid degradation is advantageous.

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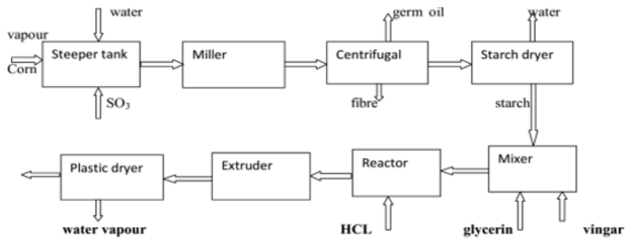

Figure1. Process flow diagram

1.1.2 Factors affecting plastic production from starch

A. Temperatures: - reaction temperature is the important factor that affects the yield of bio plastic. For example, higher reaction temperature increases the reaction rate and shortens the reaction time due to decreasing activation energy. Bio plastics produced at different temperature have different tensile strength; this tensile strength is characterizing the type of bond created during mixing process.

B. Type of process followed: -bio plastics produced using different methods have different chemical and physical characteristics.

C. Type of raw material: -starch from different crops have different composition of amylose(linear) and amylopectin (branched) so, bio plastics from different raw material resulted to have different properties (tensile strength, biodegradability etc properties). Also, bio plastic can be produced from fibrous materials with different property.

2. MATERIALS & METHODOLOGY

The experimental work has been carried out in the laboratory of Department of Chemical Engineering, Wolkite University and Ethiopia.

2.1 Equipment used in the laboratory

- Beaker
- Spatula
- Conical flask
- Measuring cylinder
- Filter cloth
- Sieve

2.2 Raw materials and chemicals used in laboratory

- Corn starch
- Water
- Methyl red
- Glycerin
- Vinegar

2.3 Sample collection

2 kgs of corn were bought from the market found in Gubre town**.**

2.4 Experimental Method

2.4.1 Corn starch production procedure

- **Cleaning:** The corn was coarsely sieved to separate contamination, e.g. stones, cobs, dust particles, foreign grain material, and fine material by means of sieve.
- **Steeping:** 2kg of corn was steeped in hot water (40ºc) soaking of corn. It involves maintaining the correct balance of water flow and temperature.
- **DE germination:** The germ of the corn was removed out, the corn kernel and weighed to be 257g of corn germ.
- **Milling:** The de-germinated corn was grounded finely to disrupt the cells of the endosperm and release the starch granules. This was containing starch, protein and fiber. The milled corn was made to dissolve in water; the protein dissolves completely in water. Whereas fiber and starch not so, fiber and starch were separated by filter cloth. There were double trails.
- **Drying:** The produced starch was dried in an oven for 2 hours at temperature of 400C. This was done in order to get the starch moisture specification.

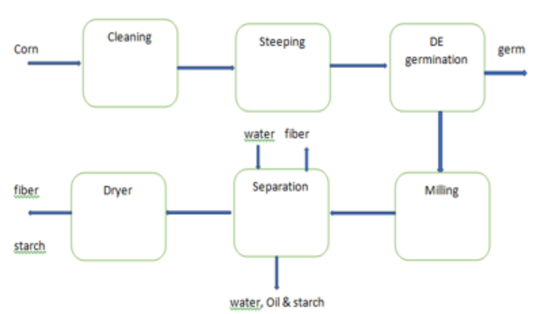

Figure 2. Block flow diagram of starch production from corn

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2.4.2 Experimental Procedure

Sample preparation: To a 500 ml beaker, the following substances were added:

- 60 ml water
- 9.5g corn starch
- 5ml of glycerin
- 5ml of vinegar

1) The prepared all raw material was being putted on water bath
2) Adjust the temperature to the required temperature. Stir occasionally. The sample was heated for 20 minutes. Do not boil the sample vigorously.
3) Stir rod was used to pour sample into a labelled weighing dish. Sample was stirred in the weigh in dish to remove air bubbles.
4) Sample made to dry on the lab bench over Three days.

Table 1 Laboratory trials

Type of Bio-plastic	Temp (° c)	Starch to Water ratio	Residence Time(minute)
Bio plasic1	70	1:6.3	20
Bio plasic2	90	1:6.3	20
Bio plasic3	95	1:6.3	20
Bio plasic4	100	1:6.3	20
No vinegar	100	1:6.3	20
No glycerin	100	1:6.3	20

2.5 Characterization of Bio-plastic

A. Tensile strength test :

Computerized tenso meter is not available to measure tensile strength of plastics. Therefore, we have used load method of tensile strength test. In this method the area of sample calculated and known mass is applied until the hanged bio plastic is broken down. Then the Elongation (mm)

- The force using the equation F=mg was calculated If number of masses added to the sample

$$F= (m1+m2.......mn)\ g$$

B. Water absorption test:

Test Procedure: For the water absorption test, the specimens are dried in an oven for 30 minutes at 100°c and then placed in a desiccators to cool. Immediately upon cooling the specimens were weighed. The material is then immersed in water at 25°C for an hour or until equilibrium. Specimens removed, patted dry with a lint free cloth, and weighed. Water absorption is expressed as increase in weight percent. Percent Water Absorption = [(Wet weight - Dry weight)/ Dry weight] x 100

C. Biodegradability test

Test procedure: Half kilo fertile soil and half kilo of animal dang are prepared with 500ml of distilled water and then the specimen dried in an oven after weighing, buried in the prepared soil-dung the bio plastic and petro based plastic together for a week. Then mass lose calculation is done.

Mass loss = Mb-Ma

$$\boldsymbol{mass\ loss\ rate} = \textbf{mass loss/No of burried day}$$

3. RESULT AND DISCUSSION

Starch production:

From the first trial 612g of starch and from second trail 595g of starch were obtained. Totally 1207g of starch was obtained. Therefore:

$$\%\ of\ starch = \frac{weight\ of\ starch}{weignt\ of\ corn} * 100$$

$$= \frac{612 + 595}{2000} * 100 = 60.35\%$$

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Comparison with the theoretical valve: The theoretical production of starch is 67.6%, hence the result obtained from lab is 60.35% is nearly the same as the expected valve.

Moisture content the of starch

The produced starch weighed after and before dying. the moisture content is calculated using the equation; -

$$Mn = \frac{(W1-Wm)-(W2-Wm)}{W1-Wm} * 100$$

Where: W1=wet weight

W2=dry weight

Wm=plate weight

Mn=percentage moisture content of starch

$$Mn = \frac{(715-135)-(507-135)}{715-135}*100 = 36\%$$

Theoretical moisture content of starch is 20%; therefore, the starch contains the correct amount of moisture.

Plastic production

Bio-plastic=f(vinegar,water,starch additives, temperature and residence time) change or replacing one item changes the characteristics of plastic. For example, we have tried to observe the influence of glycerin by making plastic without glycerin also for vinegar as well in the laboratory.

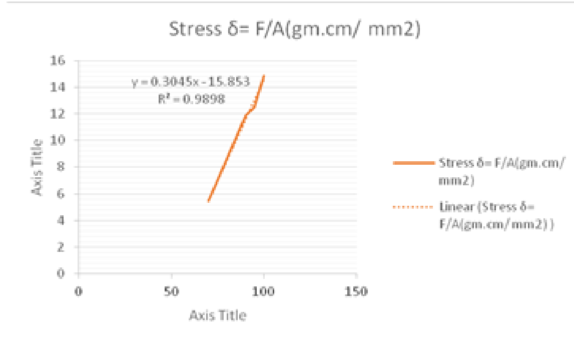
Vinegar: - Bio-plastic without vinegar has characteristics easily breakable. Tiny cracks are present on its surface this information tells what vinegar is. From the above observation, vinegar is polymerizing agent; it helps to connect the monomers each other to form the plastic (polymer) also make the plastic hard.

Glycerin: -the trial bio plastic without glycerin is too hard and brittle from this observation; glycerin helps bio plastic to be flexible plastic. Therefore, it is possible to say that by changing concentration of glycerin it is possible to make different materials that have different application. This means when soft and flexible material is needed the concentration of glycerin should increase and when hard material like plastic spoon is needed the concentration of glycerin decrease with respective the others compositions.

Effect of temperature on stress of Bio-plastic

As shown in the below graph the Stress vs. temperature, initially increases with the equation of $y=0.3045x^2-15.853$, since the strength of the material cannot increase as the temperature increases infinitely, it begins constant at point (100, 15). This implies any increase with temperature more than 100°c shows no increase in tensile stress of bio plastic.

Graph 1: Stress vs. Temperature



Tensile strength test:

Table 4.1 Tensile strength data of bio Plastic

T(°c)	R.Time(m)	Mass (g)	Li(cm)	Lf(cm)	Extension (cm)	Strain, ε= EXT/Li	Load(g.cm/s)	Stress δ= F/A(g.m/c/ mm²)
70	20	35	10	10	0	0	2.917	5.45
90	20	35	11	11.25	0.25	0.023	3.69	11.86
95	20	35	12.5	13	0.5	0.04	4.93	10.86
100	20	35	13	14.6	1.5	0.115	6.217	14.86

2.4.1 Water absorption test

Table 4.2 Water absorption data of bio plastic

Temperature	Residence time(m)	Dry weight(g)	Wet weight(g)	Water absorption in (%)
70°c	20	2.8	3.3	17.86
90°c	20	2.9	3.3	13.8
95°c	20	1.6	1.8	12.5
100°c	20	2.7	2.78	2.96

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As shown in the figure below the water absorption property of bio plastic decreases with

increasing temperature with equation y=-0.3975x+47.058

Since, the water absorption property of bio plastic cannot be zero while the temperature increases infinitely; it reaches at constant water absorption state:

-0.3975x+47.058= 0

X=118.4°C

A production of Bio-plastic above 18.4^0C cannot make the plastic to decrease its water absorption property.

2.4.2 Biodegradability test

Table 4.2 comparison of biodegradability bio plastic and petro plastic

Type of plastic	Initial mass(g)	Final mass(g)	Mass loss(g)	Time to disappearance (day)
Bio plastic	25	23.99	1.01	117.128
Petrobased plastic	0.81	0.81	0.0	∞

Mass loss of Bio plastic=16.9-15.89=1.01gm

Assuming equal mass is lost per day

Mass loss rate=$\frac{1.01gm}{7days} = 0.1442gm/days$

Maximum days needed to completely disappear the 25gm bio plastic is

No days=$\frac{25gm}{0.1} = 250days$ this is the approximate value because it considers 1.01gm bio plastic loss per week, but in reality, this cannot happen due to the organisms around the bio plastic increases exponentially from day to day because the bio plastic used as food.

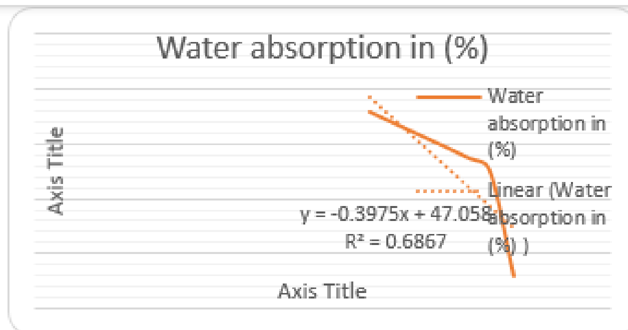
The relation of food (bio plastic) and number of organisms is inversely related, this means as the number of organisms increase exponentially the amount of food (bio plastic) decrease by same amount.

Therefore, the multiplication of bacteria is given by the equation

$Y=Yo^{kt}$

Where: -

y= number of bacteria after time t



Y_o=the initial number of bacteria

t= time

k= constant

As the result shown above the bio plastic loss amass of 1.01g per week. To estimate the time to completely degrade the whole mass of the bio plastic use the equation.

$Y=Yo^{kt,}$ where y= is the mass lost

y_o=the initial mass in gm

t=the time needed to degrade an amount of mass

k=degradation constant

$\ln 23.99 = \ln 25^7$

ln 23.99=7kln25

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$K = \frac{ln23.99}{7ln25}$=0.141

Now we can estimate how much time needed for bio plastic to reach at its minimum amount of mass by using the equation; -

$y = y_o^{-0.14t}$

Drawback of this equation is, it is impossible to estimate the time that the amount of bio plastic reach zero amounts. The petro based plastic have no any change in a week. But it is impossible to say that petro based plastic is non-degradable. However, the degree of degradability of bio plastic is much higher than petro plastic.

3.Conclusion

Biodegradable plastics are one of the most innovative materials being developed in the packaging industry. Companies cannot work fast enough to produce this highly valuable technology. How widespread biodegradable plastics will be used all depends on how strongly society embraces and believes in environmental preservation. There certainly are an abundant amount of materials and resources to create and fund more uses for biodegradable plastics. The advancement of biodegradable technology has skyrocketed in recent years and there are growing signs that the public shows a high amount of curiosity in the product. But for more profitability and better production, it is advantageous to study properties as well parameters (temperature, time &composition) because of this reason bio plastics were produced by varying temperature and residence time also biodegradability test was checked.

From laboratory study Bio plastic degrade completely less than 250 days at normal pressure and temperature. But petroleum-based plastic is difficult to estimate when it degrades fully this property also will make bio plastic popular.

The study also tries to relate temperature and strength (stress) of the bio plastic; the strength increases from 5-15(N/m^2) when the temperature increases from 70-100^{o}c. Above this temperature gives constant stress. This tells us producing bio plastic above 100^{o}c is uneconomical. So, comparing its strength and energy; producing plastic at 100^{o}c is feasible. The bio plastic plant will be construct with capital Investment of $5,192,000 in hawassa industrial zone and the expected payback period is 1.33 year. The erection of this plant will solve economic, social, political and environmental problems of the country

3.1 Recommendations:

Even though a biodegradable plastic packaging film was produced in this work, a better result would have been obtained if the necessary techniques and equipment needed were available. Polylactic acid possesses several desirable properties such as biodegradability, biocompatibility, compost ability, and low toxicity to humans than other suitable polymers. Finally, more research should be continued in this field, especially in developing countries so that we can have cleaner nations by reducing the conventional plastic waste in the environment and to create sustainable development.

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