

Development and characterization of biodegradable packaging films from avocado seed starch by incorporating aloe vera gel

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Research Article

Keywords: Avocado seed starch, Aloevera gel, Mechanical property, Antimicrobial activity, Biodegradability

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Abstract

To maintain quality and increase shelf life of food, packaging material is an essential and the rising demand. This research evaluated different ratio of Aloe Vera gel and avocado seed starch at constant glycerol as potential biodegradable packaging film. The packaging film was developed by formulation of 2%, 4% and 6% avocado seed starch and 0.5%, 1% and 1.5% aloe Vera gel at constant glycerol concentration of 1%. Physical and functional properties, morphology of the starch and FTIR analysis as well as film functional properties mechanical properties, FTIR analysis, biodegradability and antimicrobial activity of the developed packaging film were investigated. Water vapor transmission rate and permeability reduced with addition of aloe vera gel. Tensile strength of the developed packaging film increased significantly from 2.7 ± 0.15 (Mpa) to 10 ± 0.25 (Mpa) with increasing starch content and it is nonlinear with the addition of aloe vera gel. Biodegradability of the film increase with addition of aloe vera gel, the highest value 81.5% at 4% starch and 1.5% aloe vera gel. Antimicrobial testing revealed zone of inhibition values of 12-18mm against E.coli and 14-20mm against S.aureus. The 6% starch content and 1.5% aloe vera gel containing film matched with the control against E.coli (18mm) and 4% starch with 1-1.5% aloe vera gel film matched with the control against S.aureus (20mm) indicating effective antimicrobial activity.

Key words: Avocado seed starch, Aloevera gel, Mechanical property, Antimicrobial activity, Biodegradability

1. Introduction

In food processing industry Packaging material are used to protect food against contamination, dust, environmental conditions, and safe transportation[1]. There are different materials that are utilized to make food packaging, such as glass, paper, biodegradable polymer, synthetic polymer, and others[2]. Non-biodegradable plastics, particularly synthetic polymers, remain the predominant choice for packaging despite their adverse impacts on ecological systems and public health [3]. These materials are extensively utilized within the food packaging industry owing to their distinctive functional properties, safety profile, and ability to prolong product shelf life [4].

Biodegradable packaging materials are eco-friendly, inexpensive, and derived from renewable resources. Researchers are widely studying the biological sources for biodegradable films and coatings [5]. Petroleum-based plastics are generating many environmental problems, thus biodegradable polymers with different qualities are currently being produced and employed. The global food packaging sector is attracting more attention for its substantial waste production and environmental pollution[6].

Using agricultural processed waste to make eco-friendly packaging materials became a feasible option. Avocado seeds, a byproduct of the avocado fruit processing industry, are often discarded as waste. However, these seeds include necessary ingredients that may be utilized to make environmentally friendly packaging materials[1]. The demand for innovative packaging materials with little environmental effect is being driven by consumers' growing desire for ethically and ecologically produced goods [7].

Avocado seeds have a variety of bioactive substances such as lipids, proteins, fibers, and phenolic compounds, which have antioxidant and antibacterial properties. The demand for continuous and environmental friendly food packaging materials is growing due to environmental concerns and laws, which has prompted research into alternative sources such avocado seed starch [8].

Aloevera is widely recognized for its exceptional therapeutic qualities. Recently, Spanish researchers created an aloevera based gel increase the shelf life of fruits [9].

Aloevera gel is a tasteless, colorless, odorless, nontoxic, and eco-friendly substitute for artificial preservatives like sulfur dioxide. [10]discovered that treating tomatoes with 10% and 15% aloevera decreased the production of ethylene while preserving tomato quality.

Continuous and excessive use of non-biodegradable plastic packaging materials has become a serious environmental problem. However, a large number of by-products are produced during industrial avocado processing, namely peel and seed, which make about 18% to 23% of the fruit's dry weight [11]. Avocado seed starch is a byproduct of the avocado fruit processing, which is often thrown out as trash and the environment has affected as a result of these byproducts. Research has indicates the availability, affordability, and biocompatibility of avocado seed starch make it a promising material for biodegradable packaging film[12].

Since these byproducts are sources of significant phytochemical substances, it is beneficial to use them to lessen their environmental effect and add value. Thus, aloevera and avocado seed starch, two natural ingredients, will be utilized to create biodegradable food packaging materials [11]. Utilization of Avocado by product to develop biodegradable food package contributes to recycle of waste from avocado processing industry. Additionally the use of avocado seed starch to develop biodegradable packaging films provides a long-term solution to the increase issue of plastic pollution.

2. Materials and Methods

2.1. Raw materials collection, transportation and preparation

Avocado seed was taken from avocado oil processing industry for starch extraction and avocado fruit to be packed was collected from Awash melkassa research center and Aloevera was collected from Wendo Genet Agricultural research center. The raw material was taken to AASTU where the starch extraction and aloevera gel preparation were carried out. The avocado seed sample was washed with tap water, and rinsed with distilled water. Matured leaves of Aloevera plant was washed with water and rinsed with mild (25%) chlorine solution. The experimental was conducted at AASTU. Two kilograms of cleaned avocado seeds were chopped and milled to powder. The wet-milled avocado seed was soaked in four liters water and left for two hours. Next, it was filtered by 75, 54, and 45 micrometer sieves and placed for four hours for settling purposes.

After starch sediment formed and separated from the slurry the clear supernatant liquid were carefully transferred to a clean beaker. The starch sediment was washed repeatedly by distilled water till the clear suspension was observed. Starch sediment were dried in an oven at 60°C and finally it was milled and sieved to get homogenous sized starch [13].

Aloe vera gel was extracted according to [14] method. Matured leaves of aloe vera plant were washed with water and rinsed with a mild (25%) chlorine solution to disinfect the outer surface of the aloe vera leaves. After separating aloe vera gel from the outer cortex, the colorless gel-like substance, which is hydro parenchyma, was blended with a juice maker. Unwanted fibers were removed from the mixture by filtering and it was pasteurized at a temperature of 70°C for 45 minutes and cool to ambient temperature. Then citric acid was added to this gel to maintain the pH.

2.2. Experimental design factors and levels

Two variables avocado seed starch and aloe vera gel with three levels were used in the complete factorial design experiment. A completely randomized experimental design (CRD) was used to study the effects of avocado seed starch and aloe vera gel proportion on the performance of the films. The design was used to analyze the effect of aloe vera gel and avocado seed starch on mechanical, biodegradability and antimicrobial activity of the developed packing film.

Table 3.1: Experimental design

Factors		
Run	Ass (%)	Av (%)
1	2	0.5
2	2	1.0
3	2	1.5
4	4	0.5
5	4	1.0
6	4	1.5
7	6	0.5
8	6	1.0
9	6	1.5

2.3. Preparation of packaging film

A starch-based biodegradable packaging film was developed using a casting method according to [15] method. A sample of 2, 4 and 6% of avocado seed starch and 0.5, 1 and 0.5% of Aloe vera gel were mixed with 50 ml of distilled water, then adding 25% glycerol by starch weight under constant stirring for 5 minutes at room temperature. Then, the suspension solutions were heated to 80°C using hot plate for 15 minute and constantly stirred by magnetic stirrer in order to obtain a uniform bubble-free solution. The solution formed was poured into petri-dish and dehydrated in an oven at 50°C for 12 hours in order to obtain transparent and flexible films.

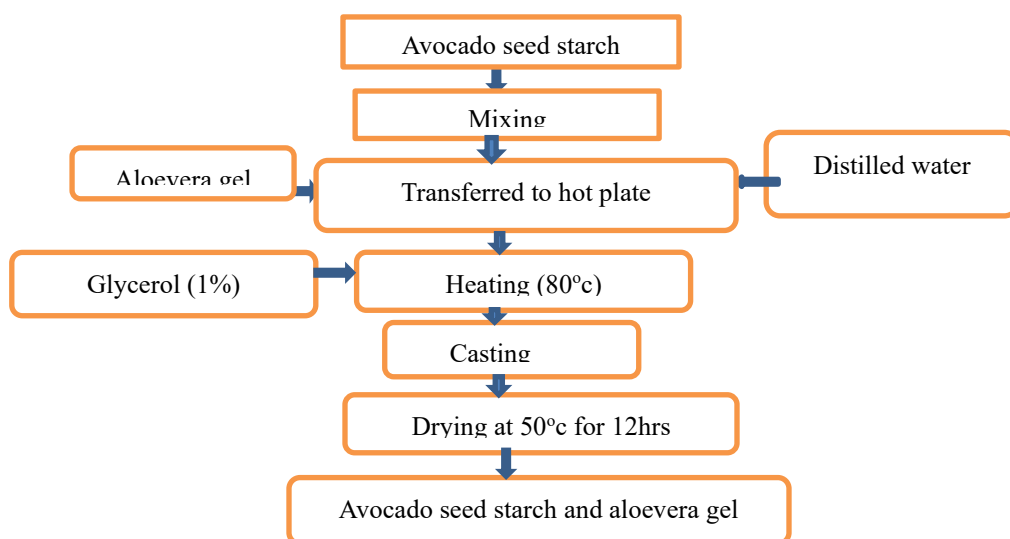


Figure 3.1. Packaging film making process from Avocado seed starch and aloe vera gel.

2.4. Characterization of Physical and functional properties of starch

2.4.1. Moisture content

Moisture content of the sample was determined by the method described by [16] method. It is achieved through mass differential analysis following a three-hour thermal dehydration process at 105°C, quantified by the formula

$$\text{Moisture content (wb\%)} = \frac{W_2 - W_3}{W_2 - W_1} * 100 \quad \text{Eq.....1}$$

Where W1 is the empty crucible mass W2 the initial mass with sample and W3 the final mass after drying.

2.4.2. Ash content

The ash content of a starch sample was determined using a high-temperature incineration method [16]. The procedure involved precise measurements and controlled heating cycles, followed by gravimetric analysis to determine the inorganic residue percentage.

A clean crucible was dried, weighted and 3 g starch sample was added to it. The sample was heated in a muffle furnace at 550°C for 5 hours to completely combust all organic matter. Post-incineration, the crucible was allowed to cool in the furnace below 250°C, and then transferred to a desiccator for a final 1 hour cooling period. The final weight of the crucible with ash was recorded

$$\text{Ash \%} = \frac{W_{ca} - W_{bc}}{W_s} \times 100 \quad \text{Eq. 1}$$

Where: Wbc = Weight of the blank crucible, Ws=Weight of the sample and Wca=Weight of the crucible with ash.

2.4.3. Water absorption capacity

The method for determining the water absorption capacity (WAC) of a sample, adapted from [17], involves a series of preparation and measurement steps. Initially, a precise quantity of sample (one gram) is introduced into a beaker containing exactly 10 ml of distilled water. This resulting suspension is subjected to continuous agitation using a magnetic stirrer for duration of five minutes to ensure thorough mixing.

Following the stirring phase, the mixture undergoes a separation process via centrifugation at a speed of 3600 rpm (revolutions per minute) for a period of 15 minutes

$$\left(WAC (\%) = \frac{w_1 - w_2}{w_s} \right) * 100 \quad \text{Eq. 2}$$

Where, W₁ = weight of residue in tube after centrifuge, W₂ = weight of empty tube before centrifuge, W_s = weight of sample.

2.4.4. Water solubility determination

The water solubility of starch can be determined by following a specific procedure involving heating a sample in water, centrifuging the mixture, and measuring the weight of the dried supernatant.

One gram (1 g) of a starch sample is combined with 10 mL of distilled water and subsequently heated for 30 minutes at 60°C without agitation, as outlined by [18].

The treated mixture undergoes centrifugation at a rate of 1600 rpm for duration of 10 minutes. The resulting supernatant liquid is carefully isolated from the solid residue. The isolated supernatant is dried completely. The final

water solubility percentage is derived using the weight of the resulting dry supernatant relative to the initial weight of the starch sample via the following equation:

$$\text{Water solubility (\%)} = \frac{\text{Weight of dry supernatant}}{\text{weight of starch sample}} * 100 \quad \text{Eq..... 3}$$

2.4.5. Determination of swelling power

One gram of the sample was poured into a pre-weighed graduated centrifuge tube. Then, 10 mL of distilled water was added to the weighed sample in the centrifuge tube, and the solution was stirred and placed in a water bath heated at 75°C for an hour. While shaking the sample gently to ensure that the starch granules remain in suspension, it was gelatinized. The samples were cooled to room temperature and centrifuged at 3000 rpm for 15 min. After centrifugation, the supernatant was decanted from the sediment into a pre-weighed petri dish; the supernatant in the petri dish was weighed and dried at 105 °C for an hour. The sediment was weighed and recorded [19].

$$\text{Swelling power } \left(\frac{\text{g}}{\text{g}}\right) = \frac{\text{Weight of swollen sediment}}{\text{Weight of dry starch}} \quad \text{Eq..... 4}$$

2.5. Physicochemical properties of the developed packaging film

2.5.1. Water solubility

The water solubility of the packaging film was determined following the methodology described by [5]. The process involved several distinct steps to measure the mass reduction after exposure to water. The sample of (2cm) times (2cm) was initially dried at 105C for 24 hours to establish the constant initial mass.

The dried sample was submerged in 10 mL of distilled water within a 25 mL centrifuge tube. The mixture was slowly agitated for 24 hours at a constant temperature of 25°C. Following agitation, undissolved residue was isolated via filtration. This remaining residue was subsequently dried for another 24 hours at 105°C to determine its final mass. The percentage of water solubility for the film was calculated using the following equation:

$$\text{Water solubility film \%} = \frac{\text{the initial mass} - \text{final mass of the sample}}{\text{the initial mass}} * 100 \quad \text{Equation.... 5}$$

2.5.2. Water absorption capacity

A standardized procedure, adapted from methodologies published by [20] and [21], was utilized to quantify the water absorption of the biodegradable film.

The protocol involved several key stages. Initially, a precisely dimensioned film specimen 2cm times 2 cm was prepared and its initial dry mass was precisely documented. This sample was subsequently submerged in a container

of distilled water for a period of 24 hours. Its final, saturated wet mass was then measured to ascertain the extent of water uptake.

$$\% \text{ of water absorption} = \frac{\text{Wet weight} - \text{Dry weight}}{\text{Wet weight}} * 100 \quad \text{Eq..... 6}$$

2.5.3. Water vapor transmission rate and Water vapor permeability

WVTR was determined using a modified desiccant method, based on established procedures from relevant literature [22]. This technique measures the amount of moisture that passes through a film over a specified period under controlled conditions. A circular section of the packaging film was prepared, sized to cover the opening of a standard petri dish. The film was placed over the opening of the petri dish and sealed securely to prevent any vapor leakage other than through the film itself. The total mass of the sealed petri dish assembly was recorded at the start of the experiment. The weighed samples were placed inside a desiccator, which contained a 70% concentration NaCl solution used to maintain a stable, high-humidity environment.

The samples were removed and weighed at predetermined time intervals: 0, 8, 24, 32, 48, and 72 hours. The recorded weights were used to generate a linear regression graph of weight change versus time. The slope of this line represented the rate of mass increase (g/h).

$$\text{WVTR} = \frac{\Delta m}{A \Delta t} \quad \text{Eq..... 7}$$

$$\text{WVP} = \frac{(\text{WVTR} * X)}{\Delta P} \quad \text{Eq..... 8}$$

Where, ΔP = the difference in water vapor pressure on both sides of the film, X =film thickness; Δm = the weight increment of the test cup; A = area of film Δt = the duration for permeation.

2.6. Mechanical properties of developed packaging film

2.6.1. Tensile strength and percentage of elongation at break

Mechanical parameters, notably tensile strength and elongation at break, were measured using a Testometric Machine using the approach described by [23]. Each sample, measuring 10 mm in width and 50 mm in length, was stretched until it failed. The film's tensile strength was measured in megapascals (MPa), and all stated results are an average of the measurements.

$$\text{Tensile Stenght (MPa)} = \frac{\text{Force (N)}}{\text{Area (Width in mm*thickness in mm)}} \quad \text{Eq... 9}$$

$$\text{Elongation at Break} = \frac{\text{Increase in Length}}{\text{Original in Length}} * 100 \quad \text{Eq..... 10}$$

2.6.2. Thickness of the biofilm

Film thickness was measured using a calibrated electronic digital micrometer. Five random measurements were performed over each dried film, with the mean value being the final thickness [24].

2.6.3. Biodegradability test

A soil burial approach was used to assess the film packaging's biodegradability in accordance with the protocol developed by [25]. At a depth of 3 cm, pre-weighed samples (2 cm x 2 cm) were buried. Weight of samples was taken every three days during a 24-day period.

$$\text{Degradation \%} = \frac{\text{Initial weight of the biofilm} - \text{Final weight of the biofilm}}{\text{Initial weight of the biofilm}} \times 100 \quad \text{Eq..... 11}$$

2.6.4. Antimicrobial activity of packaging film

The antimicrobial activity of the packaging film was evaluated using an agar diffusion technique. The process involved incubating *E. coli* and *S. aureus* strains, plating young cultures on nutrient agar, applying 9 mm film discs, and measuring the zone of inhibition after 24 hours at 37°C to determine antibacterial activity [26].

2.7. Statistical analysis

The analysis of variance (ANOVA) of the different data was performed using Minitab software. The significant differences among means were compared using Tukey's test at a 95% confidence level ($P < 0.05$). The results were expressed as means and standard deviations (mean $\pm$ SD).

3. Result and Discussion

3.1. Characterizing Physical and functional properties of avocado seed starch

3.1.1. Moisture Content

Moisture content is the main factor in all raw materials and finished goods which affect their nutritional value and performance during handling, storage, and processing [27]. Moisture content is the amount of water in a sample, which indirectly indicates its total solid content. The results are shown on (figure 4.1). The starch moisture content of this research was $9.37 \pm 0.4\%$ which is higher compared to the reported value in other investigation 7.63% [19].

Higher moisture content decrease the shelf life of starch because it facilitates the growth of microorganism, which changes other important properties of the starch like color, protein, and amylose concentration [28]. Low moisture content is advisable since it minimizes weight during transit, increases shelf life, and is frequently necessary for industrial and culinary applications.

Moisture content less than 14% ensures storage stability by lowering water activity that prevents microbial growth and enzymatic degradation.

Table 3.1. Physical and functional properties of avocado seed starch

Sample	Physical properties		
Avocado seed starch	Moisture Content (%)	Ash (%)	
	9.37±0.4	0.37±0.002	
	Functional properties		
	Water absorption (g/g)	Swelling power (g/g)	Solubility (%)
	2.37±0.08	6.1±1.6	13.2±0.69

3.1.2. Ash Content

The ash content is the residual after the combustion process of the materials into carbon-free product, which originates from minerals and inorganic salts in the fresh tuber, fertilizer usage, and can also come from soil and air pollution during processing [29]. The ash content was shown on (figure 4.1). The ash content obtained for this research was found to be 0.37±0.002 which is below the reported value by [16] which was $0.67 \pm 0.014\%$.

The value of 0.37% indicates that soluble minerals and other contaminants were eliminated from the starch granules by an effective purification procedure (such as suitable washing and centrifugation steps). The minimum ash content shows that the starch is of good quality [30].

3.1.3. Water absorption capacity

Water absorption of the materials indicates the ability of the materials to absorb water. Water absorption capacity depends on the presence of hydrophilic groups that bind to water molecules and the gel-forming capability of macromolecules [31].

The water absorption capacity of the avocado seed starches were shown on (table 4.1). The obtained value of water absorption capacity of this research was 2.37±0.08 and it was higher than the native starch's water absorption, which

was around 0.3 g/g, but lower than the other starches reported values for avocado seed starch, such as 4.56 g/g or 4.75 g/g, and this value depend on the variety and extraction method [32]. Water absorption capacity of starch is influenced by the presence of hydrophilic group and granular structure and the lower value shows more compact granule with less porous internal structure [33].

3.1.4. Swelling power of the starch

The swelling power of the materials indicates how much water the granules hold at a given temperature after centrifugation. The results of swelling power of avocado seed starch were shown on (table 4.1). The Swelling power of the obtained avocado starch was 6.1 ± 1.6 g/g and this result slightly deviates from a reported value by [34]. The swelling power indicates that, at a specific temperature, the starch absorbs and retains this amount of water per gram. A study on avocado seed starch found swelling capacity of 8.18–8.48 g/g for different varieties [32].

3.1.5. Water solubility of starch

Water solubility is starch that dissolves into water mostly amylose and small amylopectin fragments released during heating. It can be influenced by amylose and amylopectin characteristics of the starches [35]. The results of water solubility of avocado seed starch were shown on (table 4.1). The result for water solubility of this research was 13.2 which are lower than values found in other studies, which range from 16% to over 20% depending on the conditions. This higher solubility are observed at increased temperatures where amylose leaches from swollen starch granules, while the low value of 13.2% suggests it was measured under ambient conditions.

3.1.6. FTIR Analysis of starch

The result of FTIR for avocado seed starch shows typical profile of a polysaccharide (starch), very broad O–H, weak C–H stretches, strong C–O/C–O–C in $1200\text{--}900\text{ cm}^{-1}$, and no carbonyl near $1700\text{--}1750\text{ cm}^{-1}$. The result indicates that the O-H group binded with hydrogen, C-H alkanes, C=O and C-O ethers. The existing of those groups had represented avocado seed starch having amylose and amylopectin and reducing glucose [36].

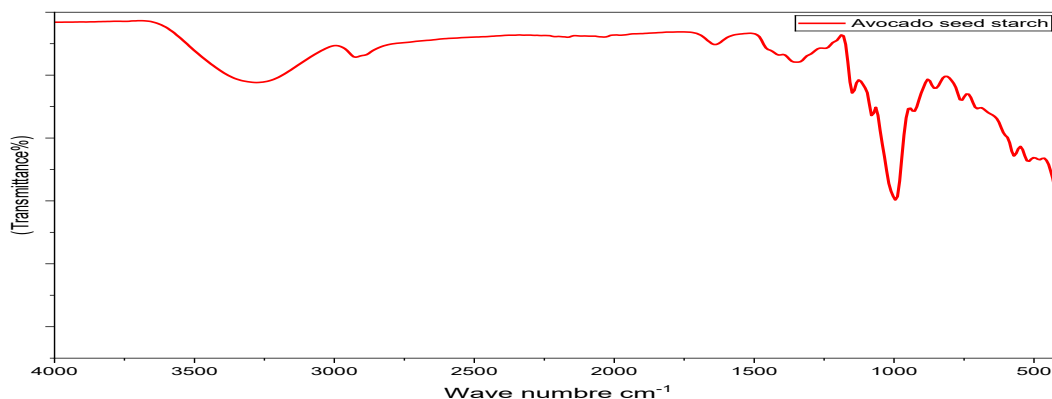


Figure 3.1. FTIR of avocado seed starch

From the FTIR result on figure 4.1, the broad band at 3279 cm^{-1} was attributed to the vibrational stretches of the starch O-H groups. This O-H group is the most characteristic feature of starch and other polysaccharides in an FTIR spectrum.

3.2. Functional properties of the developed packaging film

3.2.1. Water solubility of the film

The purpose of water solubility test was to examine the ability of the film to dissolve and retain water when used as food packaging. The values of the water solubility of the film obtained in this research were indicated in the (table 4.3) given below. Water solubility of the developed film shows significant difference ($P < 0.05$) due to starch and aloe vera gel. From the result water solubility was affected by interaction effect of avocado seed starch and aloe vera gel. The water solubility of this study ranges from 77.8 ± 0.35 to 96.0 ± 0.45 .

The highest value was obtained from the lowest starch and aloe vera gel, the lowest value of solubility was obtained from highest starch and aloe vera gel. The decrease in solubility with increasing starch content and aloe vera gel can be the result of the formation of a more densely packed and potentially more crystalline polymer network.

A higher starch concentration provides more chains for hydrogen bonding, leading to a stronger, less water accessible matrix [37].

An increase in starch concentration promotes the re association of amylose and amylopectin chains leading to a more ordered structure that is less susceptible to water dissolution [38]. The addition of aloe vera gel further reduces solubility. This may be for the interaction between starch hydroxyl groups and the polysaccharides glucomannans in the aloe vera gel [39].

Incorporating aloe vera gel into chitosan-starch films reduced their solubility, which they attributed to the formation of a more complex and stable polymeric network through intermolecular interactions.

Table 3.2. Interaction effects of starch and aloe vera gel on physical properties

Sample	WS (%)	WA (%)	WVTR(g/m ² hr	WVP(g.mm/m ² hrkpa
Ass1Av1	96.0±0.45 ^a	41.2±0.35 ^c	98.3±0.75 ^{ab}	0.0110±0.006 ^c
Ass1Av2	94.2±0.41 ^b	46.5±0.41 ^b	77.67±1.96 ^{cd}	0.0090±0.01 ^e
Ass1Av3	95.5±0.305 ^a	32.6±0.2 ^d	60.67±2.08 ^{cd}	0.0077±0.00 ^f
Ass2Av1	92.8±0.208 ^c	41.2±0.35 ^c	69.93±0.75 ^{de}	0.0093±0.0115 ^d
Ass2Av2	91.8±0.15 ^d	23.7±0.15 ^f	58.0±0.75 ^{ef}	0.0061±0.01 ^h
Ass2Av3	94.3±0.45 ^b	21.4±0.2 ^g	39.53±0.78 ^{fg}	0.0056±0.005 ⁱ
Ass3Av1	77.8±0.35 ^g	18.1±0.26 ^a	107.63±0.31 ^a	0.0145±0.06 ^a
Ass3Av2	78.6±0.52 ^f	13.8±0.15 ⁱ	88.9±1.32 ^{bc}	0.0117±0.06 ^b
Ass3Av3	86.8±0.21 ^e	15.9±0.12 ^h	39.0±0.72 ^g	0.0068±0.0115 ^g

All values are means ± standard deviation. The column with the same means with different letters is significantly different ($P < 0.05$). Ass1, Ass2 and Ass3 are 2%, 4% and 6% avocado seed starch, Av1, Av2 and Av3 are 0.5%, 1% and 1.5% aloe vera gel respectively; WS=water solubility; WA water Absorption; WVTR=water vapor transmission rate; WVP=water vapor permeability

3.2.2. Water absorption of the film

Water absorption is a measure of the film's hydrophilicity and the free volume in the polymer matrix. High WA can lead to loss of mechanical strength, structural deformation, and promote microbial growth. The water absorption in starch films can affect significantly the physical and barrier properties of starch-based films.

The water absorption capacity of the film was shown in the (table 4.3). Statistically significant ($P < 0.05$) differences were observed in packaging film developed from avocado seed starch and aloe vera gel.

The value of water absorption capacity for this research was between 13.8±0.15 to 46.5±0.41. High water absorption was associated with low starch (2%) and medium to high aloe vera gel (1-1.5%).

The hydrophilic nature of aloe vera gel boosted the film's weight while also enhancing its ability to absorb and hold water. [39].

3.2.3. Water vapor transmission rate and permeability

Water vapor transmission rate and permeability is a key indicator of a packaging film's ability to protect against moisture exchange. The water vapor transmission rate of the film obtained in this research was indicated in the

(table 4.3). The value of WVTR ranges from 39.0 to 107.63 indicating that higher WVTR at lowest starch and aloe vera gel. As the starch content increases, the film becomes thicker and the path for water molecules to travel through becomes longer and more winding. [40] Demonstrated this in sugar palm starch films, showing that a more compact structure directly correlates with reduced WVTR. WVTR decrease with increasing aloe vera gel. Its polysaccharides can form a compatible blend with starch, reducing the free volume between polymer chains. The addition of Aloe vera gel into the film matrix resulted in a more homogeneous and compact structure, which was evidenced by a significant decrease in water vapor permeability [41].

The water vapor permeability of packaging films developed by avocado seed starch and aloe vera gels is shown in the Table 4.3. The values of the water vapor permeability of the films varied significantly ($P < 0.05$) due to starch and aloe vera gel concentration. WVP ranges from 0.0056 ± 0.005 to 0.0145 ± 0.06 lowest WVP at medium starch (4%) and highest aloe vera gel (1.5) and highest WVP at highest starch (6%) and lowest aloe vera gel (0.5%). The WVP of the film depends on the composition of the raw materials from which the film developed.

Incorporation of aloe vera gel significantly reduced the water vapor permeability (WVP) and this was due to of the interaction between chitosan and Aloe vera constituents causing a reduction in hydrophobicity of chitosan groups [42]. The strong interaction between the mono systems and the polymeric matrix increases the film compactness, making it difficult for water molecules to cross through the polymeric matrix [43].

3.3. Functional group analysis of the film (FTIR)

Analysis of the film developed from avocado seed starch and aloe vera gel showed that FTIR spectrum of the sample obtained at the wavenumbers in the range of $4000-400 \text{ cm}^{-1}$ [44].

The result of FTIR for the developed packaging film was shown on (figure 4.2). The results showed broader peaks between 3269.35 cm^{-1} to 3277.38 cm^{-1} for all samples.

3.3.1. Impact of aloe vera gel concentration on absorption band at constant starch weight

When comparing film sample with the same starch at different AV volumes (4% Ass with 0.5, 1 and 1.5% AV), the primary differences are in the intensity of the absorption bands. The result indicates that increase in AV results in a wider and slightly more intense broad band in the $3272.4-3274.94 \text{ cm}^{-1}$ areas. Acemannan, a polymer found heavily in aloe vera gel, has several hydroxyl groups. More AV strengthens the polymeric network by introducing additional locations for hydrogen bonds with the starch chains [39]. The peaks in the region especially the C-O-C glycosidic bond stretch ($\sim 1149.19 \text{ cm}^{-1}$) and C-O-H stretches ($\sim 1077.86, \sim 998.89 \text{ cm}^{-1}$), show increased intensity with higher

AV content. This confirms the incorporation of more polysaccharide material from the aloe vera gel into the film matrix [45].

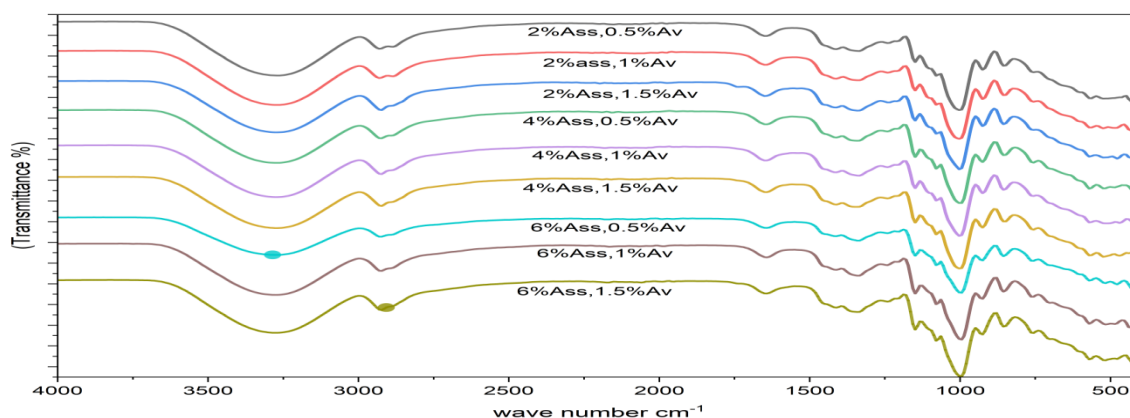


Figure 3.1. FTIR for the films with different starch and aloe vera gel ratios

3.4. Morphological Analysis of the packaging film

The morphology of avocado seed starch and developed film was indicated in (figure 4.3 A and B). The micrograph of the starch sample shows oval and spherical shapes, the most common shape visible are ovals and the medium and smaller sized ones are spherical. The majority of the displayed granules were smooth and intact surface.

There are no visible pores, fissures, or erosion patterns that would indicate enzymatic, acid, or physical modification. The presence of smooth structures would point to a good purity in the starch[46].

The surface morphology of packaging film from avocado seed starch and AV exhibited compact morphology without pores and cracks

Aloe vera gel, which is primarily water and polysaccharides (like acemannan) can integrate well with the starch polymer chains. It likely acts as a plasticizer, helping to form a more flexible and continuous matrix by reducing the strong intermolecular forces between starch chains[47].

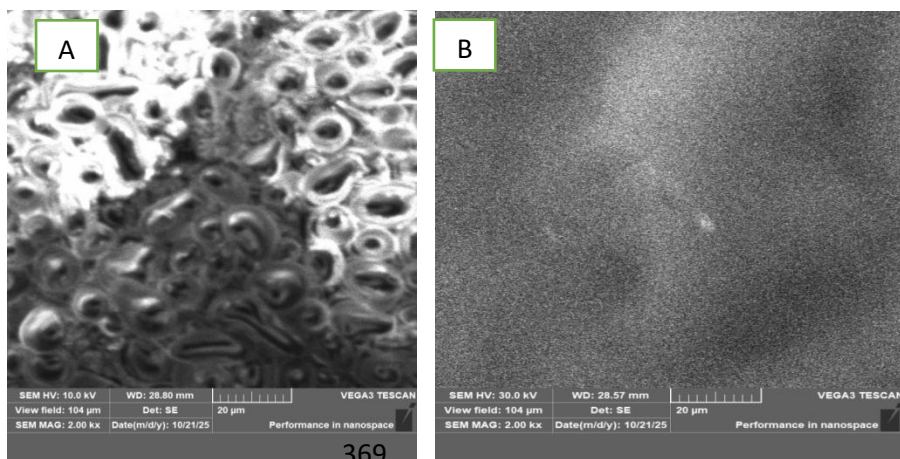


Figure 3.2. Structural Morphology of avocado seed starch (A) and packaging film (B)

3.5. Mechanical properties of the film

Evaluating mechanical qualities of food packaging material is critical for guaranteeing loss free distribution and suitable protection during transit and storage[48]. Packaging films' mechanical properties are linked to their ability to withstand stress on their surface.

Table 4.3 mechanical properties of the film

Sample	TS (Mpa)	EB (%)	Thickness (mm)
Ass1Av1	4.8±0.2 ^f	15.2±0.25 ^d	0.25±0.01 ^d
Ass1Av2	5.4±0.15 ^e	13.0±0.21 ^e	0.30±0.01 ^c
Ass1Av3	2.7 ±0.15 ^g	6.9±0.15 ^g	0.35±0.01 ^b
Ass2Av1	8.2 ±0.25 ^d	19.2±0.25 ^b	0.31±0.01 ^c
Ass2Av2	9.5±0.25 ^c	19.6±0.25 ^b	0.37±0.01 ^b
Ass3Av3	4.9±0.057 ^f	11.4±0.47 ^f	0.40±0.01 ^a
Ass3Av1	10±0.25 ^a	15.9±0.15 ^c	0.32±0.01 ^d
AssAv2	9.5 ±0.15 ^b	20.1±0.3 ^a	0.36±0.02 ^b
Ass3Av3	9.3±0.2 ^{bc}	20.4±0.40 ^a	0.41±0.0115 ^a

The mean of the same column with different letters are significantly different ($P<0.05$). Ass1, Ass2 and Ass3 are 2%, 4% and 6% avocado seed starch, Av1, Av2 and Av3 are 0.5%, 1% and 1.5% aloe vera respectively; TS=tensile strength; EB =Elongation at break.

3.5.1. Tensile strength

Since plastic films are susceptible to variability, determining the tensile strength of the film will ensure that minimum strength requirements are provided for its application for food packaging purposes [49]. The result of tensile strength of the film was shown on (table 4.4). There were significant difference ($P>0.05$) in tensile strength of the developed packaging film. The result ranges from 2.7 ± 0.15 (Mpa) to 10 ± 0.25 (Mpa) at 2% and 6% starch indicating increase in tensile strength as the value of avocado seed starch increases and it indicates excellent compatibility and a reinforcing effect of the avocado seed starch within the polymer matrix.

At higher amount of avocado seed starch, the starch granules likely form a denser, more continuous and homogeneous network that increases the film's integrity and ability to withstand stress before breaking. This is in agreement with the principle that compatible starch blends can create a more robust polymeric network [50].

In relation to addition of AV the tensile strength was not linear but decrease as the AV increases indicating that at higher amount of AV, the excess moisture and possible phase separation can weaken the polymeric structure, leading to a drop in strength as evidenced by the high standard deviations. The plasticizing effect of hydrocolloids like AV, which can improve flexibility but reduce strength at high concentrations, is well-documented in biopolymer films [51].

3.5.2. Percentage of elongation at break

Elongation at break is the ability of the films to extend before breaking and describes the nature of the film plasticity. Plasticity or extensibility is generally required for a film to regain its integrity when applied to food products [52]. The result of elongation at break for this research ranges from 6.9 ± 0.15 to 20.4 ± 0.40 (Table 4.4).

From the result Elongation at break increases as avocado seed starch increases.

At higher starch amount, the starch forms a strong, continuous, and homogeneous network highly compatible, creating a unified matrix that can distribute stress more effectively and deform to a greater extent before failure [51].

For the addition of aloe vera gel to the film, elongations at break become decrease at low to medium starch and increase at higher starch.

The aloe vera gel's high water content, as well as other components, is likely to disrupt the hydrogen-bonded starch network. This is because the cross linker reinforcement reduces chain mobility, lowering elongation at break.

Internal hydrogen bonding between polymer chains and the subsequent decrease in molecular volume, which promotes brittleness and lowers elongation at break[39].

3.5.3. Thickness of the film

The thickness of the packaging film is an important parameter as it affects the other properties of [53]. The thickness data of avocado seed starch and aloe vera gel packaging films are given in (table 4.4). The result ranges from 0.25±0.01mm to 0.41±0.0115mm.

It shows that the thickness increases with higher starch content. This is expected, as a greater mass of starch solids forms a thicker film-casting layer upon drying [50]. With an increase in aloe vera gel volume, the formed film's thickness rises likewise [54].

3.6. Biodegradability test

If packaging materials break down by at least 90% by biological action in less than six months, they are deemed biodegradable [55]. The developed packaging film biodegradability tested was conducted using the soil burial method. The film weight was recorded before it was buried and the weight loss was examined for every five days. The result of the biodegradability of the developed packaging film was shown on (table 4.5). The result indicates that degradation of the films increased as the burial time increases.

Table 4.5. Percentage weight loss of avocado film packaging materials

Sample	Weight loss in days (%)				
	0	10 th	15 th	20 th	25 th
Ass1Av1	0.073	11.43	22.6	54.2	77.5
Ass1Av2	0.060	6.90	27.78	33.33	76.9
Ass1Av3	0.115	29.20	31.25	65.45	78.9
Ass2Av1	0.066	13.11	22.64	41.46	70.8
Ass2Av2	0.126	4.88	29.06	44.58	79.7
Ass2Av3	0.076	5.56	27.94	44.90	81.5
Ass3Av1	0.067	13.64	21.05	37.78	60.7
Ass3Av2	0.076	9.33	22.06	39.62	65.5
Ass3Av3	0.052	10.00	24.44	44.12	78.9

Ass1, Ass2 and Ass3 are 2%, 4% and 6% avocado seed starch; Av1, Av2 and Av3 are 0.5%, 1% and 1.5% aloe vera respectively.

On the 25th day, all of the developed packaging film had deteriorated by more than 60.7%. The minimum biodegradation was 60.7% which was found at higher starch content (6%) and lower aloe vera gel. A medium concentration of avocado seed starch leads to significantly higher biodegradability by the 25th day which was 81.5% higher than any other combination.

The rate of biodegradability of the film depends on the physiochemical properties like chemical structure, molecular weight, affinity to water and surface area of the biofilm [56]. Moreover, addition of plasticizer was found to be increase the biodegradation of the bio plastics whereas, addition of fillers (5% w/v) was reduced the biodegradation ability of plasticized samples [57]

3.7. Antimicrobial activity of packaging film

Aloe vera gel inhibits the growth of both gram-positive and gram-negative bacteria by creating inhibition zone [6]. The value of antimicrobial activity of the packaging film against *E. coli* as gram negative and *Staphylococcus aureus* (*S. aureus*) as gram positive bacteria was conducted.

The results showed that antimicrobial activities increased as Aloe Vera gel percentage in the packaging film increase. [58] suggest that antimicrobial activity of inhibition zones depends on aloe vera gel concentration. The packaging film developed from the combination of avocado seed starch and aloe vera gel produced an inhibition zone of 12-18mm against *E.coli* and 14-20mm against *S.aureus* while the positive control (ciprofloxacin) was 18-20mm and the negative control 0mm. The 6% starch and 1.5% ml aloe vera film matched with the control against *E.coli* (18mm) and 4% starch with 1-1.5% aloe vera gel film matched with the control against *S.aureus* (20mm) indicating effective antimicrobial activity.

4. Conclusion

The study was conducted to develop biodegradable packaging film from avocado seed starch with aloe vera gel and evaluate the effect of the developed packaging film on the quality of avocado fruit. The result indicates that physical and functional properties of the extracted starch were found in the range of good categories. The result also indicates that it is possible to extract starch from avocado seed and develop biodegradable packaging film by incorporating aloe vera gel.

The physical, functional, and mechanical properties of the developed biodegradable packaging film show a significant difference at $P < 0.05$. The water vapor transmission rate and permeability of the developed packaging film were reduced with the addition of aloe vera gel. The film that has 6% avocado seed starch and 0.5% aloe vera gel has the highest tensile strength. Elongation at break increase with increasing starch content and aloe vera gel, and the highest value was 6% starch with 1.5% aloe vera gel content.

Incorporation of aloe vera gel shows excellent antimicrobial activity, with packaging film containing 6% starch and 1.5% aloe vera gel matched with the control against E.coli, while 4% starch and 1-1.5% aloe vera gel matched with the control against S. aureus. The films also demonstrated significant antioxidant and antimicrobial activities. The values also indicate that the developed packaging film was biodegradable and environmentally friendly with the highest biodegradability rate of 81.5%. These findings indicate the potential of aloe vera gel enriched avocado seed starch films as sustainable and functional packaging materials, contributing to both environmental sustainability and food safety advancements.

Data Availability

The data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' contribution

Conceptualization: Y.T.; and D.W; Methodology: Y.T., and E.K.; Software: Y.T.; Validation: D.W.; Formal Analysis: T.F.; Investigation: D.W.; Data Curation: Y.T., and T.F.; Writing—Original Draft Preparation: Y.T., and, T.F.; Writing—Review and Editing: E.K.; Visualization and Supervision: Y.T. All authors have reviewed and approved the final version of the manuscript for publication.

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5. Reference

- [1] M. S. Alamri *et al.*, “Saudi Journal of Biological Sciences Food packaging ’ s materials : A food safety perspective,” *Saudi J. Biol. Sci.*, vol. 28, no. 8, pp. 4490–4499, 2021, doi: 10.1016/j.sjbs.2021.04.047.
- [2] V. Siracusa, P. Rocculi, S. Romani, and M. D. Rosa, “Biodegradable polymers for food packaging: a review,” *Trends Food Sci. Technol.*, vol. 19, no. 12, pp. 634–643, Dec. 2008, doi: 10.1016/j.tifs.2008.07.003.
- [3] A. Agarwal, B. Shaida, M. Rastogi, and N. B. Singh, “Food Packaging Materials with Special Reference to Biopolymers-Properties Food Packaging Materials with Special Reference to Biopolymers - Properties and Applications,” *Chem. Africa*, no. August, 2022, doi: 10.1007/s42250-022-00446-w.
- [4] A. Arora and G. W. Padua, “Review: Nanocomposites in food packaging,” *J. Food Sci.*, vol. 75, no. 1, pp. 43–49, 2010, doi: 10.1111/j.1750-3841.2009.01456.x.
- [5] G. F. Nogueira *et al.*, “Edible Films and Coatings Formulated with Arrowroot Starch as a Non-Conventional Starch Source for Plums Packaging,” pp. 373–386, 2021.
- [6] N. Hanim *et al.*, “physicochemical properties of starch based film containing aloe vera : a review,” *J. Mater. Res. Technol.*, vol. 15, pp. 1572–1589, 2021, doi: 10.1016/j.jmrt.2021.08.138.
- [7] M. Ghasemlou, C. J. Barrow, and B. Adhikari, “The future of bioplastics in food packaging: An industrial perspective,” *Food Packag. Shelf Life*, vol. 43, no. January, p. 101279, 2024, doi: 10.1016/j.fpsl.2024.101279.
- [8] S. Akan, “Phytochemicals in avocado peel and their potential uses,” *Food Heal.*, vol. 7, no. 2, pp. 138–149, 2021, doi: 10.3153/fh21015.
- [9] J. Misir, F. H. Brishti, and M. M. Hoque, “Aloe vera gel as a Novel Edible Coating for Fresh Fruits: A Review,” *Am. J. Food Sci. Technol.*, vol. 2, no. 3, pp. 93–97, 2014, doi: 10.12691/ajfst-2-3-3.
- [10] K. A. Athmaselvi, P. Sumitha, and B. Revathy, “Development of Aloe vera based edible coating for tomato,” *Int. Agrophysics*, vol. 27, no. 4, pp. 369–375, 2013, doi: 10.2478/intag-2013-0006.
- [11] M. A. Tremocoldi *et al.*, “Exploration of avocado by-products as natural sources of bioactive compounds,” *PLoS One*, vol. 13, no. 2, pp. 1–12, 2018, doi: 10.1371/journal.pone.0192577.
- [12] T. Tesfaye, M. Ayele, E. Ferede, M. Gibril, F. Kong, and B. Sithole, “A techno - economic feasibility of a process for extraction of starch from waste avocado seeds,” no. 0123456789, 2020.
- [13] M. Sartika, M. Lubis, M. B. Harahap, E. Afrida, and M. H. S. Ginting, “Production of bioplastic from avocado seed starch as matrix and microcrystalline cellulose from sugar palm fibers with schweizer’s reagent as solvent,” *Asian J. Chem.*, vol. 30, no. 5, pp. 1051–1056, 2018, doi: 10.14233/ajchem.2018.21155.
- [14] C. T. Ramachandra and P. Srinivasa Rao, “Processing of Aloe vera leaf gel: A review,” *Am. J. Agric. Biol. Sci.*, vol. 3, no. 2, pp. 502–510, 2008, doi: 10.3844/ajabssp.2008.502.510.
- [15] M. P. Packaging, F. Atsani, H. Prakoso, and R. Indiarito, “Edible Film Casting Techniques and Materials and Their,” 2023.
- [16] N. Alemu, S. Balakrishnan, and B. Debtera, “Extraction and Characterisation of Avocado Seed Starch, and Its Blend with Enset Cellulosic,” *Adv. Mater. Sci. Eng.*, vol. 2022, 2022, doi: 10.1155/2022/9908295.
- [17] A. A. Adebawale, M. T. Adegoke, S. A. Sanni, M. O. Adegunwa, and G. O. Fetuga, “Functional properties

- and biscuit making potentials of sorghum-wheat flour composite,” *Am. J. Food Technol.*, vol. 7, no. 6, pp. 372–379, 2012, doi: 10.3923/ajft.2012.372.379.
- [18] M. Milkias, S. Admassu, W. Abebe, D. Wodajo, and M. Makiso, “Effect of starch isolation methods and ecotype on powder flowability , pasting , and thermal properties of Ethiopian potato (*Plectranthus edulis*) starch,” vol. 237, no. August, 2025.
- [19] S. F. Frasson, G. T. Nunes, B. Biduski, C. R. B. Mendonça, and R. Colussi, “Extraction and characterisation of avocado seed starch (*Persea americana* Miller) and application in aerogels,” *Int. J. Food Sci. Technol.*, vol. 58, no. 10, pp. 5388–5397, 2023, doi: 10.1111/ijfs.16657.
- [20] P. Tabassum, S. A. K. U. Khan, M. Siddiqua, and S. Sultana, “Effect of guava leaf and lemon extracts on postharvest quality and shelf life of banana cv. Sabri (*Musa sapientum* L.),” *J. Bangladesh Agric. Univ.*, vol. 16, no. 3, pp. 337–342, 2018, doi: 10.3329/jbau.v16i3.39489.
- [21] D. E. Hebel, A. Javadian, F. Heisel, K. Schlesier, D. Griebel, and M. Wielopolski, “Process-controlled optimization of the tensile strength of bamboo fiber composites for structural applications,” *Compos. Part B Eng.*, vol. 67, no. December, pp. 125–131, 2014, doi: 10.1016/j.compositesb.2014.06.032.
- [22] F. Nouban and M. Abazid, “Plastic degrading fungi *Trichoderma viride* and *Aspergillus nomius* isolated from Nouban, F. and Abazid, M. (2017) ‘Plastic degrading fungi *Trichoderma viride* and *Aspergillus nomius* isolated from local landfill soil in Medan’, *Iopscience.Iop.Org*, 8(February ,” *Iopscience.Iop.Org*, vol. 8, no. February 2018, pp. 68–74, 2017, doi: 10.1088/1755-1315.
- [23] M. Ekrami, A. Ekrami, M. A. Hosseini, and Z. Emam-djomeh, “Bionanocomposite Films Containing *Allium jesdianum* Boiss .,” pp. 1–18, 2022.
- [24] R. A. Shapi’i and S. H. Othman, “Effect of concentration of chitosan on the mechanical, morphological and optical properties of tapioca starch film,” *Int. Food Res. J.*, vol. 23, no. January 2016, pp. S187–S193, 2016.
- [25] A. Zuliani, M. Rapisarda, D. Chelazzi, and P. Baglioni, “Synthesis , Characterization , and Soil Burial Degradation of Biobased Polyurethanes,” 2022.
- [26] X. Hu, L. Yuan, L. Han, and S. Li, “gelatin fi lms incorporated with *Ginkgo biloba* extract,” pp. 27449–27454, 2019, doi: 10.1039/c9ra05788a.
- [27] E.-E. J., O.-E. P.C., W. G.O., and V. M.B., “Physicochemical, Functional and Pasting properties of Orange-Flesh Sweet Potato Starch, Soya bean and Groundnut Flour Complementary Food,” *Am. J. Food Sci. Technol.*, vol. 9, no. 3, pp. 96–104, 2021, doi: 10.12691/ajfst-9-3-5.
- [28] A. Gryszkin, T. Zięba, and M. Kapelko-Zeberska, “Properties of corn starch subjected hydrothermal modification,” *Int. Agrophysics*, vol. 31, no. 1, pp. 53–60, 2017, doi: 10.1515/intag-2016-0031.
- [29] G. Abera, B. Woldeyes, H. Dessalegn Demash, and G. M. Miyake, “Comparison of physicochemical properties of indigenous Ethiopian tuber crop (*Coccinia abyssinica*) starch with commercially available potato and wheat starches,” *Int. J. Biol. Macromol.*, vol. 140, no. May, pp. 43–48, 2019, doi: 10.1016/j.ijbiomac.2019.08.118.
- [30] D. H. Tejavathi, B. S. Sujatha, and C. S. Karigar, “Physicochemical properties of starch obtained from *Curcuma karnatakensis* - A new botanical source for high amylose content,” *Heliyon*, vol. 6, no. 1, p.

- e03169, 2020, doi: 10.1016/j.heliyon.2020.e03169.
- [31] A. B. Mohd Hanim, N. L. Chin, and Y. A. Yusof, “Physico-chemical and flowability characteristics of a new variety of Malaysian sweet potato, VitAto Flour,” *Int. Food Res. J.*, vol. 21, no. 5, pp. 2099–2107, 2014.
- [32] H. Cultivars *et al.*, “Properties of Flour and Starch Isolated from Avocado Seeds of,” 2022.
- [33] A. Sarifudin, T. Keeratiburana, S. Soontaranon, and C. Tangsathitkulchai, “LWT - Food Science and Technology Pore characteristics and structural properties of ethanol-treated starch in relation to water absorption capacity,” *LWT - Food Sci. Technol.*, vol. 129, no. November 2019, p. 109555, 2020, doi: 10.1016/j.lwt.2020.109555.
- [34] C. E. Chinma, C. C. Ariahu, and J. O. Abu, “Chemical composition, functional and pasting properties of cassava starch and soy protein concentrate blends,” *J. Food Sci. Technol.*, vol. 50, no. 6, pp. 1179–1185, 2013, doi: 10.1007/s13197-011-0451-8.
- [35] E. Bertoft, “Understanding Starch Structure : Recent Progress,” 2017, doi: 10.3390/agronomy7030056.
- [36] M. Hendra, S. Ginting, M. Fauzy, R. Tarigan, and A. M. Singgih, “Effect of Gelatinization Temperature and Chitosan on Mechanical Properties of Bioplastics from Avocado Seed Starch (*Persea americana* mill) with Plasticizer Glycerol,” *Int. J. Eng. Sci.*, vol. 4, no. 12, pp. 2319–1805, 2015, [Online]. Available: www.theijes.com
- [37] S. Fatma, A. Karim, J. Jai, R. Adawiyah, and A. Aziz, “Production of Thermoplastic Starch-Aloe Vera Gel Film Embedded with Polyethylene for Improved Tensile Strength and Water Absorption,” vol. 21, no. 3, pp. 93–107, 2024.
- [38] M. González-Mendoza, F. Martínez-Bustos, E. Castaño-Tostado, and S. L. Amaya-Llano, “Effect of Microwave Irradiation on Acid Hydrolysis of Faba Bean Starch: Physicochemical Changes of the Starch Granules,” *Molecules*, vol. 27, no. 11, 2022, doi: 10.3390/molecules27113528.
- [39] S. F. Abd Karim, J. Idris, J. Jai, M. Musa, and K. H. Ku Hamid, “Production of Thermoplastic Starch-Aloe vera Gel Film with High Tensile Strength and Improved Water Solubility,” *Polymers (Basel)*, vol. 14, no. 19, 2022, doi: 10.3390/polym14194213.
- [40] M. L. Sanyang, S. M. Sapuan, M. Jawaid, M. R. Ishak, and J. Sahari, “Effect of plasticizer type and concentration on tensile, thermal and barrier properties of biodegradable films based on sugar palm (*Arenga pinnata*) starch,” *Polymers (Basel)*, vol. 7, no. 6, pp. 1106–1124, 2015, doi: 10.3390/polym7061106.
- [41] A. Hadi, A. Nawab, F. Alam, and S. Naqvi, “Development of sodium alginate-aloe vera hydrogel films enriched with organic fibers: study of the physical, mechanical, and barrier properties for food-packaging applications,” *Sustain. Food Technol.*, vol. 1, no. 6, pp. 863–873, 2023, doi: 10.1039/d3fb00122a.
- [42] D. Bajer, K. Janczak, and K. Bajer, “Novel Starch / Chitosan / Aloe Vera Composites as Promising Biopackaging Materials,” *J. Polym. Environ.*, vol. 28, no. 3, pp. 1021–1039, 2020, doi: 10.1007/s10924-020-01661-7.
- [43] C. Xu, Z. Wang, Y. Hu, and Y. Chen, “Thin-Film Composite Membrane Compaction: Exploring the Interplay among Support Compressive Modulus, Structural Characteristics, and Overall Transport Efficiency,” 2024, doi: 10.1021/acs.est.4c01639.

- [44] R. K. Beevi *et al.*, “Bioplastic Synthesis Using Banana Peels and Potato Starch and Characterization,” *Int. J. Sci. Technol. Res.*, vol. 9, no. 1, pp. 1809–1814, 2020.
- [45] M. I. Pinzon, O. R. Garcia, and C. C. Villa, “The influence of Aloe vera gel incorporation on the physicochemical and mechanical properties of banana starch-chitosan edible films,” *J. Sci. Food Agric.*, vol. 98, no. 11, pp. 4042–4049, 2018, doi: 10.1002/jsfa.8915.
- [46] O. V. Castro, M. R. L. Blandón, M. J. Contreras, C. M. Mesías, and C. D. Andrade, “Characterization and application of a coating of starch extracted from avocado (*Persea americana* L . cv . Hass) seeds as an alternative to reduce acrylamide content in French fries,” *Food Sci. Biotechnol.*, vol. 31, no. 12, pp. 1547–1558, 2022, doi: 10.1007/s10068-022-01140-w.
- [47] O. M. Oluba, S. Muthusamy, and N. Subbiah, “Sustainable packaging using Aloe vera infused mango starch – wool keratin biocomposite films to extend the shelf life of mango,” pp. 1–21, 2025.
- [48] C. M. P. Yoshida *et al.*, “Effect of chitosan and aloe vera extract concentrations on the physicochemical properties of chitosan biofilms,” *Polymers (Basel)*, vol. 13, no. 8, pp. 1–12, 2021, doi: 10.3390/polym13081187.
- [49] L. Xiong and L. Zhang, “Research on the Tensile Properties of Packaging Film Based on Environmental Protection PVA-KGM,” *Adv. Transdiscipl. Eng.*, vol. 17, pp. 623–628, 2021, doi: 10.3233/ATDE210330.
- [50] T. J. Gutiérrez, N. J. Morales, E. Pérez, M. S. Tapia, and L. Famá, “Physico-chemical properties of edible films derived from native and phosphated cush-cush yam and cassava starches,” *Food Packag. Shelf Life*, vol. 3, pp. 1–8, 2015, doi: 10.1016/j.fpsl.2014.09.002.
- [51] M. A. R. Dayan, M. M. Habib, M. M. Uddin, M. Khatun, M. S. Hossain, and M. A. Rashid, “Characterization of aloe vera gel incorporated unsaturated polyester resin jute-cotton fabric composites for enhanced biodegradability, flexibility, and insulation properties,” *Heliyon*, vol. 10, no. 15, p. e35261, 2024, doi: 10.1016/j.heliyon.2024.e35261.
- [52] K. Q. Sun *et al.*, “Optimisation of compatibility for improving elongation at break of chitosan/starch films,” *RSC Adv.*, vol. 9, no. 42, pp. 24451–24459, 2019, doi: 10.1039/c9ra04053f.
- [53] A. Jain, B. Mason, and M. S. Brooks, “Development of Tailored Composite Biopolymer Film Formulations Using Minimally Refined Chitosan from American Lobster (*Homarus americanus*) Shell Waste for Different Food Packaging Applications,” pp. 1–27, 2025.
- [54] M. R. Ali and M. E. Abdel-Aziz, “Application of Edible Film and Coating Based on Aloe Vera Gel for Preservation of Physicochemical Properties of *Physalis Peruviana* L. Fruits,” *J. Microbiol. Biotechnol. Food Sci.*, vol. 11, no. 3, pp. 1–6, 2021, doi: 10.15414/JMBFS.1574.
- [55] R. Resende, A. Silva, C. S. Marques, and T. R. Arruda, “Biodegradation of Polymers : Stages , Measurement , Standards and Prospects,” pp. 371–399, 2023.
- [56] Y. Tokiwa, B. P. Calabia, C. U. Ugwu, and S. Aiba, “Biodegradability of plastics,” *Int. J. Mol. Sci.*, vol. 10, no. 9, pp. 3722–3742, 2009, doi: 10.3390/ijms10093722.
- [57] A. Shafqat, N. Al-zaqri, A. Tahir, and A. Alsalmeh, “Saudi Journal of Biological Sciences Synthesis and characterization of starch based bioplastics using varying plant-based ingredients , plasticizers and natural

624 fillers,” *Saudi J. Biol. Sci.*, vol. 28, no. 3, pp. 1739–1749, 2021, doi: 10.1016/j.sjbs.2020.12.015.
625 [58] M. M. J. Arsene *et al.*, “Phytochemical Analysis , Antibacterial and Antibiofilm Activities of Aloe vera
626 Aqueous Extract against Selected Resistant Gram-Negative Bacteria Involved in Urinary Tract Infections,”
627 2022.
628
629