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# Development of eco-friendly food packaging bio-film from cassava starch plasticized with coconut oil

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**Abstract**

The use of food packaging materials is on the rise because of continued growth of food industries. Food packaging materials' environmental effects are now a major concern for people all over the world, particularly for the public, governments, businesses, and producers. To reduce environmental pollution, encourage the recycling of packaging materials, and achieve sustainability in food packaging, numerous studies have focused on developing novel packaging solutions that utilize renewable resources that are biodegradable, compostable, or eco-friendly. This study explored the development of food packaging film of two different thicknesses from cassava starch, glycerol and coconut oil as a plasticizer and evaluating their suitability for food packaging. Cassava starch from Kenya was characterized and used as the main raw material for making the bio-based films at a rate of 80% with glycerol (10%) and coconut oil (10%) as the processing additives. The transparency and water solubility of the films were significantly different and transparency ranged from 0.646-0.668% while the water solubility was 32.61-39.085% for the 150 µm and 200 µm films, respectively. The moisture content increased with thickness, with the highest (200 µm thick) having 10.16%. There was no significant difference on the Young's modulus, tear strength, tensile strength at rapture and elongation at break, but the thicker films had higher water vapour permeability rate of 5.27× 10-9 g m-1 s-1 Pa-1 as compared to the 150 µm films which had 5.05× 10-9 g m-1 s-1 Pa-1. The film samples were proven to be biodegradable by the average cumulative weight loss of 89.59% for the 150 µm sample and 89.82% for the 200 µm sample, following 120 days of soil burial test. The biofilms obtained had sustainable and promising functional characteristics suitable for packaging of dry solid foods.

**Keywords:** *Biodegradation, Cassava Starch, Characterization, Plasticizer, Sustainability*

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## Introduction

Cassava (*Manihot esculenta Crantz*) is a climate smart, root tuber plant that thrives best in tropics and subtropics (More *et al*., 2023). Subsistence cassava farming is common in Kenya and the tuberous roots are a major source of starch due to the high yields, and this can be tapped into to create agro processing industries for its production (Jumaidin *et al*., 2020). The cassava starch is odourless, tasteless, transparent, impermeable to gases and has natural polymer properties which can be exploited as a major raw material in the packaging industries to replace the fossil fuel-based polymers (Sapper *et al*., 2019). In addition, cassava starch is biocompatible and biodegradable making it eco-friendly and suitable for replacement of

petrochemical-based non-biodegradable plastics (Bhasney *et al.*, 2017). The starch is however sensitive to water and this affects negatively the functional properties of the polymers (Sapper *et al.*, 2019). Copolymerization of the cassava starch by mixing with other processing additives such as plasticizers, increase resistance to harsh weather, low temperatures and enhances chain mobility, and improves the process including the quality (Bhasney *et al.*, 2017).

Various studies have been done to solve the hydrophilic nature of the polymers which has an end effect on the biopolymers mechanical properties (Kocira *et al.*, 2021). The use of plant based processing additives has the prospective of improving the properties of starch made films especially by reducing the water sensitivity of the materials (Sapper *et al.*, 2019). This can be successfully achieved through standardizing the raw materials and use of controlled processing methods (Akhir *et al.*, 2023). Coconut oil which is sourced from coconut plant kernels, has more fatty acids and has the prospective of being used as a natural plasticizer in making biopolymers (Bhasney *et al.*, 2017). Cassava starch is a white to off-white powder and it is used for water binding and texturizing (Mamat *et al.*, 2021). Water is used as the main solvent of natural biopolymer (Prasad & Sharma, 2019). Glycerol has plasticizing properties, but is highly hygroscopic, and it is used to prevent film brittleness (Majeed *et al.*, 2023). There are limited studies on how coconut oil enhances the functional qualities of cassava root tubers are locally available and very good source for starch which can be used for processing of safe, environmentally friendly bio-based packaging. If the innovation is scaled up can transform the lives of farmers by providing a ready market for their produces, development of starch agro-processing industries and creation of employment opportunities.

The present study aimed at developing and testing bio-based films that can preserve the quality of food products, reduce their contamination during storage, and increase their marketability and attractiveness

**Materials and methods**

***Sample selection, characterization, and preparation of local bio-raw material***

Cassava root tubers which were identified as Tajirika variety by the traders were randomly purchased at Marigiti fresh produce market in Nairobi (Kenya) and used as the local raw material for starch extraction to produce bio-based packaging material. The fresh cassava roots were then transported to the department of Food Science, University of Nairobi for immediate laboratory analysis. Samples for wet moisture content determination were randomly selected from the batch and immediately analysed in the Food chemistry laboratory. The rest of the cassava roots were washed to remove soils on the surface before peeling and starch extraction

The cassava root tubers were characterized using the standard AOAC methods and was used for starch extraction using the operative wet process. The standard AOAC test methods used include method 920:151 for Moisture content, method 940:26 for Ash content, test method 2011.25 for crude fibre, test method 2001:11 for crude protein, and test method 996.06 for crude fat determination.

***Extraction of starch from fresh cassava root tubers***

The method described by Kringel *et al.*, 2020, was used for starch extraction from the fresh cassava root tubers but with slight modifications. The cassava root tubers were first peeled, rinsed, and grated into fine particles. Distilled water at 25 °C was used to wash and extract the starch from the ground cassava on a cheese cloth. The residual fibre on the screen was washed four times with distilled water. After discarding the fibre on the cheese cloth, the extracted starch was let to sediment, and then the water was drained off. The sediment was then washed with distilled water and filtered using the cheese cloth to eliminate any left-over fibre. The starch obtained was then dried in an oven at 45 °C for six hours and this continued in a solar tunnel dryer for four hours after which it was milled into powdered starch and stored in airtight containers to avoid contamination and moisture gain. The solar tunnel dryer has both

the drying and collector chambers (each seven metres long) made of stabilized UV visqueen sheets with those in the collector painted with black food grade paint for absorbing heat. It has a power system and fan for generating air current along the tunnel.

***Formulation and preparation of bio-based packaging cassava films***

Preliminary experiments (data not shown) were used to determine the quantities for each component to be used with a range of 75–85% (cassava starch), coconut oil (5–10%) and glycerol (5–15%). The method described by Dos Santos Caetano *et al.,* 2018, with a few modifications was used to formulate and obtain the bio-based cassava starch film.

80% cassava starch, 10% glycerol and 10% coconut oil and 100 mL of distilled water for every four grams of starch, were used as described by Dos Santos Caetano *et al.* (2018).

The ingredients were dispersed in the water by heating to 90 °C under constant stirring for one hour in a water bath. The mixture gelatinized to form a viscous homogeneous film forming solution which was then processed into films by casting into two different plastic petri dishes with internal diameters of 88 mm and 138 mm. Drying was then done under circulated air at 35 ± 2°C for 12 hours, after which they were conditioned for 10 days at 23°C and 75% relative humidity to acclimatise it to the environment until characterisation. The films cast in 88 mm and 138 mm were named as A and B, respectively.

***Moisture content***

This was done according to AOAC 2010 test method 920:151 (AOAC, 2010). A dry clean aluminium dish was weighed ($W_1$), then 5 g of the sample added into the dish ($W_2$), and oven dried at 100 °C for 2 hours. Then removed, transferred into a desiccator to cool, and weighed ($W_3$). Percentage moisture content was calculated using equation [1]

$$\%Moisture = Weight\ of\ water\ in\ sample / Weight\ of\ wet\ sample \times 100$$

$$\%Moisture = (W2 - W3)/(W2 - W1) \times 100$$

[1]

Where;

W1 is initial empty aluminium dish weight

W2 is wet sample + aluminium dish weight

W3 is dried sample+ aluminium dish weight

***Ash content determination***

Ash content was determined according to AOAC (2010) method 940:26. 5 g of grated cassava sample was put in an empty dry crucible and put at 550 °C for 2 hours in a muffle furnace. The sample was then allowed to cool, weighed and the percentage total ash content calculated using equation (2)

$$\%\ Ash, wet\ weight\ basis\ (wwb) = Weight\ of\ Ash(g)/\ Weight\ of\ wet\ sample(g) \times 100 \quad [2]$$

***Crude fibre determination***

Crude fibre was determined according to AOAC, (2010) test method 2011.25. Approximately, 2 g of sample was weighed ($W_1$) into a 600 ml beaker and 25 mL of 2.04N sulfuric acid ($H_2SO_4$) added. The solution was boiled 30 minutes, removed, and filtered via a glass wool fitted in a Buchner funnel and washed thrice using hot boiling water. The residue plus glass wool were then transferred to another 600 mL beaker and added to 25 mL of 1.72N potassium hydroxide, topped to 200 mL using boiling distilled water, and left to boil for 30 minutes. The contents were filtered as above and residue and fibre dried for 2 hours at 130 $^oC$, cooled in a desiccator and weighed ($W_2$). The content was later ignited at 600 $^oC$ to constant weight, cooled and weight taken ($W_3$).

Percentage crude fibre content was calculated using the equation (3):

$$\%Crude\ fibre = (W2 - W3)/W1 \times 100$$

[3]

W1 is initial sample weight

W2 is weight of crucible + sample

W3 is final weight + dry sample

***Determination of crude protein***

Crude protein was determined according to AOAC (2010) test method 2001:11. About 0.2 g of sample was weighed into digestion tube, after which 20 mL of concentrated $H_2SO_4$ acid was added then thoroughly mixed, and after that, 5 g of Kjeldahl catalyst added. The sample was digested by heating in a fume chamber to obtain a clear digested solution which was then distilled in a Kjedhal distiller unit, and back titration was carried out using 1N NaOH to a pink

colour as the end point. The difference in titre values was multiplied by a protein conversion factor of 6.25 to obtain the protein content (%) on a fresh weight basis. The readings were taken in duplicates.

$$\%N = \frac{(0.014MeN/100)\times titre \times digest\ volume(100mL) \times Normality of\ acid(0.025N)}{\text{Weight of sample (0.2g)}\times \text{Volume of aliquot used(10mL)}} x100$$

Therefore,

$$Crude\ protein = \%N \times 6.25 \quad [4]$$

***Crude fat determination***

Determination of Crude fat content was done using the solvent extraction method based on AOAC (2010) method 996.06. About 2 g of dried sample was weighed in an extraction thimble, fitted in a reflux flask with 250 ml petroleum ether. Extraction was done for 6 hours in a Soxhlet extraction apparatus connected to an electro thermal heating mantle and condenser. The extract was dried in an air oven at 105°C for 1 hour.

The fat content was calculated as a percentage of the initial sample weight and recorded in duplicates.

Calculation of % Crude fat:

$$\%\,(fat + Moisture) = (W1) - W2/W3 - W4 \times 100$$
$$\%\,Fat\ (wt./wt.) = (\%\,Fat + \%\,Moisture) - (\%\,Moisture) \quad [5]$$

Where:

$W_1$ is Initial weight of sample + Glass wool + Thimble;
$W_2$ is Final weight of sample +Thimble + Glass wool;
$W_3$ is Weight of wet sample + Thimble;
$W_4$ is Weight of Thimble

***Starch extraction and yield***

The method described by Kringel *et al*. (2020) was used for the extraction of starch from fresh cassava root tubers. Cassava root tubers were peeled, rinsed, and milled into fine particles. Distilled water at a temperature of 25 °C was used to extract starch from the grounded cassava on a cheese cloth. The residual fibre on the screen was washed 3-4 times with distilled water. After discarding the fibre on the cheese cloth, the extracted starch was let to sediment and the sediment put on the cheese cloth and washed with distilled water to eliminate any leftover fibre. The starch was then dried in an oven at 45 °C for six hours and then continued in a solar tunnel dryer for 4 hours and milled. The powdered starch was stored in an airtight container to avoid contamination and moisture gain.

The percentage starch yield from the extraction was calculated using the following formula

$$Extraction\ yield\ \% = starch\ weight/ Cassava\ weight x100 \quad [6]$$

***Total starch content***

The total starch content was done using a kit assay based on the AOAC method 996.1 (2000), by quantifying glucose using glucose oxidase and enzymatically hydrolyzing starch using amylase or amyloglucosidase.

***Protocols for testing the bio-based films***

*Determination of film thickness*

A manual micrometer (YATO YT7205) was used to measure the thickness of the film with an accuracy of 0.01 mm with an average of ten random measurements used to calculate the mean thickness of each film as per Pelissari *et al*. (2012).

***Determination of moisture content***

Film samples were dried at 105°C until a constant weight was achieved, and their moisture content gravimetrically calculated as described by Pérez-Vergara *et al*., 2020.

***Transparency analysis***

Transparency of the films was determined as described by Bhasney *et al*., 2017. Films (2 × 4 cm) from both samples (A and B) were evaluated by measuring the light transmittance at 600 nm (Hitachi 2900 UV/VIS spectrophotometer, Tokyo, Japan). Transparency values (T) of the films were calculated using equation [7]

$T = (-logT600)/X$ [7]

Where; X is the film thickness (mm)

T600 is the fractional transmittance at 600 nm.

***Water solubility evaluation***

Water solubility of the plastic films was determined according to the method described by Pérez-Vergara *et al*. (2020). Film samples (2 × 2 cm) were prepared, weighed, dipped in 50 mL of distilled water for 24 h with stirring after every 8 hours, and then dried at 60°C to a constant weight.

Water solubility (WS) was calculated using equation [8]:

$WS = (initial\ dry\ weight - final\ dry\ weight)/(\text{initial dry weight}) \times 100)$ [8]

***Biodegradability tests***

The biodegradation of the films was done as described by Nissa *et al.,* (2019), using the soil burial test. Film samples (1 × 1 cm) without any defects were buried 7.5 cm deep in compost soil. They were then stored at temperatures of 25 ± 2 °C and relative humidity (RH) of 40-46% in an open environment. Sampling and weight measurement were conducted every 10 days for 120 days by gently wiping the sample using dry tissue paper to remove any soil traces and then weighing. Using equation [9], the weight loss of the films was calculated.

$\%Weight\ loss = (W0 - Wf)/W0\ x100$ [9]

Where: *W*O is the initial sample weight; and

*W*f is the final sample weight.

***Calculation of water vapour transmission rate***

This was determined according to ASTM E96/E96M - 22a, 2022 method. Film samples were analysed using the Desiccant method by sealing them onto open mouth of aluminium cup of 14 centimetres in diameter, and then placed in a controlled environment.

The films were first conditioned at 23 ± 2 °C and 50 ± 2% RH for 24 h, used to hermetically cover the aluminium cups containing 5 g of small pellets of anhydrous calcium chloride and then placed in an environmental climate test chamber (Model VCL 003, *Vötschtechnic, Balingen, Germany)* set at a temperature of 23°C and 50% Relative Humidity. Weight measurements were taken after every 2 days until six steady state data points were gotten, with shaking done to mix the desiccant before each weighing.

The time versus weight change data was plotted (Figure 4), and the rate of WVT for the corresponding test determined from the slope (G/t).

Water vapor transmission rate (WVTR) was calculated using the formula:

$WVTR = (G/t)/A$

Where G represents the weight difference between two weight measurements in gram (g), t is the time between two weight measurements (day), and

A is the tested area ($m^2$) of the film sheet (A =cup mouth area in $m^2$).

***Determination of the mechanical properties***

Mechanical properties of the films were determined in triplicate as per ASTM standard method D882 (ASTM E 96 (1995), 1995) and Kenya Standard-KS ISO 3377-1, at the Kenya Bureau of Standards. Four replicates of each film were tested for Elastic modulus (E), tensile strength (σ), elongation at break (ε) and tear strength using tensile testing machine (Model Tinius Olsen H10KT – 0463, Redhill, England). The load cell used was 5 kN. The bio-plastic samples were conditioned as per the laboratory testing procedures, prepared, and cut by a standard die cutter according to the International Organization of Standards (ISO 527-2:2012).

***Sealing experiment***

Film samples were sealed using a Thimonier S.A. sealer (DIBX Annee1985, Thimonier S.A., Lyon, France) at 85°C for 30 s.

***Data analysis***

The statistical analysis of the Data was done using R software (Version 4.3.0) for ANOVA (weight loss and Pearson correlation. Separation of means/posthoc analysis was performed using HSD Tukey test at $p \leq 0.05$.

**Results**

***Raw materials analysis***

Table 1 show the proximate composition of the cassava root tuber used for the starch extraction in wet weight basis. The moisture content had a mean value of 67.86% and starch extraction yield of 25.60%. The results for crude protein, fat, fibre, and total ash content were, 1.04, 0.35, 1.08, and 0.8% respectively.

Table 2 shows the properties of the starch which was extracted and used as the main raw material for making the biofilm. The pH, starch content%, moisture%, crude fibre% and Ash% were 5.49, 60.24, 13.12, 0.18 and 0.62%, respectively.

**Table 1**

***Cassava root tuber characterization***

| Test | Content (%) | Test method |
|---|---|---|
| Moisture | 67.86±0.368 | AOAC 2010 (920:151) |
| Starch | 25.60±0.424 | AOAC 2010 (996.1) |
| Crude Protein | 1.04±0.042 | AOAC 2010 (2001:11) |
| Crude Fat | 0.35±.070 | AOAC 2010 (996.06) |
| Crude Fibre | 1.08±0.099 | AOAC 2010 (2011.25) |
| Ash | 0.8±.0849 | AOAC 2010 (940:26) |

*Values are expressed as mean±SD; Values were determined on a wet weight basis.*

**Table 2**

*Cassava Starch characterization*

| Test | Results | Test Method |
|---|---|---|
| pH | 5.49±0.127 | AOAC 2010 (981.21) |
| Starch content, % | 60.24±0.198 | AOAC 2010 (996.1) |
| Moisture, % | 13.12±0.057 | AOAC 2010 (920:151) |
| Crude Fibre, % | 0.18±0.070 | AOAC 2010 (2011.25) |
| Ash, % | 0.62±0.042 | AOAC 2010 (940:26) |

*Values are expressed as mean±SD; Values were determined on a wet weight basis.*

***Characterization of the films***

The developed biofilms gave the following results after characterizing their functional properties important for food packaging materials:

***Film thickness and moisture content***

There were significant differences ($p<0.05$) in the thickness and moisture content of the films. In Petri dishes of 88 mm (sample A) and 138 mm (sample B) diameter, the film samples had average thicknesses of 150 µm and 200 µm, whereas the moisture content was 9.964 and 10.160% respectively (Table 3). The moisture content, ranged from an average of 9.96% for the 150 µm thick film to 10.16% for the 200 µm thick film.

**Table 3**

Moisture content and film thickness

| Sample type | Sample A(150 µm) | Sample B (200 µm) |
|---|---|---|
| Size (mm) | 0.151±0.003[b] | 0.200±0.003[a] |
| Moisture Content | 9.964±0.004[b] | 10.160±0.006[a] |

*Values (means± standard errors) with different superscripts across the row are statistically different (Tukey's test, P < 0.05).*

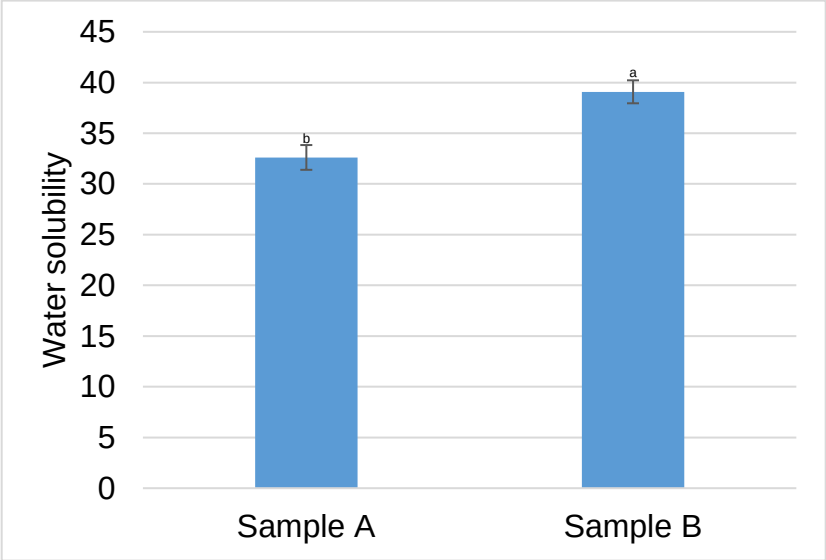
***Transparency and water solubility***

The transparency of the film samples was significantly ($p<0.05$) different with Samples A and B having values of 0.646 and 0.668 respectively. Transparency increased with the film thickness. Sample A had lower light transmittance than sample B and that indicated it had greater opacity.

Water solubility as shown in Figure 1, was higher in sample B (39.09%) as compared to sample A (32.61%).

**Figure 1**

Water solubility (%) of the cassava-based films




***Mechanical properties***

In terms of the mechanical proprieties (Table 4), there was no significant ($p>0.05$) difference between samples A and B, for the tensile strength which was 18.19 and 17.85 MPa respectively. There was no significant ($p>0.05$) difference between the biofilms A and B on elongation at break, tear strength, tensile strength, and Young's modulus (Table 4). The elongation at break was 3.015% and 2.99% for sample A and B respectively.

**Table 4**

Mechanical properties of Biofilm

| Sample | Sample A (0.15mm) | Sample B (0.20mm) | p-Value |
|---|---|---|---|
| Elongation at Break% | 3.015±0.04[a] | 2.99±0.01[a] | 0.861 |
| Tear strength (kN/m) | 0.57±0.01[a] | 0.57±0.01[a] | 0.961 |
| Tensile strength (MPa) | 18.19±0.41[a] | 17.85±1.63[b] | 0.916 |
| Young's modulus(MPa) | 325.525±3.95[a] | 319.335±1.71[a] | 0.974 |

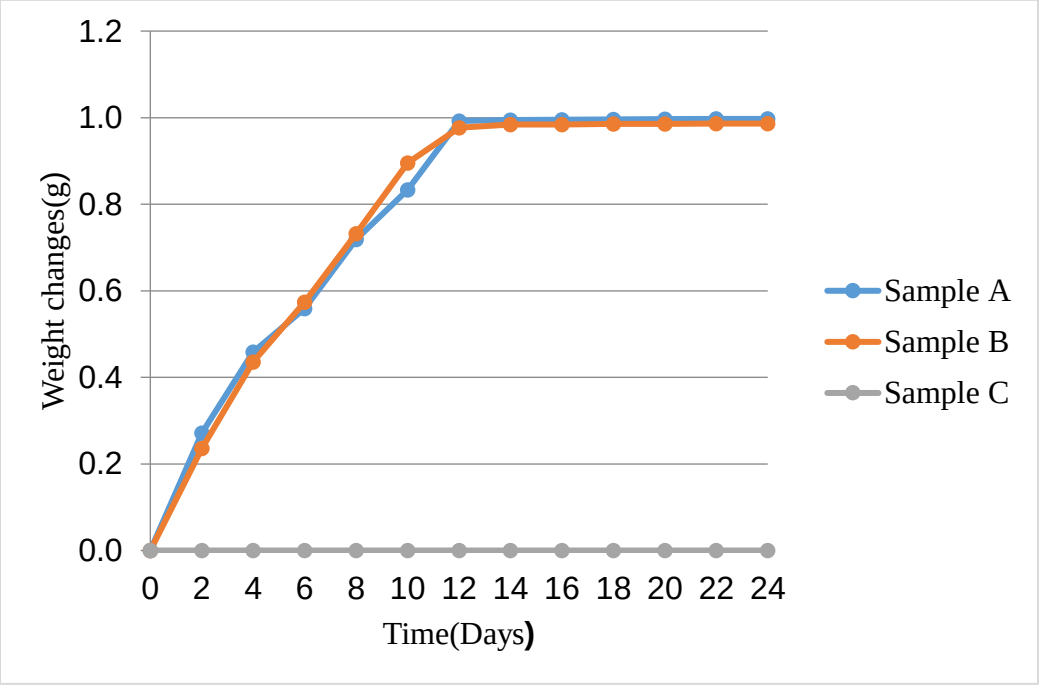
*Values (means± standard errors) with different superscripts across the row are statistically different (Tukey's test, P < 0.05).*

***Water vapour permeability***

The water vapour permeability of the 150 µm (A), 200 µm (B) samples and control sample C (Aluminium foil), under controlled conditions (53±3% RH and 25±2°C) was analyzed as shown in figure 2. The water vapour permeability correlation value (Figure 3) for sample B ($R^2$ = 0.9848) was higher than for sample A ($R^2$ = 0.9801). Sample B films had higher permeability values compared to sample A (150µm) films. The water vapour transmission rate for sample A was $5.05\times 10^{-9}$ g $m^{-1}$ $s^{-1}$ $Pa^{-1}$ and for the thicker sample (B) was $5.27\times 10^{-9}$ g $m^{-1}$ $s^{-1}$ $Pa^{-1}$

**Figure 2**

Water vapor transmission




***Biodegradation test***

The cumulative weight loss of the films was used to determine the materials biodegradation characteristics as a result of moisture and microbial action during the soil burial period.

The soil burial test carried out for sample A (0.15 mm) and B (0.20 mm), the findings are as shown in figure 4, where the curves rose exponentially for the first 90 days for both films.

The average cumulative weight loss for sample A was 89.59% and for sample B was 89.82% after

120 days. The colour started to turn brown after 10 days, the films became brittle after 50 days and developed cracks and started to fragment after 80 days of the soil burial test.

**Figure 3**

Graphic analysis of water vapour Transmission

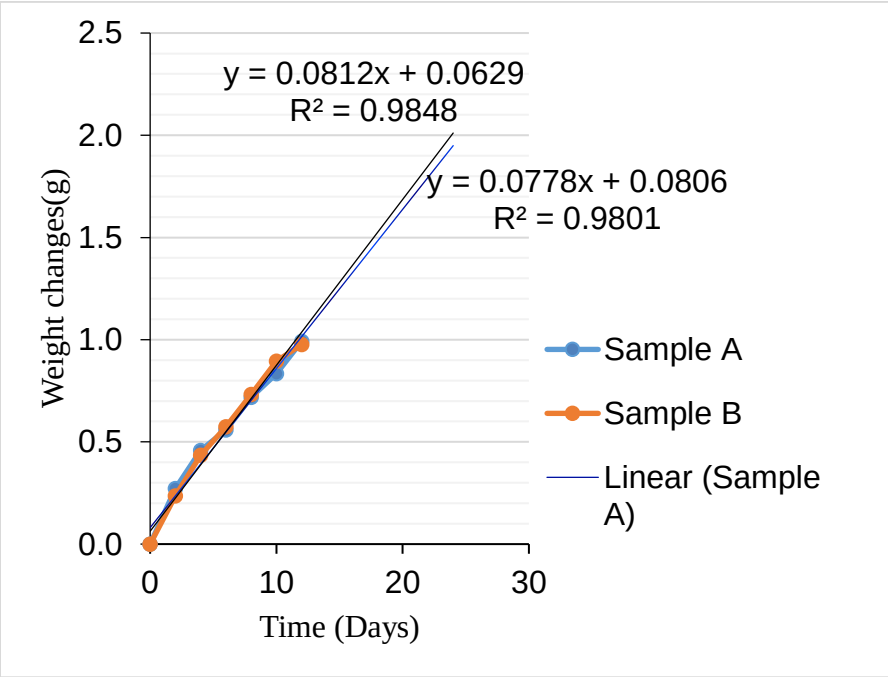
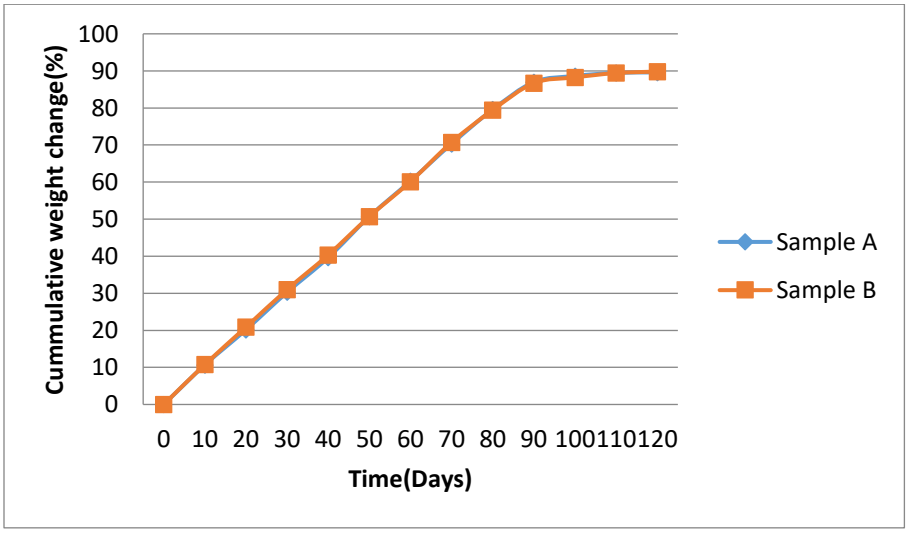



**Figure 4**

Soil Burial Test weight changes



**Discussion**

The cassava roots after analysis gave promising results on the starch extraction yield of 25.60% which is ideal for value addition. The results from characterization were within the ranges reported by Mugalavai *et al*. (2018) for starch (27-36%), crude protein (0.5-2%), Fat (0.5-1%), crude fibre (1%) and total ash (0.5-1.5%). The extraction yield which is the amount that was physically recovered from cassava root tuber was higher than that from Tawau and Semporna in Malaysia (21.71-22.58%) but the total starch was within the range of 51.77- 61.21% reported by Mamat *et al.,* 2021. The starch yield is affected by the source of the cassava root tubers and the method used for extraction therefore the difference could have been as a result of the extraction method and the geographical location of the source (Mamat *et al.,* 2021).

The film thickness is a key characteristic which determines properties like gas and water vapour permeability (Rodrigues *et al*., 2021). The moisture content results were comparable to the ones reported in films made from wheat starch, 9.6% and corn starch 9–16.5%, using different additives, (Domene-López *et al*., 2019) but different from moisture content for native yam starch (52%) and native cassava starch (34%) which were higher (Pérez-Vergara *et al*., 2020; Gutiérrez *et al*., 2014). The type of starch and quantities of glycerol used are key determinants of the moisture content, because glycerol has hydrophilic properties and when used as a plasticizer in the starch, it helps in retaining the water (Pająk *et al*., 2019). Also, the glycerol interferes with the starch macromolecules through intra and intermolecular interactions causing the film material to be hygroscopic (Pérez-Vergara *et al*., 2020). Notably, the moisture content values for the films were lower than the 17.22% reported by Żołek-Tryznowska and Kałuża, 2021 for tapioca starch films.
Transparency of the films allows effective printing, decipherable reading, and good visual appearance because these factors allow contrast of inscriptions which are important factors for food packaging materials (Żołek-Tryznowska & Kałuża, 2021). The high opacity results is an important quality factor in packaging materials because lower opacity lowers consumer acceptance despite the product quality (Guzman-Puyol *et al*., 2022).

The variation of the water solubility could be attributed to the thickness of the film whereby increase in thickness resulted in increased water solubility (Jumaidin *et al*., 2020). Related results for water solubility (24%, 32% and 23.2-33.7%) were reported for cassava, yam, and sweet potato starch films respectively (Pérez-Vergara *et al.,* 2020). Packaging materials should be water insoluble and therefore the use of the developed biodegradable films depends on their water solubility property in order to maintain the food quality through water resistance (Ballesteros-Mártinez *et al.,* 2020).

The films mechanical properties, mainly elongation at break (%), tear strength (kN/m), tensile strength at rapture (MPa), Young's modulus (MPa) were analyzed, as they are the properties which explain the perfunctory resistance of the packaging materials (Rabelo *et al*., 2021). Tensile strength was within the range for films made from mango kernel starch (10-33 MPa), but lower than those from yam starches (22-36 MPa) (Rabelo *et al*., 2021; Rodrigues *et al*., 2021). The tensile strength shows the highest tension that the film material can be subjected to before rapture while the young modulus indicates the stiffness of the film. The elongation at break results agreed with the findings of edible films based on pumpkin, lentil and quinoa starches which ranged from 3.35 to 4.44% (Pająk *et al*., 2019). The elongation at break gives the maximum stretch the film can be subjected to and the low values obtained were an indication that the film material was brittle (Rabelo *et al*., 2021). To improve the film to serve as a potential packaging material, the ratio of plasticizers used should be increased to ease the intermolecular forces of the starch polymer chains and make the matrix softer as per previous studies (Bhasney *et al*., 2017; Gutiérrez *et al*., 2014)

The different water vapour permeability correlation values demonstrate the film thickness had an effect on the water vapour permeability. For the control sample C (aluminium foil), there was no weight change, because the material has excellent barrier properties (Lamberti & Escher, 2007). The water vapour permeability is an

essential parameter considered for food packaging materials because moisture gain causes deterioration of food quality, due to microbial growth, chemical and enzymatic reactions (Bhasney *et al*., 2017). The present study showed that the films were hygroscopic and could absorb water to become delicate when exposed to high relative humidity. This can be attributed to glycerol which is a highly hygroscopic molecule and therefore contributes to high water vapour transmission rate (Liu *et al*., 2023). The use of coconut oil improved the quality of the films, because it is known to have hydrophobic properties which hinders water molecules diffusion into the cassava starch film matrix, and further reduces the amorphous regions that correspondingly decreases the water molecules diffusion *(Bhasney et al*., 2017; Ulloa *et al*., 2012).

The water vapour transmission rate defines the amount of water vapour that passes through film material over a given period and serves as moisture barrier indicator in food packaging materials. The water vapour transmission results were in agreement with the findings reported by Gutiérrez *et al*., 2014 ($5.8 \pm 0.2 \times 10^{-9}$ g $m^{-1}$ $s^{-1}$ $Pa^{-1}$) for corn starch films plasticized with coconut oil. Apart from the packaging material composition, water vapour transmission rate is also affected by relative humidity and temperature (Liu *et al*., 2023).

The loss in weight during the soil burial test was because of continued microbial activity and moisture loss during the soil burial period. The hygroscopic nature of the films encourages microbial activity which causes biodegradation and loss in weight (Jumaidin et al., 2020). Both samples showed similar trend of weight loss during the study period and this could have been due to similar exposure conditions (Tai *et al*., 2019). The colour change, brittleness cracks and fragments that developed on the films during the soil burial test, demonstrated their biodegradability under the test conditions (Nissa *et al*., 2019). The cassava starch contributed to the degradation after the treatment, because starch matrix has hydrophilic character that leads to higher rate of water absorption, starch hydrolysis rate and therefore aids the film biodegradation process (Akhir *et al*., 2023). The chemical structure of the films and the rich environmental microbial flora catalyses the biodegradation process (Nissa *et al*., 2019). The materials undergo biodegradation, resulting in decreased biofilms residual weight and increased of weight loss to form water, carbon dioxide, and compost (Tai *et al*., 2019).

**Conclusion and recommendation**

This study showed that the film thickness was influenced by the quantity of the film forming solution used and the composition which also influenced the formation and properties of the films. The raw materials used (cassava starch, glycerol, and coconut oil) are locally available, safe and therefore a potential area of investment to create agro processing industries. The films had outstanding properties making them suitable for utilization in packaging dry solid foods. The films obtained had good strength, good barrier properties, and were naturally degradable, making them environmentally friendly. The films also had good sealing properties that can be used for hermetic sealing and therefore can be used to preserve dry food products from microbial contamination. The biofilms were made from natural non-toxic ingredients and have the potential of providing the initial, main protective barrier, to act as the smallest distribution unit in food packaging.

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