STUDIES ON MECHANICAL, BIODEGRADABILITY AND WATER ABSORPTION CHARACTERIZATION OF STARCH-BASED PACKAGING FILMS FORMULATED FROM AGRICULTURAL WASTES

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ABSTRACT

Biodegradable polymers derived from agricultural wastes are increasingly favoured over synthetic petroleum-based plastics owing to their sustainability, renewability, biodegradability, low toxicity and cost-effectiveness. Some studies emphasize structural characterization while paying less attention to the mechanical, biodegradability and water absorption performance of the final product. This study evaluated the mechanical properties, biodegradability and water absorption behaviour of starch-based biodegradable packaging films formulated from a composite of yam peels, potato peels and sugarcane bagasse. The Starch was extracted from the samples using a wet milling method, and biodegradable films were formulated through gelatinization, glycerol plasticization, pH adjustment with acetic acid and calcium chloride crosslinking. Mechanical characterization revealed a tensile strength of 8.42 ± 0.58 MPa, elongation at break of 42.76 ± 4.21%, Young's modulus of 186.35 ± 18.47 MPa, tear strength of 1,284 ± 96 gf (MD) and 1,167 ± 88 gf (TD) and fold endurance of 74 ± 9 double folds. Soil burial test over 12 weeks demonstrated progressive biodegradation of the TPS film, with weight loss increasing from 18.42% (week 3) to 37.65% (week 6), 56.89% (week 9) and 74.23% (week 12), while the LDPE control remained essentially intact with only 0.79% weight loss. FTIR of the biodegraded polymer confirmed molecular-level degradation: O–H stretching shifted from 3284 to 3274 cm^{-1}, a new carbonyl C=O band appeared at 1716 cm^{-1} indicating oxidative degradation products, the C–O–C band shifted from 1154 to 1150 cm^{-1} indicating glycosidic cleavage, and the C–O band at 1080 cm^{-1} disappeared entirely. The water absorption test showed that the TPS film absorbed 32.20% water after 24 hours, compared to only 0.40% for LDPE. Absorption increased progressively from 8.40% (3 h) to 15.60% (6 h), 24.80% (12 h) and 32.20% (24 h), consistent with the bulk absorption mechanism characteristic of starch-based materials. The combined mechanical, biodegradability and water absorption evidence confirms that starch-based films from agricultural wastes are viable biodegradable alternatives to conventional petroleum-based packaging materials.

Keywords: biodegradable, packaging, mechanical, absorption, FTIR, sustainable

1. INTRODUCTION,

The extensive use of synthetic petroleum-based plastics in modern packaging systems has become one of the most pressing environmental challenges of the twenty-first century. Plastics such as polyethylene, polypropylene, polystyrene and polyethylene terephthalate dominate global packaging markets due to their durability, lightweight nature, flexibility and low production cost (Wang *et al*., 2024). However, these same attributes make them environmentally persistent, as they are highly resistant to natural degradation processes. Global plastic production has continued to rise steadily, exceeding 400 million tonnes annually, with packaging accounting for the largest share of plastic use and waste generation (Shen *et al*., 2023). A substantial proportion of this plastic waste is improperly managed, leading to widespread accumulation in landfills, waterways, agricultural soils and marine ecosystems.

In response to the growing environmental challenges, global attention has increasingly shifted toward sustainable materials and circular economy approaches aimed at reducing dependence on fossil-based plastics. Biodegradable polymers have emerged as promising substitutes for conventional plastics, particularly in packaging applications where product lifespan is relatively short and waste generation is high (Naser *et al*., 2022). Among these, starch-based polymers have gained significant attention due to their renewability, abundance, low cost and complete biodegradability (Rhim, 2020). Starch being a polysaccharide is composed of amylose and amylopectin and is the primary carbohydrate component in many agricultural wastes. Its extraction from crop residues provides a renewable feedstock for biodegradable polymer production, including thermoplastic starch (TPS) and as a precursor for polylactic acid (PLA) synthesis (Singh *et al*., 2020).

Agricultural wastes such as yam peels, potato peels, cassava peels and sugarcane bagasse are rich in natural polymers including cellulose, hemicellulose, lignin and starch. These materials serve as sustainable feedstocks that can be directly utilized or chemically and biologically transformed into biodegradable polymers (Ogunleye *et al*., 2023). Globally, billions of tonnes of agricultural residues are produced annually, particularly in agrarian economies, yet a significant proportion of this biomass remains underutilized or is disposed of through open burning and indiscriminate dumping (Kumar *et al*., 2024). Such practices contribute to air pollution, greenhouse gas emissions, soil degradation and public health hazards, while simultaneously representing a loss of potentially valuable raw materials.

Although weight loss and mechanical trials have shown the feasibility of starch-based biodegradable films, direct mechanical, biodegradability and water absorption evidence of film performance is required to verify the underlying mechanisms. Mechanical testing illuminates tensile strength, elongation, stiffness and tear resistance, while soil burial and water absorption tests offer complementary biodegradability and hydrophilicity evidence of film performance (ASTM D882-18; ASTM D1922-21; Mahaputri *et al*., 2025; Onovo *et al*., 2025). In order to provide direct mechanical, biodegradability and water absorption evidence that complements the structural and thermal characterization results, this study examined the mechanical properties, biodegradability and water absorption behaviour of starch-based biodegradable packaging films formulated from a composite agricultural waste sample of yam peels, potato peels and sugarcane bagasse. The mechanical and biodegradability properties of the formulated film are not sufficiently revealed by structural and thermal measurements alone, even though they offer quantitative data on the overall film performance and thermal stability (Bhardwaj *et al*., 2023; Liu *et al*., 2023). Because it allows the assessment of tensile strength, elongation, tear resistance, biodegradation rate and water absorption without substantially disrupting the material structure, mechanical testing, soil burial and water absorption tests are

among the most sensitive and popular methods for examining starch-based biodegradable polymers (Rhim, 2020; Zhang *et al*., 2022).

2. MATERIALS AND METHODS

2.1 Sample Collection and Preparation

The agricultural waste samples (yam peels, potato peels and sugarcane bagasse) were collected in accordance with Ogunleye *et al*. (2023) from homes, food vendors and small-scale agro-processing points within the vicinity of Modibbo Adama University, Yola. Samples were taken from several locations within the area to ensure proper representation, and each type of waste was combined to form a composite sample. The samples were manually sorted to remove extraneous materials such as stones, metal fragments, leaves and deteriorated portions. The samples were then thoroughly washed with tap water to remove soil and debris, followed by three rinses with distilled water to ensure purity. After cleaning, the samples were spread and air-dried at ambient temperature (28 ± 2°C) for 72 hours, with periodic turning to prevent microbial growth, until a constant weight was achieved (Okoro *et al*., 2021).

2.2 Extraction of Starch from Agricultural Waste

The starch was extracted from the composite sample using the method described by Oyewole and Obieze (2019). 100 g of milled agricultural waste was suspended in 500 mL of distilled water and allowed to steep for 4 hours at room temperature. The mixture was blended for 5 minutes, filtered through cheesecloth and allowed to sediment for 6 hours. The supernatant was decanted, and the starch sediment was washed repeatedly with distilled water until a clear supernatant was obtained.

2.3 Formulation of Biodegradable Polymer

Ten (10)g of dried extracted starch was weighed and transferred into a 250 mL beaker, after which 100 mL of distilled water was added and the mixture was stirred using a magnetic stirrer to obtain a uniform suspension. The suspension was heated at 75°C with continuous stirring for 25 minutes until a viscous gel was formed. Subsequently, 2.5 mL of glycerol was added gradually to the hot starch gel, and the mixture was stirred continuously for 10 minutes. Thereafter, 5 mL of acetic acid was added while maintaining the temperature at 65°C, and the pH of the mixture was adjusted to 8.5 using sodium hydroxide (NaOH) solution, followed by continuous stirring for 30 minutes. The reaction mixture was then neutralized by gradually adding dilute hydrochloric acid (HCl) to adjust the pH to 7.0 and was stirred for 5 minutes. For crosslinking, 2.5 g of calcium chloride ($CaCl_2$) was dissolved in 20 mL of distilled water, and the resulting solution was added slowly to the polymer mixture under continuous stirring. The resulting polymer solution was poured into clean casting trays and spread evenly to form films, after which the films were dried in an oven at 55°C for 24 hours.

2.4 Production of Biodegradable Packaging Materials

The dried biodegradable polymer films were fabricated into packaging bags by cutting the films into rectangular sheets of suitable dimensions (approximately 30 cm × 40 cm) using scissors. Each film sheet was then folded into the desired bag shape, and the open edges were sealed using a household pressing iron as the heat source. The iron was gently applied along the edges of the folded film for a few seconds, allowing the polymer layers to soften and fuse together.

2.5 Characterization of Packaging Materials

2.5.1 Mechanical Properties

Tensile properties were determined according to ASTM D882-18 using a universal testing machine (Instron 3365, Instron Corporation, USA). Film specimens were cut into rectangular strips (100 mm × 15 mm). The initial grip separation was set at 50 mm, and crosshead speed was 50 mm/min. A 500 N load cell was employed. Tensile strength (MPa), elongation at break (%) and Young's modulus (MPa) were computed from stress-strain curves. A minimum of 10 replicate specimens from each batch were tested. Tear resistance was determined according to ASTM D1922-21 using an Elmendorf tear tester (Thwing-Albert, USA). Specimens were cut in both machine direction (MD) and transverse direction (TD), with a minimum of 10 specimens per direction. Flexibility was assessed through fold endurance (MIT flex test) according to ASTM D2176-21.

2.5.2 Biodegradability Assessment (Soil Burial Test)

The biodegradability of the formulated packaging material was evaluated using a soil burial test following the method of Mahaputri *et al*. (2025) with modifications. The biodegradable film samples were cut into suitable pieces and buried directly in soil at a depth of approximately 5 cm. Low-density polyethylene (LDPE) film samples of equal dimensions were buried alongside the TPS samples to serve as a non-biodegradable control. The buried samples were left undisturbed under natural soil conditions at ambient temperature. At three-week intervals (weeks 3, 6, 9 and 12), triplicate samples of both TPS and LDPE were carefully retrieved and visually examined for signs of degradation. The retrieved samples were gently cleaned, dried to constant weight and weighed to determine percentage weight loss.

2.5.3 Water Absorption Test

The water absorption capacity of the formulated biodegradable packaging film was evaluated following the method of Onovo *et al*. (2025) with modifications. Low-density polyethylene (LDPE) film samples of equal dimensions were tested alongside the thermoplastic starch (TPS) samples to serve as a non-biodegradable, hydrophobic control. The film samples were cut into uniform pieces (approximately 2 cm × 2 cm) and pre-dried in an oven at 50°C for 24 hours to remove any residual moisture. The dried samples were then cooled in a desiccator and weighed to obtain the initial dry weight (W_0). Each sample was subsequently immersed in 100 mL of distilled water in separate beakers at room temperature (25 ± 2°C). At predetermined time intervals of 0, 3, 6, 12 and 24 hours, the samples were carefully retrieved from the water, gently blotted with filter paper to remove excess surface moisture and immediately weighed to obtain the final weight (W_1).

2.5.4 FTIR Spectral Analysis of the Biodegraded Polymer

FTIR spectroscopy was used to monitor molecular-level changes in the starch-based biodegradable polymer after 12 weeks of soil burial degradation. The spectra of the undegraded and degraded films were compared to identify changes in functional groups and chemical structure.

3. RESULTS AND DISCUSSION

3.1 Mechanical Properties of the Biodegradable Packaging Film

Table 1: Mechanical Properties of the Biodegradable Packaging Film

S/N	Property	Mean ± SD	Unit
1	Tensile strength	8.42 ± 0.58	MPa
2	Elongation at break	42.76 ± 4.21	%
3	Young's modulus	186.35 ± 18.47	MPa
4	Tear strength – MD	1,284 ± 96	gf
5	Tear strength – TD	1,167 ± 88	gf
6	Fold endurance	74 ± 9	double folds

The results indicate that the developed thermoplastic starch (TPS) film possessed a satisfactory combination of strength, flexibility, stiffness and resistance to mechanical damage, demonstrating its potential for lightweight packaging applications. The film recorded a tensile strength of 8.42 ± 0.58 MPa, indicating that it could withstand a reasonable amount of tensile stress before rupture. The relatively low standard deviation suggests good consistency among the tested specimens and indicates that the casting and drying processes produced a relatively uniform polymer film. The tensile strength can be attributed to the formation of a cohesive starch-based polymer matrix during gelatinization and drying, with interactions among the starch molecules and other formulation components contributing to the structural integrity of the film.

The elongation at break was 42.76 ± 4.21%, indicating that the film could undergo considerable deformation before breaking and therefore possessed appreciable flexibility. This relatively high elongation is advantageous for packaging applications because the film must be capable of bending, stretching and handling without becoming excessively brittle. The flexibility may be associated with the incorporation of glycerol as a plasticizer, which increases polymer-chain mobility and reduces intermolecular interactions within the starch matrix, thereby improving flexibility and reducing brittleness.

The Young's modulus was 186.35 ± 18.47 MPa, demonstrating that the film possessed moderate stiffness and could maintain its structural form while still allowing sufficient deformation during handling. The combination of moderate tensile strength, relatively high elongation and intermediate stiffness suggests that the formulation achieved a useful balance between rigidity and flexibility, which is desirable in biodegradable packaging materials.

The tear strength was 1,284 ± 96 gf in the machine direction and 1,167 ± 88 gf in the transverse direction, indicating that the film possessed good resistance to the propagation of tears in both directions. The slightly higher tear strength in the MD compared with the TD may be associated with some degree of polymer-chain orientation or structural alignment that occurred during casting, spreading or drying of the film. However, the relatively small difference between the two values indicates that the material exhibited reasonably balanced tear resistance and was not highly anisotropic.

The fold endurance of 74 ± 9 double folds further demonstrates that the biodegradable film could withstand repeated bending and folding before failure. This property is particularly important for packaging bags because the material is expected to undergo folding, bending and manipulation during fabrication, storage and use. The observed fold endurance is consistent with the relatively high elongation at break and can also be attributed to the plasticizing effect of glycerol, which enhances molecular mobility and reduces brittleness within the starch matrix.

The tensile strength of 8.42 ± 0.58 MPa is notably higher than the 2.04 ± 1.24 MPa reported by Staker *et al*. (2024) for potato-based thermoplastic starch films, indicating superior cohesive strength in the present

formulation. The elongation at break of 42.76 ± 4.21% demonstrates appreciable flexibility, comparable to the 47.2 ± 3.6% reported by Staker *et al*. (2024) for choline chloride/urea plasticized TPS films, and can be attributed to glycerol's plasticizing effect (Saud *et al*., 2019). The tear strength values of 1,284 ± 96 gf (MD) and 1,167 ± 88 gf (TD) indicate good resistance to tear propagation in both directions. The slightly higher value in the machine direction suggests some degree of polymer-chain orientation during casting and drying, a phenomenon also observed in starch-based HDPE blown films where superior tensile strength in MD over TD indicated higher orientation in that direction (Gonzalez *et al*., 2021).

3.2 Biodegradability Assessment (Soil Burial Test)

Table 2: Biodegradability of the Formulated Biodegradable Packaging Film with LDPE as Control

Parameter	Week 0	Week 3	Week 6	Week 9	Week 12
TPS Initial Weight, W_0 (g)	0.500	0.500	0.500	0.500	0.500
TPS Final Weight, Wt (g)	0.500	0.408	0.312	0.216	0.129
TPS Weight Loss (%)	0.00	18.42	37.65	56.89	74.23
LDPE Initial Weight, W_0 (g)	0.500	0.500	0.500	0.500	0.500
LDPE Final Weight, Wt (g)	0.500	0.498	0.497	0.497	0.496
LDPE Weight Loss (%)	0.00	0.31	0.52	0.68	0.79

The soil burial test conducted over a 12-week period, with measurements taken at 3-week intervals, demonstrated a clear and progressive biodegradation of the thermoplastic starch (TPS) film, while the low-density polyethylene (LDPE) control remained essentially intact. The TPS film exhibited substantial weight loss at each interval, increasing from 18.42% at week 3 to 37.65% at week 6, 56.89% at week 9 and ultimately reaching 74.23% at week 12. In stark contrast, the LDPE control showed negligible weight loss throughout the entire test period, reaching only 0.79% after 12 weeks. This striking difference confirms the biodegradability of the formulated TPS film and the non-biodegradable nature of conventional LDPE.

The progressive weight loss of the TPS film can be attributed to the susceptibility of its primary components, starch and glycerol, to microbial attack in the soil environment. Starch, being a polysaccharide composed of glycosidic-linked glucose units, is readily metabolized by a wide range of soil microorganisms, including bacteria and fungi, which produce amylolytic enzymes capable of hydrolyzing these glycosidic bonds (Onovo *et al*., 2025). The resulting oligosaccharides and glucose units are subsequently assimilated by the microorganisms, leading to progressive breakdown of the polymer matrix. Glycerol, incorporated as a plasticizer to improve film flexibility, is also readily biodegradable and contributes to the early stages of weight loss through leaching and microbial consumption.

The progressive nature of the weight loss suggests that biodegradation occurred throughout the bulk of the film rather than being confined to the surface. This is consistent with the hydrophilic nature of starch, which allows water and microorganisms to penetrate the polymer matrix, facilitating bulk degradation. The initial weight loss of 18.42% at week 3 can be attributed primarily to the leaching of water-soluble components and the onset of microbial colonization. The subsequent increase in weight loss at weeks 6, 9 and 12 indicates that enzymatic degradation of the starch matrix became increasingly active as microbial populations established and proliferated within the film.

The visual observations recorded during the test corroborate the gravimetric data. The TPS film progressed from smooth and intact at week 0, to slightly rough and discolored at week 3, to noticeably softened and eroded at week 6, to cracked and embrittled at week 9 and finally to extensively fragmented and disintegrated at week 12. These visual changes are consistent with the biodegradation behaviour of starch-based films reported in the literature, where progressive surface erosion, discoloration and loss of structural integrity accompany the breakdown of the starch matrix (Onovo *et al*., 2025).

The LDPE control exhibited only 0.79% weight loss after 12 weeks, confirming its resistance to microbial degradation. This negligible weight loss can be attributed primarily to the loss of surface impurities or loosely bound additives rather than actual polymer degradation. LDPE consists of long hydrocarbon chains with strong carbon-carbon bonds that are resistant to microbial attack, lacking the functional groups such as hydroxyl or glycosidic linkages that enzymes can readily recognize and cleave (Onovo *et al*., 2025). Consequently, LDPE persists in the environment for extended periods, typically decades to centuries, and its lack of biodegradability is a major environmental concern.

3.3 Water Absorption Test

Table 3: Water Absorption of the Formulated Biodegradable Packaging Film and LDPE Control

Parameter	0 hr	3 hr	6 hr	12 hr	24 hr
TPS Initial Weight, W_0 (g)	0.500	0.500	0.500	0.500	0.500
TPS Final Weight, Wt (g)	0.500	0.542	0.578	0.624	0.661
TPS Water Absorption (%)	0.00	8.40	15.60	24.80	32.20
LDPE Initial Weight, W_0 (g)	0.500	0.500	0.500	0.500	0.500
LDPE Final Weight, Wt (g)	0.500	0.501	0.501	0.502	0.502
LDPE Water Absorption (%)	0.00	0.20	0.20	0.40	0.40

The water absorption results demonstrate that the thermoplastic starch (TPS) film exhibited substantial and progressive water absorption over the 24-hour test period, reaching 32.20% at 24 hours, while the LDPE control showed negligible absorption, reaching only 0.40%. The relatively high water absorption of the TPS film can be attributed to the hydrophilic nature of starch, which contains numerous hydroxyl groups capable of forming hydrogen bonds with water molecules, and the hygroscopic properties of glycerol, which readily absorbs moisture from the surrounding environment (Onovo *et al*., 2025).

The progressive increase in water absorption from 8.40% at 3 hours to 15.60% at 6 hours, 24.80% at 12 hours and 32.20% at 24 hours indicates that water molecules gradually penetrated the polymer matrix, causing swelling and structural changes within the film. This behaviour is consistent with the bulk absorption mechanism characteristic of starch-based materials, where water penetration extends beyond the surface layer (Onovo *et al*., 2025). In contrast, the LDPE control exhibited only 0.40% water absorption after 24 hours, confirming its hydrophobic nature due to its long hydrocarbon chains and lack of polar functional groups necessary for hydrogen bonding with water molecules (Onovo *et al*., 2025).

The water absorption results have important implications for packaging applications. The relatively high water absorption of the TPS film suggests that it may be suitable for applications where moisture absorption is desirable, such as in agricultural mulching films or moisture-regulating packaging, but may require additional modification, such as cross-linking or blending with hydrophobic polymers, for applications requiring high moisture barrier properties (Onovo *et al*., 2025). The results also highlight the importance of

considering environmental humidity and storage conditions when evaluating the performance of starch-based biodegradable films.

3.4 FTIR Spectral Analysis of the Biodegraded Polymer

Table 4: FTIR Absorption Bands of the Starch-Based Biodegradable Polymer Before and After Degradation

S/N	Functional Group	Before Degradation (cm^{-1})	After 12 Weeks Degradation (cm^{-1})	Shift (cm^{-1})
1	O–H stretching	3284	3274	-10
2	C–H stretching	2924	2921	-3
3	C=O stretching	—	1716	+1716
4	H–O–H bending	1647	1632	-15
5	CH_2 bending	1418	1412	-6
6	C–O–C stretching	1154	1150	-4
7	C–O stretching	1080	—	—
8	C–O stretching	1022	1023	+1
9	Glycosidic linkage	928	930	+2

The FTIR spectra of the starch-based biodegradable polymer before and after 12 weeks of degradation showed characteristic absorption bands associated with the functional groups present in starch and glycerol. The undegraded polymer exhibited a broad O–H absorption band at 3284 cm^{-1}, a C–H stretching band at 2924 cm^{-1}, a water-related band at 1647 cm^{-1} and bands around 1418, 1154, 1080, 1022 and 928 cm^{-1}. These observations are consistent with recent studies on starch-based films. A study published in 2023 reported broad O–H absorption in the 3000–3500 cm^{-1} region and C–H/C–H_2 stretching bands within the 2830–2920 cm^{-1} region in starch-based edible films containing glycerol (Kumar *et al*., 2023). Similarly, recent studies have identified absorption bands around 2920–2930 cm^{-1} as C–H or CH_2 stretching, bands around 1640 cm^{-1} as bending vibrations associated with absorbed water and bands within approximately 1150–950 cm^{-1} as characteristic C–O, C–O–C and carbohydrate vibrations in starch-based bioplastics (Abdullah *et al*., 2025; Rani & Mallika, 2025).

Following 12 weeks of degradation, several changes were observed in the spectrum. The O–H band shifted from 3284 to 3274 cm^{-1}, C–H from 2924 to 2921 cm^{-1}, H–O–H from 1647 to 1632 cm^{-1} and the CH_2-related band from 1418 to 1412 cm^{-1}. The C–O–C band also shifted from 1154 to 1150 cm^{-1}, while the bands around 1022 and 928 cm^{-1} changed slightly to 1023 and 930 cm^{-1}, respectively. Changes in peak position and intensity following degradation have been reported in recent studies of starch-based films subjected to biodegradation conditions, where changes in FTIR spectra were associated with modifications in the molecular and structural environment of the starch matrix (Kumar *et al*., 2024). In particular, the O–H region is sensitive to changes in hydrogen bonding and interactions involving water, starch and plasticizers, while changes in the 1150–950 cm^{-1} region may reflect modifications in C–O, C–O–C and glycosidic structures (Rani & Mallika, 2025).

Most notably, a new absorption band appeared around 1716 cm^{-1} after degradation. Absorption in the approximately 1700–1750 cm^{-1} region has been associated with carbonyl (C=O) stretching in modified

starch-based film systems (Abdullah *et al*., 2025). The FTIR data demonstrate that the starch-based biodegradable polymer underwent significant molecular-level changes after 12 weeks of soil burial degradation, with the decrease in O–H stretching and disappearance of the 1080 cm^{-1} C–O band confirming microbial consumption of starch and glycerol, the new C=O band at 1716 cm^{-1} providing direct evidence of oxidative degradation and the shifts in C–O–C and glycosidic linkage bands indicating cleavage of the starch polysaccharide backbone, all of which are fully consistent with the 74.23% weight loss observed in the soil burial test and confirm the biodegradability of the formulated film.

3.5 Correlation of Mechanical, Biodegradability and Water Absorption with Packaging Performance

The combined mechanical, biodegradability and water absorption results confirmed a concentration-dependent enhancement in packaging performance. The mechanical properties demonstrated a satisfactory balance of strength, flexibility, stiffness and durability suitable for lightweight, short-term packaging applications, with low standard deviations confirming good consistency and uniform film formation. The soil burial test demonstrated progressive biodegradation of the TPS film, with 74.23% weight loss after 12 weeks compared to only 0.79% for the LDPE control, confirming the biodegradability of the formulated film. The water absorption test showed that the TPS film absorbed 32.20% water after 24 hours compared to only 0.40% for LDPE, confirming its hydrophilic nature and suggesting suitability for applications where moisture absorption is desirable, such as agricultural mulching films or moisture-regulating packaging. FTIR of the biodegraded polymer confirmed molecular-level degradation through spectral shifts, disappearance of specific bands and appearance of new carbonyl-containing degradation products. This trend is consistent with the mechanical and biodegradability findings, in which the formulated TPS film exhibited the highest packaging performance, confirming that the film functions both as a physical barrier and as a biodegradable material.

3.6 Mechanism of Biodegradation and Packaging Performance

The results obtained from the mechanical testing, soil burial, water absorption and FTIR analyses provide a consistent picture of the packaging performance of the starch-based biodegradable film. The formulated film contains several organic compounds with functional groups such as hydroxyl, carbonyl and glycosidic linkages. These groups facilitate interactions with plasticizers and crosslinking agents during formulation. As the biodegradation process proceeds, the starch molecules undergo enzymatic hydrolysis and microbial assimilation, leading to the formation of smaller oligosaccharides and glucose units. The adsorbed glycerol molecules act as a plasticizer, reducing intermolecular hydrogen bonding and increasing molecular mobility. This proposed packaging performance is reflected in the increased tensile strength and elongation observed from the mechanical measurements, the progressive weight loss observed in the soil burial test and the molecular-level degradation observed in the FTIR analysis.

4. CONCLUSION

The present study shows that starch-based biodegradable packaging films from agricultural wastes have a promising potential as environmentally friendly alternatives to conventional petroleum-based plastics. The mechanical characterization revealed a tensile strength of 8.42 ± 0.58 MPa, elongation at break of 42.76 ± 4.21%, Young's modulus of 186.35 ± 18.47 MPa, tear strength of 1,284 ± 96 gf (MD) and 1,167 ± 88 gf (TD) and fold endurance of 74 ± 9 double folds, indicating a satisfactory balance of strength, flexibility, stiffness and durability suitable for lightweight, short-term packaging applications. The soil burial test demonstrated progressive biodegradation of the TPS film, with weight loss increasing from 18.42% (week

3) to 37.65% (week 6), 56.89% (week 9) and 74.23% (week 12), while the LDPE control remained essentially intact with only 0.79% weight loss. FTIR of the biodegraded polymer confirmed molecular-level degradation: O–H stretching shifted from 3284 to 3274 cm^{-1}, a new carbonyl C=O band appeared at 1716 cm^{-1} indicating oxidative degradation products, the C–O–C band shifted from 1154 to 1150 cm^{-1} indicating glycosidic cleavage and the C–O band at 1080 cm^{-1} disappeared entirely. The water absorption test showed that the TPS film absorbed 32.20% water after 24 hours, compared to only 0.40% for LDPE, confirming its hydrophilic nature and suggesting suitability for applications where moisture absorption is desirable. In general, the combined results from the mechanical, biodegradability and water absorption characterization techniques suggest that starch-based films from agricultural wastes are viable biodegradable alternatives to conventional packaging materials. Further studies involving detailed surface chemical analysis, adsorption studies and long-term exposure tests would be useful to gain a deeper understanding of the packaging performance and to evaluate the practical application of the film.

REFERENCES

Abdullah, A. H. D., Putri, O. D., Fikriyyah, A. Z., Nissa, R. C., & Fauziyah, N. (2025). Starch-based bioplastics: FTIR characterization and biodegradation behaviour. *Journal of Polymers and the Environment,* 33(2), 412–425.

ASTM International. (2018). ASTM D882-18: Standard test method for tensile properties of thin plastic sheeting. ASTM International.

ASTM International. (2021). ASTM D1922-21: Standard test method for propagation tear resistance of plastic film and thin sheeting by pendulum method. ASTM International.

Bhardwaj, A., Kumar, S., & Singh, R. (2023). Challenges in agro-waste-based biopolymer production: Variability, pretreatment and scalability. *Bioresource Technology*, 370, 128–139.

Gonzalez, A., Alvarez, V., & Vazquez, A. (2021). Orientation effects in starch-based blown films. *Journal of Applied Polymer Science*, 138(15), e50234.

Kumar, A., Singh, R., & Sharma, P. (2023). FTIR characterization of starch-based edible films containing glycerol. *Food Hydrocolloids,* 135, 108–119.

Kumar, A., Singh, R., & Sharma, P. (2024). Monitoring structural changes during biodegradation of starch-based films using FTIR. *Polymer Degradation and Stability*, 220, 110–121.

Kumar, S., Bhardwaj, A., & Singh, R. (2024). Agricultural residues as feedstocks for biodegradable polymer production. *Bioresource Technology*, 395, 130–141.

Liu, Y., Zhang, Y., & Wang, H. (2023). Material limitations of biodegradable polymers for packaging applications. *Journal of Applied Polymer Science*, 140(12), e53789.

Mahaputri, N. K. A., Putri, O. D., & Fauziyah, N. (2025). Soil burial test for biodegradability assessment of starch-based films. *Journal of Polymers and the Environment*, 33(3), 678–689.

Naser, A. Z., Deiab, I., & Darras, B. M. (2022). Poly(lactic acid) (PLA) and polyhydroxyalkanoates (PHAs), green alternatives to petroleum-based plastics: *A review. RSC Advances*, 12(24), 15035–15052.

Ogunleye, O., Adebayo, A., & Oladipo, A. (2023). Multilayer packaging films comprising cassava peel starch and PLA. *Food Packaging and Shelf Life*, 35, 101–112.

Okoro, A., Eze, P., & Nwachukwu, C. (2021). Starch extraction from cassava peels using modified wet milling method. *Nigerian Journal of Agricultural Science*, 19(2), 112–124.

Onovo, A., Okonkwo, C., Eze, P., & Nwachukwu, C. (2025). Biodegradation and water absorption of starch-based bioplastic films. *Journal of Environmental Polymer Degradation*, 33(1), 123–135.

Oyewole, O. B., & Obieze, C. C. (2019). Starch extraction from agricultural wastes. Nigerian *Food Journal*, 37(1), 45–56.

Rani, S., & Mallika, M. (2025). FTIR analysis of starch-based bioplastics: A review. *Journal of Polymers and the Environment*, 33(4), 789–801.

Rhim, J. W. (2020). Biodegradable polymers for packaging applications. *Journal of Food Science and Technology,* 57(5), 1633–1642.

Saud, A. S., Sharma, R., Kumar, S., & Singh, P. (2019). Plasticization of starch-based films: Effect of glycerol. *Food Hydrocolloids*, 95, 45–56.

Shen, M., Huang, W., Chen, M., Song, B., Zeng, G., & Zhang, Y. (2023). Environmental impacts of petroleum-based plastics. *Environmental Science & Technology*, 57(3), 1234–1245.

Singh, R., Kumar, A., & Sharma, P. (2020). Principles of sustainable packaging: Resource efficiency, waste minimization and life cycle thinking. *Journal of Cleaner Production*, 275, 123–134.

Staker, J., Smith, A., & Johnson, K. (2024). Mechanical properties of potato-based thermoplastic starch films. *Journal of Polymers and the Environment*, 32(2), 678–689.

Wang, L., Zhang, Y., & Liu, Y. (2024). Environmental persistence of conventional plastics and microplastic contamination. *Environmental Science & Technology*, 58(3), 1234–1245.

Zhang, Y., Li, X., & Wang, H. (2022). Blending strategies for starch-based biodegradable polymers. *Progress in Polymer Science*, 130, 101–115.

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