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Full Length Research Paper

A comparative study of the physicochemical properties of starches from root, tuber and cereal crops

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Some properties of starches from cassava, potato and sweet potato were compared with cereal starches from maize, wheat, millet and sorghum. The aim was to determine the properties of tuber and root crop starches and compare them with cereal starches in addition to unravelling the potential of commonly grown sorghum and millet climate resilient crops as cheap and sustainable sources of starch. Significant variations were observed for amylose content and solution properties of starches, where blue values for amylose ranged from 0.355 in potato to 0.476 in cassava, but were averagely low in cereal starches. Amylose leaching increased with temperature with the highest value (0.432) in cassava at 80°C compared with cereal starches (average 0.361). Starch amylosis increased with time of hydrolysis and was highest (>16%) for millet and sorghum and least for potato (<8.5% average). Average swelling power at 80°C was high for cassava (8.58 g/g) and potato (8.44 g/g) compared with sweet potato (6.88 g/g) and low among cereal starches (5.17 g/g). Similarly, starch solubility was low in potato (0.77 g/g) and sweet potato (0.577 g/g) compared with cassava (1.23 g/g). The paste clarity was also high for cassava (48.32%) and potato (42.16%) and least for sweet potato derived starches (23.22%) and all the cereal starches (14.97%). These properties demonstrate the untapped potential of cassava and tuber based starches for use in food and non-food applications previously dominated by cereal starches.

Key words: Tuber starch, root crop starches, cereal starches, amylose, amylosis.

INTRODUCTION

The robustness of starch as a food and industrial product has made it one of the most important plant products. It can be obtained cheaply and in large amounts hence, it is flexible in application and can satisfy demand in many processing and manufacturing ventures (Satin, 2006). However, one of the most important issues in its utilisation is the cost of starch production and the quality of independent and/or blended products from it. These issues have been the main determinants in the choice of starch for industry hence, positioning cereal starches and especially maize as a starch of choice due to its availability, although, it's processing is far much more expensive compared with other starches (Perez-Carillo and Serner-Saldiva, 2006). Starch is important in bread making, as a meat binder, in confectionary and as an additive in most food and beverages. This is in addition to its use in textiles, paper and plywood industries, as filler in biodegradable plastics and in the mining and construction industry (Satin, 2006). The uses of starch in these applications depend on its physicochemical and functional properties which are determined by its structure that depends on its granule and crystalline properties (Nuwamanya et al., 2010b). These properties also depend on the amylose amylopectin ratio, chemical properties and molecular characteristics of amylose and amylopectin (Tetchi et al., 2007). However, the properties that define cassava, potato and sweet potato starches are not well detailed compared with the current market starches from maize and wheat (Satin, 2006). By detailing these properties, notably functional and solution properties, various starches can be differentiated and assigned specialised roles.

With the onset of industrialisation in the East African region, the demand for starch especially in the dietary, textiles and paper industries has increased tremendously

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(Nuwamanya, 2010a). This demand has always relied on imported cereal starch which as expected is of a high cost in addition to the unreliable supply. The solution to this is to locally produce starch that can be used in its native form or modified to suit its applications. However, this cannot be possible without providing empirical evidence that these starches are of comparable value for the intended applications. Thus, the study of characteristics of starch from tuber and root crops that are mainly grown in East Africa provides a convincing entry point for commercialisation and, increased production of these crops. The properties of starch for cassava from selected Ugandan varieties have been studied (Nuwamanya et al., 2009; 2010a, b). However, the properties of starch produced from potato and sweet potato varieties in Uganda have not been studied extensively. Much as comprehensive work is being carried out to breed farmer preferred varieties, commercial varieties and varieties with improved nutritional qualities, there is need to understand marketable products from tuber and root crops which in most cases is starch. This study presents a report on functional and physicochemical properties of starch from marketable varieties of root, tuber and cereal crops typically grown in the EA sub-region.

MATERIALS AND METHODS

Materials

Potato tubers were collected from Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI) in Kabale, South-Western Uganda. The collected potato varieties were Victoria, Kachpot and Kinigi selected due to their good tuber culinary qualities, high shelf life and yield. Sweet potato tubers, cassava roots and maize samples were sourced from Namulonge at the National Crops Resources Research Institute (NaCRRI). Sweet potato varieties included; New Kawogo, Dimbuka and Naspot 5 all high yielding and disease resistant varieties. Two cassava varieties MH97/2961 and MH/00067 combining resistance to cassava mosaic disease (CMD) and desirable culinary qualities were used. The tubers and roots were transported in ice boxes at 4°C to limit post harvest physiological deterioration and upon arrival; they were peeled, washed thoroughly with tap water and kept at -20°C. Maize and wheat samples used were Longe 5 and 4 for maize and VW 309 and PASA for wheat (kind gift from Buginyanya Zonal Agricultural Research and Development Institute, BUGZARDI). Sorghum varieties Epuripur and Sekedo and varieties PESE and Seremi for millet were collected from the National Semi Arid Agricultural Research Institute (NaSAARI), Serere - Uganda.

Starch isolation

Owing to their size, the potato tubers were cut into small chips, blended in the presence of sodium bisulphite solution using a warring blender to disrupt cells to aid the release of starch on extraction (Aprianita et al., 2009). The resultant pulp was sieved using a double piece cheese cloth. The mixture produced was left to stand for 2 to 5 h after which the top water layer was decanted off leaving the starch. The resultant starch was double washed with distilled water, centrifuged at 1500 rpm for 10 min and resultant top water layer decanted before it was left to dry in an air forced chamber at 40°C. Dry starch was then stored at room temperature awaiting analysis. Cassava and sweet potato starch was extracted as published (Nuwamanya et al., 2009). It was also air dried and analysed as for potato starch. Maize starch were extracted by steeping in presence of 0.05 M H_2SO_4 at 50°C for 48 h followed by grinding and centrifugation of the resultant mash that resulted into settling of starch which was obtained after removing the supernatant and drying the remaining residue at 40°C in an air forced oven. Wheat, sorghum and millet starch like maize starch were obtained after steeping in hot water for 8 h and subsequent grinding. The resultant mash was centrifuged to allow the starch to settle down. The starch was then washed several times using clean distilled water. Starch obtained was then dried in an air forced oven at 40°C and then stored at room temperature.

Proximate analysis

Total dry matter was determined for tuber and root crops according to Benesi (2005). Moisture, protein and ash content were determined using standard methods (AACC, 2000). The lipid/oil content was determined using standard methods (AOAC, 2000). The total amount of soluble sugars were determined using 0.5 g starch after extraction using ethanol (95%) and subsequent quantification using the Dubois et al. (1956) method. The crude fibre was determined according to Ceballos et al. (2007).

Physicochemical properties of starch

Amylose content

Starch was dispersed into ethanol and consequently gelatinised with 0.1 M sodium hydroxide. An aliquot of the gelatinised starch was treated with 0.1 M citric acid before it was treated with an iodine solution. The resulting solutions absorbance was measured spectrophotometrically at 620 nm. The same samples were also measured at 570 and 680 nm and pattern difference observed in different crops.

Amylose leaching

A starch suspension (0.5% w.w) dry basis was heated at temperature ranges of 60 to 80°C for 30 min. Centrifugation were carried out at 1000 rpm for 15 min. The amount of released amylose was estimated by determining the amount of amylose in the resultant solution as proposed by Chrastil et al. (1987).

Water binding capacity

Water binding capacity (WBC) was determined according to the method described by Medcalf and Gilles (1965) with a few modifications. An aqueous suspension was made by dissolving 1 g of starch in 20 ml of water. The suspension was agitated for 1 h on shaker after which it was centrifuged for 10 min at 2200 rpm. The free water was decanted from the wet starch, drained for 10 min and weighed.

Paste clarity

Paste clarity was determined according to Ceballos et al. (2007). A 1% aqueous solution of starch was boiled at 93°C with repeated shaking for 30 min. The solution was transferred into a cuvette after cooling and transmittance was then measured at 650 nm using a spectrophotometer.

Starch and cold water solubility

Starch solubility and cold water solubility were determined according to Yuan et al. (2007) with slight modifications to allow determination of cold water solubility at 30°C. Starch suspension (2%) was incubated in a water bath at temperatures from 30 to 90°C, with a constant shaking at constant temperature for 30 min. Subsequently, the sample was cooled to room temperature and centrifuged at 3000 rpm for 15 min. The total amount of soluble starch (carbohydrates) was measured by hydrolysis and consequent determination of sugars according to Dubois et al. (1956).

Swelling power

Swelling power of starch was determined according to van Hung et al. (2007) with slight modifications. Starch powder (0.2 g, db) and distilled water (5 ml) were weighed directly into centrifuge tubes and covered. Tubes were then placed in a water bath and heated at 40, 50, 60, 70, 80 or 90°C for 30 min after equilibration of the sample temperature for 1 min with repeated shaking. The heated samples were cooled quickly to room temperature by a cold water bath and then centrifuged at 3000 *g* for 15 min. The supernatant was removed carefully and the swelling power determined as the ratio of weight of starch sediment to original weight of starch before heating.

Starch amylosis

Starch amylosis for different sources of starch was determined after treatment of 0.1 g starch with hot ethanol (95%), digestion with α-amylase and estimation of glucose produced. Glucose was quantified from resultant solution (0.1 ml) as total reducing sugar in solution using the Megazyme total carbohydrate kit purchased from Megazyme International Ireland Ltd. (Wicklow, Ireland).

Statistical analysis

The results obtained were analysed using Genstat discovery edition 3 software (Genstat, 2010). Average results were reported for the different parameters among the different starch sources and averages for cereal, tuber and root crop starches. Properties of crop varieties showing peculiar characteristics were discussed. Variations among the different parameters where analysed using the analysis of variance at 5% level of significance.

RESULTS AND DISCUSSION

Proximate analysis

Results for the proximate analysis of various starches are shown in Table 1. The moisture content (MC) varied among different botanical sources of starch with cassava displaying the highest MC (16.5%) compared with the sweet potato (9.33%) among the root and tuber starches. In contrast, the MC of cereal starches was lower than that of root and tuber starches. Maize variety Longe 5 had the highest MC (15%) comparable to that of cassava and much higher than for most cereal starches. The low MC among cereal starches may explain why they are preferred over tuber starches because they have prolonged shelf life. The low moisture content of potato and sweet potato starch makes them easy to store at room temperature and less prone to fungal and microorganism infections making them amenable for utilization in low MC starch applications similar to cereal starches. Free sugar content widely varied among different crops and varieties within the same crop. Sorghum, maize and sweet potato samples had high free sugar contents above 0.5% with millet displaying the lowest levels (<0.2%). The ash, fat and protein contents were high among cereal starches than root and tuber crops (that is, ash 0.283 and 0.618, protein 1.157 and 4.440, fat 0.406 and 3.093; for (root and tubers) and cereals, respectively). Low associated compounds composition in tuber and root starches shows the high purity displayed and the ease of extraction for these starches compared to the cereal starches (Nuwamanya et al., 2010c). This also means the low cost of production of the tuber and root crop starches in comparison to cereal starch. Total fibre content was low in cereals than in root and tubers. Starch pH was also on the average lower among cereal starches. Such differences in proximate parameters of starch highlight the requirement of particular modification procedures, if starches are to be applied in specific uses. High biomolecule (protein and fat) concentrations among cereal starches explain the reasons why they are difficult to extract and produce in highly pure forms.

Starch amylose properties

The amylose content and amylose properties of starch dictate most of its uses and in most instances determine the properties of starch. Results obtained for the total amylose content showed significant variations in the amylose content for the different botanical sources with high amylose contents observed for cassava (0.48) and sweet potato (0.42) (Table 2). However, the blue values obtained for sweet potato varied significantly with variety Dimbuka showing high amylose content (0.54) than cassava suggesting the possibility of using starch from this variety for applications requiring high amylose starches. Among potato varieties, Victoria had the lowest amylose content (0.286) and considerable variations were observed among the earlier stated varieties. In comparison, average amylose contents in cereals were; maize (0.285), wheat (0.463), millet (0.383) and sorghum (0.306). Amylose content values obtained show that, cassava is comparable to wheat starch, while sweet potato starch is comparable to maize and sorghum starches. However, it should be noted that amylose is not the only determinant in starch functionality. Thus,

Table 1. Proximate analysis of root, tuber and cereal starches.

Crop	Variety	M C (%)	R.S.C	Ash (%)	Protein (%)	C F (%)	TF (%)	DM (%)	pH
Cassava	MH97/2961	15.00	0.373	0.31	0.56	0.55	4.90	40.60	5.71
	TMS192/0067	18.00	0.137	0.31	0.47	0.55	4.91	37.35	4.63
	Mean	**16.50**	**0.255**	**0.31**	**0.52**	**0.55**	**4.90**	**38.98**	**5.17**
Potato	Kiniga	13.08	0.471	0.25	1.87	0.36	3.92	28.35	8.88
	Victoria	13.03	0.084	0.25	1.92	0.30	14.7	28.25	8.70
	Kachpot	15.00	0.045	0.28	1.66	0.60	5.89	30.50	8.65
	Mean	**13.67**	**0.200**	**0.26**	**1.82**	**0.318**	**8.17**	**29.03**	**8.74**
Sweet potato	Dimbuka	9.02	0.846	0.33	0.90	0.45	13.7	35.94	6.34
	Naspot5	9.07	0.818	0.25	1.00	0.15	8.82	36.63	6.89
	New kawogo	10.00	0.08	0.25	1.50	0.45	12.8	38.03	6.91
	Mean	**9.331**	**0.581**	**0.28**	**1.13**	**0.35**	**11.8**	**36.87**	**6.71**
Maize	Longe 5	15.69	0.277	0.46	2.45	2.87	3.68	N/A	2.13
	Longe 4	11.54	0.833	0.62	1.95	3.03	3.94	N/A	2.56
	Mean	**13.65**	**0.555**	**0.54**	**2.20**	**2.95**	**3.81**	**N/A**	**2.35**
Wheat	Vw309	12.0	0.379	0.50	6.30	3.04	3.53	N/A	6.07
	PASA	8.00	0.113	0.70	6.58	3.97	6.83	N/A	5.68
	Mean	**10.0**	**0.246**	**0.60**	**6.44**	**3.51**	**5.18**	**N/A**	**5.88**
Sorghum	Epuripur	9.30	0.492	0.70	3.68	3.02	2.60	N/A	3.06
	Sekedo	9.10	0.569	0.55	4.60	5.04	3.70	N/A	3.46
	Mean	**9.20**	**0.563**	**0.63**	**4.14**	**4.03**	**3.15**	**N/A**	**3.23**
Millet	Pese	9.20	0.192	0.55	4.02	1.97	2.53	N/A	4.39
	Seremi	9.40	0.163	0.85	5.94	1.79	4.20	N/A	4.44
	Mean	**9.30**	**0.178**	**0.70**	**4.98**	**1.88**	**3.37**	**N/A**	**4.42**

Mean values of triplicate analyses for each parameter and each starch source are presented in this study. M.C, Moisture content; R.S.C., reducing sugar content; D.M, dry matter content.

differences were still observed in solution properties of these starches. High amylose starches like cassava and wheat have an increased tendency of water absorption, although, the stability of resulting starch water mixtures is low and the visco-elastic properties are lower coupled to their high tendency to retrograde (Soh et al., 2006). This limits the application of such starches in bread making and other food application due to poor dough development and extensibility. High amylose starches also tend to have high water absorption indices leading to drier dough. Firmness also increases as amylose content becomes higher; hence, increasing resistance of starch to take up water. The disruption of starch structure during heating results into release of amylose into the solution a process called amylose leaching. The amount of leached amylose can be quantified and it gives an insight into the behaviour of starch during heating. The results show that, increasing temperature results into high proportions of leached amylose (Table 2). This is consistent with previously reported data by Palav and Seetharaman (2006) and Zuluaga et al. (2007). While at 60°C the leached amylose (blue values) ranged from 0.011 to 0.065, the value at 80°C ranged from 0.055 to 0.434. It is important to mention that the blue values obtained for different varieties and different crops were quite variable suggesting differences in the molecular structure and granule properties of the starches. Generally, it has been established that, root and tuber crops are characterised by high amylose leaching compared with cereals. Higher values were obtained for cassava starch, while very low values were obtained for potato starch among the tuber and root crop starches. Among cereal starches, higher values were observed for wheat and maize. No significant differences were observed for amylose leaching among cereal starches at 70 and 60°C, although, at the same temperatures

Table 2. Comparison of amylose content with amylose leaching different varieties of root, tuber and cereal starches taken at temperatures 60 to 80°C.

Starch source	Variety	Total amylose	AL 80 (°C)	AL 70 (°C)	AL60 (°C)	RT80 (°C)	RT70 (°C)	RT60 (°C)
Cassava	MH97/2961	0.477	0.434	0.301	0.065	0.928	0.642	0.138
	TMS192/0067	0.475	0.429	0.246	0.015	0.904	0.518	0.032
	Mean	**0.476**	**0.432**	**0.274**	**0.040**	**0.916**	**0.571**	**0.085**
Potato	Kiniga	0.401	0.090	0.015	0.011	0.230	0.039	0.027
	Victoria	0.286	0.089	0.023	0.016	0.327	0.086	0.059
	Kachpot	0.379	0.055	0.027	0.009	0.136	0.074	0.026
	Mean	**0.355**	**0.078**	**0.022**	**0.012**	**0.231**	**0.066**	**0.037**
Sweet potato	Dimbuka	0.539	0.289	0.079	0.043	0.545	0.149	0.080
	Naspot 5	0.343	0.220	0.039	0.016	0.646	0.113	0.046
	New kawogo	0.370	0.273	0.043	0.034	0.735	0.117	0.093
	Mean	**0.417**	**0.261**	**0.054**	**0.031**	**0.642**	**0.126**	**0.073**
Maize	Longe 5	0.238	0.192	0.053	0.029	0.807	0.223	0.122
	Longe 4	0.332	0.130	0.098	0.031	0.392	0.302	0.093
	Mean	**0.285**	**0.161**	**0.076**	**0.030**	**0.599**	**0.263**	**0.108**
Wheat	VW 309	0.498	0.147	0.012	0.011	0.295	0.024	0.022
	PASA	0.437	0.184	0.013	0.009	0.421	0.030	0.021
	Mean	**0.468**	**0.166**	**0.013**	**0.010**	**0.358**	**0.027**	**0.022**
Sorghum	Epuripur	0.281	0.061	0.054	0.036	0.217	0.192	0.128
	Sekedo	0.331	0.067	0.052	0.037	0.202	0.157	0.112
	Mean	**0.306**	**0.064**	**0.053**	**0.037**	**0.210**	**0.175**	**0.120**
Millet	Pese	0.361	0.024	0.015	0.011	0.067	0.042	0.031
	Seremi	0.405	0.028	0.023	0.017	0.069	0.052	0.042
	Mean	**0.383**	**0.026**	**0.019**	**0.014**	**0.068**	**0.047**	**0.037**

Mean values of triplicate analyses for each parameter and each starch source are presented in this study. AL, Amylose leaching at different temperatures; RT, Ratio of amylose leaching to total amylose at different temperatures

cassava still showed high values of amylose leaching. This shows that the stability of starch structure in these starches is variable specifying them for different functions. In addition, variations in amylose leaching patterns are a reflection of differences in granule structure, size and distribution and the crystalline nature of the starch (Zuluaga et al., 2007). Release of amylose into solution is due to the disruption of the crystalline structure of amylopectin. Since starch properties depend on the nature of its crystalline structure, it is postulated that weaker amylopectin structures in cassava starches are easily destroyed by heating and hence, easily releases amylose. This affects gelatinization properties of starch; hence, affecting the use of starches industrially especially in adhesives, binders and other end-use products (van Hung et al., 2007). The sudden increase in the amount of leached amylose at 70°C for cassava and 80°C for sweet potato coincides partly with gelatinisation temperatures of these starches and hence, improved leaching is expected at temperatures above the gelatinisation temperatures (Zuluaga et al., 2007). Amylose is known to limit the expansion of starch paste during heating leading to increase in the pasting temperature of starch. Leaching out of amylose allows attainment of peak viscosity at low temperature and hence, most starches with high amylose leaching tendencies like cassava have low pasting temperatures (Varavinit et al, 2003). It also shows the ability to separate the different components of starch during heating (Soh et al., 2006). The separation of these compounds allows the individual interplay of amylose and amylopectin in starch functionality allowing each to exert its effects independently. The ratio of leached amylose to the total amylose content of starch given as a percentage is shown in Figure 1. The percentage amylose leached at lower temperature (60°C) was high for wheat and maize

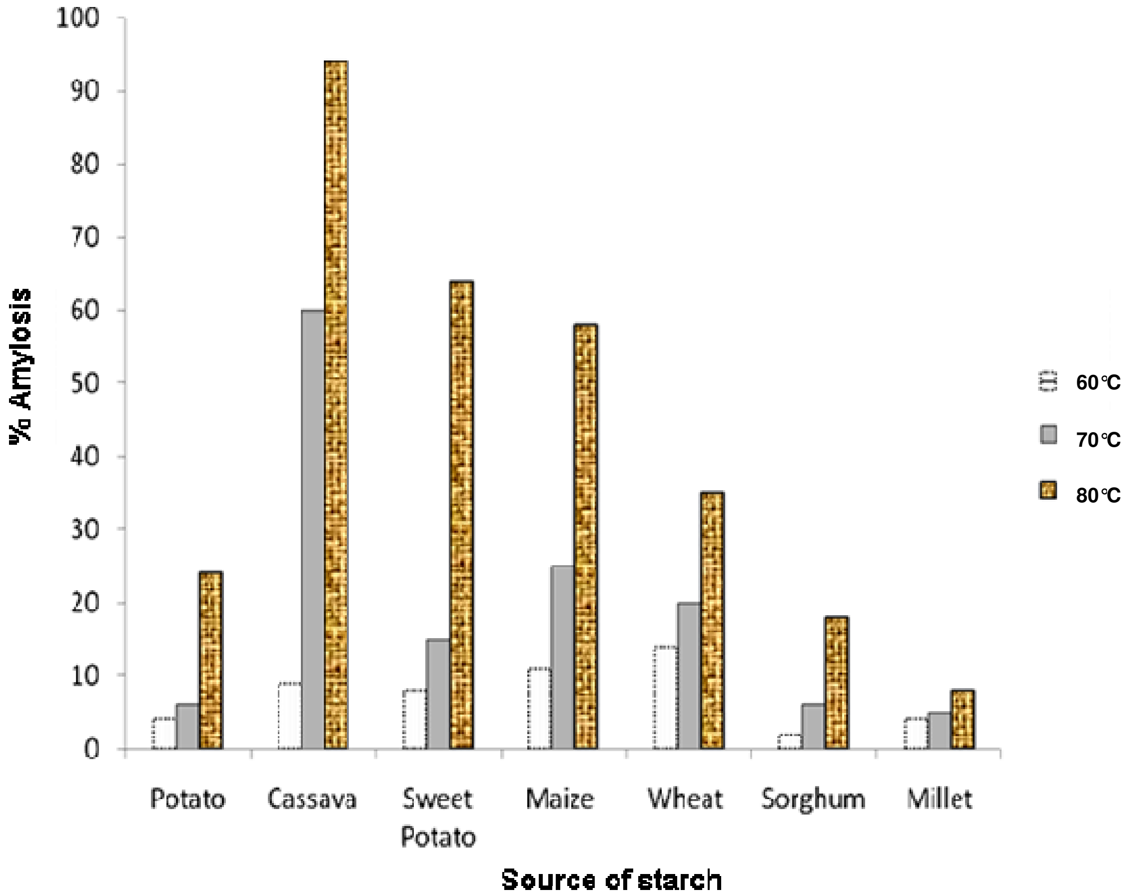

Figure 1. Ratio of leached amylose as percentage to total amylose at different temperature for the different starch sources used in this study.

starch, while at the 70°C it was high for cassava<maize<wheat in that particular order. At 80°C, amylose leaching was high for cassava<sweet potato <maize in that particular order. This highlights the effect of total amylose content on the amount of amylose that leaches into solution. At high temperatures, high amylose starches tend to have higher values of amylose leaching with the exception of wheat. At low temperatures, the trend was not clear but maize was an exception showing high values of leaching at both low and high temperatures. In sweet potato and potato starch, it was observed that there was no relationship between the leached amylose and the total amylose. Thus, other factors affect the loss of amylose during heating rather than the total amylose content. General trends for amylose leaching were thus, not attained hence, calling for further studies with much more specific procedures for quantifying amylose. The differences observed can be attributed to differences in amylose complexation behaviour of different starches in addition to chain length of amylose, interchain interaction of amylose and amylopectin in the starch granules and phosphate content (Zuluaga et al., 2007).

Swelling power

Results for starch swelling power at different temperatures ranging from 60 to 90°C are shown in Table 3 and Figure 1. Swelling power significantly increased exponentially with temperature with a twofold change between the temperatures of 60 to 80°C. Though increments in swelling power were observed up to 90°C, they were not so different from swelling powers at 80°C but rather the pattern was lost. Such phenomenon was reported by Zuluaga et al. (2007) and was possibly attributed to additional interactions between starch and other components at this temperature. Generally, the swelling power was high in cassava and low in potato at all temperatures. It was relatively the same among cereals except being low for maize at 90°C. In potato and cereals, relative high increments in SP were observed between 60 and 70°C, while in sweet potato high increments were observed between 70 and 80°C. High increments in SP were observed in cereals between 80 and 90°C, while linear small increases in swelling power were observed for cassava between 70 and 90°C. The swelling behaviour of starches was irregular at high

Table 3. Swelling power (SP g/g) and solubility (SOL) of different varieties of root, tuber and cereal crop starches taken at temperatures from 60 to 90°C.

Crop	Variety	SP60 (°C)	SP70 (°C)	SP80 (°C)	SP90 (°C)	SOL60 (°C)	SOL70 (°C)	SOL80 (°C)	SOL90 (°C)
Cassava	MH/2961	2.31	6.33	8.12	9.92	0.142	0.775	0.800	0.818
	TMS192/0067	2.56	7.73	9.03	10.45	0.239	0.921	1.660	2.316
	Mean	**2.435**	**7.03**	**8.575**	**10.19**	**0.191**	**0.848**	**1.230**	**1.567**
Potato	Kiniga	1.19	4.39	8.31	10.40	0.023	0.424	0.700	0.860
	Victoria	0.50	3.88	9.51	10.50	0.051	0.392	0.800	0.814
	Kachpot	0.61	3.76	7.50	9.49	0.038	0.506	0.810	0.829
	Mean	**0.767**	**4.01**	**8.440**	**10.13**	**0.056**	**0.441**	**0.770**	**0.834**
Sweet potato	Dimbuka	0.20	1.76	5.90	8.60	0.028	0.304	0.880	0.982
	Naspot 5	0.60	2.04	7.07	9.00	0.039	0.150	0.380	0.693
	New kawogo	0.47	1.60	7.67	8.94	0.033	0.189	0.470	0.809
	Mean	**0.423**	**1.80**	**6.88**	**8.85**	**0.033**	**0.214**	**0.577**	**0.828**
Maize	Longe 5	0.36	3.05	3.88	7.94	0.345	0.565	1.068	1.128
	Longe 4	0.52	2.77	4.03	7.67	0.156	0.423	0.925	0.963
	Mean	**0.44**	**2.91**	**3.96**	**7.805**	**0.251**	**0.494**	**0.997**	**1.046**
Wheat	VW 309	0.46	4.90	6.17	10.76	0.220	0.149	0.266	0.876
	PASA	0.50	5.96	6.44	10.97	0.160	0.349	0.721	0.978
	Mean	**0.48**	**5.43**	**6.31**	**10.87**	**0.190**	**0.249**	**0.247**	**0.927**
Sorghum	Epuripur	0.46	2.89	4.09	8.38	0.140	0.430	0.855	0.988
	Sekedo	0.52	3.08	6.40	10.59	0.145	0.273	0.751	0.958
	Mean	**0.49**	**2.99**	**5.25**	**9.49**	**0.143**	**0.352**	**0.803**	**0.973**
Millet	Pese	0.33	2.79	5.62	9.27	0.100	0.184	0.220	0.578
	Seremi	0.55	3.01	4.70	8.84	0.067	0.100	0.190	0.675
	Mean	**0.44**	**2.90**	**5.16**	**9.06**	**0.084**	**0.142**	**0.205**	**0.627**

Mean values of triplicate analyses for each parameter and each starch source are presented in this study.

temperatures (80 and 90°C) but was high for cassava and low for potato. At 60°C the swelling behaviour was almost the same for all starches except for cassava (Figure 2). Different studies have shown that, swelling power is well correlated to amylose and its properties. However, it has been postulated that the level of amylose lipid complexation, total leached amylose in addition to the phosphate content, have a significant effect on the swelling power. Amylose lipid complexes reduce swelling power, while existence of phosphate groups in starch increases the water binding capacity of starch, hence, the swelling power (Zuluaga et al., 2007). Much as it is expected that high amylose starches will have high swelling powers, it was observed that at high temperatures these patterns change where some starches with high amylose had lower swelling powers at higher temperatures. This was also observed when waxy, normal and high amylose wheat was compared (Van Hung et al., 2007). This can be attributed to the presence of lipid compounds especially in the cereal starches affecting the overall swelling power. Swelling power affects the viscosity of starch with low swelling power resulting into low break down viscosities (Yuan et al., 2007). Granule size too largely affects swelling power with large granule size resulting into high swelling powers (Wickramashinge et al., 2009). These inherent starch characteristics previously reported for the various botanical starches are reflected in these results. Such

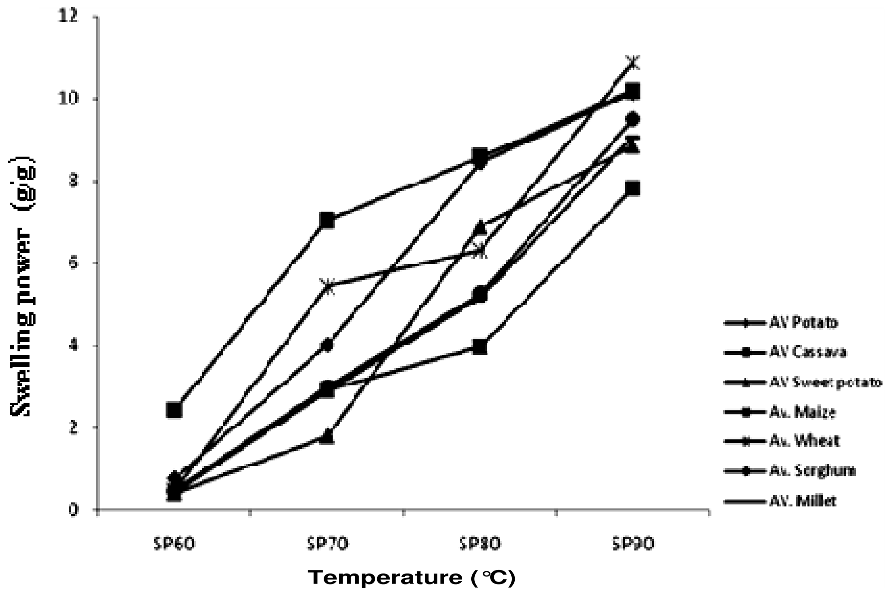

Figure 2. Comparison of swelling power (SP) at different temperatures (60 to 90°C) across different starch sources.

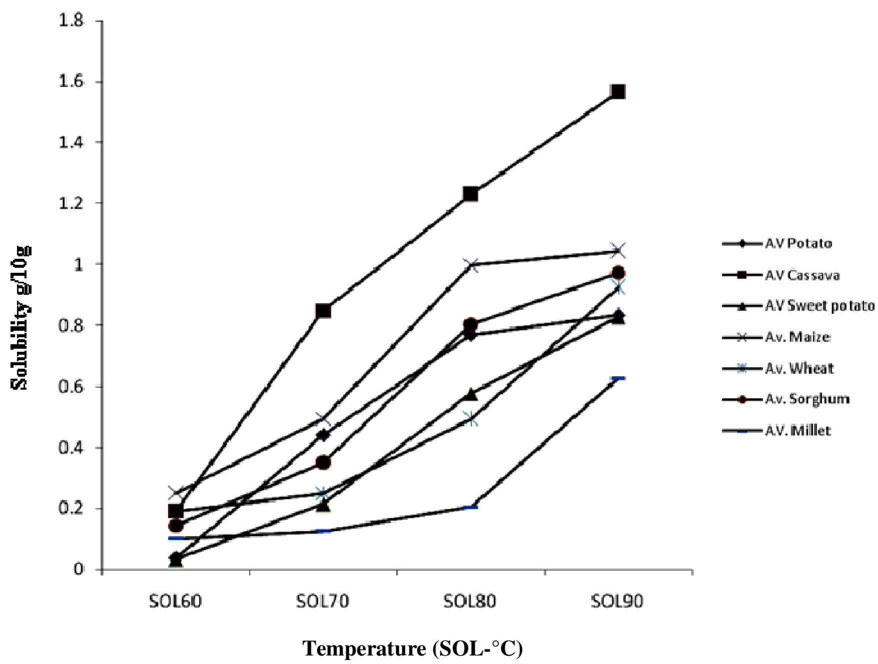

Figure 3. Comparison of solubility (average solubility) for different starch sources at different temperatures (60 to 90°C).

differences can be deduced and should be taken into consideration whenever starch is to be used for any applications.

Solubility

A lot of variability was observed for solubility among the different starches as shown in Table 3 and Figure 3. At high temperatures, starch solubility behaved alike for both tuber and root crops and cereals. Specific increments were observed for solubility with low values (0.023 for potato) at 60°C and high for cassava (2.13) at 90°C. Low solubility values were observed for potato and sweet potato and high values for maize > cassava >

wheat at all temperatures ranges. Increments in solubility between 60 and 70°C for cassava starch followed a similar pattern as swelling power. At all temperature ranges, millet starch showed low average solubility values compared with other cereal starches. This can be attributed to the possibility of amylose complexing with especially lipids in millet starch preventing it from dissolving in solution. Other factors could be the high stability of millet starch amylopectin structure; hence, preventing it from possible degradation during heating (Graffhanm et al., 1999). Processes that lead to break down of starch and release of amylose into solution also affect positively the solubility of starch. Treatments such as heating and chemical treatment increases solubility, while treatments that reinforce the crystalline structure reduce the solubility of starch (Jyothi et al., 2007). Solubility patterns resembled those of swelling power as observed in Figures 1 and 2, although, these patterns did not follow similar trends among different botanical sources of starch.

Starch paste clarity

Results for paste or gel clarity are shown in Table 4. Starch paste clarity values are given as the percentage transmittance read directly from a spectrophotometer. Generally, the paste clarity was high for cassava starch but substantively low for millet starch. Among tuber and root starches, the clarity was averagely high in cassava and potato starch (> 40%) but was low among sweet potato starch (22%). It was generally low among all cereal starches averaging less than 25%. Sorghum had the highest paste clarity value (22%) and varied between varieties, with variety Epuripur having the highest value (23%). Among the cereal starches, the paste clarity of sorghum and especially the white variety Epuripur was comparable to that of sweet potato. The low clarity among cereals can be attributed to the high protein and tannin contents. Other interfering colored substances in the testa are also important. The low paste clarity observed for sweet potato starch can be attributed to the high amounts of carotenes which interfere with transmission of the light by the starch gel. Cassava starch has fewer impurities on proximate analysis and will thus; transmit more light compared with potato and sweet potato. In general, the more amounts of interfering substances there are and cases of contamination, starch clarity generally lowers as was observed by Jyothi et al. (2007). High paste clarity observed for cassava makes it a better option for application in food and industry textile where high clarity is required. Clarity characteristics of starches are dependent on the botanical source of starch and the overall purity of the starch in case of cereal starches. Apart from that, starch clarity is also affected by the amylose content especially in cereal starches (Davis et al., 2003). High paste clarity is easily achieved with chemical modification as suggested by Zhang et al. (2005), but with starches such as cassava, such modification procedures may not necessary make it cheaper and better than most other starches. Varietal differences observed for paste clarity among tubers is important since it can be possible to select the most convenient variety in such a case. The low paste clarity observed among cereal starches suits them for use in gravies and thickened foods where low transparency is expected. The appearance of a starch gel is important with the preference for particular clarity attributes varying from one product to another. In particular, the use of a starch paste in a particular product means that it should not compromise the acceptability of this product among the users, for example starch gels used in fruit pies should be pure and highly transparent to maintain the visual properties of the particular fruit.

Amylosis

Hydrolysis of starch using enzyme amylase allows us to understand the total portion of starch that can be digested over a particular time. It also provides information on the physical structure of starch, in addition to giving an understanding on the amorphous nature of starch (Franco et al., 2002). In this study, starch was digested for a total period of 24 h and the reducing sugars produced were quantified from the solution after 4, 8 and 24 h. At 4 h, high amylosis values were generally observed for cereal starches compared with the tuber and root crop starches. Highest values were observed for millet>sorghum>cassava>wheat, with wheat and cassava almost showing the same amylosis values. The lowest amylosis values were obtained for potato starch. Individual crop variety analyses revealed that the sorghum variety Sekedo had the highest amylosis values after four hours of hydrolysis, while New Kawogo (sweet potato) and Kiniga (potato) had the lowest. Hydrolysis values after 8 h (results not shown) were not so different from those at 4 h. After 24 h of hydrolysis, amylosis values obtained ranged from 22 to 45% in different starches. This shows that, apart from amylose that is targeted by the enzyme amylase, other components of starch especially amylopectin are also broken down into sugars during prolonged hydrolysis. Thus, high amylosis values may be expected for starches with low amylose contents as suggested by Riley et al. (2006) which may also explain the high digestibility values observed for millet compared with other starches. Enzymatic starch granule hydrolysis is one of the most important reactions in many industrial processes. This depends on structural modifications after treatment of starch which influences the *in vitro* hydrolysis and the access to the ultra structure of starch granules. On hydrolysis of starch using glucoamylases, porous starch granules are formed changing the nutritional quality of starch that depends on

Table 4. Paste clarity (PC), water binding capacity (WBC) and starch amylosis values for root, tuber and cereal crop starches.

Starch source	Variety	PC	WBC(g/g)	TC (%)	Am (4 h)	Am (24 h)
Cassava	MH97/2961	46.08	0.99	71.89	8.38	13.19
	TMS192/0067	55.02	0.96	74.47	6.64	12.77
	Mean	**50.55**	**0.98**	**73.18**	**7.51**	**12.98**
Potato	Victoria	45.40	1.01	75.16	4.85	9.62
	Kiniga	48.62	0.91	75.02	2.81	7.32
	Kachpot	32.45	1.26	69.08	0.98	8.34
	Mean	**42.16**	**1.06**	**73.09**	**2.88**	**8.43**
Sweet potato	Dimbuka	20.20	0.91	68.43	0.81	8.43
	Naspot 5	25.18	0.92	67.74	2.81	10.39
	New Kawogo	22.86	0.93	73.55	2.72	7.23
	Mean	**22.75**	**0.92**	**69.91**	**2.11**	**8.68**
Maize	Longe 5	24.05	1.05	81.85	6.81	9.19
	Longe 4	14.92	1.15	79.32	5.53	10.81
	Mean	**19.49**	**1.10**	**80.59**	**6.17**	**10.00**
Wheat	VW 309	15.57	0.90	79.33	3.57	14.89
	PASA	11.37	0.95	70.79	6.04	10.81
	Mean	**13.47**	**0.93**	**75.06**	**4.81**	**12.85**
Sorghum	Epuripur	22.99	1.06	79.21	7.15	9.28
	Sekedo	20.80	0.99	68.26	5.36	18.64
	Mean	**21.90**	**1.03**	**73.74**	**6.26**	**13.96**
Millet	Pese	4.62	1.07	79.33	3.15	16.00
	Seremi	5.43	1.05	75.11	5.06	16.94
	Mean	**5.03**	**1.06**	**77.22**	**4.11**	**16.74**

Mean values of triplicate analysis for each parameter and each starch source are presented in this study. PC, Paste clarity; WBC, water binding capacity; TC, total carbohydrate; Am, percentage starch amylosis at different hours (4 and 24).

its native structure and on its processing. Starch digestibility in the human small intestine can vary from rapid digestion to indigestibility, giving a wide range of options where intermediate and slow digestible starch has been shown to have potential health benefits (Sajilata et al., 2006). Thus, variety differences in amylosis observed in sweet potato show the possibilities of selection for high digestibility or low digestibility among different crops and improvement to attain a certain value of digestibility. In particular, low digestibility values for cereals apart from millet are important in preparing foods where slow releases of sugar are expected. Figure 4 shows the relative percentage of starch digested with amylase at different times. At 4 h of hydrolysis, total percentage of starch digested (% amy 4 h) was low, hence, a low ratio of digested starch to total starch or carbohydrate (R a/t 4 h %). However, at 24 h total digested starch was high, hence, a high percentage ratio of digested starch to total carbohydrate as expected.

Generally, percentage starch digested after 4 and 24 h was correlated to total carbohydrate content of starch except for maize. This is important since it shows that as the starch content increases, the amount of available carbohydrate increases; hence, increasing the nutritional (caloric or energy) value of the crop.

Water binding capacity (WBC)

Results for WBC are presented in Table 4. The WBC was generally the same for all the starches analysed although, it was on average high for maize and low for sweet potato starch. In particular, the WBC was high for the potato variety Kachpot (1.26 g/g) making it

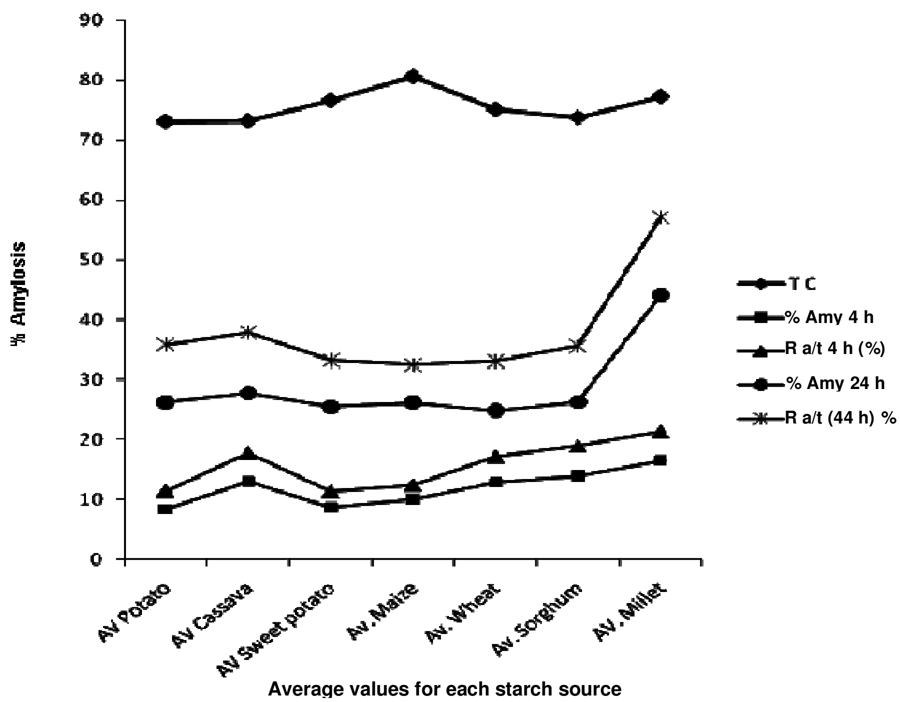

Figure 4. Percentage average starch amylosis at 4 h (%Amy 4 h) and at 24 h (% amy 24 h) as a ratio of total carbohydrate (TC) at 4 h (R a/t 4 h %) and 24 h R a/t 24 h %).

Table 5. Differences in amylose reading (absorbencies) after measurement at 570, 620 and 80 nm for cereal root and tuber starches.

Crop/starch source	A570 nm	A620 nm	A680 nm
Cassava	0.382	0.483	0.264
Potato	0.280	0.322	0.298
Sweet potato	0.489	0.584	0.506
Maize	0.221	0.162	0.088
Wheat	0.261	0.207	0.164
Sorghum	0.301	0.229	0.179
Millet	0.266	0.220	0.158
Waxy sorghum	0.085	0.059	0.033
Waxy maize	0.039	0.027	0.015

Values are averages of triplicate readings taken at different times for the three wavelengths.

distinctively different from all the starches analysed. Water binding capacity is affected by the presence of minerals like phosphorus in starch where starches having high phosphorus contents (especially cereal starches) have high water binding capacities (Zuluaga et al., 2007). The water binding capacity refers to the total amount of water held by a starch gel under a defined state of conditions (Pinnavaia and Pizzirani, 1998). It is highly dependent on the crystalline properties of starch being high for starches with low crystallinity and hence, is correlated to the amylose content of starch (Agama-Acevedo et al., 2008). It also depends on the associative forces among starch components where weak inter associative forces result into high WBC (Aryee et al., 2006; Riley et al., 2006). In the use of starch in solution and especially in food industries, the amount of water taken up by starch is very important. This depends on the type of starch and their native form is dependent on the botanical source of starch. Modification of starch with procedures like hydroxypropylation increases the WBC considerably making it better for industrial use. This depends on introduction of more hydrophilic groups in the starch allowing WBC to increase with increase in temperature like other solution properties of starch (Zhang et al., 2005). However, in this case, no significant differences were observed for WBC, although, differences occurred in individual crop varieties. This gives premise for variety specific selections for this parameter in addition to modification of starch from particular crops to meet the applications' demands.

Differences in amylose readings for cereal and tuber starches

The amylose amylopectin ratio affects a number of starch properties being important in solution properties such as starch disassociation, association and re-association in addition to kinetic properties of starch (Zuluaga et al., 2007; Perez-Carillo and Serna-Saldivar, 2006; Zhang et al., 2005). This ratio plays a major role in starch products for various applications of starch (van Hung et al., 2007). Since this ratio can be altered easily through genetic engineering and other breeding procedures (Satin, 2006), crop plants with different amylopectin amylose ratios have been produced (Davis et al., 2003); hence, specifying starches for particular functions in addition to introducing new applications for particular starches. Attempts to determine the amylopectin/amylose ratio were reported by Mahmood et al. (2007) by using different wave length ranges as provided by the spectrophotometer. This gives a percentage of either amylose or amylopectin after taking absorbencies at different wave lengths. In this study, using the cold sodium hydroxide (NaOH) without defatting method for determining amylose, we observed that the change in absorbance over the different wavelengths followed different patterns for tuber and root crops compared with cereals (Table 5). In tubers and root crops, absorbencies followed the pattern A570 nm<A620 nm>A680 nm, while in cereal crops the pattern was A570 nm>A620 nm>A680 nm. Following the suggestion of Nishi et al. (2001), where it is purported that taking absorbance readings at 680 nm takes care of both amylose and amylopectin, it was observed that this may depend on the botanical source of starch in addition to its constituents. Thus, crop specific wavelengths for maximum absorbance of the iodine complex are required. These can be generalised and used for both tuber and root crops. Furthermore, for tuber and root crops, the ratio of the absorbance of iodine complex at 570 nm (A570) to absorbance at 620 nm (A620) (*A570/A620*) gave an approximate amylopectin ratio (potato: 0.869, sweet potato: 0.791 and cassava: 0.837). For cereals (A620/A570) gave approximate amylopectin ratio of maize 0.733 for maize, 0.763 for wheat, 0781 for sorghum and 0.827 for millet. Such results show that, it is possible to obtain the amylose, amylopectin ratio from taking absorbencies at different wavelengths. Indeed the results are in agreement with reported levels of amylose (or amylopectin) for potato, cassava, sweet potato (Moorthy, 2002), wheat (van Hung et al., 2007), maize (Agama-Acevedoa et al., 2008). However, the rightful estimation of amylose amylopectin ratio requires specific techniques that may involve iodine staining in addition to other techniques.

Conclusion

Parametric differences in starch physicochemical and functional characteristics were observed in this study as was expected with distinctive properties observed for the tuber starches compared to the cereal starches. It was observed that considerable variations occur in starch and amylose properties of starch from different botanical sources. It was also observed that though there might be similarities in the starches from different botanical sources, these similarities are variety specific making recommendation of crop specific applications difficult. However, the properties reviewed showed that different crops can be put to the same application making selection and use of cheap available sources for starch possible. The study highlighted the possibility of applying tuber and root crop starches for purposes that were once tagged to cereal starches. In fact in some instances, tuber and root crop starches exhibited superiority over cereal starches

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