

# Impact of Acetylation, Ethylene Glycol Plasticization, and Rice Husk Ash Reinforcement on Manihot Esculenta Crantz CV. TMS 92/0326 Starch-Based Bioplastic Films

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## Abstract:

This study analyzes the effect of acetylation, plasticization with ethylene glycol and rice husk ash - filler reinforcement on the properties of the Manihot esculenta Crantz cv. TMS 92/0326, a variety of cassava, used in starch films at different concentrations of plasticizer (2, 3, 4, 5 g/100 g starch), and with rice husk ash (0, 0.5 g and 1 g/100 g starch; respectively). Also, the combined effects of plasticizer and filler concentration on tensile strength were analyzed. The results indicate that the percentage (%) yield of extracted starch was high (85.2%) as expected for this species (Manihot esculenta Crantz cv. TMS 92/0326 variety) of Cassava. The modification by acetylation reduced the temperature of gelatinization of the cassava starch from 63°C (extracted-native starch) to 55°C, leading to better processability and flexibility of the films, in addition the percentage (%) yield after modifications as well was decreased to 79% with the substitution of hydroxyl groups with acetyl groups in the starch molecules. The results also suggest that increasing rice husk ash content has a favorable effect on water and acid resistance, with better performance at 1.0 g of filler. Despite this modifications and

reinforcement of the films, they remained soluble in 1M NaOH, indicating their deterioration in alkaline environments.. Colour of all films were white to milky (high ethylene glycol level), with thickness being the same for all formulations (0.41–0.53 mm). The tensile strength test also revealed significant improvement in the films with rice husk ash reinforcement (2g of ethylene glycol and 1g of rice husk ash) having the highest tensile strength of 9.05 MPa. This formulation showed good compromise between flexibility and tensile strength. Nonetheless, greater plasticizer content resulted in decreased tensile strength, suggesting that there could be a compromise between flexibility and strength. FTIR data confirmed successful acetylation with ester groups observed at 1740 cm<sup>-1</sup>. These results show that optimal combinations of acetylation, plasticization and rice husk ash filler strengthening efficiently balance flexibility, strength and acid, alkaline, moisture and water resistance. This result makes this formulations a Promising alternative for biodegradable packaging materials.

**Keywords:** Acetylated Starch, Ethylene Glycol, Rice husk ash-filler, Water resistance, Acid resistance, Tensile strength

## 1. Introduction

Plastic pollution from conventional petroleum-derived polymers has raised global concern, leading to a surge in interest for biodegradable alternatives made from renewable materials. Starch-based bioplastics stand out among such alternatives because starch is inexpensive, widely available and biodegradable, which is particularly advantageous in tropical regions with abundant cassava cultivation. However, films produced from native (unmodified) starch often suffer from high brittleness and significant sensitivity to moisture due to strong intermolecular hydrogen bonding among hydroxyl groups (Krogars *et al.*, 2002; Liu *et al.*, 2009). These drawbacks severely limit the utility of native starch films for packaging or other load-bearing applications.

Chemical modification of starch, such as acetylation, has been widely employed to improve the physical properties of starch-based films. By replacing some of the hydroxyl groups with acetyl moieties, the acetylation process reduces hydrogen bonding and introduces a degree of hydrophobicity, which can lower gelation temperature and improve film flexibility (Lawal 2011; Shogren 2003). Nevertheless, while acetylation enhances processability and reduces moisture affinity compared to native starch, the resulting films may still lack sufficient mechanical strength and stability for practical use, particularly under conditions of moisture or chemical exposure (Bertuzzi *et al.*, 2007).

To increase flexibility and processability, plasticizers are often added to starch-based films. Polyols such as glycerol, sorbitol, and ethylene glycol have been used for this purpose, as they improve chain mobility and flexibility (Talja *et al.* 2007). However, the addition of plasticizers typically increases the number of hydrophilic sites and free volume in the polymer network, making the films more susceptible to water uptake, swelling and reduced mechanical strength (Talja *et al.*, 2007; Liu *et al.*, 2009). Thus, while plasticization improves flexibility, it often exacerbates moisture sensitivity, a serious drawback for packaging materials expected to resist water or humidity.

An effective strategy to counteract plasticizer-induced weaknesses is to incorporate reinforcing fillers into the starch matrix to enhance its mechanical properties and reducing water uptake in starch-based films (Mbey, Hoppe & Thomas 2012). The layered structure of Filler increases the tortuosity of diffusion pathways, thereby restricting the permeation of water and small molecules, and improving the barrier properties of the composite (Mbey, Hoppe & Thomas 2012).

Despite these developments, relatively few studies have systematically explored the combined effect of acetylation, plasticization with ethylene glycol and agricultural waste filler such as rice husk ash reinforcement on both chemical uptake behaviour ( water, acid, alkaline) and mechanical properties( Tensile strength) of starch-based films and even none specifically focusing on the starch of *Manihot esculenta* Crantz cv. TMS 92/0326.

The use of cassava starch, particularly the TMS 92/0326 variety, as a raw material for starch-based bioplastics offers a more sustainable solution compared to traditional petroleum-based plastics. Unlike their petroleum-based counterparts, which can persist in the environment for centuries, starch-based bioplastics are biodegradable and break down naturally, helping to reduce plastic waste and contribute to a cleaner, more sustainable world (Zhang *et al.*, 2022). Given its elevated starch content, TMS 92/0326 presents a promising option for the development of biodegradable plastics. This characteristic is particularly relevant in light of the increasing global interest in environmentally sustainable materials, thereby contributing to a reduction in the dependence on non-renewable plastics and promoting a more environmentally conscious future (Müller *et al.*, 2023).

Cassava, a major crop in several tropical areas such as Africa, Asia, and Latin America, serves as a fundamental food source. The incorporation of cassava starch-based bioplastics into the market landscape offers novel avenues for this crop, potentially generating additional employment opportunities and stimulating local economies. Furthermore, this transition encourages the adoption of sustainable agricultural approaches, thereby reconciling food production with the cultivation of industrial crops (Adeoti *et al.*, 2021). The TMS 92/0326

cultivar, engineered for elevated yield and disease resistance, presents an optimal solution for large-scale starch production, thereby mitigating any detrimental impact on the availability of food crops. Consequently, it represents a strategic option for maximising cassava's economic value while simultaneously safeguarding food security (IITA, 2020).

Furthermore, TMS 92/0326 suitability for industrial applications is enhanced by its classification as a bitter cassava variety, characterised by high concentrations of cyanogenic compounds. This characteristic renders it unsuitable for direct human consumption without appropriate processing. Given that this variety is not primarily cultivated for food, its utilisation in industrial applications, such as bioplastics, minimises competition with food crops. This, in turn, facilitates the effective allocation of land and resources to address both food and industrial requirements (IITA, 2020 ;Tantawy *et al.*, 2019).

Therefore, this study aims to examine how varying proportions of ethylene glycol (as plasticizer) and Rice husk ash (as filler) influences the moisture absorption, water uptake, acid resistance and tensile strength (

mechanical property) of acetylated cassava starch films. The goal is to identify formulations that balance flexibility, strength, and environmental resistance, making them suitable candidates for biodegradable packaging applications.

## 2 Methodology

### 2.1 Sample Collection/

#### Sample Area:

Cassava tuber were purchased from a farm in Ekosodin community Benin City, Edo State. It is located along the longitude  $5.6028^{\circ}$  E and latitude  $6.3589^{\circ}$  N of the central province of Edo state, Nigeria. Additional materials such as HCl (Reagent 36%- WW), Sodium hydroxide pellets (MOLYCHEM-98% Purity), Acetic Anhydride (APC- 98% Purity), Ethylene glycol (SRL-99% Purity), were sourced from Pyrex-IG Scientific company Benin City, Edo State Nigeria and were all of analytical standard. Rice husk were purchased from a local rice processing factory at Illeh community, Ekpoma, Edo State. It is located along the longitude  $6.0814^{\circ}$  E and latitude  $6.7583^{\circ}$  N of the southern province of Edo state, Nigeria.

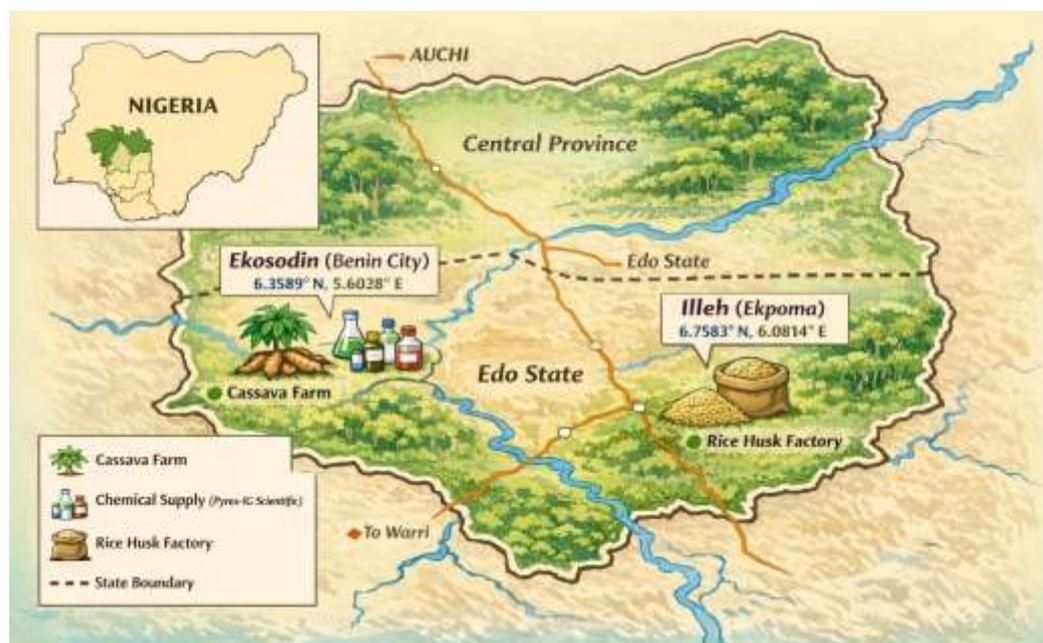


Figure 1.0: Map of Edo state, Nigeria, describing the location of sample area



Figure 1.1: *Manihot esculenta* Crantz cv. TMS 92/032 tubers



Figure 1.2: Rice husk

### 2.2.0. Extraction of Starch:

Extraction of cassava starch was carried out using methodology described by (Ezeoha and Ezenwanne 2013). The cassava tubers were mechanically grated after being manually peeled and cleaned with distilled water, three times as much water as the shredded cassava was added to the mixture. A coarse sieve and a filter cloth were used to sieve and filter the mixture, respectively. The filtrate was allowed to settle for six

hours, then mixed with an equal amount of water and left to settle for a day. At the end of 24 hours, the wet starch was decanted, manually dewatered, and then oven-dried at 105 °C for 4 hours to reduce its moisture content.

%Starch yield was calculated using:

$$\text{Starch yield (\%)} = \frac{\text{weight of extracted starch (g)}}{\text{weight of cassava tubers}} \times 100 \text{ ----- (1)}$$



Figure 2.0: Extracted starch(native) without modification.

**2.2.1 Preparation of Rice husk ash :** Rice husk ash was obtained by collecting clean, dry rice husks, ensuring they are free from dirt and contaminants. The combustion process was carried out with a furnace at a temperature of  $650^{\circ}\text{C}$ . This temperature promotes the complete combustion of the organic material. The rice husks were allowed to burn for several hours until they transform into a fine, light

gray ash. Once the burning process is complete, the ash is allowed to cool naturally within the furnace, ensuring it is not disturbed while still hot. The cooled rice husk ash was ground into fine powder using a Ball Mill. The ash is stored in a dry, airtight container to prevent moisture absorption, which could compromise its properties.



Figure 2.1: Rice husk ash

### 2.3 preparation of Acetylated Starch.

The extracted starch was modified via acetylation using the method reported by (Henry 2007) with some modification. Starch (20g) was dispersed in  $100\text{cm}^3$  of distilled water and then constantly stirred for 30 minutes. The slurry was adjusted to pH 8.0

with 3%NaOH, 1.2g of acetic anhydride was added to the slurry. After the addition of the acetic anhydride, the reaction was allowed to proceed for another five minutes. The pH of the slurry was adjusted to 4.5 with 0.5M HCl and filtered through Whatman No 1 filter paper. The residue obtained was washed for

four times with distilled water to remove completely some acids that may be present in the product and finally air- dried at room temperature. The yield was calculated

$$\frac{\text{yield}}{\text{weight of native starch (g)}} \times 100 = \frac{\text{weight of modified starch (g)}}{\text{weight of native starch (g)}} \times 100 \text{ -----(2)}$$



Figure 2.2: Chemical modified starch ( Starch acetate).

**2.4.Determination of Gelatinization**

Temperature, PH, and Moisture content of extracted starch

1 g of dried extracted starch was placed in a beaker filled with 10 ml of distilled water and subjected to heat treatments using a hot plate. While stirring and noting the temperature at which gel formed. The gelatinization temperature was recorded using a thermometer. The pH of the starch was recorded using a calibrated FP20 Mettler Toledo pH meter.

The moisture content was determined using the methodology proposed by (Alobi *et al.*, 2017). A weighed quantity of the starch was dried in an oven at 105 C for 24 h. The dried sample was weighed, and the percentage moisture content was calculated using the Equation

$$\frac{\text{initial-final weight}}{\text{initial weight}} \times 100 = \text{Moisture content (\%)} \text{ -----(3)}$$

**2.5 Fourier Transform Infrared (FT-IR) spectroscopy determination of native starch and modified starch.**

The FT-IR spectrum of native starch and modified starch were acquired on a Perkin Elmer FT-IR spectrophotometer (Perkin Elmer, Inc., MA, USA) using a potassium bromide (KBr) disc prepared from powdered samples mixed with dry KBr. The spectra were recorded (16 scans) in the transparent mode from 4000 to 400 cm-1 (Bernardino-Nicanor *et al.*, 2017).

**2.6 Determination of Degree Substitution of Acetylated Starch (DS):**

The acetyl group (AG expressed as percentage on dry basis) and the degree of substitution (DS) of cassava starch were determined according (Mark and Mehltretter, 1972). A 5g of starch sample was weighed, transferred to a 250 ml conical flask and dispersed in 50 ml distilled water. Few drops of phenolphthalein indicator were added and titrated with 0.1N sodium hydroxide to permanent pink colour. Then 25.0 ml of 0.45N NaOH was added to it and shaken vigorously for half an hour. The stopper and neck of flask was flushed with little distilled water and then the excess alkali was titrated with 0.2N HCl to disappearance of pink colour. A total of 25.0 ml of 0.45N NaOH was titrated as blank. Acetyl group and degree of substitution were calculated as follows:

$$\% \text{ Acetyl} = \frac{(\text{Blank-sample}) \text{ml} \times M(\text{HCl}) \times 0.43 \times 100}{\text{weight of sample}} \text{ -----(4)}$$

$$\text{DS} = \frac{162 \times \% \text{Acetyl}}{4300 - (42 \times \% \text{Acetyl})} \text{ -----(5)}$$

**2.7 Preparation of Biodegradable Plastic Film and Casting of films:**

The preparation was done following a refined modification of the method proposed by ( Nwaka *et al.*, 2025). 10 g of the acetylated starch powder was weighed in a beaker to which 100 mL of distilled water was added. It was stirred at 350 rpm for 10 min on a

magnetic stirrer. Rice husk ash powder was then added at different weights, 0g : 0% (w/w), 0.5g :5% (w/w), 1g: 10% (w/w) and stirred. Ethylene glycol was also added at different weights (2g, 3g, 4g, 5g) and stirred at 350 rpm for 15 min. The solution was heated at about 80 °C to form gel with continuous stirring. The

slurry was then poured onto a Mold, dried in a hot air oven at 50 °C and stored at room temperature.

Table 1: Experimental Design for Biodegradable plastic Film Formulation

	ETHYLENE GLYCOL (plasticizer)	RICE HUSK ASH (FILLER)
starch acetate	2g	0g
		0.5g
		1.0g
	3g	0g
		0.5g
		1.0g
	4g	0g
		0.5g
		1.0g
	5g	0g
		0.5g
		1.0g

**2.8 Water Absorption Resistance**

The water absorption resistance analysis was carried out as reported by Nwaka *et al.*, (2025) with slight modifications.

The prepared bioplastic films was evaluated by soaking them in water at room temperature for one hour, drying them with cotton pieces, and weighing them. The percentage of water absorption was calculated

$$\text{Water absorption (\%)} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100 \text{ -----(6)}$$

**2.9 Acid Absorption Resistance**

Acid Absorption Resistance analysis was carried out as reported by Nwaka *et al.*, (2025) with slight modifications.

For acid absorption resistance, the bioplastic films were soaked in 1M hydrochloric acid solution, and their weights were recorded after one hour. The percentage of acid absorption was calculated

$$\text{Acid Absorption (\%)} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100 \text{ -----(7)}$$

**2.10 Base Absorption Resistance**

Base absorption Resistance analysis was carried out as reported by Nwaka *et al.*, (2025) with slight modifications.

The base absorption resistance was tested by soaking the films in 1M sodium hydroxide solution and weighing them at regular intervals. The percentage of base absorption was calculated

$$\text{Base Absorption (\%)} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100 \text{ -----(8)}$$

**2.11. Thickness of the Film**

The thickness of the bioplastic was observed using the micrometer screw gauge. Each sample was recorded at five different points. The mean value was recorded as the thickness of the bioplastic.

**2.12. Tensile Strength of The Bioplastic Film**

Tensile strength was determined using the Tensile Strength Test Machine TM 2101-T7, following ASTM D638 with a maximum force of 10kN.

### 3.0 Results and Discussion

Table 2: Percentage Yield, Moisture and the pH of the Extracted Cassava

%yield	%moisture	pH	Gelatinization temperature °C
85.2	12.3	6.0	63

The percentage yield of 85.2% reflects a high extraction efficiency, which is typical for cassava starch extraction processes of this variety (IITA, 2020). The moisture content of 12.3% suggests that the cassava starch extract retains a stable level of water, which is crucial for preventing microbial growth and ensuring the stability of the bioplastic. According to research, the moisture content of starches plays a significant role in the overall performance of bioplastics by affecting their mechanical properties and biodegradability (Sajjad *et al.*, 2020). The pH of 6.0 indicates that the cassava starch extract is slightly acidic, close to neutral pH 7.0, making it suitable for various applications, including food-related bioplastics, where slightly acidic

close to neutral pH prevents undesirable chemical reactions or degradation.

The gelatinization temperature of 63°C is within the expected range (60-75) °C for cassava starch. The gelatinization temperature is an essential factor in the processing of starch-based materials, as it determines the temperature at which starch will undergo irreversible changes, leading to thickening. This temperature is consistent with the findings from literature, where cassava starch typically exhibits gelatinization temperatures around 63°C (Sajjad *et al.*, 2020).

Table 3: Degree of substitution (DS) percentage yield and gelatinization temperature of modified acetylated starch

Sample	Percentage yield	DS	Gelatinization temp °C
Starch acetate	79	0.34	55

The modification of cassava starch through acetylation resulted in a percentage yield of 79%, slightly lower than the extracted-native starch yield, suggesting some loss during the acetylation process. This result aligns with previous studies that reported a decrease in yield due to the acetylation process, as it involves the substitution of hydroxyl groups with acetyl groups, which can lead to some degree of degradation (Gani *et al.*, 2019).

The Degree of Substitution (DS) of 0.34 indicates a moderate level of acetylation, which is in line with findings from similar studies that have shown how acetylation can be controlled to adjust the physical properties of starch for various applications (Gani *et al.*, 2019). The lower DS value suggests that the starch remains partially native, which could

explain the relatively mild changes in its properties.

The gelatinization temperature of 55°C for the acetylated starch is significantly lower than that of the native starch, reflecting the impact of acetylation on the starch's thermal properties. Acetylation introduces acetyl groups into the starch molecule, reducing the intermolecular interactions between starch chains, which in turn lowers the temperature required for gelatinization (Zhang *et al.*, 2015). This reduction in gelatinization temperature is advantageous for the processing of starch-based bioplastics, as it allows for easier manipulation at lower temperatures, thereby saving energy and enhancing the processability of the material.

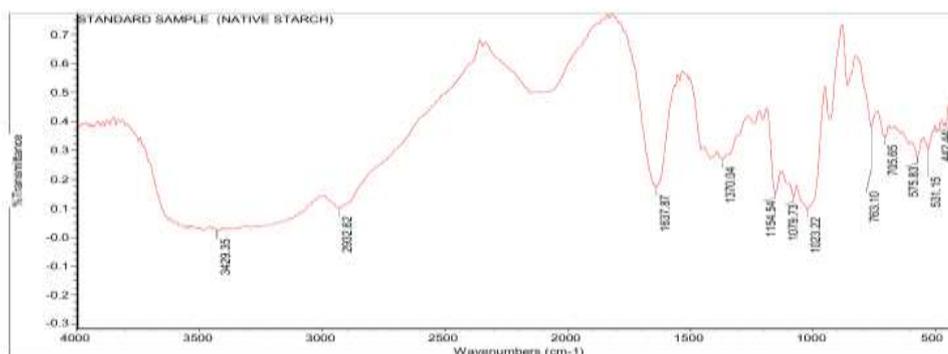


Figure 3.0: FTIR for Native Starch

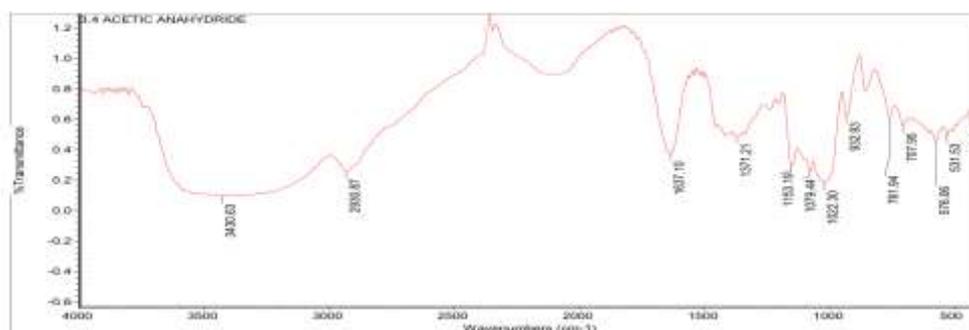


Figure.3.1: FTIR for Acetylated Starch.

Fourier Transform Infrared (FTIR) spectroscopy was used to identify and confirm the functional groups present in the native and chemically modified starch samples. The spectra for native acetylated starch are presented in Figures 3.0 and 3.1 respectively. Distinct differences in absorption bands among the samples provide evidence of successful chemical modification of the starch molecules.

The native starch spectrum (Figure 1) exhibited characteristic absorption bands typical of polysaccharides. A broad band around  $3400\text{ cm}^{-1}$  corresponds to O–H stretching vibrations of hydroxyl groups involved in intra- and intermolecular hydrogen bonding. The weak band near  $2920\text{ cm}^{-1}$  arises from C–H stretching vibrations of methylene groups, while the strong absorption in the  $1150\text{--}1000\text{ cm}^{-1}$  region represents C–O–C and

C–O stretching of the glycosidic linkages. A weak band around  $1640\text{ cm}^{-1}$  is attributed to bound water molecules.

The acetylated starch spectrum (Figure 2) displayed a distinct absorption peak around  $1740\text{ cm}^{-1}$ , which is attributed to the carbonyl (C=O) stretching vibration of ester groups, confirming acetylation. An additional peak at  $1230\text{--}1260\text{ cm}^{-1}$  corresponds to C–O stretching of the acetyl ester linkage. The observed decrease and narrowing of the O–H stretching band intensity around  $3400\text{ cm}^{-1}$  reflects the replacement of hydroxyl groups by acetyl moieties, reducing intermolecular hydrogen bonding. Slight intensity variations in the  $1000\text{--}1150\text{ cm}^{-1}$  region also indicate modifications to the starch backbone.

Comparative analysis of the spectra clearly demonstrates that the acetylation chemical modifications were successfully achieved.

Table 4: Absorption and solubility test on plastics films

	ETHYLENE GLYCOL (plasticizer) (g)	FILLER (Rice husk ash) (g)	% Water absorption	% 1M HCl absorption	Solubility in base (1M NaOH)
Starch Acetate	2	0	18.0	18.0	Soluble
		0.5	31.3	24.6	Soluble
		1.0	23.0	21.8	Soluble
	3	0	24.5	26.4	Soluble
		0.5	26.5	27.5	Soluble
		1.0	22.3	22.1	Soluble
	4	0	29.3	33.5	Soluble
		0.5	26.9	34.1	Soluble
		1.0	26.3	27.4	Soluble
	5	0	36.3	41.0	Soluble
		0.5	36.5	35.2	Soluble
		1.0	30.1	31.3	Soluble

The results from table 4 reveals key insights into their performance under various conditions, focusing on their absorption resistance and solubility in different environments. As the amount of rice husk ash filler increases, both the water absorption resistance and acid absorption resistance (in 1M HCl) show a noticeable improvement. For instance, films with higher concentrations of filler demonstrate higher resistance to water and acid absorption, suggesting that rice husk ash acts as an effective reinforcing agent in these materials. This trend is further enhanced

when the ethylene glycol plasticizer is added, with the highest resistance recorded at 1.0 g of both ethylene glycol and rice husk ash. However, despite the improved resistance to water and acid, all the films remain soluble in a 1M NaOH solution, indicating that starch acetate films are vulnerable to degradation in alkaline conditions, regardless of the filler or plasticizer concentration. This consistent solubility in base limits the potential applications of these films in alkaline environment.

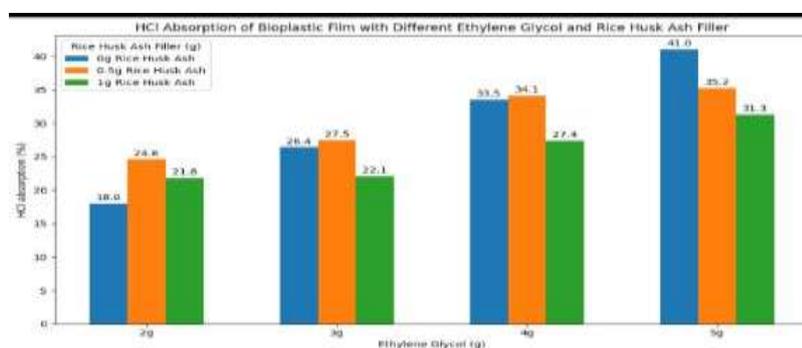


Figure 3.2: % HCl Absorption Test on Bioplastic film

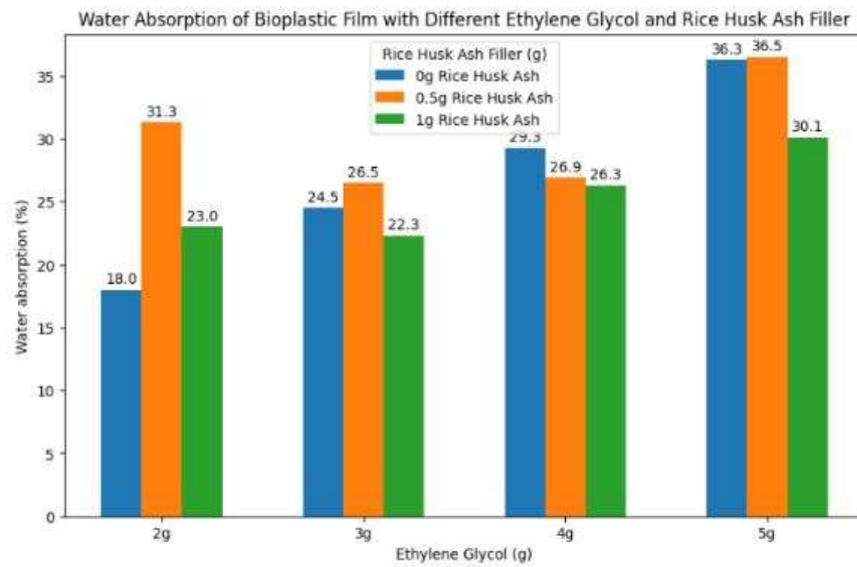


Figure 3.3: % Water Absorption Test on Bioplastic film.

Table 5: Bioplastic Formulation; Colour and Thickness

	ETHYLENE GLYCOL (plasticizer) (g)	FILLER (kaolinite) (g)	Colour	Thickness (mm)
Starch Acetate	2	0	White	0.413
		0.5	Milky	0.512
		1.0	Milky	0.518
	3	0	White	0.412
		0.5	Milky	0.520
		1.0	Milky	0.525
	4	0	White	0.420
		0.5	Milky	0.521
		1.0	Milky	0.522
	5	0	White	0.421
		0.5	Milky	0.530
		1.0	Milky	0.531

The colour of the films ranged from white to milky as the ethylene glycol content increased alongside the filler (Table 5). This colour change likely reflects the plasticizer's and filler effect on the transparency of the films. Film thickness was slightly increased with higher ethylene glycol content, indicating the

influence of the plasticizer and filler on the film's density and structure. Thickness values were within a narrow range (0.41–0.53 mm), suggesting minimal effect on film's overall thickness with changes in formulation.

Table 6: Tensile strength of bioplastic film

Ethylene Glycol plasticizer (g)	Rice husk ash filler (g)	Tensile Strength (MPa)
2	0	2.34
	0.5	5.78
	1	9.05
3	0	1.42
	0.5	3.44
	1	8.78
4	0	0.80
	0.5	1.65
	1	2.34

5	0	0.91
	0.5	1.38
	1	1.67

Tensile strength increased with the addition of Rice husk ash filler, as seen in films with 1g filler showing the the highest tensile strength (9.05 MPa) was achieved with the formulation containing 2g plasticizer (ethylene glycol) and 1g Rice husk ash filler. This demonstrates that a lower plasticizer content with a high filler loading yields the strongest.

This significant improvement is attributed to the reinforcing effect of rice husk ash filler,

which increases the rigidity of the starch-based films. However, excessive plasticizer content (5g ethylene glycol) reduced tensile strength, suggesting that while plasticizers enhance flexibility, they also weaken the mechanical integrity of the films at higher concentrations. The optimal tensile strength was achieved with a balanced combination of 2g ethylene glycol, and 1g Rice husk ash filler.

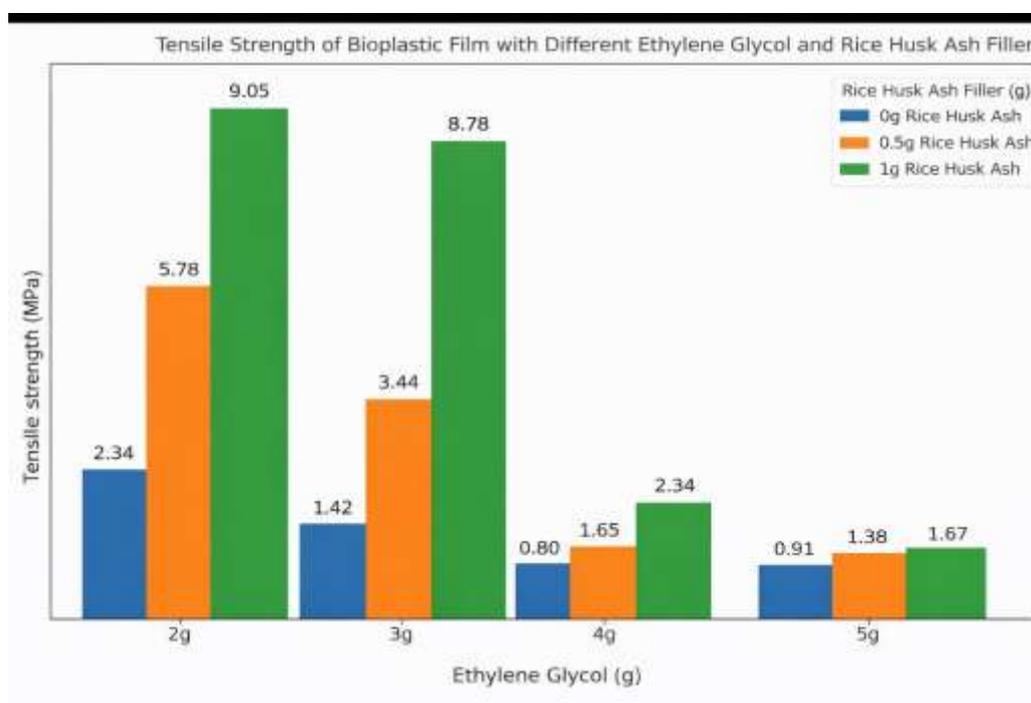


figure 3.4: Bar chart of Tensile strength of biofilm at different concentration of plasticizer and fillers.

#### 4.0 Conclusion

The results of this research reveal the effective modification of cassava starch films through acetylation, plasticization with ethylene glycol, and reinforcement with rice husk ash. Acetylation lowered the temperature at which gelatinisation occurs, although it also caused a little drop in yield. Adding ethylene glycol to the starch films made them more flexible. Adding Rice husk ash as a filler, on the other hand, made the films stronger and more

resistant to water and acid. The films with 1g of Rice husk ash had the best mechanical integrity. The study found a clear trade-off: adding rice husk ash as filler enhanced tensile strength, while adding plasticiser made it more flexible as the expense of mechanical strength. The formulation made with 2g of plasticiser and 1g of rice husk ash had the maximum tensile strength, making it good for uses that need strong mechanical integrity. For applications prioritizing flexibility, a higher plasticiser content would be preferred. The results also demonstrate the versatility of *Manihot esculenta* Crantz cv. TMS 92/0326 starch, a widely available and

sustainable resource, in the production of functional, eco-friendly bioplastics. This study contributes to advancing the development of starch-based films that could reduce plastic pollution, offering a promising alternative to conventional petroleum-derived plastics.

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**Declaration**

The authors declare that this manuscript is original and unpublished.