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Full Length Research Paper

A comparison of functional properties of native Malawian cocoyam, sweetpotato and cassava starches

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Cassava, cocoyam and sweetpotato constitute underexploited but yet important sources of starch for the Malawi industry. The functional properties of starches isolated from cassava, cocoyam and sweetpotato were studied and compared. Results revealed diverse functional properties among the starches from the different sources. With increasing temperature, water binding capacity, swelling power and solubility of the starches increased. Cocoyam and sweetpotato starches exhibited lower water binding capacity and swelling power, paste clarity and viscosity but higher degree of syneresis than cassava starches. Solubility was higher in cocoyam starches than sweetpotato and cassava starches. Cocoyam starches had higher gelatinization temperatures than sweet potato and cassava starches but similar transition enthalpies with cassava. Retrogradation studies by differential scanning calorimetry and turbidometry revealed higher levels of retrogradation for cocoyam and sweetpotato starches compared to cassava starches. Thus starches from sweetpotato, cocoyam and cassava would play different roles in various industrial applications.

Key words: Sweetpotato, cocoyam, cassava, starch, functional properties.

INTRODUCTION

Starch is widely used in different applications in the food and non-food industries. Its application is primarily determined by its functional properties which vary with botanical source (Wickramasinghe et al., 2009; Nwokocha et al., 2009; Yuan et al., 2007; Amani et al., 2004). The demand for starch in industries worldwide is currently being met by a restricted number of crops mainly corn, potato and wheat. Tropical root and tuber crops of which sweetpotato (*Ipomoea batatas*), cocoyam (*Colocasia esculenta*) and cassava (*Manihot esculenta*) are important representatives, remain underexploited sources of starch for the industry worldwide despite being rich in starch (Ellis et al., 1998). In Malawi, these three crops are grown mainly as subsistence crops limiting their potential contribution to the starch-based industries. Hence there is need for unveiling the characteristic properties of

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starches from these crops in order to unravel the potential and increase the competitiveness of starches from these crops on the world markets. This study therefore, was undertaken to determine and compare the functional properties of native starches from sweetpotato, cocoyam and cassava grown in Malawi.

MATERIALS AND METHODS

Starch from 15 genotypes of sweetpotato (A45, Babache, Kakoma, Kamchiputu, Kenya, Lunyangwa, LU96/303, LU96/304, Mafutha, Mugamba, Mugande, Salera, Semusa, Tainoni and Zondeni), 7 cocoyam accessions collected from different cocoyam growing districts of Malawi (Chitipa, Mzimba (Mzuzu), Nkhotakota, Machinga, Mulanje, Thyolo and Zomba) and five genotypes of cassava (Gomani, Maunjili, Mbundumali, Mkondezi and Sauti) were used for this study.

Starch isolation

Starch was isolated from the fresh tubers as follows: Fresh tuberous roots were washed, peeled, washed again and chopped to about 1 cm^3 cubes. About 500 g of the chopped tubers were transferred into a heavy duty blender (Warring Commercial, model CBCSA 33BL34), 1 L of water added, and pulverized at a high speed for 5 min. The suspension was then filtered using a 250 μm sieve. The filtrate was allowed to stand for four hours to facilitate starch sedimentation and the top liquid was decanted and discarded. The sediment was resuspended in 1 L of water and the whole process was repeated three times. The sediment was then washed and dried in an air-dried for 48 h. The dried starch was ground and stored in polyethylene bottles prior to analysis.

Water binding capacity (WBC)

Water binding capacity (WBC) of the starches was determined using 2.5% starch suspensions at three temperatures; 50, 70 and 90°C. Dried starch samples of 0.125 g were weighed in triplicates into pre-weighed centrifuge tubes and 5 ml of distilled water added. The samples were heated at each of the above temperature for 1 h with constant shaking and thereafter centrifuged for 15 min at 1500 × *g*. The free water was decanted and the tubes allowed draining off for 10 min at a 45° angle. Subsequently the sample tubes were weighed, and the gain in weight used to calculate the water binding capacity. Water binding capacity was calculated using the following equation(Mishra and Rai, 2006):

WBC (g H_2O g^{-1}) = (Mass of wet starch - Mass of dry starch)/ Mass of dry starch.

Swelling power and solubility

Swelling and solubility of the starches was determined in triplicates as follows: Dried starch samples (0.100 g) were mixed with 5 ml of distilled in 10 ml centrifuge tubes, heated for 1 h at 50, 70 or 90°C while shaking every 5 min. The slurry was centrifuged for 30 min at 1500 × *g*, and the weight of the sediment in grams (B) determined (Kojima et al., 2006). The supernatant (A) was diluted with water until the total volume was 10 mL, and the amount of starch in it was determined by anthrone-sulphuric acid method (Brook et al., 1986). The solubility and the swelling power were calculated using the following equations, where (S) is the sample weight in grams.

Solubility (%) = (100 x A)/S
Swelling power (g g^{-1}) = B/(S-A)

Clarity and stability of starch pastes

Clarity and stability of the starch pastes was determined by the method of Craig et al. (1986) as follows: a 1% aqueous suspension of starch was made by adding 10 mL of distilled water to exactly 0.1 g of starch (dry basis) in a centrifuge tube with screw caps and vortex mixed. The suspension was heated in a boiling water bath for 30 min with constant stirring every 5 min and thereafter cooled to room temperature for 1 h. The percentage transmittance (%T) was measured at 650 nm against a water blank on a spectrophotometer (Spectronic Unicam, Heλios, Cambridge, United Kingdom).

The stability of the starch pastes was determined by placing triplicate starch paste samples prepared above in disposable cuvettes and stored for 5 days at 4°C in a refrigerator. Turbidity was determined every 24 h by measuring absorbance at 640 nm against a water blank (Sandhu and Singh, 2007).

Syneresis

A 5% aqueous starch suspension was made by adding 5 ml of distilled water to 0.25 g (db) in screw-capped centrifuge tube. The suspension was heated in a boiling water bath for 30 min with constant stirring and then cooled rapidly to room temperature on ice bath. After cooling, the tubes with the starch pastes were reweighed to determine the amount of starch paste and then placed in a still-air freezer at -20°C for 48 h. After the freezing period, the samples were placed in a 40°C water bath for 1.5 h to thaw and equilibrate. Syneresis was measured in triplicate as % amount of water released after centrifuging at 1500 x g for 30 min (Singh et al., 2004).

Viscosity

The viscosity of the starch pastes was determined using a Brookfield Digital Viscometer model RTDV II (Brookfield Engineering Laboratories Inc, Stoughton MA 02072, USA) with modifications (ISI, 2002). A 10% starch suspension was prepared in duplicate for each sample by weighing 10 g of dried starch samples into a 600 mL beaker and adding distilled water to bring to the total weight of starch and water to 500 g. The starch suspension was heated in a water bath at 95°C for 30 min with constant stirring. The resultant gelatinized starch was weighed and water added to replace the evaporated water until the gross weight of 500 g. The starch gel was cooled to 50°C in a water bath set at 50°C while stirring and viscosity measured in centipoises (cps) with spindle no. 2 at 100 rpm.

Thermal properties

Thermal properties of raw starches and retrograded were obtained using differential scanning calorimetry (DSC 822e, Mettler, Toledo, Switzerland). Starch samples were prepared by mixing dried starch with distilled water in a ratio of 1:3. Exactly 3.0 mg, in triplicates, of dried starch were weighed into DSC aluminium pans and distilled water added using a transfer pipette to make a starch: water ratio of 1:3. The pans were hermetically sealed and samples were left to stand for 1 h at room temperature for moisture equilibration. The sealed pans were heated from 20 to 95°C under nitrogen gas at a heating rate of 10°C/min to gelatinize the starch samples. From the

DSC thermograms, onset temperature (T_o), peak temperature (T_p), conclusion temperature (Tc) and enthalpy of gelatinization (ΔH_G) were determined using instruments software (STARe SW 9.00). Temperature range and peak height index (PHI) were also calculated as T_c - T_o and as the ratio $\Delta H_G/(T_p-T_o)$ respectively (Peroni et al., 2006)

The gelatinized samples from the gelatinization studies described above were stored at 4°C (refrigerator) for a period of 7 days, equilibrated at room temperature for 2 h, and then rescanned in the DSC from 20 to 95°C at 10°C/min to measure the retrogradation transition temperatures and enthalpy. The degree of retrogradation was determined as the ratio of enthalpy change of retrograded starch to enthalpy change of gelatinized starch (Gunaratne and Hoover, 2002).

Data analysis

Data obtained was subjected to analysis of variance (ANOV A) using Statistix 8 for Windows (Analytical Software Tallahassee, USA). Principal component analysis (PCA) was also performed on the determined functional properties of the starches using NCSS 2004 (Number Cruncher Statistical systems, Kaysville, Utah, USA) in order to identify the main variables that described the similarities and differences between starches and also to find the relationships between the measured properties. Pearson correlation coefficients for relationships between various functional properties were also calculated.

RESULTS AND DISCUSSION

Water binding capacity (WBC)

The water binding capacity of the starches significantly increased with temperature with high increases observed between 50 to 70°C for all starches (Table 1). Generally, cassava starches exhibited significant higher WBC values than sweetpotato and cocoyam starches at all temperatures. Between 50 to 90°C, WBC values ranged from 1.49 to 38.70, 1.28 to 28.31 and 1.47 to 24.71 g H_2O g^{-1}, for cassava, cocoyam and sweetpotato starches, respectively. Variations in WBC within the same botanical source were also observed. Among the cassava genotypes, starch from Sauti displayed the highest WBC at the three temperatures whilst among the cocoyam accessions, starch from Chitipa accession exhibited higher WBC values at 70 and 90°C. No consistent trends were observed among sweetpotato starches. Water binding is a measure of the amount of water that starch granules are able to hold and depends on the capacity of starch molecules to hold water through hydrogen bonding. These observed differences in WBC therefore, indicate the differences in the intensity of the hydrogen bonds forms and the degree of availability of water binding sites among the starches (Hoover and Sosulski, 1986). This ability to hold water is a desirable characteristic in the food industry for consistency of food products. Therefore cassava starches are better suited for the food industry as gelling agents than cocoyam and sweetpotato starches (Gbadamosi et al., 2013). They could also be used in frozen food products as stabilisers and emulsifiers as starches with high WBC usually bind more water preventing syneresis (Otegbayo et al., 2013).

Swelling power and solubility patterns

The swelling power of the starches increased with increasing temperature from 50 to 90°C. This is probably due to the breaking of intermolecular hydrogen bond in the amorphous areas (De la Torre-Gutiérrez et al., 2008). There were significant variations in swelling power among the starches. Generally, the cocoyam and sweetpotato starches exhibited lower swelling power than cassava starches at all temperatures; cassava starches exhibited the highest swelling power (Table 2). The swelling power of the cocoyam starches ranged from 2.29 to 34.10 g g^{-1} from 50 to 90°C while that of sweetpotato starches ranged from 2.49 to 28.22 g g^{-1} from 50 to 90°C. Swelling power of cassava starches ranged 2.50 to 43.81 g g^{-1} from 50 to 90°C. These results agree with those reported by Wickramasinghe et al. (2009). They reported higher swelling power for cassava starches than taro (*Colocasia esculenta*) and sweetpotato starches. Gbadamosi et al. (2013) also reported higher swelling power for cassava starches than cocoyam starches. However they reported lower values of swelling power for cassava and cocoyam starches than the ones observed in this study. Bentacur-Ancona et al. (2001) reported higher swelling power values (58.8 g g^{-1}) for cassava values than the ones obtained in this study.

Solubility of the starches increased with increasing temperature (Table 3). This is because an increase in temperature increases the mobility of starch granules thereby facilitating dispersion of starch molecules in water. The heated and swollen starch granules consequently for allow amylose exudation (Adebowale et al., 2002). Cocoyam starches generally displayed higher solubility than cassava and sweetpotato starches, and sweetpotato starches displayed the lowest solubility. Solubility of cocoyam, cassava and sweetpotato starches ranged from 0.22 to 15.68%, 0.36 to 10.11% and 0.41 to 9.43% from 50 to 90°C, respectively. These results contrast those of Gbadamosi et al. (2013) who reported higher solubility for cassava starches that cocoyam starches.

Both swelling power and solubility provide evidence of the magnitude of interactions between starch chains within the amorphous and crystalline regions. Swelling power is influenced by a strong bonded micellar network and amylopectin molecular structure decreasing with increasing crystallite formation by the association between long amylopectin chains (Srichuwong et al., 2005; Gujska et al., 1994; Sasaki and Masuki, 1998). Thus, the differences in the extent of swelling observed in this study indicate differences in structures among the starches. The differences in solubility of the starches could largely be due to granular and molecular structural

Table 1. Water binding capacity of the cocoyam, sweetpotato and cassava starches.

Botanical source	Accession/genotype	Water binding capacity [g H_2O g^{-1} starch]		
		50°C	70°C	90°C
Cocoyam	Chitipa	1.50^{ij}	**13.42^{fgh}**	**28.31^{c}**
	Machinga	1.31^{k}	6.07^{m}	24.35^{f}
	Mulanje	1.39^{jk}	6.31^{m}	22.04^{h}
	Mzuzu	1.28^{k}	10.91^{j}	22.69^{gh}
	Nkhotakota	1.48^{ij}	2.35^{n}	25.72^{d}
	Thyolo	1.49^{ij}	10.98^{j}	25.65^{de}
	Zomba	1.60^{fghi}	6.04^{m}	22.60^{gh}
	Mean	1.44±0.13	8.01±3.68	24.48±2.20
Sweetpotato	A45	1.80^{cd}	8.22^{l}	20.58^{i}
	Babache	1.66^{efg}	8.09^{l}	20.05^{ijkl}
	Kakoma	1.83^{cd}	11.96^{i}	19.37^{kl}
	Kamchiputu	1.71^{def}	13.67^{f}	19.96^{ijkl}
	Kenya	1.48^{ij}	13.46^{fg}	19.54^{jkl}
	Lunyangwa	1.51^{hij}	13.74^{f}	17.70^{m}
	LU96/303	1.57^{ghi}	11.90^{i}	17.84^{m}
	LU96/304	1.50^{ij}	13.07^{fgh}	19.28^{l}
	Mafutha	1.60^{fghi}	13.09^{fgh}	19.96^{ijkl}
	Mugamba	1.63^{fgh}	14.84^{e}	20.31^{ijk}
	Mugande	1.86^{c}	12.75^{h}	20.17^{ijkl}
	Salera	1.47^{ij}	11.14^{j}	23.13^{g}
	Semusa	1.52^{hij}	9.53^{k}	18.14^{m}
	Tainoni	1.73^{def}	12.84^{gh}	24.72^{ef}
	Zondeni	1.77^{cde}	10.01^{k}	20.49^{ij}
	Mean	1.64±0.15	11.88±2.05	20.08±1.86
Cassava	Gomani	1.82^{cd}	15.43^{de}	34.39^{b}
	Maunjili	2.22^{b}	17.53^{a}	34.07^{b}
	Mbundumali	1.49^{ij}	15.88^{cd}	38.30^{a}
	Mkondezi	1.79^{cde}	16.18^{bc}	38.70^{a}
	Sauti	**3.40^{a}**	**16.74^{b}**	**38.46^{a}**
	Mean	2.14±0.70	16.35±0.80	36.78±2.20

Means followed by the same letter within the same column are not significantly different from each other ($p \leq 0.05$); Means for botanical source expressed as mean ± standard deviation.

Table 2. Swelling power of the cocoyam, sweetpotato and cassava starches.

Botanical source	Genotype/ accession	Swelling power (g g^{-1} starch)		
		50°C	70°C	90°C
Cocoyam	Chitipa	2.50^{jklm}	16.08^{ef}	34.10^{c}
	Machinga	2.32^{n}	7.54^{q}	29.39^{de}
	Mulanje	2.40^{mn}	7.74^{q}	26.63^{gh}
	Mzuzu	2.29^{n}	12.79^{mn}	27.57^{fg}
	Nkhotakota	2.50^{klm}	3.36^{r}	28.16^{ef}
	Thyolo	2.51^{jklm}	13.03^{lmn}	29.95^{d}
	Zomba	2.61^{ghijk}	7.44^{q}	28.52^{ef}
	Mean	2.44±0.13	9.71±4.18	29.19±2.46
Sweetpotato	A45	2.70^{efg}	9.50^{p}	23.12^{ij}
	Babache	2.67^{fgh}	9.35^{p}	22.42^{jk}

Table 2. Contd.

	Kakoma	2.85^{c}	13.72^{kl}	21.77^{kl}
	Kamchiputu	2.73^{def}	15.63^{fg}	22.89^{ijk}
	Kenya	2.49^{lm}	15.17^{ghi}	22.13^{jk}
	Lunyangwa	2.52^{jkl}	15.46^{fgh}	19.96^{m}
	LU96/303	2.58^{hijkl}	13.45^{lm}	20.67^{lm}
	LU96/304	2.51^{jklm}	14.73^{hij}	21.61^{kl}
	Mafutha	2.62^{fghij}	14.88^{ghij}	22.61^{ijk}
	Mugamba	2.64^{fghi}	16.83^{de}	23.22^{ij}
	Mugande	2.89^{c}	14.35^{jk}	22.73^{ijk}
	Salera	2.49^{lm}	12.58^{n}	25.99^{h}
	Semusa	2.54^{ijkl}	11.34^{o}	20.81^{lm}
	Tainoni	2.66^{fghi}	14.48^{ijk}	28.22^{ef}
	Zondeni	2.79^{cde}	11.39^{o}	23.81^{i}
	Mean	2.64±0.14	13.52±2.23	22.80±2.11
Cassava	Gomani	2.84^{cd}	17.28^{cd}	37.36^{b}
	Maunjili	3.24^{b}	19.43^{a}	38.48^{b}
	Mbundumali	2.50^{jklm}	17.96^{bc}	43.44^{a}
	Mkondezi	2.79^{cde}	18.32^{b}	43.81^{a}
	Sauti	4.44^{a}	18.76^{ab}	43.39^{a}
	Mean	3.16±0.71	18.35±0.84	41.30±2.95

Means followed by the same letter within the same column are not significantly different from each other ($p \leq 0.05$); Means for botanical source expressed as mean ± standard deviation.

differences among the starches (Bello-Pérez et al., 2000; Tian and Rickard, 1991). The high swelling power of cassava starches coupled with high water binding capacity makes them ideal for their exploitation in the food industry where they could be utilised as thickeners.

Paste clarity and stability

Generally, cassava starches had higher paste clarity (33.8±6.0%) than sweetpotato (16.1±2.5%) and cocoyam (15.9±3.5%) starches (Table 4). The paste clarity of the cocoyam and sweetpotato starches was comparable. Maunjili starch exhibited the highest paste clarity among the cassava starches whilst Mugande, Semusa and Kenya starches displayed higher paste clarity among sweetpotato starches. Chitipa and Mzuzu starch provided the highest clarity among the cocoyam starches. Nwokocha et al. (2009) also reported higher paste clarity for cassava starches than cocoyam starches. Amylose and phosphorus contents are known to influence clarity of starch pastes. High amylose content may result in more opaque starch pastes (Schmitz et al., 2006), while presence of high amounts of phosphate groups tends to increase starch paste clarity (Jane et al., 1996). Lower paste clarity of cocoyam and sweetpotato starches compared to cassava starches suggests the presence of amylose molecules of high susceptibility to retrogradation (Craig et al., 1989).

For the five days of refrigerated storage, opacity of the cocoyam, sweetpotato and cassava starch paste increased (Table 4). Greater increases in opacity were observed in cocoyam and sweetpotato starches than in cassava starches indicating higher retrogradation tendencies for cocoyam and sweetpotato starches than cassava starches. Turbidity development during storage arises from interaction of several factors, such as granule swelling, granule remnants, leached amylose and amylopectin, amylose and amylopectin chain length, intra or interbonding, and lipid (Jacobson et al., 1997). The high retrogradation tendencies displayed by cocoyam and sweetpotato starches in this study suggest that these starches are not ideal for food products that require freezing and thawing. However low retrogradation tendencies displayed by cassava starches makes them ideal for such application.

Paste viscosity and Syneresis

Generally cassava starches exhibited higher paste viscosity than sweetpotato and cocoyam staches (Table 5). The paste viscosity ranged from 10140 to 14033 cps, 5333 to 8733 and 6067 cps 12733 cps for cassava, cocoyam and sweetpotato starches, respectively.Thus cassava starches displayed the highest tendency to form viscous pastes than cocoyam and sweetpotato starches. Gbadamosi et al. (2013) reported the contrary; they found

Table 3. Solubility of the cocoyam, sweetpotato and cassava starches

Botanical source	Genotype/ accession	Solubility (%)		
		50°C	**70°C**	**90°C**
Cocoyam	Chitipa	0.22^{o}	10.30^{a}	15.68^{a}
	Machinga	0.31^{mn}	6.19^{d}	14.32^{b}
	Mulanje	0.30^{n}	6.11^{d}	12.48^{c}
	Mzuzu	0.55^{defgh}	6.85^{c}	10.66^{e}
	Nkhotakota	0.51^{fghij}	4.46^{jkl}	7.45^{l}
	Thyolo	0.54^{efghi}	8.05^{b}	11.69^{d}
	Zomba	0.58^{abcde}	5.91^{de}	14.08^{b}
	Mean	0.43±0.15	6.84±1.79	12.34±2.61
Sweet potato	A45	0.41^{kl}	2.93^{m}	6.43^{no}
	Babache	0.47^{jk}	2.86^{m}	5.95^{qr}
	Kakoma	0.54^{efghi}	5.55^{ef}	6.70^{mn}
	Kamchiputu	0.58^{abcde}	6.13^{d}	9.15^{hi}
	Kenya	0.52^{efghij}	4.98^{gh}	7.98^{k}
	Lunyangwa	0.50^{ghij}	4.20^{kl}	6.31^{op}
	LU96/303	0.53^{efghij}	4.07^{l}	6.06^{pq}
	LU96/304	0.61^{abcd}	4.53^{ijk}	5.72^{r}
	Mafutha	0.56^{cdefg}	5.29^{fg}	7.29^{l}
	Mugamba	0.48^{ij}	5.91^{de}	8.48^{j}
	Mugande	0.63^{ab}	4.14^{l}	6.69^{mn}
	Salera	0.50^{hij}	4.07^{l}	6.98^{m}
	Semusa	0.57^{bcdef}	3.13^{m}	7.52^{l}
	Tainoni	0.64^{a}	4.46^{jkl}	8.23^{jk}
	Zondeni	0.58^{abcde}	2.93^{m}	9.43^{gh}
	Mean	0.54±0.07	4.35±1.07	7.26±1.15
Cassava	Gomani	0.62^{abc}	4.90^{hi}	10.11^{f}
	Maunjili	0.48^{ij}	4.61^{hij}	8.86^{i}
	Mbundumali	0.36^{lm}	6.30^{d}	9.54^{g}
	Mkondezi	0.38^{lm}	6.27^{d}	9.46^{g}
	Sauti	0.56^{cdefg}	5.39^{f}	9.06^{i}
	Mean	0.48±0.11	5.49±0.74	9.41±0.45

Means followed by the same letter within the same column are not significantly different from each other ($p \leq 0.05$); Means for botanical source expressed as mean ± standard deviation.

that cocoyam starches had the greatest tendency to form viscous pastes. Since starches are used in industries to impart viscosity, the use of cassava, sweetpotato or cocoyam starches will be determined by the desired viscosity of the end product. Cassava starches could be explored in the adhesive industries where high viscosity provides and appreciable binding capacity.

Syneresis is the exeudation of water from frozen gels during retrogradation process and is therefore an indication of retrogradation tendencies of the starch pastes (Otegbayo et al., 2013). The degree of syneresis ranged from 28.9 to 49.2%, 11.5 to 36.7% for cocoyam and sweetpotato starches respectively, and was 0% and for cassava starches (Table 5). Thus cassava starches were more stable to freeze-thawing than cocoyam and sweetpotato starch. Cassava starch could therefore be better suited for use in frozen products than cocoyam and sweetpotato starches (Vaclavik and Christian, 2014). Higher tendencies to lose water for sweetpotato and cocoyam starches indicate that they will have limited application in frozen food products.

Gelatinization

The gelatinization temperatures ranged from 69.4-81.4, 68.5-79.2 and 60.1-76.8°C for cocoyam, sweetpotato and cassava starches, respectively (Table 6). Generally, cocoyam starch exhibited higher onset, peak, and conclusion temperatures than sweetpotato and cassava

Table 4. Clarity and stability of the starch pastes.

Botanical source	Genotype/ accession	Paste clarity and stability at 4°C (%T)				
		Day 1	Day 2	Day 3	Day 4	Day 5
Cocoyam	Chitipa	20.4^{e}	10.0^{ef}	8.4^{ghi}	7.6^{fg}	7.0^{ef}
	Machinga	13.6^{lm}	5.9^{klmn}	4.8^{no}	4.1^{mno}	2.8^{l}
	Mulanje	16.8^{ghij}	7.6^{hijk}	6.2^{kl}	4.9^{klm}	4.2^{jk}
	Mzuzu	19.8^{ef}	10.5^{e}	9.2^{f}	8.2^{f}	7.4^{ef}
	Nkhotakota	12.6^{mn}	5.5^{lmn}	3.9^{pq}	3.0^{p}	2.5^{l}
	Thyolo	10.9^{n}	4.7^{mn}	4.1^{0pq}	3.5^{op}	2.9^{l}
	Zomba	17.1^{hij}	9.1^{efghi}	6.6^{k}	5.1^{jkl}	4.5^{ij}
	Mean	15.9±3.5	7.6±2.2	6.2±2.0	5.2±1.9	4.5±1.9
Sweetpotato	A45	10.9^{n}	4.5^{n}	3.6^{q}	2.9^{p}	2.5^{l}
	Babache	15.8^{ijk}	7.5^{hijk}	6.6^{k}	5.7^{ij}	5.1^{hij}
	Kakoma	16.2^{hijk}	8.6^{fghij}	6.5^{kl}	5.9^{i}	5.5^{ghi}
	Kamchiputu	17.6^{ghi}	8.0^{ghij}	5.2^{mn}	4.8^{klm}	4.6^{hij}
	Kenya	18.0^{fgh}	9.4^{efgh}	8.8^{fgh}	8.2^{f}	7.8^{e}
	Lunyangwa	15.8^{ijk}	8.1^{fghij}	6.6^{k}	6.1^{i}	5.6^{gh}
	LU96/303	16.4^{hijk}	9.2^{efghi}	8.1^{hij}	7.0^{g}	6.5^{fg}
	LU96/304	15.4^{jkl}	8.0^{ghij}	7.6^{j}	6.2^{hi}	5.5^{ghi}
	Mafutha	17.6^{ghi}	8.5^{fghij}	7.7^{ij}	7.0^{gh}	6.6^{fg}
	Mugamba	17.7^{ghi}	9.8^{efg}	8.9^{fg}	8.1^{f}	7.7^{e}
	Mugande	18.7^{efg}	9.6^{efg}	8.7^{fgh}	7.6^{fg}	7.1^{ef}
	Salera	15.2^{jkl}	7.3^{ijkl}	6.5^{kl}	5.6^{ijk}	5.0^{hij}
	Semusa	18.7^{efg}	10.5^{e}	9.2^{f}	8.0^{f}	7.1^{ef}
	Tainoni	14.4^{klm}	6.6^{jklm}	5.8^{lm}	4.7^{lmn}	4.1^{jk}
	Zondeni	12.9^{mn}	5.2^{mn}	4.6^{nop}	3.9^{no}	3.3^{kl}
	Mean	16.1±2.5	8.0±2.1	7.0±1.7	6.1±1.6	5.6±1.5
Cassava	Gomani	23.5^{d}	20.5^{d}	18.4^{e}	18.0^{e}	16.8^{d}
	Maunjili	40.9^{a}	35.9^{a}	34.0^{a}	32.8^{a}	33.0^{a}
	Mbundumali	33.1^{c}	28.6^{c}	27.2^{b}	25.4^{d}	23.6^{c}
	Mkondezi	36.6^{b}	33.0^{b}	31.5^{b}	29.0^{b}	27.1^{b}
	Sauti	35.0^{bc}	31.8^{b}	30.5^{c}	27.6^{c}	26.4^{b}
	Mean	33.8±6.0	30.0±5.5	28.3±5.7	26.6±5.1	25.4±5.6

Means followed by the same letter within the same column are not significantly different from each other ($p \leq 0.05$).

starches. Thus cassava starches gelatinised at lower temperature range than cocoyam and sweetpotato starches. The low gelatinisation temperatures for cassava starches suggest they could be used in the adhesive industries as minimal heat energy would be required when producing hot-melt glues. The enthalpy of gelatinisation ranged from 13.1-15.1, 8.3-14.7 and 10.5-12.9 J/g for cassava, cocoyam and sweetpotato starches, respectively. On average, enthalpies of gelatinisation for cocoyam and cassava starches were comparable but higher than those of sweetpotato starches. These results are in agreement with those reported by Nwokocha et al. (2009). They reported lower gelatinisation temperature range for cassava starches (60.11- 72.67°C) than cocoyam starches (72.96- 80.25°C) however the gelatinisation enthalpy was higher in cocoyam starches than cassava starches. Pérez et al. (2005) also reported higher enthalpy of gelatinisation for cocoyam starches than cassava starches. During gelatinisation, there is loss of molecular order within starch granule and therefore the gelatinisation enthalpy gives an overall measure of degree of organisation (crystallinity). Thus the higher gelatinisation enthalpy values for cassava and cocoyam starches suggest a more orderly arrangement of starch molecules. Therefore there is lower degree of organisation in sweetpotato starches leading to lower enthalpies of gelatinisation (Singh et al., 2006).

Temperature range values of the starches ranged from 16.7±1.8, 12.0±2.5 and 10.7±1.2°C for cassava, cocoyam and sweetpotato starches, respectively. Cassava starches exhibited a higher temperature range than that of cocoyam and sweetpotato starches. The peak height

Table 5. Viscosity and degree of syneresis of the starch pastes.

Botanical source	Genotype/ accession	Syneresis [%]	Viscosity [cps]
Cocoyam	Chitipa	46.5^{a}	5640^{nop}
	Machinga	49.2^{a}	5453^{op}
	Mulanje	47.1^{a}	5733^{nop}
	Mzuzu	47.2^{a}	8733^{hij}
	Nkhotakota	28.9^{cde}	7067^{kl}
	Thyolo	32.9^{bc}	5333^{p}
	Zomba	32.9^{bc}	6240^{mno}
	Mean	40.7±8.6	6314±1251
Sweetpotato	A45	26.4^{de}	8160^{j}
	Babache	24.5^{e}	7320^{k}
	Kakoma	32.3^{cd}	6307^{lmn}
	Kamchiputu	14.4^{fg}	6560^{klm}
	Kenya	11.5^{g}	9800^{efg}
	Lunyangwa	18.0^{f}	9053^{ghi}
	LU96/303	33.8^{bc}	11700^{c}
	LU96/304	30.0^{cd}	9080^{ghi}
	Mafutha	26.8^{de}	9507^{fgh}
	Mugamba	32.8^{bc}	10373de
	Mugande	36.4^{b}	10633^{d}
	Salera	36.3^{b}	8547^{ij}
	Semusa	29.9^{cd}	12733^{b}
	Tainoni	33.0^{bc}	8600^{ij}
	Zondeni	36.7^{b}	6067^{mnop}
	Mean	28.1±8.3	8963±1927
Cassava	Gomani	0.0^{h}	13000^{b}
	Maunjili	0.0^{h}	10140^{def}
	Mbundumali	0.0^{h}	12267^{bc}
	Mkondezi	0.0^{h}	14033^{a}
	Sauti	0.0^{h}	11733^{c}
	Mean	0.00±0.0	12235±1393

Means followed by the same letter within the same column are not significantly different from each other ($p \leq 0.05$).

Table 6. Thermal properties: onset (T_o), peak (T_p) and conclusion (T_c) temperatures, temperature range (R), peak height index (PHI) and transition energy (ΔH_G) of the native starches.

Botanical source	Genotype/ accession	T_o [°C]	T_p [°C]	T_c [°C]	R [°C]	PHI	ΔH_G [J/g]
Cocoyam	Chitipa	61.8^{k}	69.4^{l}	78.6^{hi}	16.8^{b}	2.1^{n}	14.2^{bcd}
	Machinga	71.4^{b}	76.7^{b}	82.4^{bc}	11.1^{fg}	2.4^{jk}	11.4^{hijk}
	Mulanje	70.2^{c}	75.7^{c}	82.6^{b}	12.5^{e}	2.6^{def}	14.0^{bcd}
	Mzuzu	68.2^{gh}	73.1^{ghi}	79.2^{efgh}	11.0^{fgh}	1.7^{o}	8.3^{n}
	Nkhotakota	75.6^{a}	78.7^{a}	83.7^{a}	8.1^{m}	4.8^{a}	14.7^{ab}
	Thyolo	67.8^{h}	73.3^{g}	80.9^{cd}	13.1^{e}	2.7^{de}	14.6^{abc}
	Zomba	71.3^{b}	76.4^{b}	82.5^{b}	11.2^{fg}	2.7^{de}	13.8^{cde}
	Mean	69.4±4.0	74.8±2.9	81.4±1.8	12.0±2.5	2.7±1.0	13.4±2.1
Sweetpotato	A45	69.8^{cd}	74.9^{de}	81.4^{c}	11.6^{f}	2.5^{ghi}	12.91^{fghi}
	Babache	69.8^{cd}	74.6^{e}	80.6^{d}	10.8^{ghi}	2.6^{def}	12.4^{ghijk}
	Kakoma	68.0^{h}	73.0^{hi}	78.6^{hi}	10.6^{ghi}	2.0^{n}	10.5^{m}
	Kamchiputu	64.3^{j}	70.9^{k}	78.9^{ghi}	14.5^{d}	1.8^{o}	11.6^{kl}

Table 6. Contd.

	Kenya	68.2^{gh}	73.1^{ghi}	79.0^{ghi}	10.8^{ghij}	2.5^{efg}	12.5^{abcd}
	LU96/303	70.9^{b}	75.1^{d}	80.7^{d}	9.7^{kl}	3.5^{b}	14.0^{bcde}
	LU96/304	68.7^{ef}	73.4^{fg}	79.2^{fgh}	10.4^{hij}	2.5^{hij}	11.7^{kl}
	Lunyangwa	68.8^{ef}	73.3^{gh}	78.6^{ghi}	9.9^{jkl}	2.5^{ijk}	11.1^{lm}
	Mafutha	67.9^{h}	72.8^{i}	78.5^{i}	10.4^{ghi}	2.5^{ijk}	12.1^{ijk}
	Mugamba	68.5^{fg}	72.9^{i}	78.8^{ghi}	10.3^{ijk}	2.8^{d}	12.0^{jk}
	Mugande	69.1^{e}	73.7^{f}	79.5^{ef}	10.4^{hij}	2.7^{de}	12.2^{hijk}
	Salera	68.6^{fg}	73.4^{fg}	79.7^{e}	11.1^{fg}	2.5^{ijk}	12.0^{jk}
	Semusa	69.7^{d}	73.2^{gh}	79.2^{efg}	9.5^{l}	3.2^{c}	12.9^{fgh}
	Tainoni	68.0^{h}	72.0^{j}	77.5^{j}	9.5^{l}	3.3^{c}	12.6^{ghij}
	Zondeni	66.8^{i}	71.8^{j}	77.8^{j}	11.0^{fgh}	2.3^{kl}	11.6^{kl}
	Mean	68.5±1.5	73.2±1.1	79.2±1.0	10.7±1.2	2.6±0.4	12.3±1.1
Cassava	Gomani	60.8^{l}	65.6^{o}	76.9^{k}	16.1^{c}	3.1^{c}	14.0^{bcd}
	Maunjili	58.2^{o}	67.4^{n}	77.5^{j}	19.3^{a}	1.6^{o}	15.1^{a}
	Mbundumali	62.1^{k}	68.6^{m}	76.2^{l}	14.1^{d}	2.2^{lm}	13.4^{def}
	Mkondezi	60.2^{m}	65.7^{o}	76.8^{k}	16.6^{bc}	2.5^{fgh}	13.1^{efg}
	Sauti	59.1^{n}	65.4^{o}	76.4^{kl}	17.3^{b}	2.1^{mn}	14.1^{bcd}
	Mean	60.1±1.4	66.5±1.3	76.8±0.6	16.7±1.8	2.3±0.5	14.0±0.8

Means followed by the same letter within the same column are not significantly different from each other ($p \leq 0.05$); Mean for botanical source are expressed as mean ±SD.

index values of the cassava, sweetpotato and cocoyam starches fell within the same range. The peak height index values ranged from 1.6-3.1, 1.8-3.5 and 1.7-4.8 for cassava, sweetpotato and cocoyam starches. However, significant ($p<0.001$) variations in PHI values were observed within starches from different sweetpotato and cassava genotypes, and cocoyam accessions. Temperature range of gelatinization and PHI are indicative of the distribution of starch granules; the more heterogeneous the granules, the broader the temperature range and the lower the PHI (Sandhu et al., 2005; Karim et al., 2000). Higher amylopectin content can also lead to the narrowing of temperature range of gelatinization (Krueger et al., 1987). Thus, the differences in gelatinization temperature range and PHI of cassava, sweetpotato and cocoyam starches indicate the differences in heterogeneity and amylose/amylopectin ratio.

Retrogradation

Retrograded starches displayed lower gelatinization temperatures and smaller enthalpies (Table 7) than raw starches indicating weaker crystallinity (Sasaki, 2005). Enthalpy of retrogradation was significantly higher for cocoyam starches than both sweetpotato and cassava starches resulting in higher levels of retrogradation. Cocoyam starches exhibited higher degree of retrogradation than sweetpotato and cassava starches indicating rapid retrogradation for cocoyam starches. Higher retrogradation tendencies are attributed to crystallization involving small amylose molecules and long chain amylopectin (Peroni et al., 2006; Gudmundsson, 1994) whereas lower degree of retrogradation is attributed to higher content of short branches of amylopectin chains and long amylose molecules (Spence and Jane, 1999). The greater degree of retrogradation in cocoyam starches could therefore be attributed to higher contents of short amylopectin branches (Shi and Srib, 1992). Thus, the differences in the retrogradation tendencies of the starches confirm composition and structural differences exist among the starches from the three crops.

Principal component analysis (PCA)

The results of PCA are presented in Tables 8 and 9 and Figures 1 and 2. The first three principal components explained 85% of the total variability. Principal components 1, 2, and 3 accounted for 63.4, 13.6, and 8.3% of the variability, respectively.

Principal component 1 separated mostly cocoyam starches (Nkhotakota, Machinga, Mulanje and Zomba) from cassava starches (Sauti, Maunjili, Mkondezi, Gomani and Mbundumali) whereas component 2 separated the cocoyam and cassava starches from most of the sweetpotato starches (Figure 1). The factor loading revealed that principal component 1 contrasted cassava starches with cocoyam starches with respect to paste clarity, viscosity, water binding capacity and swelling

Table 7. Thermal properties of the retrograded starches: onset (T_o), peak (T_p) and conclusion (T_c) temperatures, temperature range (R), and transition energy (ΔH_G).

Botanical source	Accession/genotype	T_o (°C)	T_p (°C)	T_c (°C)	R (°C)	ΔH_G (J/g)	Retrog. (%)
Cocoyam	Chitipa	45.9^{m}	56.1^{p}	62.5^{j}	16.6^{ab}	3.5^{hij}	23.4^{l}
	Machinga	49.7^{kl}	58.6^{n}	65.2^{h}	15.5^{def}	5.0^{b}	41.6^{b}
	Mulanje	51.2^{j}	59.3^{jkl}	66.2^{def}	15.0^{defg}	4.4^{cde}	31.2^{efg}
	Mzuzu	52.0^{fgh}	59.0^{m}	65.3^{gh}	13.3^{j}	3.8^{g}	45.3^{a}
	Nkhotakota	51.8^{fghi}	59.7^{hi}	66.0^{defg}	14.2^{ghij}	5.4^{a}	37.0^{c}
	Thyolo	52.5^{ef}	59.3^{klm}	65.8^{fgh}	13.3^{j}	4.2^{def}	27.4^{ij}
	Zomba	52.9^{e}	60.4^{de}	66.1^{def}	13.3^{j}	4.8^{b}	35.1^{cd}
	Mean	50.8±2.3	58.9±1.3	65.3±1.3	14.4±1.3	4.4±0.7	34.5±7.4
Sweetpotato	A45	49.2^{l}	58.2^{o}	65.7^{fgh}	16.5^{abc}	3.2^{k}	24.9^{l}
	Babache	50.0^{k}	59.1^{lm}	66.8^{bcd}	16.8^{a}	4.1^{f}	32.9^{def}
	Kakoma	51.3^{ij}	59.6^{ij}	66.0^{efgh}	14.6^{fghi}	3.6^{ghi}	36.2^{c}
	Kamchiputu	52.1^{fgh}	59.7^{hi}	65.8^{fgh}	13.7^{ij}	2.9^{l}	25.2^{kl}
	Kenya	52.2^{fg}	60.0^{fg}	66.3^{cdef}	14.1^{ghij}	3.4^{ghi}	27.3^{jk}
	LU96/303	52.0^{fgh}	60.2^{ef}	66.8^{bcd}	14.8^{efgh}	4.4^{cde}	31.5^{efg}
	LU96/304	51.4^{hij}	60.6^{d}	67.0^{bc}	15.6^{cdef}	4.2^{ef}	36.0^{c}
	Lunyangwa	49.5^{kl}	58.5^{n}	65.5^{fgh}	16.0^{abcd}	3.3^{jk}	30.0^{ghi}
	Mafutha	51.8^{ghij}	59.9^{gh}	66.6^{bcde}	14.8^{efgh}	3.6^{ghi}	30.2^{fg}
	Mugamba	52.4^{efg}	60.5^{d}	67.1^{b}	14.7^{fghi}	4.4^{cd}	37.0^{c}
	Mugande	53.9^{cd}	61.4^{b}	67.4^{ab}	13.5^{j}	3.6^{ghi}	29.9^{ghi}
	Salera	53.6^{d}	61.1^{c}	67.4^{ab}	13.8^{ij}	3.7^{gh}	30.7^{fg}
	Semusa	54.1^{bcd}	61.7^{a}	68.0^{a}	13.9^{hij}	4.5^{c}	33.4^{de}
	Tainoni	54.8^{a}	61.6^{ab}	66.8^{bcd}	12.0^{k}	3.5^{ghi}	28.1^{hij}
	Zondeni	50.0^{k}	59.4^{jk}	65.7^{fgh}	15.7^{bcde}	3.4^{ijk}	29.5^{ghij}
	Mean	51.8±1.7	60.1±1.1	66.6±0.8	14.7±1.4	3.7±0.5	30.9±3.8
Cassava	Gomani	54.3^{abc}	59.3^{jkl}	63.4^{i}	9.1^{l}	1.1^{n}	7.9^{n}
	Maunjili	54.6^{ab}	59.7^{hi}	63.9^{i}	9.2^{l}	1.6^{m}	10.6^{m}
	Mbundumali	54.4^{abc}	59.7^{hi}	64.0^{i}	9.2^{l}	1.6^{m}	11.9^{m}
	Mkondezi	54.7^{ab}	59.7^{hi}	63.7^{i}	9.0^{l}	1.4^{m}	10.5^{m}
	Sauti	54.6^{ab}	59.5^{ijk}	63.8^{i}	9.2^{l}	1.1^{n}	8.0^{n}
	Mean	54.5±0.2	59.6±0.2	63.8±0.4	9.2±0.4	1.4±0.2	9.8±1.8

Means followed by the same letter within the same row are not significantly different from each other ($p \le 0.05$); Mean for botanical source are expressed as mean ±SD.

power, gelatinisation temperatures, syneresis and degree of retrogradation. Cassava starches exhibited higher paste clarity, viscosity, water binding capacity and swelling power but lower gelatinisation temperatures, syneresis and degree of retrogradation (Figure 2). Principal component 2 contrasted cassava and cocoyam starches with sweetpotato starches with respect to gelatinisation enthalpy, swelling power and water binding capacity: Cassava and cocoyam starches displayed higher gelatinisation enthalpy, swelling power and water binding capacity than sweetpotato starches (Figure 2).

The factor loading revealed that cassava starches were contrasted with cocoyam starches in terms of high paste clarity, viscosity, water binding capacity and swelling power, lower gelatinisation temperatures and lower degree of retrogradation and syneresis. The plot also showed that that cocoyam starches (Nkhotakota, Zomba, Mulanje and Machinga) had the lowest negative scores. These starches were discriminated in terms of their higher degree of syneresis and retrogradation, higher gelatinization temperatures and lower water absorption capacity, swelling power, viscosity and paste clarity.

The correlation matrix (Table 9) showed that swelling power, water binding capacity, viscosity and paste clarity were closely related. These variables were positively correlated. On the other hand gelatinisation temperatures (T_o, T_p) and syneresis were also close to each other. Kong et al. (2009) also reported significant positive correlation between gelatinization temperatures, T_o, T_p, and T_c and the enthalpy. There was significant negative correlation between swelling power, water binding capacity, viscosity and paste clarity with gelatinisation

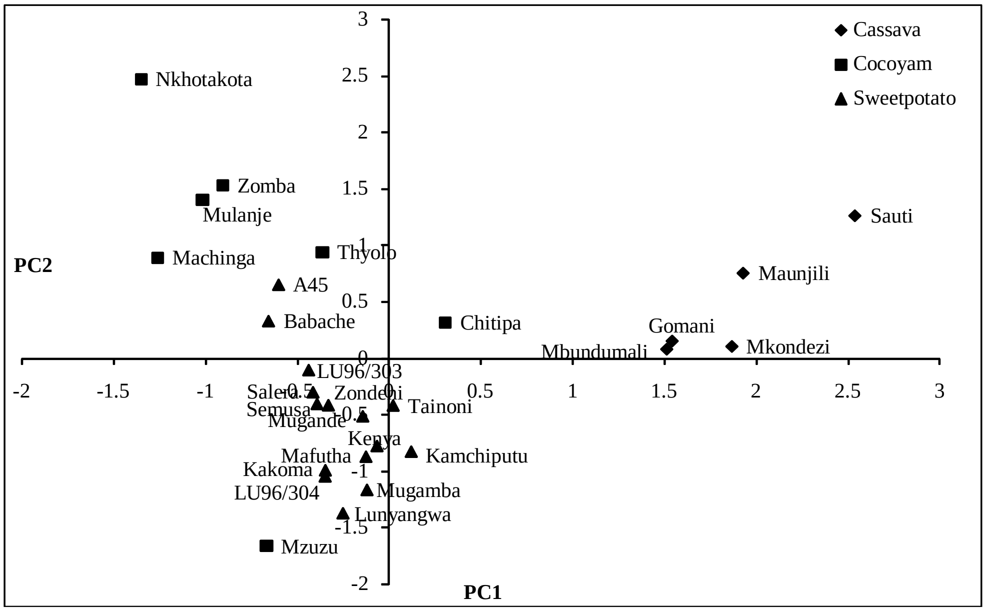

Figure 1. PC1 and PC2 plot for cocoyam, sweetpotato and cassava starches.

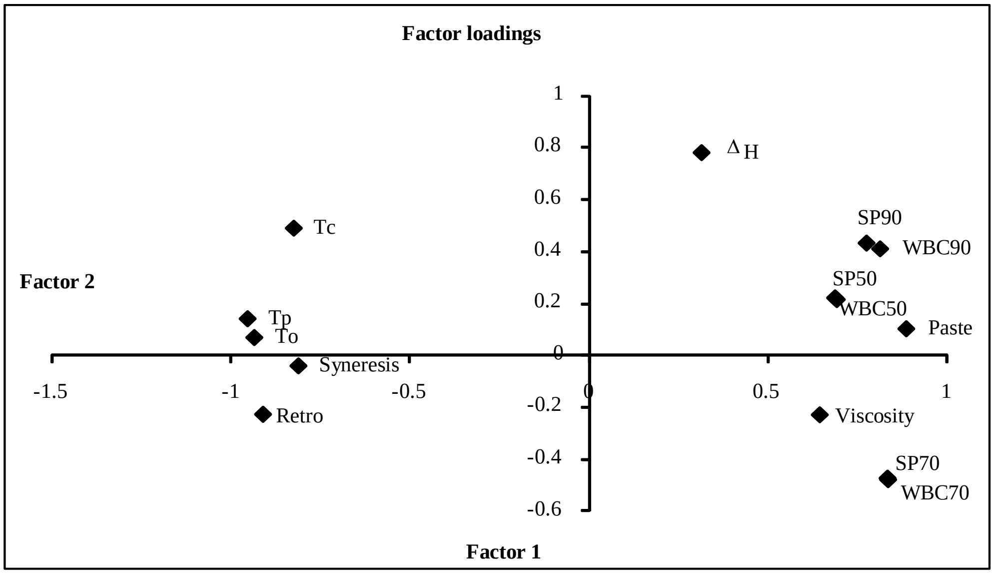

Figure 2. PCA loading plot for functional properties of the cocoyam, sweetpotato and cassava starches.

temperatures (T_o, T_p, T_c), retrogradation and syneresis.

This is in agreement with results of Singh et al. (2006), who reported a significant correlation between swelling power and gelatinization temperatures, and syneresis. However, swelling power was negatively correlated with setback viscosity. Singh et al. (2004) also reported positive correlation between swelling power and light transmittance, peak and conclusion gelatinisation temperatures but a negative correlation with water binding capacity.

Conclusions

The results of this study have revealed differences in functional properties of starches from cassava, sweetpotato and cocoyam grown in Malawi. Cassava starches were contrasted with cocoyam and sweetpotato

Table 8. Principal component analysis of the functional properties of the cocoyam accessions, sweetpotato and cassava starches.

Variable	Eigenvectors		
	PC1	PC2	PC3
Paste	0.30	0.07	0.12
To	-0.31	0.05	-0.07
Tp	-0.32	0.10	-0.06
Tc	-0.28	0.36	0.00
∆H	0.11	0.57	0.11
Retro	-0.31	-0.17	-0.07
WBC50	0.23	0.16	-0.64
WBC70	0.28	-0.35	0.01
WBC90	0.27	0.30	0.25
SP50	0.23	0.16	-0.63
SP70	0.28	-0.34	0.03
SP90	0.26	0.31	0.27
Viscosity	0.22	-0.16	0.12
Syneresis	-0.27	-0.03	-0.02
Eigen values	8.9	1.9	1.2
Individual %	63.4	13.6	8.3
Cumulative %	63.4	77.0	85.3

Table 9. Correlation coefficients between the functional parameters of the cocoyam, sweetpotato and cassava starches.

	Paste	To	Tp	Tc	∆H	Retro	WBC50	WBC70	WBC90	SP50	SP70	SP90	Viscosity
To	-0.83**												
Tp	-0.80**	0.97**											
Tc	-0.64**	0.82**	0.88**										
∆H	0.30	-0.23	-0.17	0.13									
Retro	-0.76**	0.85**	0.86**	0.65**	-0.54**								
WBC50	0.55**	-0.57**	-0.58**	-0.46*	0.28	-0.61**							
WBC70	0.67**	-0.82**	-0.85**	-0.90**	-0.01	-0.66**	0.45						
WBC90	0.81**	-0.76**	-0.75**	-0.49**	0.48*	-0.80**	0.49*	0.46					
SP50	0.56**	-0.58**	-0.59**	-0.47*	0.27	-0.60**	1.0**	0.46	0.49**				
SP70	0.67**	-0.83**	-0.85**	-0.90**	-0.01	-0.65**	0.46	1.0**	0.46	0.44			
SP90	0.80**	-0.74**	-0.72**	-0.45*	0.47*	-0.76**	0.49**	0.42	0.99**	0.46	0.43		
Viscosity	0.62**	-0.43	-0.57**	-0.59**	0.11	-0.53**	0.3	0.60**	0.42	0.32	0.59**	0.36	
Syneresis	-0.71**	0.66**	0.70**	0.61**	-0.33	0.81**	-0.53**	-0.64**	-0.61**	-0.53**	-0.62**	-0.54**	-0.65**

*, ** significant at p = 0.05 and p = 0.01, respectively.

starches as having water binding capacity, swelling power, paste clarity, viscosity, and resistance to retrogradation and lower gelatinisation temperatures. Cocoyam starches were characterised by higher degree of retrogradation and syneresis, and lower paste viscosity; sweetpotato starches displayed intermediate properties. Thus cassava starches could be explored for various applications use in the food and adhesive. Modification of cocoyam and sweetpotato could help improve their functional properties for specific use in the starch based industry.

Conflict of Interest

The authors have not declared any conflict of interest.

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