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Exploring the Effects of Fibres Dosing and Plasticizers Content on the Properties of Bioplastics Obtained Potato Peel Waste Reinforced with Baobab Fibres for Packaging Applications

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ABSTRACT

Environmental safety has become a paramount concern across various sectors in recent decades due to the widespread use of synthetic polymers in the manufacturing of plastics, leading to an increased risk of environmental pollution. This underscores the need for environmentally friendly composite materials that offer superior mechanical performance compared to traditional materials. These specific properties have promoted the use of composites in numerous industries, including automotive, sports, construction, packaging, and biomedical applications. Growing awareness of the environmental issues caused by synthetic materials has stimulated interest in developing sustainable, eco-friendly composites, particularly those incorporating renewable resources such as natural fibres and biopolymers. This research focuses on the development of green composites derived from potato peel waste (PPW), specifically a starch-based plastic (SBP) matrix reinforced with baobab fibres, with a view to using materials and processes with minimal ecological impact. Starch-based plastic was synthesised from sweet potato starch and plasticised using sorbitol. The matrix was reinforced with varying amounts of baobab fibres to enhance its mechanical properties. The composites were characterised using Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and tensile testing. The results demonstrated that the incorporation of baobab fibres into the starch-based plastic matrix significantly improved tensile strength and elongation at break, indicating the potential of this green composite for diverse industrial applications.

Keywords: *Potato Waste plastic Resin, Baobab Fibres, Mechanical Performance, packaging applications and Green Composite.*

INTRODUCTION

Plastics are ubiquitous in nearly all human activities. However, their widespread use has raised significant environmental concerns, particularly when utilised for short periods before disposal. Plastic waste, especially packaging materials that end up floating or littering oceans, rivers, seas, and lakes, poses a major threat to wildlife, including birds, fish, and other species in these ecosystems (Umar, 2015). Due to their resistance to microbial action and other environmental factors, many plastics take up to 10 centuries to degrade in nature. Proper disposal of plastics after use remains a significant challenge, and while recycling and reuse help reduce environmental pollution caused by post-consumer plastic materials, these processes have limitations. Recycled plastics typically do not retain the same properties as their virgin counterparts, making them unsuitable for similar applications due to the deterioration of their properties during recycling (Neha *et al.*, 2021).

The non-degradability of conventional plastics, coupled with escalating water and land pollution, has led to growing concerns, necessitating the search for solutions to prevent the accumulation of thousands of tonnes of solid waste annually. Awareness of the waste issue and its environmental impact has spurred interest in degradable polymers, increasing the demand for materials that pose minimal or no environmental burden (Umar, 2015). A variety of biodegradable polymers are available, including aliphatic polyesters such as poly(caprolactone) (PCL), poly(butylene succinate) (PBS), poly(butylene succinate-co-adipate) (PBSA), and poly(lactic acid) (PLA) (Vinceto, 2013).

Biodegradable polymers present a potential solution to waste disposal issues associated with petrochemical-based plastics. These materials are designed to degrade under environmental conditions or in municipal and industrial biological waste treatment facilities. Other environmental benefits of biodegradable plastics include reduced greenhouse gas emissions, renewability of base materials, biocompatibility, reduced dependence on fossil fuel depletion, CO_2 neutrality, and non-toxic degradation products. For instance, biodegradable plastics such as poly(lactic acid) (PLA) can fully degrade in a few weeks to a few years (Layla *et al.,* 2018).

One of the most promising bio-based plastics is starch-based plastic, an aliphatic polyester derived from plants, which is readily biodegradable and developed as an alternative to conventional polymers like polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (Vinceto, 2012). Starch $(C_6H_{10}O_5)_n$ is a biopolymer of natural origin, composed of anhydrous glucose units linked by alpha-D glycosidic bonds. These bonds form a linear chain structure (amylose) and a branched polymeric structure (amylopectin) within the starch molecule. Starch is primarily sourced from cereal grains such as corn, wheat, and rice, as well as from root crops like tapioca and sweet potato (Tailor & Francis, 2018).

Corn starch is the most commonly used in plastic production due to its relative abundance and spherical shape, which minimally disrupts flow during processing (Ravindra *et al.,* 2018). However, sweet potato starch is seen as a more promising candidate for plastic production due to its high starch and amylose content, as well as its spherical shape, which makes it suitable for plastic materials (Gumel *et al.,* 2023).

Plate A: Potato peel waste (Gumel, *et al.,*2023).

Starch-based plastics (SBP), in addition to being biodegradable, possess notable properties comparable to conventional polymers, making them a viable substitute in several applications, such as packaging, sanitary product barriers, disposable cups and plates, and agricultural use. SBP exhibits high modulus, reasonable strength, good heat sealability, clarity, low greenhouse gas emissions, and low energy consumption during production (Akbar *et al.,* 2019). However, raw starch has limitations when used as plastic, such as brittleness, stiffness, and moisture sensitivity (Norhafezah *et al.,* 2015). These shortcomings can be mitigated using plasticisers like glycerol to enhance elongation and impact properties. Other low-molecular-weight compounds used as plasticisers include Biomax strong, triacetin, tributyl citrate, poly(ethylene glycol), citrate esters, partial fatty acid esters, and ethylene oxide (Akbar *et al.,* 2019).

Plasticisers are employed to lower the glass transition temperature (Tg), increase ductility, and improve the processability of SBP (Akbar *et al.,* 2019). Nonetheless, the high biodegradability and hydrophilic nature of SBP result in some drawbacks in its plastic properties, necessitating polymer blends such as SBP–poly(glycolic acid) (SBP–PGA) or SBP–phosphates to achieve more desirable characteristics (Yeret *et al.,* 2018).

Fillers, which are inert materials added to a polymer matrix, play a crucial role in modifying or enhancing the properties of composite materials. The primary purpose of fillers is to improve the properties of composites, reduce costs, and enhance biodegradability. Fillers can be either natural or synthetic and vary in shape, size, or composition, depending on the desired properties of the composite (Gumel *et al.,* 2023). The use of natural fillers in composite fabrication provides several environmental advantages, including high strength, lightweight properties, corrosion resistance, low cost, low density, abrasion resistance, non-irritation to the skin, reduced energy consumption, lower health risks, renewability, and biodegradability. These characteristics make natural fibre/polymer composites a promising solution for future applications (Justyna, 2019).

Baobab and jute fibres are lignocellulosic materials containing 58-63% cellulose, 20-24% hemicelluloses, 12-15% lignin, and small quantities of components such as fats and pectins (Diyana *et al.,* 2021). Baobab (Borassus), a member of the Malvaceae family, is a deciduous tree native to the arid regions of central Africa (Gumel *et al.,* 2023). The tree is long-lived and multipurpose, widespread throughout the hot, dry regions of Africa. Every part of the baobab tree is useful; for example, its leaves are used in cooking, while its fibres are traditionally employed to make hats, mats, baskets, and ropes (Shehu *et al.,* 2017).

Due to the mechanical properties of baobab fibres, such as tensile strength, elongation at break, flexibility, Young's modulus, strain, and break load, they are highly valued in polymer composites (Arifa *et al.,* 2021). Several studies on the mechanical properties of natural fibre-reinforced SBP composites have been conducted to replace synthetic fibres in composites. In this study, retted long baobab fibre was used as reinforcement with SBP as the matrix (Haura, 2017).

MATERIALS AND METHODS

The starch used in this study was sourced from potato waste obtained from a local potato chips vendor in Kabuga, located within Dala Local Government Area, Kano State. Meanwhile, the baobab fibre was derived from a baobab tree in Dan Zaki Village, situated in Gezawa Local Government Area, Kano State.

Chemical Reagents:

The reagents used in this research such as HCl, NaOH, acetic acid, ethanol, glycerol, sorbitol, THF and ammonium oxalate (Sigma Aldrich), were analytical grade procured from a local vendor, Seman Laboratury and Scientific Equipment and Reagents Supply Company located opposite Bayero University Kano old Campus, Kano State.

Apparatus and Equipment

In addition to laboratory glass wares, apparatus and instruments used in this research were; Fourier Transformed Infrared Spectroscopy (Carry 630), Incubator shaker (Innova 4000), Hot air oven, Scanning Electron Microscope (SEM), Tensile Tester.

Extraction of Starch from Potato Peel Waste

The method for extracting starch from sweet potato peel waste was adapted from Neha et al. (2021) with slight modifications. Initially, 500g of potato peel waste was crushed and finely pounded to obtain powder, which was then sieved through a 250µm mesh to ensure uniformity.

For the preparation of starch suspension, 200g of the finely sieved powder was mixed with 600ml of water and stirred continuously for 10 minutes. The mixture was then allowed to settle for 3 hours. Following this, the fine starch was separated from the suspension by carefully decanting the liquid portion. The remaining solid starch was oven-dried at 50°C for 72 hours. The dried starch was stored in an airtight container until further use.

Extraction of Baobab Fibre

Baobab fibres were manually extracted from the bark of the tree by cutting sections from the upper portion of the trunk. The fibres were mechanically removed, cleaned thoroughly, and dried at room temperature for two weeks before undergoing chemical retting.

Chemical Retting of Fibres

The retting process followed the method adapted by Sani and Auwal (2017). The raw baobab fibres (2g) were submerged in a 15% ammonium oxalate solution (w/v, 1:20) for 1 hour. After soaking, the fibres were washed thoroughly under running tap water, rinsed with distilled water, and then dried in a hot air oven at 50°C for 3 hours.

Preparation of Starch-Based Plastics

Potato peel starch was utilised as the matrix at a constant mass of 15g for each film. Glycerol was employed as a plasticiser at a concentration of 5ml per mixture to improve the plasticity and flexibility of the final film. The preparation process involved adding 15g of potato peel powder to 100ml of distilled water in a 1-litre beaker, followed by stirring. The mixture

Preparation of Starch-Based Plastics (SBP)

Potato peel starch served as the matrix in the production of the SBP, with a constant mass of 15 g used for each film. Glycerol, in two different quantities of 5 ml, was incorporated as a plasticiser to enhance the plasticity and flexibility of the films.

For the film preparation, 100 ml of distilled water was measured into a 1-litre beaker, followed by the addition of 15 g of potato peel powder. The mixture was stirred with a glass rod and heated to approximately 120°C until starch gelation occurred. After the starch solution cooled, 5 ml of glycerol, 5 ml of 0.1M HCl, and variable amounts of castor oil were added. The mixture was stirred, heated to 70°C for 15 minutes until it became transparent, and then poured into moulds lined with foil paper. The films were allowed to cool at room temperature for 3 days. Afterward, the films were baked at 18°C for 15 minutes and then allowed to cool again for 24 hours.

The final plastic films were carefully removed from the aluminium foil and stored in glass containers. The procedure was repeated with glycerol at 5 ml and fibre dosing of 1, 2, 3, 4, and 5 g for each film, with the composite being fabricated in duplicate. A total of 10 samples were prepared, with the composition of the SBP detailed in Table 1.

3.7. CHARACTERIZATION PROCESS

The starch-based plastics were characterised using the following techniques:

Fourier Transform Infrared Spectroscopy (FTIR): This technique was employed to analyse the chemical structure and identify the functional groups present in the starch-based plastic materials.

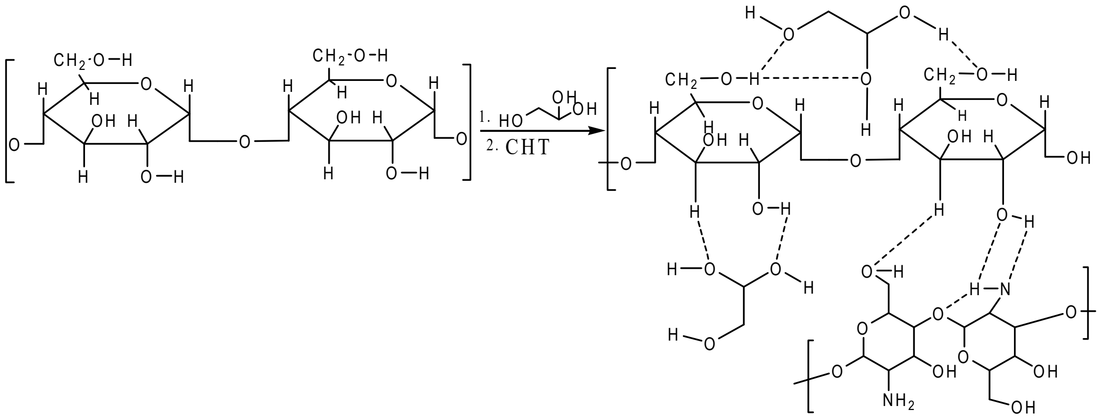
Scanning Electron Microscopy (SEM): SEM was utilised to examine the surface morphology and microstructural properties of the starch-based plastic, providing detailed visual insights into the fibre distribution and bonding within the matrix.

Tensile Strength Testing: The mechanical properties of the starch-based plastics were evaluated through tensile strength testing, which measured the material's resistance to deformation and its elongation at break.

Table1: Composition of starch-based plastics reinforced with variable amount of baobab fibre dosing.

SampleS of the plastic (SBP)	**PPW starch (g)**	**Distilled Water (mL)**	**Glycerol (mL)**	**Castor oil (g)**	Baobab fibre (g)
1	20. 00	100	5	1	0
2	20. 00	100	5	2	1
3	20. 00	100	5	3	2
4	20. 00	100	5	4	3
5	20.00	100	5	5	4

Results and Discussion



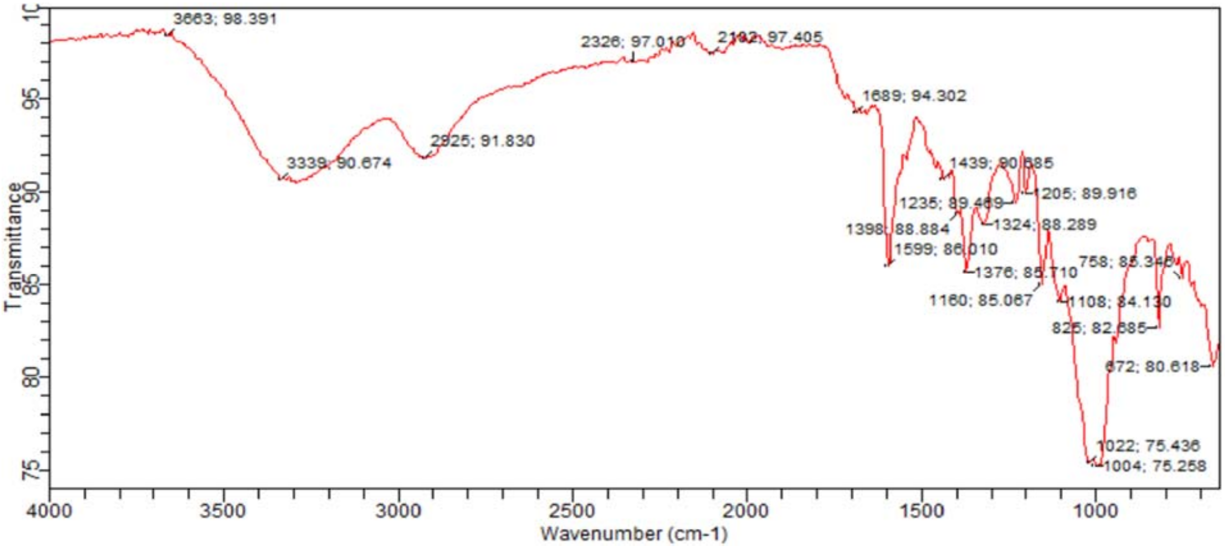
Scheme 1: Proposed molecular interaction between starch and glycerol (Enrique *et al.,* 2021).

Fourier Transformed Infrared Spectroscopy (FTIR)

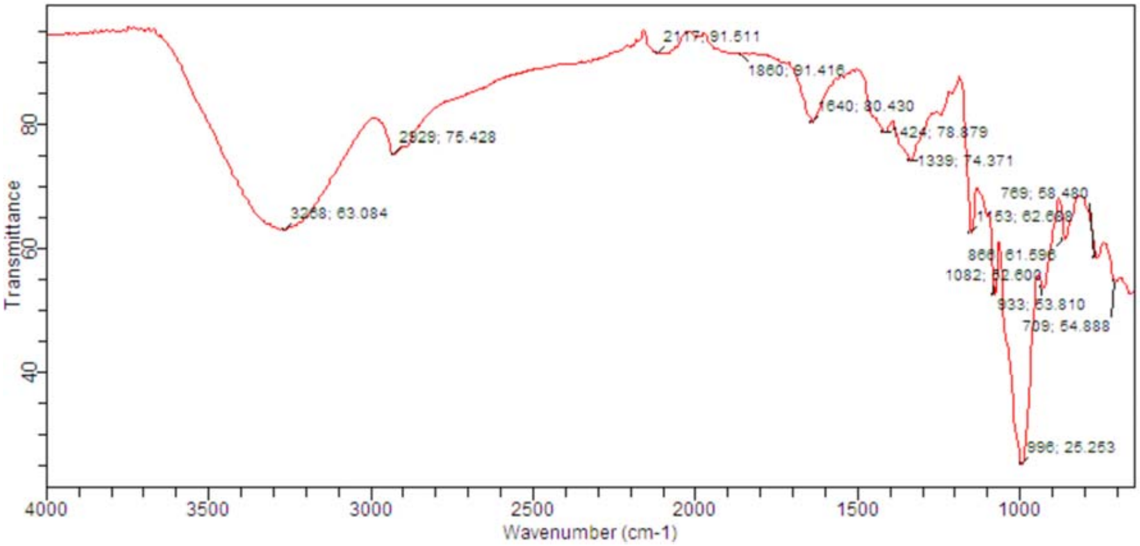
Unmodified Baobab fibre

Table 2. Fourier transformed infrared spectroscopy for modified and unmodified baobab fibre.

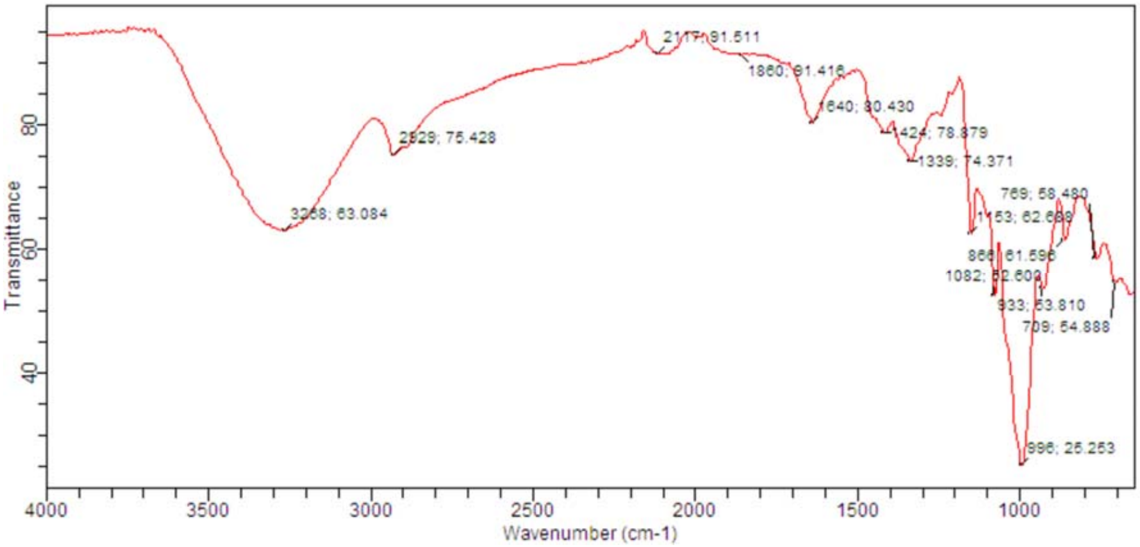
Baobab fibre	OH stretching	C –H Vibration	C = O Stretching	C =C Stretching	C – H Bending	OH Bending
Unmodified	3393	2881	1737	1510	1365	665
Mercerized baobab Fibre.	3285	2851	1689	1596	1376	668
Benzoylated Baobab Fibre.	3317	2982	1729	1484	1376	560



Unmodified Baobab Fibre



(a) Mercerized Baobab Fibre



(c) Benzoylated baobab fibre.

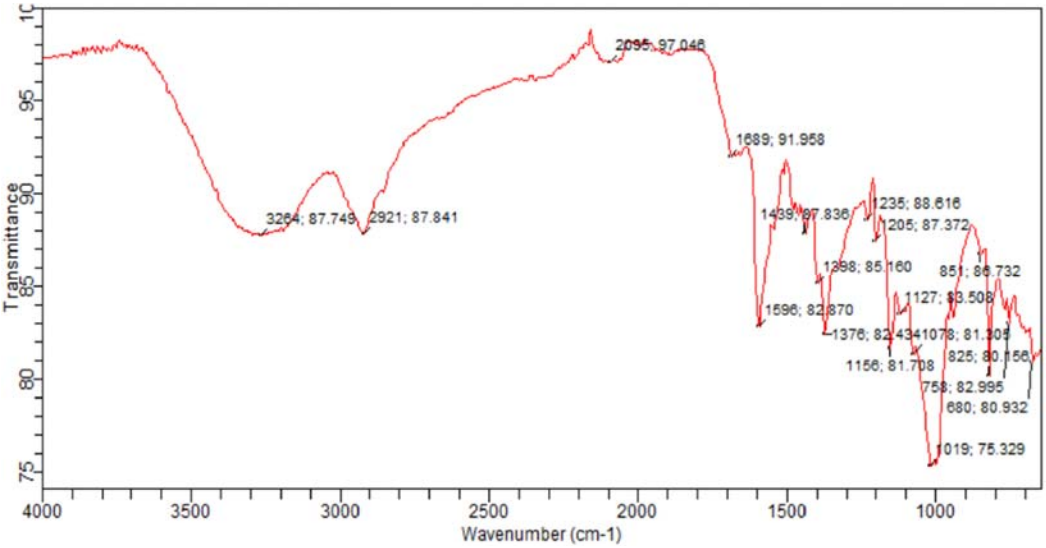
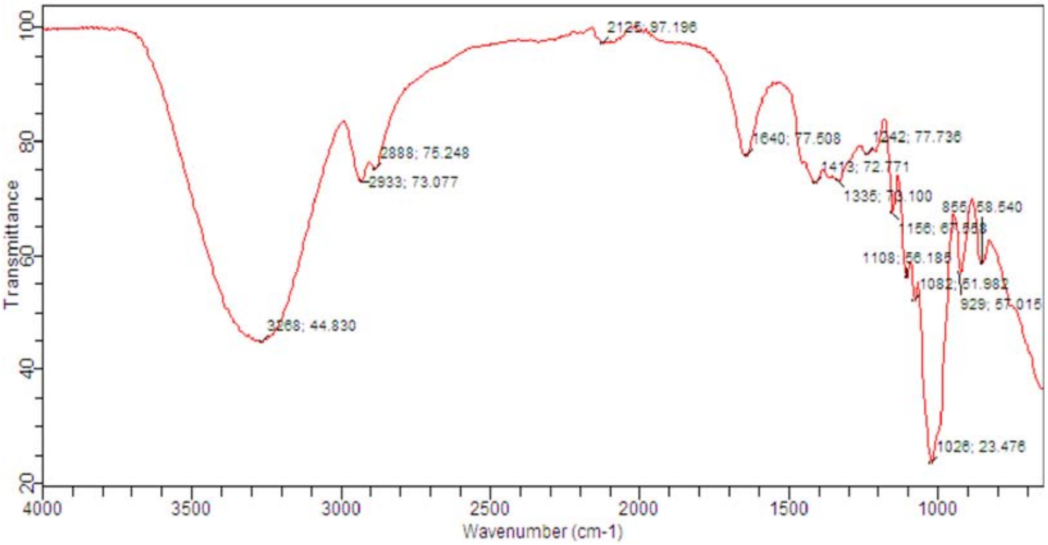
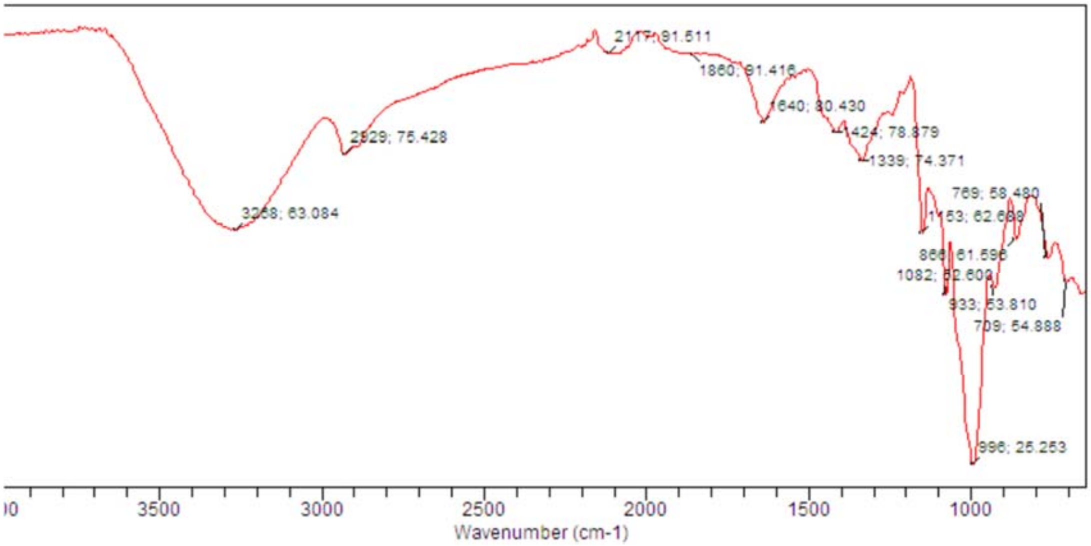


Table 3: Fourier transformed infrared spectrum of Potato peel waste and Potato waste plastic with their absorption bands (Cm^{-1}).

Absorption band (CM^{-1})/ Functional group	OH stretching	N –H Vibration	C = O Stretching	C =C Stretching	C – H Bending	OH Bending
Potato waste Starch	3481	-	1737	1594	1367	672
Potato waste starch Plastic	3287	-	1687	1562	1374	678



(d) Potato waste plastic.



(e) potato waste starch

Figure 1: FT-IR spectral data of baobab fibres before and after modification

Discussion of Results

FT-IR Analysis

The FT-IR spectral images of the baobab fibres, along with their corresponding absorption bands, are presented in **Figure 1 (a-c)**. The spectral data reveal a prominent peak in the range of 3200–3600 cm^{-1}, indicating the presence of O-H (hydroxyl group) stretching vibrations within the fibres. These peak experiences a downshift following alkaline modification and an upward shift upon bleaching. The downshift in the alkaline modification occurs due to the removal of impurities and unwanted materials from the surface of the fibres. Conversely, the upward shift in the bleached fibres can be attributed to benzoylation, which enhances compatibility between the fibres and polymer matrices.

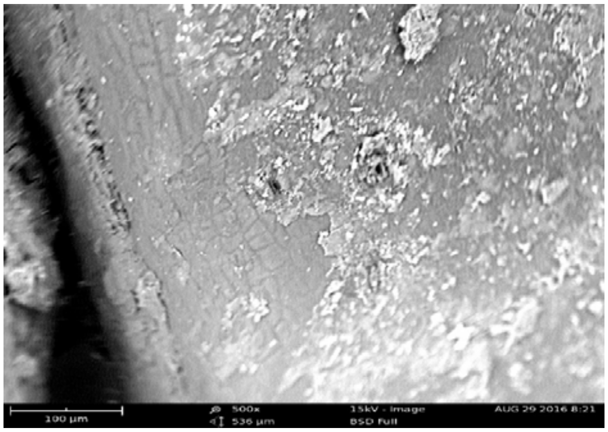
Additionally, a distinct absorption peak in the range of 2900–2800 cm^{-1} is observed in the spectra of unmodified, mercerised, bleached, and benzoylated fibres, corresponding to C-H stretching. Another absorption peak located between 1670–1820 cm^{-1} highlights the presence of C=O stretching, which is associated with the carbonyl groups in hemicelluloses and lignin. Furthermore, peaks at 1737 cm^{-1} and 1735 cm^{-1} were detected in both unmodified jute and baobab fibres, respectively.

The absorption peak at 1596 cm^{-1} in the unmodified fibres suggests the presence of C=C stretching, which diminishes after treatment with NaOH and bleaching. This reduction is likely due to the removal of unsaturated components present in small quantities within the fibres (Inayatul Mutmainna *et al.,* 2019). Moreover, absorption peaks at 1365 cm^{-1}, 1367 cm^{-1}, and 1367 cm^{-1} in the baobab fibres exhibit a decline in intensity as the concentration of the chemical modifiers increases. Lastly, the O-H bending peak is observed within the 690–600 cm^{-1} range in the fibres.

Mechanical Properties

Tensile strength of the bioplastics: Tensile strength is the measurement of the force required to pull something to the point where it breaks. The tensile strength for SBP was performed by using Universal Testing Machines Electronic System based on the standard ASTM D638, 1991. The tensile strength for each sample was recorded as shown in Table 3

Scanning Electron Microscope (SEM)



.Figure 2a:micrograph of unmodified baobab fibre

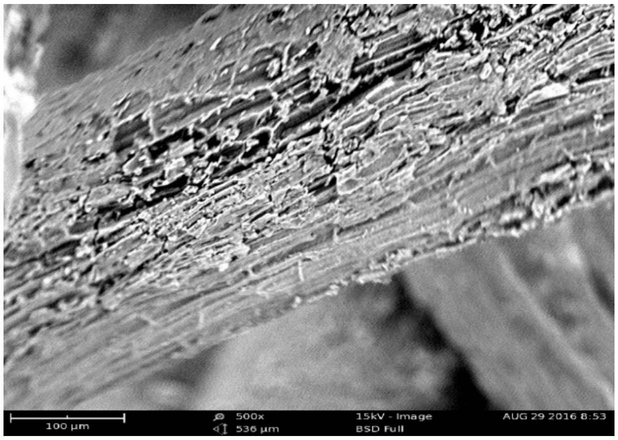


Figure 2b: micrograph of mercerized baobab fibre.

2.4

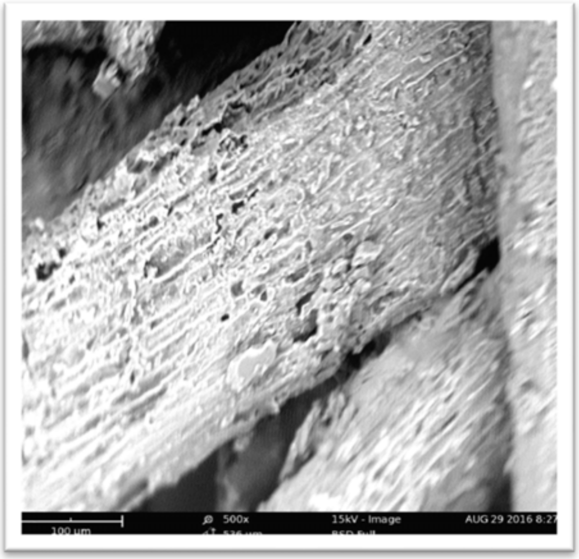


Figure 2c: micrograph of benzoylated baobab fibre.

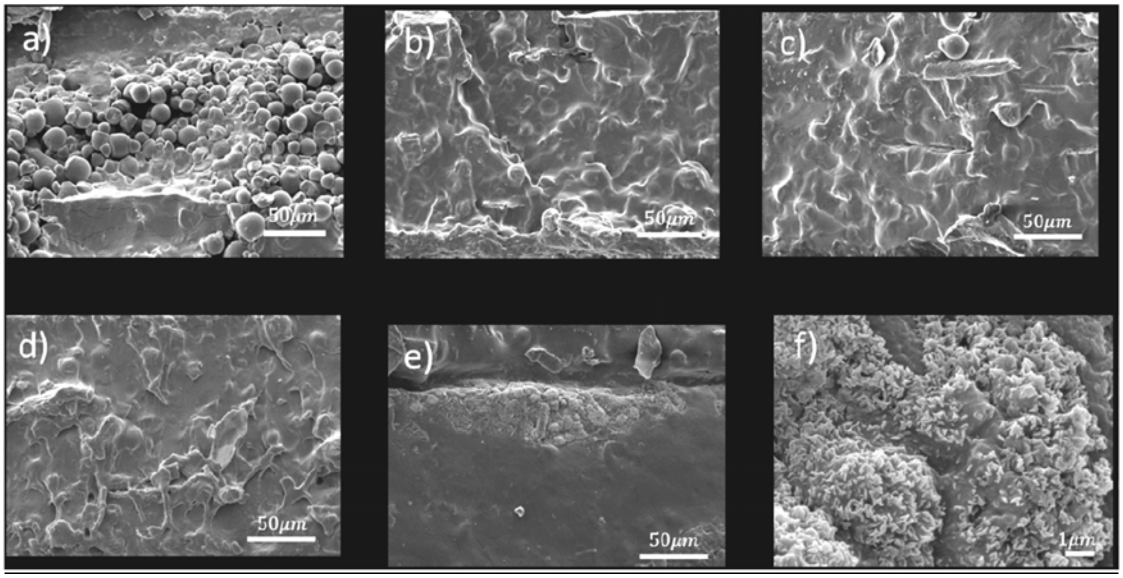


Figure (3 a – f); Micrograph of the bioplastics.

The cross-section image of starch-based bioplastics with the addition of variable amount of Baobab fibres is shown in Fig.(3a–f).

Table 4.4; Tensile properties of SBP

Sample	**Tensile strength (MPa)**			**Elongation at break (%)**
1	TPS - 1	8.50	83.35	11.32
2	TPS - 2	8.50	84.15	21.32
3	TPS - 3	9.40	92.17	19.76
4	TPS - 4	13.30	130.41	15.08
5	TPS - 5	20.40	200.04	24.96
6	Bioplastic+ glycerol	0.26	0.03	57.00

As shown in **Table 3**, the incorporation of varying amounts of baobab fibre reinforcement led to a notable increase in tensile strength, from initial values of 8.50, 8.95, and 9.40 kgf/mm² (equivalent to 83.85, 84.15, and 92.17 MPa, respectively) to 13.30 and 20.40 kgf/mm² (equivalent to 130.41 MPa and 200.04 MPa, respectively). The tensile strength of the starch-based plastic (SBP) composite for all five samples exceeded the moderate mechanical properties range for plastics, which is typically between 1–10 MPa. Previous studies by Enrique et al. (2021) have similarly shown that the tensile strength of SBP without any fibre reinforcement is significantly lower, ranging from 0.40–0.47 kgf/mm². This increase in tensile strength can be attributed to the higher fibre content, which enhances the composite's strength and resistance to breakage.

CONCLUSION

Starch derived from potato peel and plasticized with glycerol was used to develop a plastic matrix reinforced with varying amounts of baobab fibre. The resulting composite films demonstrated good workability and promising properties for use as packaging materials. This was confirmed by the findings from FT-IR, SEM, and mechanical testing, which revealed strong interactions between the polymer matrix and the fibres. Therefore, potato peel waste presents significant potential for future applications in sustainable material development.

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