

Research Article

A Comparative Study on Characteristics and Properties of Food Packaging Film from Cassava Starches of Different Varieties Grown in Ethiopia

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Abstract

The present study investigates cassava starches from different Ethiopian varieties for the development of biodegradable food-packaging films. Cassava is a vital food crop in Ethiopia and is, therefore, regarded as a very friendly and renewable raw material for replacing synthetic plastic packaging due to its high starch content. This research work aimed at investigating, comparing the physicochemical, mechanical, and barrier properties of films developed from two different cassava varieties, namely Kello and Qulle. The methodology followed the isolation of starches from cassava root, the evaluation of their characteristics, as well as the pasting behavior. Edible films were prepared by using a casting technique and their mechanical properties included tensile strength and elongation at break, and barrier properties such as water vapor transmission and solubility were determined. From the test results, it can be obtained that Kello variety absorbed more water and had greater swelling power; therefore, it performed better in terms of flexibility. On the other hand, Qulle has a greater tensile strength and less solubility; hence, it will be suitable for dry food packaging. Again, both varieties fulfill minimum mechanical and barrier requirements for the different applications of packaging. Further research is suggested to refine production processes and broaden their applications in the food industry.

Keywords

Cassava Starch, Biodegradable Food Packaging, Physicochemical Properties, Mechanical Properties, Sustainable Packaging

1. Introduction

Food packaging films are thin-layer materials that are used to store, distribute, and protect a variety of foods. They also protect food from dirt, liquids, gasses, and liquids. Packaging films are used to package food items such meat, cheese, snack foods, biscuits, dairy products, dry meals, liquid and semi-solid foods, and other bakery goods. They help prolong the shelf life of food [1]. So far, the most popular packaging

film for foodstuffs is plastic materials like polyethylene and polystyrene. But these materials are not biologically degradable and dangerous substances may migrate into food from the plastic materials. When compared to plastic packaging, edible films have the advantages of maintaining the product's original appearance, allowing for direct consumption, being environmentally friendly, and being safe for the

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environment [2].

As a result, it is crucial to use renewable and biodegradable films in place of traditional polymers. Producing starch-based food packaging films is a viable option for this because of its affordability, biodegradability, thermoplastic nature, and widespread availability. Food packaging films can be made by extracting the starches from a range of starchy source materials, including barley, maize, rice, sweet potatoes, and cassava [3]. Cassava (*Manihot esculenta*) is a significant source of starch. It offers several advantages over other starch crops, especially in many developing countries, due to its unique adaptability to various ecological conditions, minimal labor needs, ease of cultivation, high yield potential, and resilience to drought in areas where other crops struggle to thrive [4].

Due to the chemical composition and structure differences of starches from different sources, food packaging films made up of various types of starches may have different physico-chemical, mechanical [3], and barrier properties among themselves making use for food packaging a necessity. Taking this into consideration, this study was dealt with a comparative investigation on the physico-chemical, mechanical and barrier properties of food packaging film based on various types of Ethiopian cassava starches. Cassava is among the major food crops produced and consumed for food security in smallholder farmers, especially in southern part of Ethiopia [5]. Apart from its food values, cassava root is also used as an industrial raw materials source for starch, bio plastics, glucose and other bakery; confectionery and foods products. It is additionally an effective cash crop for corporations and a vital supply of cheap excessive-quality starch more affordable than other starches normally used in the food industry [6]. Toward the dream of biobased and biodegradable food packaging films from cassava starch. Currently, there is researches being done on cassava starch due to its low price and better film-forming ability.

In this study, cassava, an increasingly grown crop in Ethiopia with high starch content is proposed as a potential source for food packaging films with less information on their suitability for edible film production and little known about the various varieties physico-chemical, mechanical and barrier properties. In addition, cassava cultivars have also been known to attribute for differences in starch physicochemical properties induced by genetic make-up and exploitation of activities on crop growth. Different physicochemical property changes of starch also influence the mechanical, barrier and physicochemical properties of food packaging films. Because of these weaknesses, the starch was isolated from some cassava types, but this was not used as a by-products [7]. This study aims to address these gaps by comparing the physico-chemical, mechanical, and barrier properties of films from different cassava varieties grown in Ethiopia. The primary objective of this study was to conduct a comparative analysis of the mechanical, barrier, and physico-chemical traits of films derived from various cassava types cultivated in Ethiopia.

2. Materials and Methods

2.1. Materials

The main raw material for this study was cassava (*Manihot esculenta*), sourced from the Hawassa Agricultural Research Center (HARC) in Ethiopia. Situated at an altitude of 1700 meters, HARC provided cassava samples, which were carefully processed through washing, manual peeling, and thorough rinsing with distilled water to remove debris. These steps ensured the cassava roots were clean and prepared for subsequent starch extraction, forming the basis for film production. A variety of chemicals and reagents supported the cassava starch analysis, focusing on measuring the film's physical and chemical properties. Potassium hydroxide (KOH) and sodium hydroxide (NaOH) were used for determining crude fiber, fat, and amylose content. Additional chemicals, such as boric acid, hydrochloric acid, sulfuric acid, potassium sulfate, and copper sulfate, were essential for assessing crude protein, fiber, and nitrogen content. Other reagents, including 99% ethanol, glacial acetic acid, iodine, and potassium iodide, aided in evaluating amylose and amylopectin. Glycerol served as a plasticizer in the film-forming process, sunflower oil was utilized for oil absorption tests, and sodium chloride was applied in water vapor transmission rate (WVTR) experiments. The study employed a range of instruments for experimental analysis, including an oven (Thermostatic drier), muffle furnace, and texture analyzer instrument facilitated measurements of chemical properties, film thickness, and material strength.

2.2. Methods

2.2.1. Extraction of Cassava Starch

Cassava starch was extracted according to the method defined by Chisenga et al. [8] with slight modifications. The cassava roots were taken to the laboratory immediately after harvesting. They were thoroughly cleaned, peeled, chopped into small pieces, and then blended. The resulting pulp was combined with clean water in a 1:10 ratio, meaning the volume of water was ten times greater than that of the pulp. This mixture was well-stirred and then filtered through cloth. The liquid obtained was allowed to settle, and the clear liquid on top was carefully poured off, while the remaining residue was rinsed. The starch was rinsed with distilled water and, after further decanting, left to dry on aluminum trays in sunlight for 48 hours at room temperature. This process ensures the starch reaches its minimum moisture content. Once dried, it was stored in airtight plastic containers at room temperature. Additionally, samples from both types were preserved at room temperature for future analysis.

2.2.2. Characterization of Starch

(i). Moisture Content

Moisture content in both varieties of cassava starch was measured based on methods developed by Nuwamanya et al. [6] with minor modification. In this procedure, 3-gram samples of dried cassava starch were weighed and heated in an oven at 130 °C for 3 hours. The moisture content was determined by calculating the percentage weight loss relative to the original wet weight of the sample. The moisture content was then calculated using the following Equation (1).

$$MC(\%) = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

where W_i is the sample's initial weight prior to drying, MC is its moisture content, and W_f is its final weight following drying.

(ii). Total Ash Content

To determine the total ash content, we used a modified version of the method described by Chisenga et al. [8]. Samples weighing 3 grams each were placed in crucibles and heated in a muffle furnace at 550 °C for 3 hours. The percentage of total ash (dry weight basis) was calculated using Equation (2).

$$\text{Total ash} = \frac{W_2 - W}{W_1 - W} \times 100 \quad (2)$$

where W stands for empty crucible weight in grams, W_1 for crucible weight plus dry sample material, and W_2 for crucible weight plus ash.

(iii). Crude Fiber Content

To determine the crude fiber content, we followed the AOAC Official Method 962.09 [9]. The crude fiber content was calculated by using Equation (3).

$$\text{Total crude fiber} = \frac{(W_1 - W_2)}{W_s} \times 100 \quad (3)$$

where W_1 is the weight of the dried crucible with fiber. W_2 = crucible weight with ash W_s = Dry weight of the sample.

(iv). Crude Fat Content

The fat content was calculated by the method previously explained by Nielsen [10]. Petroleum ether was used with a Soxhlet apparatus to extract the fat from the sample. Extraction thimbles were filled with samples. The Soxhlet extraction chamber was filled with the thimbles containing the sample. Petroleum ether is used to wash the fat into the extraction flasks. After removing the extraction flasks from the extraction chamber, they are put in the drying oven along with the extraction beaker, and they are allowed to air dry for 30

minutes at 100 °C overnight. After cooling in a desiccator, weigh the beaker. Finally, the fat content was calculated by using equations (4) and (5).

$$\text{Weight of fat in sample} = (\text{Beaker weight} + \text{fat}) - \text{Beaker weight} \quad (4)$$

$$\text{Crude fat (\%)} = \frac{(\text{weight of fat in sample})}{\text{weight of dried sample}} \times 100 \quad (5)$$

(v). Crude Protein and Nitrogen Content

To determine the crude protein content, we followed the AOAC Official Method 976.05 [9]. The percentage of nitrogen was calculated using Equation (6).

$$\text{Nitrogen(\%)} = \frac{V_{HCl} \times N_{HCl} \times (F1) \times MW_n}{\text{sample weight on dry basis}} \times 100 \quad (6)$$

Given that the molecular weight of nitrogen is 14.00, the volume of HCl in liters used until the titration endpoint is V , and the normality of HCl is usually about 0.1N, along with the molecular weight of nitrogen represented as MW_n and an acid factor of 1, the conversion of nitrogen percentage to protein percentage can be determined using Equation (7) with the appropriate conversion factors.

$$P(\%) = 6.25 \times N\% \quad (7)$$

(vi). Carbohydrate

According to Saleh et al. [11], the method of difference was used to determine the starches' carbohydrate content. The residual will be the total carbohydrate content after the percentages of the sample's moisture, crude fiber, ash, and protein content are subtracted from 100%. Consequently, the starch samples' total carbohydrate content was calculated by Equation (8).

$$\text{Carbohydrates (\%)} = 100 - (\text{protein\%} + \text{fiber\%} + \text{moisture\%} + \text{ash\%}) \quad (8)$$

(vii). Amylose and Amylopectin Content

The procedure outlined by Hassan et al. [12] was used. Consequently, to gelatinize the starch, a 0.10-gram sample was mixed with sodium hydroxide and ethanol and heated. Following cooling, acetic acid and iodine solution were added to dilute the mixture. Using a spectrophotometer, the absorbance at 620 nm was determined. Equations (9) and (10), respectively, were used to calculate the amounts of amylose and amylopectin.

$$\text{Amylose content(\%)} = 3.06 \times \text{absorbance} \times 20 \quad (9)$$

$$\text{Amylopectin content} = 100 - \text{Amylose content} \quad (10)$$

(viii). Swelling Power

The techniques outlined by Hefnawy et al. [13] were used to calculate swelling power. For 30 minutes, 0.1 g samples were heated in a water bath with 10 ml of distilled water at 60 °C while being constantly stirred. For fifteen minutes, the samples were centrifuged at 1600 rpm. Equation (11) was used to weight and compute the precipitated portion.

$$\text{Swelling power} = \frac{\text{Weight of sedimental paste}(g)}{\text{Weight of the sample(dry basis)}(g)} \quad (11)$$

(ix). Water Solubility

The techniques explained by Hassan et al. [12] were used to determine water solubility. The 0.5 g samples were heated for 30 minutes without mixing in a 10 ml distilled water bath at 60 °C. For ten minutes, the samples were centrifuged at 1600 rpm. Five milliliters of the supernatant were separated, dried, weighed, and computed using the Equation (12).

$$\text{Solubility} = \frac{\text{weight of dry supernatant } (g)}{\text{Weight of the dry starch } (g)} \times 100 \quad (12)$$

(x). Water Absorption Capacity

The approach outlined by El-Safy [14] was used to determine the starch's capacity to absorb water. One gram of the starch sample was combined with 10 milliliters of distilled water in a beaker. The mixture was stirred for five minutes using a magnetic stirrer. Following this, the suspension was subjected to centrifugation at 3600 rpm for 30 minutes. The volume of the resulting supernatant was measured using a 10-milliliter graduated cylinder. The water absorption was determined by subtracting the supernatant volume from the initial volume of water added.

2.2.3. Oil Absorption Capacity of Starch

The starch samples' ability to absorb oil was assessed using the techniques previously detailed by Eltayeb et al. [15]. Thus, to measure oil absorption, 10 milliliters of sunflower oil were mixed with 1 gram of the sample and stirred for 5 minutes. The mixture was then centrifuged to separate the oil. The remaining oil volume was measured, and the difference between the initial and final oil volumes was used to calculate the oil absorption capacity in milliliters of oil per gram of starch.

2.2.4. Pasting Properties of Starch

The pasting properties of starches were evaluated using a Rapid Visco Analyzer (RVA), following the method described by Ikegwu et al. [16] with slight modifications. Consequently, 2 g of the samples and 25 g of distilled water were combined to create a mixture. After adjusting the starches' starting moisture content, the time-temperature profile was set up to keep the system at 50 °C for one minute and heat it from 50 to 95 °C in three minutes and forty-two

seconds. Following three minutes and thirty seconds at 95 °C, the sample was cooled to 50 °C for four minutes and forty-eight seconds, and it was then maintained at that temperature for two minutes. The pasting profile was used to read the peak viscosity, trough, breakdown, final viscosity, setback, peak duration, and pasting temperature with the aid of the thermocline for Windows software.

2.3. Development of Packaging Film

Packaging films were prepared using a casting technique, based on the methodology outlined by Adamu et al. [17] with some modifications. This method involved mixing 5 g of starch with 70 ml of water and 40 g of glycerol for every 100 g of starch to make film-forming solutions (FFS). At room temperature, this mixture was constantly swirled for ten minutes. To create a homogenous, bubble-free filmogenic solution, the resultant suspension was then heated on a hot plate from room temperature to around 70 °C while being agitated. To create transparent and flexible films, the FFS was put into petri dishes and dried for 24 hours at 50 °C in an oven (700 LT, Italy). The films were gently removed from the petri dishes and ready for additional characterization after being allowed to cool for two days.

2.4. Characterization of the Packaging Film

2.4.1. Moisture Content

The technique outlined by Costa et al. [18] was used to determine the films' moisture content (MC). Approximately 50 mg of film will be dried using this procedure for 24 hours at 105 °C (until the equilibrium weight). Equation (13) can be used to determine the sample's weight loss and moisture content.

$$\text{Moisture content} = \left(\frac{M_i - M_f}{M_i} \right) \times 100 \quad (13)$$

where M_i and M_f are the masses of the original and dried samples, respectively, and $M_i - M_f$ is the weight loss of the samples.

2.4.2. Film Thickness

The thickness of the film was measured with an electronic digital micrometer (Mitutoyo Co., Japan). A calibrated digital micrometer was used to measure the dry film thicknesses with a precision of 0.01 mm. The final thickness of the film is calculated using the mean thickness value, which was obtained from random measurements taken at five different film positions.

2.4.3. Tensile Strength and Percentage Elongation at Break

The elongation at break (EB) and tensile strength (TS) of

edible films were measured using a texture analyzer (TA Plus) following the ASTM D882-02 standard protocol. Film samples were cut into rectangular strips measuring 100 mm in length and 15 mm in width. During testing, the strips were clamped between grips with an initial separation of 50 mm, and force-deformation data was recorded as the samples were stretched at a speed of 10 mm/min. The thickness and width of the film samples were manually input into the connected computer system. The analyzer's software, pre-installed by the manufacturer, automatically calculated the TS and EB values. Young's modulus was derived from the strain-stress curves. Each type of starch film was tested five times per specimen from two different films, and the most accurate results were selected.

2.4.4. Water Solubility

Film solubility was measured using a variation of the technique outlined by Ojo Mofoluwaso Olufunmilola [19]. To determine the dry film mass, the film samples are precisely weighed after being cut into 4.0 cm² square pieces. The films are kept at room temperature in test beakers with 50 milliliters of distilled water for twenty-four hours while being slowly stirred mechanically with a shaker. After being filtered out of the water, the samples are dried in an electrical oven set at 105 degrees Celsius for 24 hours. The water-soluble stuff was calculated as a percentage of the initial weight using the weight difference. Equation (14) is used to determine the film's percentage solubility.

$$WS(\%) = \frac{\text{Initial dry weight} - \text{Final dry weight}}{\text{Initial dry weight}} \times 100 \quad (14)$$

2.4.5. Color of the Film

The color of the film was examined using the Commission Internationale d'Eclairage (CIE) standard colorimetric measuring scale [20]. A Spectrophotometer (CM-600d) was used to measure the color of the edible films by measuring the values of L*, a*, and b*. The color of the films was evaluated following the ASTM D2244-02 standard, utilizing the D65 standard illuminant and a 10-degree viewing angle. Prior to measurement, the colorimeter was calibrated using standard black and white plates. Film samples were positioned appropriately to assess their color properties. Calibration was performed with a standard white plate (L = 94.64, a = -0.72, b = 1.7). The color difference between the samples was determined using Equation (15).

$$\Delta E = \sqrt{(L - L_o)^2 + (a - a_o)^2 + (b - b_o)^2} \quad (15)$$

where the white plate color standard, which serves as the film background, and the sample color parameter differ by L, a, and b.

2.4.6. Transparency of the Film

As previously mentioned by Immanuel [21], the UV-Vis spectrophotometer (UVD 3200, Labomed, Inc.) was used to measure the films' transparency (in terms of opacity) at a wavelength of 600 nm. To record the absorbance spectrum, the samples were chopped into rectangular pieces and put straight into the cuvette. The empty cuvette served as the reference value for all measurements. Equation (16) was used to determine the opacity value of each film.

$$\text{Opacity} = \frac{\text{Abs}_{600}}{x} \quad (16)$$

In this case, Abs₆₀₀ = Absorbance at 600 nm, x = Film Thickness (mm).

2.4.7. Water Vapor Transmission Rate

The water vapor transmission rate was measured using the Desiccant Method, as outlined by Syarifuddin et al. [22] with minor modifications. Cassava starch edible films were placed on petri dishes with anhydrous calcium chloride as a desiccant. After sealing, cups were weighed and placed in a desiccator with 70% NaCl. Weights were recorded at set intervals, and the transmission rate was calculated from the weight change and film area. For every sample, the average of three measurement replications was provided. Equation (17) was used to get the water vapor transmission rate.

$$WVTR = \frac{\Delta m}{\Delta t A} \quad (17)$$

where A is the film's exposed surface area (m²) and Δm/Δt is the moisture gain weight per time (g/h).

2.4.8. Water Absorption of the Film

The water absorption (WA) test was conducted following the ASTM D-570-98 standard. Film samples were first dried at 40 °C for 24 hours, cooled in a desiccator, and then cut into 2.5 x 2.5 cm squares. The samples were initially weighed in their air-dried state (W₁) and then immersed in distilled water in a petri dish at room temperature for 24 hours. After soaking, the samples were removed, gently blotted with a dry towel to remove surface water, and reweighed (W₂). The difference between the initial and final weights was determined using Equation (18), as outlined below.

$$\text{Water Absorption}(\%) = \frac{W_2 - W_1}{W_1} \times 100 \quad (18)$$

where the weights of the wet and air-dried samples are represented by W₂ and W₁, respectively. For each type of film, measurements were taken three times, and the average value was computed.

3. Results

3.1. Proximate Composition of Starches

The proximate composition of starches from the cassava varieties Kello and Qulle is shown in Table 1. The results reveal important insights that can significantly influence the development of biodegradable food packaging films. Starch's functional properties, such as moisture content, ash, fat, protein, crude fiber, and total carbohydrate, directly impact its performance as a biopolymer. By understanding these characteristics, researchers can optimize the formulation of starch-based films to enhance their mechanical properties, biodegradability, and overall suitability for food packaging applications.

Moisture content is a crucial factor in the formulation of biodegradable films, as it affects the film's mechanical strength and barrier properties. The moisture levels of Kello (11.04%) and Qulle (10.6%) are lower than those reported in previous studies, indicating a potentially more stable film that could resist microbial degradation during storage. Lower moisture content can also enhance the film's shelf life, making it a suitable candidate for food packaging, where durability and protection from environmental factors are essential.

The ash content, which reflects the mineral composition of the starch, plays a role in the film's thermal and mechanical properties. Kello's ash content (1.01%) is higher than that of Qulle (0.13%), suggesting that Kello could contribute additional mineral content to the film, potentially improving its structural integrity. Both varieties fall below the 1.5% threshold observed in previous studies, indicating they are low in minerals, which is beneficial for maintaining the uniformity and flexibility of the packaging film. This characteristic can lead to a more homogenous film structure that is less prone to brittleness.

Furthermore, the low fat and protein content in both varieties implies minimal interference with the film's formation and performance. The total carbohydrate content, particularly high in both Kello (86.45%) and Qulle (88.7%), indicates a strong potential for film formation, as carbohydrates are the primary polymers used in biodegradable packaging. The very low crude fiber content further suggests that these starches would produce smooth films that are not only aesthetically pleasing but also functional in terms of barrier properties. Generally, we can say that the proximate composition of these cassava starches highlights their potential for developing effective biodegradable food packaging films, aligning with current sustainability goals in the packaging industry.

Table 1. Proximate composition of the extracted starches.

Proximate analysis	Results from this study (%)		Previous study	
	Kello	Qulle	Result (%)	Reference
Moisture	11.04	10.6	14.04 – 16.66	[24]
Ash	1.01	0.13	<1.5	[24]
Fat	0.11	0.13	0.37	[25]
Protein	0.51	0.35	0.28 - 0.52	[26]
Crude fiber	0.01	0.09	1.17 - 2.31	[27]
Total carbohydrate	86.45	88.7	83.92 - 85.55	[27]

3.1.1. Swelling Power of the Starch

Table 2 presents the results of the swelling power analysis for starches from two cassava varieties. The variation in swelling power between the two types could be attributed to factors such as starch granule size, the degree of interaction between crystalline and amorphous regions, and the molecular composition of amylose and amylopectin. Kello starch exhibits a greater swelling power, likely due to its lower amylose content compared to Qulle starch. The study conducted by Cornejo-ram fez et al. [28], indicates that starches with a low amylose concentration are thought to have a higher swelling capacity.

Table 2. Swelling power of starches.

S/No	Samples	Swelling power (g/g)
1	Qulle	5.31
2	Kello	7.46

The swelling power values obtained in this study align with findings from Chisenga et al. (2019), who reported that the

swelling powers (g/g) of cassava starches from six different varieties ranged from 2.22 to 15.63 g/g at temperatures between 50 °C and 90 °C. However, the results in this study were slightly lower than those reported in earlier research. For instance, Charles et al. [29] found swelling power values reaching as high as 27.2 to 42.3 g/g, while Onitilo et al. [30] reported values between 9.0 and 16.9 g/g at 80 °C. Additionally, the swelling power values in this research were lower than those of corn starch (4–18 g/g) and significantly lower than potato starch (42–168 g/g) as noted by Ayetigbo et al [23]. Swelling power is crucial for characterizing starches, reflecting their solubilization potential and non-covalent interactions, which affect the quality of cassava roots for consumption and their industrial applications [6].

3.1.2. Water Absorption Capacity

Table 3 shows the results for the two cassava starches' capacity to absorb water. When starch granules are combined with water, their physical characteristics and composition are known to affect their ability to absorb water [31]. The integrity of starch in an aqueous dispersion can be determined by measuring the volume it occupies after swelling in excess water.

Table 3. Water absorption capacities of starches.

S/No	Samples	Water absorption capacity (g/g)
1	Qulle	24.753
2	Kello	9.628

The variation in water absorption capacity (WAC) observed in the table indicates differences in hydrogen bonding among the starches, influenced by their size, shape, structural features, and water binding sites. These differences may also stem from variations in starch content or how their granules interact with water [23]. A higher WAC suggests a looser starch polymer structure, while a lower value indicates a more compact molecular structure [23]. For example, Chinma [32] reported a WAC of 18.0 g/g for cassava starch. The increased WAC in cassava starch may be linked to the abundance of polar amino acids, which facilitate water interaction. Compared to other samples, cassava starch exhibits a higher WAC, potentially due to its greater carbohydrate content [32]. While food materials often absorb water based on protein content, the low protein levels in cassava starch suggest that WAC is primarily due to the loose association of amylose and amylopectin molecules [33].

3.1.3. Oil Absorption Capacity

Table 4 highlights the oil absorption capacity of starches from the two cassava varieties. Oils can interact with amylose

to form complexes, which hinder starch granule swelling and complicate gelatinization. Consequently, the interaction between oil and starch is likely to influence the starch's physical properties [31].

Table 4. Oil absorption capacity.

S/No	Samples	Oil absorption capacity (g/g)
1	Qulle	21.81
2	Kello	19.84

The oil absorption capacities measured in this study were lower than those reported for bean starches (2.42–3.35 g/g) by Olu-owolabi et al. [34]. Eke-Ejiofor [35] found cassava starch to have an oil absorption capacity of 1.0 g/g. However, the values from this study were higher than those reported by Ezeocha and Okafor [36], who noted ranges of 9.20–11.30 g/g for cassava and potato starches. Starch's oil absorption capacity indicates its emulsifying ability, enhancing mouthfeel and flavor retention. This capacity is influenced by the lipophilic properties of starch molecules and factors like amino acid content and protein structure [37].

3.1.4. Water Solubility

The solubility of starch in water can be used to assess the number of interactions between starch chains in the crystalline and amorphous domains. Granular and molecular structural variations among the starches may be the cause of the variations in starch solubility shown in Table 5.

Table 5. Water solubility of the extracted starches.

S/No	Samples	Water solubility (%)
1	Qulle	36.80
2	Kello	31.52

Cassava starch solubility values in this study were found to be aligning with previous reports of 1.62–71.15% [8]. Starch solubility is positively correlated with amylose content, as higher amylose levels enhance solubility. Qulle starch, which contains more amylose than Kello starch, demonstrates greater solubility. The solubility of starch reflects the extent of intermolecular cross-linking within its granules. Compared to other tuber crops, cassava starch exhibits higher solubility, partly due to its pronounced swelling during gelatinization. This behavior is influenced by factors such as swelling power and the presence of components like phosphorus [38].

3.1.5. Amylose and Amylopectin

Table 6 shows the amount of amylose and amylopectin in the separated cassava starches. The main causes of the variations in amylose and amylopectin content in cassava are variations in genotype or variety [39]. Amylose and amylopectin are the two main components of starch, a complex carbohydrate found in plants. They are both polysaccharides composed of glucose

units, but they differ significantly in their structure and properties. It is classified as waxy starch when the amylose percentage is 0–2% and as semi-waxy starch when the amylose content is 3–15%. Additionally, normal or regular starch is defined as having an amylose value of 15–35% and greater than 40% [8]. As a result, the cassava starch types in the current study can be categorized as regular or normal starches.

Table 6. Amylose and amylopectin content of the starches.

Parameters	Results from this study (%)		Results from previous study	
	Kello	Qulle	Result	Reference
Amylose content	18.15±0.01	25.29±0.01	14.20 – 25.31	[39]
Amylopectin	78.23±0.99	74.71 ±0.99	74.69 – 85.80	[39]

The amylose content in Kello starch (18.15%) was lower than that in Qulle starch (25.29%). This suggests that Kello starch may have a softer texture and lower gel strength compared to Qulle starch. Additionally, the amylopectin content in Kello starch (78.23%) was higher than that in Qulle starch (74.71%). This indicates that Kello starch may have a higher viscosity and better water-holding capacity. The results obtained in this study are generally consistent with previous reports, which have shown a wide range of amylose and amylopectin contents in different starch sources. The variation in these contents can be attributed to factors such as plant variety, growing conditions, and processing methods.

3.1.6. Pasting Behavior of the Starch

Table 7 summarizes the pasting properties of starch from two cassava varieties: Qulle and Kello. The peak viscosity (PV) for Qulle starch is 1551.0 cP, which is slightly lower than Kello's PV of 1612.0 cP, indicating that Kello starch can achieve a higher viscosity when heated. The trough viscosity (TV) for Qulle is 869.0 cP, while Kello's TV is marginally lower at 844.0 cP. This suggests that both varieties retain a

similar ability to maintain viscosity, although Qulle has a slight advantage in this aspect. The breakdown viscosity (BV) shows that Qulle has a BV of 692.0 cP compared to Kello's 777.0 cP, which indicates that Qulle starch is somewhat more stable during cooking, as lower breakdown values suggest less viscosity loss upon cooling.

The final viscosity (FV) is higher for Qulle at 1345.0 cP compared to Kello's 1286.0 cP, indicating that Qulle starch can form a stronger gel upon cooling. The setback viscosity (SB) is also slightly higher for Qulle (486.0 cP) than Kello (463.0 cP), which reflects its ability to retain viscosity over time, contributing to a more desirable textural quality in applications. The pasting temperature (PT) for both varieties is similar, with Qulle at 68.40 °C and Kello at 67.95 °C, indicating that both starches gelatinize at comparable temperatures. The peak time for both varieties is also close, with Qulle at 5 minutes and Kello at 4.87 minutes, suggesting that they require similar times to reach peak viscosity. Generally, while both starches exhibit favorable pasting properties, Qulle starch demonstrates slightly better stability and gel strength than Kello.

Table 7. Pasting properties of starches.

Samples	PV (cP)	TV (cP)	BV (cP)	FV (cP)	SB (cP)	PT (°C)	Peak time (min)
Qulle	1551.0	869.0	692.0	1345.0	486.0	68.40	5.0
Kello	1612.0	844.0	777.0	1286.0	463.0	67.95	4.67

Where: TV: Trough (minimum viscosity) (cP), PV: Peak viscosity (cP), SB: Setback (cP), FV: Final viscosity (cP), BV: Breakdown viscosity, and PT: Pasting temperature (°C).

3.2. Characterization of the Packaging Film

3.2.1. Moisture Content

Moisture content is a critical parameter in the characterization of films, as it directly influences their physical and mechanical properties. A higher moisture content can lead to increased flexibility and softness, but it can also compromise the film's strength and durability. Conversely, a lower moisture content can result in brittleness and cracking. In Table 8, the Kello variety exhibits a slightly higher moisture content (11.53%) compared to the Qulle variety (10.52%). This difference might not be substantial enough to cause significant variations in the films' performance under standard conditions. However, it could become more relevant in environments with fluctuating humidity or when the films are subjected to extreme temperatures. Further analysis, such as moisture absorption and desorption studies, would be necessary to fully understand the implications of this moisture content difference on the films' long-term behavior.

Table 8. Moisture content results of the films.

S/No	Samples	Moisture content values (%)
1	Kello	11.53
2	Qulle	10.52

3.2.2. Color of the Packaging Film

Color perception in films is a complex phenomenon influenced by various factors, including the film's composition, thickness, and the specific wavelengths of light it absorbs and reflects. When light interacts with a film, certain wavelengths are absorbed while others are transmitted or reflected. The combination of these reflected wavelengths determines the perceived color. Color plays a crucial role in packaging for several reasons. It can evoke emotions, influence consumer perceptions, and even impact product sales. For example, red can be associated with energy and excitement, while blue might convey trust and reliability. Additionally, color can be used to differentiate products and make them stand out on store shelves.

Table 9 shows significant differences in the color parameters between the Kello and Qulle varieties. The L^* value, representing lightness, is considerably higher for Kello (90.14) compared to Qulle (45.02), indicating a lighter appearance. The a^* and b^* values, related to red-green and yellow-blue axes, respectively, also differ significantly. Kello has an a^* value of -0.92, while Qulle's a^* value is -0.39, suggesting a slightly more reddish hue for Kello. Similarly, Kello's b^* value of 1.61 indicates a more yellowish tone compared to Qulle's -1.12. These differences in color parameters could be attributed to variations in the film's

composition or manufacturing processes. Understanding these color differences is essential for packaging design, as they can impact the overall visual appeal and consumer perception of the product.

Table 9. Assessment of the color of the films.

Parameters		Samples	
Samples	Reference	Kello	Qulle
L^*	90.14	45.02 ± 0.51	46.52 ± 0.12
a^*	-0.92	-0.39 ± 0.10	-0.45 ± 0.02
b^*	1.61	-1.12 ± 0.86	-3.17 ± 0.19
ΔE^*		44.29	45.36
Chroma (C^*)		2.68	4.50

3.2.3. Film Transparency

Transparency in packaging film refers to its ability to allow light to pass through. It's a crucial property for many packaging applications, as it can enhance product visibility, create a sense of freshness, and even influence consumer perceptions. For example, clear packaging can make products look more appealing and inviting, while opaque packaging can suggest a premium or exclusive quality. Table 10 shows that both the Kello and Qulle varieties have relatively high transparency levels, with values of 12.72% and 13.10%, respectively. These values suggest that both films are reasonably transparent, allowing a certain amount of light to pass through.

Table 10. Transparency of the films.

S/No	Samples	Transparency (%)
1	Kello	12.72
2	Qulle	13.10

However, a slight difference exists, with the Qulle variety exhibiting slightly higher transparency than the Kello variety. This difference might be attributed to variations in the film's composition or manufacturing process, such as the presence of additives or variations in thickness. While the difference is small, it could be relevant in applications where even subtle variations in transparency can impact the overall appearance and perceived quality of the packaged product.



Figure 1. Appearance of the developed film.

3.2.4. Film Thickness

Film thickness is a critical property that affects the physical and mechanical characteristics of packaging films. It influences factors such as strength, barrier properties, and overall performance. A thicker film can provide better protection against punctures and tears, but it may also be less flexible and more costly. Conversely, a thinner film can be more pliable and economical, but it may compromise durability and product protection. Table 11 shows that the Kello variety has a slightly thicker average thickness of 0.12 mm compared to the Qulle variety, which measures 0.11 mm.

Table 11. Results of film thickness.

S/No	Samples	Thickness (mm)
1	Kello	0.12±0.02
2	Qulle	0.11±0.03

While this difference might seem small, it could be significant depending on the specific application and the desired balance between strength and flexibility. For example, a thicker film might be preferable for packaging heavy or sharp products, while a thinner film could be more suitable for applications requiring a lightweight and flexible material.



Figure 2. Film thickness measurement using digital micrometer.

3.2.5. Mechanical Properties of Films

(i). Tensile Strength

Tensile strength evaluates a material's ability to withstand breaking under tension. The Kello variety has a tensile strength of 14.634 MPa, whereas the Qulle variety shows a slightly higher tensile strength of 15.952 MPa. This suggests that the Qulle variety is better able to resist tearing or breaking when subjected to pulling forces. The values for tensile strength of both samples are shown in Table 12.

Table 12. Summary for mechanical properties of the films.

S/No	Samples	TS (MPa)	E (%)	Y (MPa)
1	Kello	14.634	75.417	22.457
2	Qulle	15.952	60.252	32.351

(ii). Elongation (E)

Percent elongation indicates a material's ability to stretch before breaking. As it indicates in Table 12, Kello variety has a higher percent elongation of 75.417%, meaning it can stretch more before failing. In contrast, the Qulle variety has a percent elongation of 60.252%, indicating a lower degree of elasticity.

(iii). Young's Modulus (Y)

Young's modulus is a measure of a material's stiffness. A higher Young's modulus indicates a stiffer material, while a lower value suggests a more flexible one. As shown in Table 12, Qulle variety has a higher Young's modulus of 32.351 MPa compared to the Kello variety's 22.457 MPa. This suggests that the Qulle variety is stiffer and less likely to deform under stress.

3.2.6. Water Absorption

The results indicate in Table 13 shows that both Qulle and Kello films exhibited significant water absorption, with Kello demonstrating a slightly higher capacity (31.18%) compared to Qulle (28.09%). This suggests that both films are hydrophilic, meaning they have an affinity for water. The observed difference in water absorption between the two films could be attributed to factors such as the chemical composition, molecular structure, or processing conditions used in their production. Further analysis and comparison with other materials would be necessary to draw definitive conclusions about the implications of these water absorption properties for specific applications. Understanding the water absorption behavior of these films is crucial for assessing their suitability in various environments, particularly those with high humidity or direct exposure to water.

Table 13. Water absorption of the film.

S/No	Samples	Water Absorption (%)
1	Qulle	28.09
2	Kello	31.18

3.2.7. Water Vapor Transmission Rate

The results show in Table 14 indicates that both Kello and Qulle films exhibit relatively low water vapor transmission rates (WVTR), with Kello having a slightly lower WVTR of 0.114 g/h.m² compared to Qulle's 0.121 g/h.m². This indicates that both films offer a moderate barrier against the passage of water vapor. However, further evaluation against specific standards or requirements would be necessary to assess their performance in different applications. Factors such as the thickness, density, and chemical composition of the films likely influence their WVTR. Additionally, the environmental conditions, including temperature and humidity, can affect the rate of water vapor transmission. Understanding the WVTR of these films is important for applications where moisture control is critical, such as packaging, construction materials, or medical devices.

Table 14. Water vapor transmission rate of the film.

S/No	Variety	water vapor transmission rate WVTR (g/h.m ²)
1	Kello	0.114
2	Qulle	0.121

3.2.8. Water Solubility of the Film

The water solubility results in Table 15 for the films made from Qulle and Kello show notable differences, with Qulle exhibiting a higher solubility of 29.15% compared to Kello's 27.28%. This variation may be attributed to differences in their chemical compositions, where Qulle may contain more hydrophilic groups, leading to greater interaction with water. Additionally, the morphological characteristics of the films—such as crystallinity—could influence how water penetrates and affects their structural integrity. In terms of applications, the higher solubility of Qulle suggests it could be advantageous for uses requiring rapid disintegration in water, like biodegradable packaging or controlled release systems. Conversely, Kello's lower solubility may make it preferable for applications needing moisture resistance, such as protective coatings. Understanding these solubility characteristics is crucial for optimizing material selection based on specific environmental and performance requirements.

Table 15. Water solubility results.

S/No	Samples	Water solubility (%)
1	Qulle	29.15
2	Kello	27.28

4. Conclusion

In conclusion, the study demonstrates the potential of cassava starch-based films as eco-friendly alternatives to synthetic plastics in food packaging. By comparing starches from two Ethiopian cassava varieties, Kello and Qulle, the research reveals significant differences in their physicochemical, mechanical, and barrier properties, influenced by genetic and environmental factors. The findings offer valuable insights into the applicability of these starches for biodegradable packaging films, with each variety showing unique strengths. The Qulle variety exhibits superior tensile strength, making it ideal for applications needing robust packaging, while the Kello variety, with better flexibility, suits uses where stretchability is prioritized. Both varieties provide adequate strength for packaging processes, handling, and storage. Additionally, the films' water vapor transmission rates (WVTR) and water solubility are key for food preservation. Qulle starch-based films, with higher solubility and lower WVTR, are better for dry foods, while Kello's lower solubility makes it more suited to moist or semi-solid food packaging. The study also highlights the impact of starch granule structure, specifically amylose and amylopectin ratios, on film performance. Kello starch, with lower amylose, offers enhanced flexibility and swelling, whereas Qulle's higher amylose contributes to greater mechanical stability. This research supports the development of sustainable packaging solutions using cassava starches, with both varieties showing promise for commercial application based on specific packaging needs.

Abbreviations

MC	Moisture Content
WVTR	Water Vapor Transmission Rate
ASTM	American Society for Testing and Materials
FTIR	Fourier Transform Infrared Spectroscopy
RVA	Rapid Visco Analyzer
TS	Tensile Strength
EAB	Elongation at Break

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Conflicts of Interest

The authors declare no conflicts of interest.

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