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Comparative Investigation of Cassava Peels-Derived Starch as an Alternative to Tuber-Derived Starch

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ABSTRACT
The current global circular economy drive has necessitated the investigation of alternative materials from precursor materials to reduce pressure on the mainstream and valorise their waste products. This study investigated the possibility of using Dry Cassava Starch Peel Extract (DCSPE) as an alternative to the conventional Wet Cassava Tuber Starch Extract (WCTSE). Cassava tubers were obtained, washed, and grated to release starch granules from the fibrous tubers, then soaked for 3 hours to obtain the starch extract. The various functional properties were determined in triplicate experimental data and analysed using Welch's independent-samples *t*-test at $p < 0.05$. The starches' structural composition was analysed via Fourier transform infrared spectroscopy (FTIR), while the starches' composition was examined using Gas chromatography-mass spectrometry (GC-MS). The improved gelatinisation temperatures of DCSPE (70.60 ± 0.36 °C) indicate greater thermal stability than WCTSE (65.07 ± 0.15 °C). DCSPE exhibited FTIR spectra with functional groups like those of WCTSE. The GC-MS analysis revealed highest glucose in DCSPE (42.42%). DCSPE can usefully replace WCTSE as binders for non-food industrial applications.

Keywords: Cassava tuber, Circular economy, Extract, Peels, Starch

INTRODUCTION

Cassava (*Manihot esculenta Crantz*) is a crucial global food and industrial crop due to its ability to produce large quantities of starch-rich roots across a wide range of agroecological conditions (Borku, 2025; Villadiego-del Villar et al., 2026). About 334 million tonnes of cassava were produced worldwide in 2023, with Nigeria accounting for about 18% of the total, followed by the Democratic Republic of Congo, Thailand, Ghana, and Brazil (Li et al., 2025; Otekunrin, 2024). Over 500 million people rely on cassava as a primary source of carbohydrates, especially in tropical regions, where it is the second-most important source of calories after rice and maize (Borku, 2025).

Cassava starch, traditionally extracted from the tuberous root (tapioca), is a vital feedstock for industrial, food, and feed applications. A significant part of the processed cassava value chain is supported by the worldwide cassava starch sector, with food-grade and industrial starch production and export markets dominated by the Asia-Pacific (Amelework et al., 2021; Gatune, 2016). However, cassava supply is inadequate due to logistical constraints, climate variability, and poor infrastructure development in the main producing zones, resulting in low yields (10–15%) in Southeast Asia and 30–40% post-harvest losses in some parts of Africa (Stathers et al., 2020).

Large-scale processing of cassava tubers for starch, gari, and *fufu* (a delicacy in West Africa) leaves a significant amount of cassava peels. The 10–15% by mass of cassava peels in cassava tubers has been underutilized. Only small quantities are used as animal feed, while the rest is left to decompose, resulting in resource waste and environmental pollution. The valorization of the underutilized biomass can offer a substantial feedstock for sustainable starch extraction (Li et al., 2025; Tonisi et al., 2026). Cassava peels contain a significant amount of extractable starch, with their physicochemical properties (such as thermal stability, amylose/amylopectin ratios, and granule structure) falling within ranges appropriate for both food and industrial use (Fronza et al., 2023; Olivato, 2024). Additionally, new bioprocessing methods and optimisation approaches (such as acid hydrolysis and hot-water extraction followed by controlled drying) have increased peel biomass yields, indicating viability at greater scales (Afzia & Ghosh, 2026).

The novelty and sustainability of starch extraction from dry and wet cassava peels align perfectly with the goal of advancing a circular economy by harnessing abundant agro-industrial waste into a high-value product, thereby minimizing environmental pollution. The conversion of cassava peels to starch will reduce overreliance on primary tuber starch, which requires large volumes of water, extensive land, high energy inputs, and encourage an integrated biorefinery concept. The extracted starch from peels can serve as a suitable raw material for biopolymer production, a thickener, and other high-value applications (Afzia & Ghosh, 2026; Fronza et al., 2023; Olaniyan et al., 2025). The use of peel-derived starch as a sustainable alternative can further reduce the carbon and water footprints associated with starch supply chains, in addition to its industrial prospects (Afzia & Ghosh, 2026; Fronza et al., 2023; Olaniyan et al., 2025). The advantage of extracting starch from dry cassava peels is the prolonged shelf life of the peels in their dried form, due to their low moisture content (Freitas, 2026). This study was

therefore aimed at providing useful information on the sustainable production of starch from cassava peels as an alternative to tuber-derived starch, and at investigating the functional, structural, and compositional properties of the starches.

MATERIALS AND METHODS

Extraction of Cassava Starch

Tropical Manihot Selection 92/0326 variety of freshly harvested cassava tubers, and dry cassava peels were sourced from local cassava processing plant in Zango, Lokoja, Adavi Local Government Area, Kogi State, Nigeria. The Cassava tubers were washed to remove sand, dirt, and stones that come with them during harvesting, before peeling was done to avoid starch contamination. Two batches of tubers were separately grated and crushed to release starch granules from the fibrous tissue, while dry cassava peels were cut into small pieces, blended separately, and extracted to obtain their starch. The slurry was sieved through a double layer of cheesecloth and allowed to settle for 3 hours before decanting. The recovered starch was air dried for 24 hours after which it was oven dried at 45 °C for 24 hours and stored for analysis. The extraction yield was determined using Equation 1 (Hasmadi et al. 2021).

$$Extraction\ Yield\ (\%) = \frac{Starch\ wight\ (g)}{Cassava\ weight\ (g)}\ X100 \qquad (1)$$

Determination of Functional Properties

Gelatinization Temperature

A starch suspension was prepared by mixing 2 g of starch with 100 mL of distilled water. The mixture was heated gradually in a water bath with continuous stirring. The temperature at which thickening began was recorded (Hasmadi et al. 2021).

Pasting Property (viscosity)

1 g of Starch slurry was heated with constant stirring until a paste formed. The viscosity was observed and measured using a viscometer at 64 °C (Brookfield DV III Ultra) (Chandanasree et al., 2016).

Retrogradation

The prepared 2 g of starch paste was allowed to cool and stored for 24 hours. Gel formation and water separation were observed.

Water Absorption Capacity

A 2 g weight of starch was mixed with water and centrifuged. The retained water in the residue was measured and expressed as a percentage of the weight of water absorbed by 1 g of starch (Andriyani et al. 2024).

Swelling Power and Solubility

A 2 g weight of starch was heated at 90 °C in excess water, centrifuged, the swollen granules were weighed, and the Swelling power was calculated using Equation 2. The supernatant from the heated starch was evaporated, and the dried residue was weighed to determine solubility (Equation 3) (Andriyani et al. 2024).

$$Swelling\ Power\ \left(\frac{g}{g}\right) = \frac{W_p}{W_d} \qquad (2)$$

Where W_p=Weight of swollen sediment/paste after centrifugation (g)

W_d =initial dry weight of starch sample (g)

$$Solubility\ (\%) = \frac{W_s}{W_d}\ X\ 100 \qquad (3)$$

Where W_s=Weight of dried solid recovered from the supernatant (g)

W_d =initial dry weight starch sample used (g)

Viscosity

The thickness of the 200 m starch paste was measured using a viscometer at 40 °C (Brookfield DV III Ultra).

Gel Strength

The gel formed after cooling was pressed to determine firmness using a Texture Analyzer (TA). The starch slurry was first heated to 95 °C to fully gelatinize it, then allowed to cool in a refrigerator for 24 hours before being placed on a TA platform for testing. Using the TA provides a standardized measure directly linked to the starch final application. The gel strength was obtained from the relation:
Gel strength (N.mm) = Breaking force x Breaking point

Freeze–thaw Stability

A 1 g gel was repeatedly frozen at -1.4 °Cand thawed, and the water separation was weighed. The Freeze-thaw stability was determined according to Equation 4.

$$Freeze - thaw\ stability\ (\%) = \frac{w_s}{w_t}\ X100 \qquad (4)$$

Where W_s=Weight of water separated after centrifugation (g)

W_t =Total initial weight of the sample (g)

Syneresis

A 1 g of gel was weighed and stored under refrigeration at -5 °C for one hour, the water released over time was weighed, and the syneresis was calculated according to Equation 5.

$$Syneresis\ (\%) = \frac{w_r}{w_t} X100 \qquad (5)$$

Where W_r=Weight of water released (supernatant) (g)

W_g =initial weight of the gel sample (g)

Determination of Amylose/Amylopectin Content

The amylose content was determined using an amylose/amylopectin assay kit (Megazyme International, Wicklow, Ireland) by selectively precipitating amylopectin with concanavalin A (Con A) and removing it by centrifugation (Hasmadi et al. 2021).

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 29. Data were expressed as mean ± standard deviation (SD) for three independent observations. Differences between WCTSE and DCSPE were assessed using Welch's independent-samples *t*-test. The Shapiro–Wilk test was used to assess normality, while Levene's test was used to assess homogeneity of variance. Statistical significance was considered at $p < 0.05$.

FTIR Analysis

The starch samples were analysed using a Fourier-Transform Infrared (FTIR) spectrometer coupled to the attenuated total reflectance technique with a ZnSe crystal (IR-Affinity, Shimadzu, Kyoto, Japan). The analysis region was 4000 – 500 cm−1 (Garces et al., 2021). FTIR was used to identify chemical bonds and functional groups across a wide range of materials by measuring their infrared absorption.

Gas Chromatography– Mass Spectrometry analysis (GC - MS)

The GC–MS analysis was primarily used for qualitative chemical profiling. Relative abundance was assessed from chromatographic peak areas where applicable; the resulting peak-area percentages were interpreted as relative chromatographic abundance rather than absolute concentrations. The starch powder sample for Gas

Chromatography–Mass Spectrometry (GC–MS) analysis was first converted to volatile compounds, as native starch is non-volatile. The starch powder was initially dried in an oven at about 50 – 60 °C to remove moisture, then finely ground to ensure uniformity. A known weight of dried starch was hydrolysed with dilute acid, such as hydrochloric acid, to break it down into simpler sugars. The resulting hydrolysate was then neutralized and filtered to remove impurities. Since sugars are not sufficiently volatile for GC–MS, a derivatization step was performed with silylating agents to convert them into volatile derivatives. The prepared sample is then diluted with hexane, filtered through a micro-filter, and transferred into a GC vial for injection into the GC-MS system for analysis. 10 µL of each sample was dissolved in 0.5 mL of hexane and dried over anhydrous sodium prior to GC-MS analysis. The analyses were performed on a Varian 3800/4000 gas chromatograph mass spectrometer; a non-polar fused silica capillary column (30 m x 0.25 mm, 0.25 µm film thickness) was used. The oven temperature was set to 70 °C for 4 min, ramped at 8 °C/min to 240 °C, and held at 240 °C for 20 min. The flow rate of the carrier gas, helium, was 1 mL/min. The injection volume was 1 µL of diluted oil in hexane. The mass spectrometer detector was operated in electron ionization mode, and all spectra were acquired over a mass range of 40 to 800 m/z using Automatic Gain Control (AGC). The identification of compounds was based on the retention time match and mass spectra match against standards and NIST mass spectra library. Using computer searches on a NIST Ver. 08 MS data library and comparing the spectrum obtained through GC-MS, compounds present in the plant samples were identified. Interpretation of the GC-MS mass spectrum was performed using the National Institute of Standards and Technology (NIST) library, which contains more than 62,000 patterns. The mass spectrum of the unknown component was compared with the spectrum of the known components stored in the NIST library.

RESULTS AND DISCUSSION

The extraction yield of starch from DCSPE (14.08%) is higher than 10.7% from WCTSE. The starch extraction yields in this study is lower than the 21.71% reported by Hasmadi et al. (2021).

Functional Properties of Cassava Starches from Different Sources

Table 1 presents the functional qualities of starch from various sources. The functional characteristics of most of the starch samples differed significantly ($p < 0.05$) according to the statistical analysis.

Gelatinisation Temperature

The gelatinisation temperatures (65.07 – 70.60 °C) obtained for the starch samples agree well with reported values for cassava starch, ranging from 60 °C to 75 °C (Chamorro et al., 2025). The gelatinisation temperature of DCSPE (70.60 ± 0.36°C) was significantly higher than that of WCTSE (65.07 ± 0.15°C). Stronger intermolecular hydrogen bonds and improved crystalline arrangement within amylopectin double helices are suggested by the noticeably higher DCSPE value of 70.60 ± 0.36 °C. This is because higher thermal energy is required to disrupt enhanced crystalline order (Haixia et al., 2024; Song et al., 2025). Peel-derived starch's higher gelatinisation temperatures of DCSPE suggest its use for high-temperature processing systems, including extrusion, and binder in the manufacturing of charcoal, since higher gelatinisation temperatures are associated with enhanced heat resistance (Puri et al., 2025).

Pasting properties and viscosity behaviour

The ultimate viscosity of DCSPE (473.67 ± 9.29 cP) is higher than WCTSE (316.33 ± 4.0 cP), and the pasting viscosity of DCSPE (15.66 ± 0.50 cP) is higher than WCTSE (12.39 ± 0.51). Increased granule swelling and polymer leaching, especially amylopectin, which controls viscosity development during heating (Vamadevan & Bertoft, 2020), are indicated by the higher pasting viscosity in DCSPE. The increased molecular reassociation and network formation during cooling are reflected in the noticeably higher ultimate viscosity in DCSPE. This is consistent with studies in the literature showing that starches with comparatively higher amylose content yield stronger gels and higher ultimate viscosities due to reassociation and chain tangling. Despite substantial swelling, the reduced viscosity of DCSPE at the end points suggests poorer gel network formation, suggesting that amylopectin connections predominate over amylose interactions (Vamadevan & Bertoft, 2020; Xie et al., 2009).

Water Absorption Capacity and Swelling Power

WCTSE showed higher swelling power (8.15 ± 0.08) over peel-derived starch, and water absorption (2.73 ± 0.19 g/g). The absorption of water molecules by starch granules is due to the existence of hydrogen bonds between water molecules and hydroxyl groups. This high amount of hydroxyl groups in starch favours hydration and swelling (Chamorro et al., 2025). The decreased swelling in DCSPE (6.44 ± 0.10 g/g) could be attributed to higher crystallinity and stronger internal bonding in the starch samples. The low protein and lipid content of cassava starch enhanced its swelling capability (Chamorro et al., 2025; Puri et al., 2025; Xie et al., 2009). It can therefore be inferred that the structure of WCTSE is less compact and more native.

Solubility Behaviour

The highest solubility recorded in WCTSE (12.71 ± 0.08%) implies higher molecular disintegration and leaching of the soluble starch fraction. The release of amylose into the aqueous phase and the breaking of hydrogen bonds play significant roles in determining solubility (Vamadevan & Bertoft, 2020). This is consistent with an earlier report that structural weakening enhances starch polymer solubilisation during heating (Chi et al., 2019; Suri & Singh, 2023). From an industrial standpoint, high solubility is preferred in applications where quick dispersion is required, like instant foods, drinks, and sauces, (Puri et al., 2025).

Gel Strength and Retrogradation Behaviour

The highest gel strength recorded in DCSPE (1.16 ± 0.05) indicates a higher capacity to form a network of rigid three-dimensional structure. This phenomenon is attributed to the formation of crystalline junction zones due to increased amylose reassociation during cooling (Suri & Singh, 2023; Xie et al., 2009). Higher retrogradation and syneresis is linked to robust gel formation. This is substantiated by the high syneresis of 13.85 ± 1.62% in DCSPE, which implies water evacuation due to molecular realignment. The amylopectin aids long-term structural ordering, while amylose recrystallisation is the primary driver of retrogradation. The significant gel formation in DCSPE signifies higher effective amylose interactions (Vamadevan & Bertoft, 2020; Xie et al., 2009).

Freeze–Thaw Stability and Syneresis

A marked difference was observed in the freeze–thaw stability of the two cassava starches. WCTSE exhibited significantly higher freeze–thaw stability (84.33 ± 1.49%)

than DCSPE (61.06 ± 0.19%). This result indicates that WCTSE was more resistant to structural changes and water separation during repeated freezing and thawing cycles (Suri & Singh, 2023). The superior freeze–thaw stability of WCTSE may be associated with its higher amylopectin content (68.08%) and lower amylose content (31.92%). Amylopectin-rich starch systems generally exhibit reduced molecular reassociation during storage at low temperature, thereby limiting retrogradation and the consequent expulsion of water from the starch matrix. In contrast, DCSPE, which contained a considerably higher amylose content (45.46%), showed lower freeze–thaw stability. The relatively high amylose content may promote reassociation and retrogradation during storage, particularly under repeated freezing and thawing conditions. Formation of more ordered starch structures during retrogradation can reduce the ability of the gel network to retain water, thereby increasing the tendency towards phase separation. This interpretation is further supported by the higher syneresis observed for DCSPE (13.85 ± 1.62%) compared with WCTSE (10.08 ± 0.04%). Thus, the higher syneresis and lower freeze–thaw stability of DCSPE are consistent with greater structural reorganisation of its starch matrix during storage (Zhang et al., 2025).

Amylose and Amylopectin Composition

The amounts of amylose and amylopectin significantly influenced the functional properties of the starches. DCSPE (45.46 ± 1.65%) had the highest amylose, followed by WCTSE (31.92 ± 1.00 %). The amylopectin of WCTSE (68.08 ± 1.00) is higher than DCSPE (54.45 ± 1.1.65%). Linear amylose chains readily reassociate through hydrogen bonding during cooling and the formation of rigid gel networks. The high amylose content accounts for the higher viscosity, gel strength, and retrogradation properties observed in DCSPE. WCTSE's higher freeze-thaw stability, high solubility, and weaker gel structure can be attributed to its high amylopectin content. Amylopectin's branching structure minimises retrogradation and recrystallisation.

Table 1: Functional Properties of Cassava Starches

Property	WCTSE	DCSPE
Gelatinisation temperature (°C)	65.07 ± 0.15	70.60 ± 0.36
Pasting viscosity (cp)	12.39 ± 0.51	15.66 ± 0.50
Viscosity (cp)	316.33 ± 4.04	473.67 ± 9.29
Water absorption (g/g)	2.73 ± 0.19	1.88 ± 0.06
Swelling power (g/g)	8.15 ± 0.08	6.44 ± 0.10
Solubility (%)	12.71 ± 0.14	8.12 ± 0.04
Gel strength	0.74 ± 0.03	1.16 ± 0.05
Freeze–thaw stability (%)	84.33 ± 1.49	61.06 ± 0.19
Syneresis (%)	10.08 ± 0.04	13.85 ± 1.62
Amylose (%)	31.92 ± 1.00	45.46 ± 1.65
Amylopectin (%)	68.08 ± 1.00	54.45 ± 1.65

Note: Values are mean ± SD, n = 3. Welch's t-test was used because it does not require equal population variances. Holm adjustment was applied to control the family-wise error rate across the quantitative comparisons.

Results of instrumental Analysis on Starch Samples

FTIR Analysis (Structural Characterisation)

The presence of amylose and amylopectin without substantial chemical change is confirmed by the FTIR spectra (Figure 1) of WCTSE, and DCSPE, which show distinctive absorption bands typical of starch polymers. Hydroxyl groups (O–H stretching) involved in intra- and intermolecular hydrogen bonding are linked to a broad absorption band around 3400 cm^{-1} (Monroy et al., 2018). Differences in water interactions and hydrogen-bonding strength are indicated by intensity variations between samples. The aliphatic CH vibrations of glucose units are represented by the absorption band at 2920–2930 cm^{-1} (C–H stretching) (Chamorro et al., 2025). The absorbed water in the amorphous areas of starch is responsible for the absorption band at 1640 cm^{-1} (H–O–H bending) (Chamorro et al., 2025). The high freeze-thaw stability, solubility, and stronger band in WCSPE indicate higher water affinity. The absorption band around 900–1200 cm^{-1} (C–O and C–O–C stretching) shows that the region confirms to starch structure. The absorption band at 1000 cm^{-1} represent a crystalline region, while the peaks around 1080–1020 cm^{-1} depict an amorphous region (Daza et al., 2023; Monroy et al., 2018). Higher intensity of amorphous area bands (1020–1080 cm^{-1}) in WCSPE represents decreased crystallinity, which elucidates the high swelling, freeze-thaw stability and solubility. DCSPE shows a more ordered structure at the absorption band at 1000 cm^{-1}, suggesting a more prominent crystalline presence, which supports the strong retrogradation, high gel strength and high viscosity (Capron et al., 2007). The low syneresis, moderate viscosity, and high swelling properties of WCTSE correspond to an intermediate spectral fingerprint, suggesting a balanced amorphous–crystalline structure. The absence of new peaks in the FTIR spectra of the native starch indicates that the extraction process did not introduce new functional groups (Ramos et al., 2024).

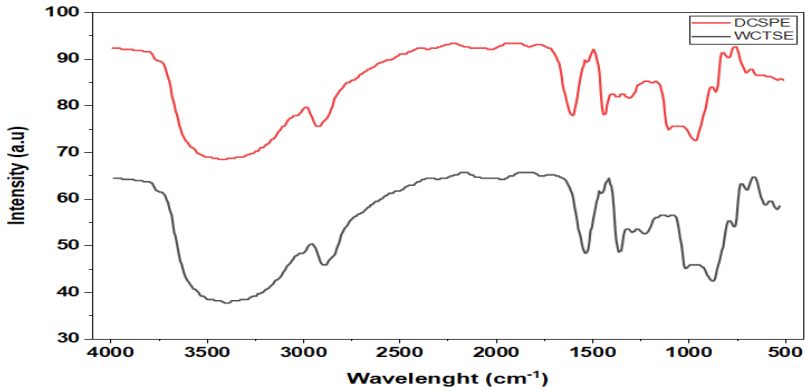

Figure 1: FTIR of extracted cassava starch from different sources

Compositional Analysis of Cassava Starches via GC-MS

The GC-MS results of cassava starch from WCTSE and DCSPE are presented in Figure 2. DCSPE has the highest glucose content of 42.42%, followed by WCTSE (38.62%). This implies that cassava starch is a polysaccharide: and the high glucose content in DCSPE can be attributed to partial depolymerisation during drying (Chamorro et al., 2025). Maltose is the second most abundant component in the starch samples with 27.35% in WCTSE and 25.69% in DCSPE. The presence of maltose and levoglucosan in all samples suggests that starch polymers have undergone thermal degradation, consistent with pyrolytic breakdown mechanisms (Leng et al., 2018). All samples contained organic acids, including butyric, lactic, propionic, and acetic acids, which are products of fermentation or oxidative breakdown of carbohydrates (Leng et al., 2018). Propionic acid (2.18%) and butyric acid (0.98%) are more abundant in DCSPE, which may indicate thermal change during drying. The existence of residual lipids was indicated by the detection of palmitic acid (C16:0), stearic acid (C18:0), and oleic acid (C18:1) in all samples. These fatty acids can form amylose–lipid complexes, which affect retrogradation and gelatinisation behaviour (Marinopoulou et al., 2016; Panyoo & Emmambux, 2017). Levoglucosan and furfural are signs of the heat breakdown of carbohydrates. The partial hydrolysis and reorganisation of starch is confirmed by the presence of sugars, acids, and breakdown products (Marinopoulou et al., 2016; Olawoye et al., 2023; Wang & Copeland, 2015). The highest levels of breakdown products were observed in DCSPE, suggesting that drying promotes depolymerisation. For food applications requiring native starch functionality, WCTSE is appropriate.

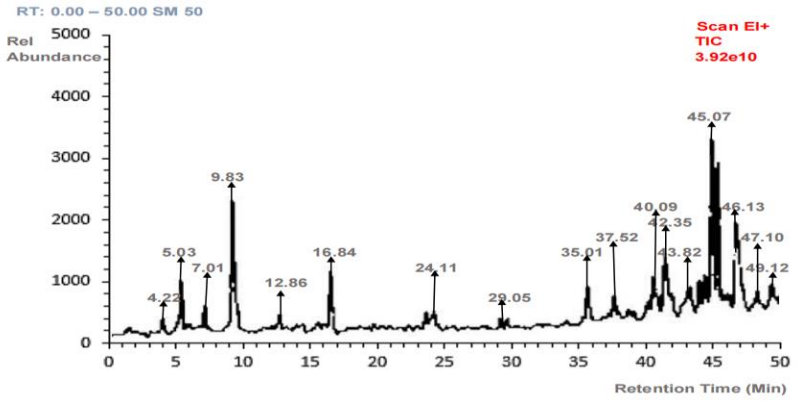

Figure 2: GC-MS analysis of DCSPE

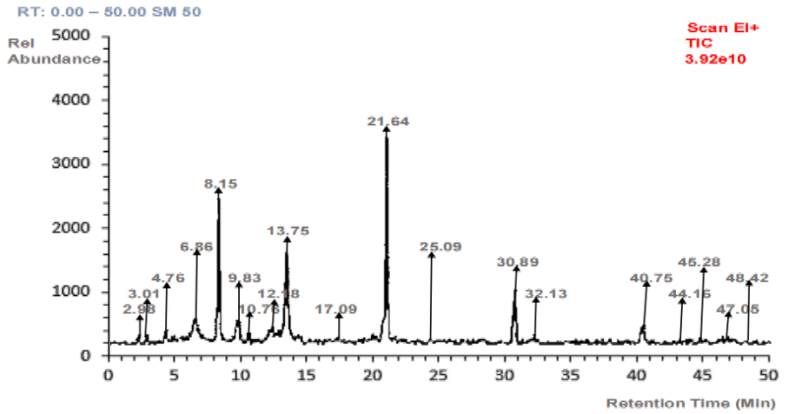

Figure 3: GC-MS analysis of WCTSE

Table 2: GC-MS analysis for the quantitative determination of starch components from different sources

	WCTSE			DCSPE		
NO #	**RT**	**Compound Detected**	**Peak Area %**	**RT**	**Compound Detected**	**Peak Area %**
1	2.98	Glycerol (derivative)	4.28	4.22	Glycerol	3.93
2	3.01	Acetic acid	3.16	5.03	Fructose	6.26
3	4.76	Palmitic acid (C16:0)	2.35	7.01	Levoglucosan	5.62
4	6.86	Stearic acid (C18:0)	1.83	9.83	Maltose (TMS derivative)	25.69
5	8.15	Maltose	27.35	12.86	Acetic acid	2.54
6	9.83	Oleic acid (C18:1)	1.55	16.84	Ethanol	3.54
7	10.76	Ethanol	5.08	24.11	Palmitic acid (C16:0)	2.18
8	12.18	Lactic acid	1.09	29.05	Stearic acid (C18:0)	1.62
9	13.76	Fructose	7.12	35.01	Propionic acid	2.19
10	17.04	Formic acid	2.45	37.52	Oleic acid (C18:1)	1.39
11	21.64	Glucose	38.62	40.09	Butyric acid	0.98
12	25.09	Propionic acid	0.84	42.35	Xylose (derivative)	1.09
13	30.89	Butyric acid	0.98	43.82	Arabinose	1.47
14	32.13	Xylose (derivative)	0.64	45.07	D-Glucose	42.42
15	40.75	Levoglucosan	6.45	46.13	Myo-inositol	0.33
16	44.16	Arabinose	0.13	47.10	Acetaldehyde	1.87
17	45.28	Myo-inositol	0.08	49.12	Furfural	1.63
18	47.05	Acetaldehyde	0.93			
19	48.42	Furfural	1.78			

CONCLUSION

This study demonstrated the valorisation of cassava peels waste processing for derivation of starch within the circular-economy framework as alternative to cassava tubal derived starch. The compositional and functional properties of DCSPE and WCTSE cassava starches were also investigated. DCSPE contained substantially more amylose than WCTSE (45.46 ± 1.17% versus 31.92 ± 0.71%, respectively), with a corresponding lower amylopectin content (54.45 ± 1.18% versus 68.08 ± 0.71%). These compositional differences were reflected in several functional properties. DCSPE exhibited a significantly higher gelatinization temperature (70.60 ± 0.36 °C), pasting viscosity (15.66 ± 0.50 cP) and final viscosity (473.67 ± 9.29 cP) than WCTSE (65.07 ± 0.15 °C, 12.39 ± 0.51 cP and 316.33 ± 4.04 cP, respectively. These characteristics indicate greater thermal resistance and stronger viscosity development during pasting, which may be advantageous as binder in the processing of charcoal and other non-food applications. The FTIR and GC–MS results further demonstrate similar characteristics between the DCSPE and WCTSE.

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