International Scholars Journals

African Journal of Crop Science ISSN 2375-1231 Vol. 6 (4), pp. 001-011, April, 2018. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Physicochemical and functional characteristics of cassava starch in Ugandan varieties and their progenies

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Accepted 09 January, 2018

Due to poor root quality traits in improved, disease resistant cassava (*Manihot esculenta* Crantz.) varieties and hence low acceptability among farmers, a study was undertaken to improve these varieties by crossing them with disease susceptible, farmer preferred local landraces. Five improved varieties and four local landraces were used and hybridisations among them were made in a poly-cross nursery block. Starch isolated from the nine cassava varieties and their F_1 progenies was analysed for physicochemical and functional properties. Significant differences were observed between varieties, progenies and within the F_1 progenies. The amylose content ranging between 19.0 - 25.0% was negatively correlated to swelling power and solubility but positively correlated to starch content. Average starch granule sizes ranged between 7.0 - 12.0 μm, though smaller granules ranged between 2 6.9 μm and large granules between 13 – 20 μm. Granules were mainly truncated in shape and similar across varieties and their progenies. Individual parents had peak viscosity, set back viscosity and viscosity at breakdown higher than the progenies suggesting inherent genetic and biochemical differences among parents used in the study. Variations were also observed in the parents and progenies for starch swelling power, solubility and starch content on dry basis. Starch associated molecules such as proteins and lipids did not vary significantly but dietary fibre significantly ($P< 0.05$) varied both in parents and F_1 families. Significant correlations ($r > 0.45$) were observed among starch properties including swelling power and breakdown viscosity. Based on these results, selections for lines with different starch quality and quantity properties can be made among the F1 families for future dietary and industrial uses.

Key words: Progenies, starch granules, viscosity, physicochemical properties.

INTRODUCTION

In recent years, cassava has received more attention as a root crop not only for its resistance to abiotic stresses (Chavez et al., 2005; Baguma, 2004) but also its high productivity with considerable starch yield (up to 30% of the fresh root or 80% of root dry matter) and purity (Ceballos et al., 2006; Benesi, 2005). Cassava has been grown in Uganda since the 1860s with the recurrent introduction of varieties to mitigate possible losses of germplasm due to viral disease outbreaks that have always threatened the crop (NARO, 2005). Such introductions have not always suited the preferences of local consumers despite their resistance to diseases and/or pests hence the continued need to provide cultivars which are resistant to disease and/or up to the taste of the local consumers (Baguma, 2004). With the added importance of cassava starch in industry, these cultivars are required to be able to produce starch suitable for

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suitable for dietary and industrial applications. Thus different breeding programmes aimed at producing cultivars with high quality starch producing cassava roots have been initiated in Uganda (NARO, 2005). Starch constitutes the main component of the cassava root (Ceballos et al., 2006) and thus plays an important role in the use of cassava as a food and industrial crop. Cassava starch has been studied and characterised for its different properties such as granule structure, pasting properties and functional properties such as swelling power and solubility (Zaidul et al., 2007; Gomes et al., 2005; Charles et al., 2004). Studies have shown that cassava starch granules are truncated with various shapes and sizes ranging from 2 - 40 m (Moorthy, 2002) and displays an A-type x-ray pattern (Tukomane et al., 2007) . The starch has pasting properties typical of other tuber and root starches with low amounts of proteins, lipids and fibre (Charles et al., 2004). In particular, this study was aimed at detailing the different starch attributes of cassava that can be exploited for a number of emerging starch industries. The production of bio-ethanol requires crops with appreciable amounts of starch and/or sugar which can be easily turned into ethanol by fermentation. Production of cultivars with high sugar concentrations in addition to starch would thus reduce the cost of production of bio-ethanol (Ceballos et al., 2008). Other industries that require cassava with novel starches include the production of glucose syrups and in the emerging construction and mining industry where cassava starch is required because of its good viscosity properties. In addition, the food and dietetics industry require improved starches ideal for delivering health benefits to people since starch forms a major part of the nutritional components among most communities (Morell and Mathews, 2005). A good example for this cause is the production of resistant starch which passes through small intestines into the large bowel where it is fermented to produce a range of products such as short chain fatty acids that are important in the prevention of cancer (Topping and Cliffton, 2001). Starches with a low glycemic index are also important in health (Baguma, 2004). These starches release glucose at a slow rate hence important in helping patients with type II diabetes (Morell and Myers, 2005). For increased diversity in terms of progeny combinations produced and seed number, a poly-cross nursery block was used. The poly-cross approach has been used in a number of crops such as sugar cane, maize, (KoLliker, 2005), sweet potato (Ernest et al., 1993) and cassava to increase on the diversity, yield and maximize the number of progenies that could be presented among each of the progeny parents. This necessitated its use in this study where screening of starch properties from four land races and five improved cultivars including two Nigerian landraces and three IITA lines and their progenies was undertaken. The physico-chemical and functional properties of starch from progeny lines in each of the female parents used in the poly cross were accessed and the relationships among these properties determined to see how they affect each other.

MATERIALS AND METHODS

Field experiments were set up at the National Crops Resources Research Institute (NaCRRI), Namulonge, in Central Uganda. Namulonge has served as the screening site for many cassava properties, justifying its suitability for this experiment (Otim-Nape et al., 1998). Parental lines included locally grown varieties namely; Bao, Bamunanika, Kakwale and Nyaraboke preferred by farmers due to their good root qualities but are yet, low yielding. These were recipients for gene conditioning high yield and other superior root qualities. Donor parents included introductions from IITA (Nigeria) namely NASE 10, NASE 12 and 95/SE-00036 characterized by a high yield potential (20-35 kg/ha), and Nigerian landraces TME 5 and TME14 that combine high dry matter content, high yielding tuber potential and resistance to the dreaded cassava mosaic disease.

Due to insufficient knowledge on the specific combining abilities and flowering habits of the selected parents, a poly-cross mating design was used to maximize hybridization and seed production. In doing so, every individual had an equal chance of mating with each other in the population (du Ploy, 1985). To prevent pollen from undesired sources, the crossing block containing 100 plants per parent was isolated from the nearest cassava field by a distance of 100 m. At harvest, seeds in each family were collected and then bulked to form half-sib families. In the following year, seeds were pre-germinated in a high humidity chamber at a 30°C. Pre-sprouting was necessary because seeds often have a dormancy period of a few months after maturity and require relatively high temperatures (30 - 35°C) for optimum germination (Ceballos et al., 2004). Adequate soil moisture and freedom from weeds was maintained to ensure high and uniform germination of the seeds. The seedlings were maintained in the nursery for four weeks. Clonal evaluation consisted of nine half-sib families consisting of 1,077 progenies that were planted using family replication procedure (Jaramillo et al., 2005).

Harvesting and collection of root samples

1077 progenies constituting 10 progeny families and their respective parents were harvested at 12 months after planting; two roots were randomly collected per progeny and prepared for starch extraction by peeling and washing with distilled water.

Starch extraction

Native cassava starch extraction was carried out using a method described by Benesi (2005). A hundred grams of the fresh tuberous cassava roots were washed, peeled, and homogenized with 100 ml of 1 M NaCl to aid the release of starch from the solution using a Waring blender.

The mixture was stirred with a stirring rod for 2 min and filtered using a triple cheese (muslin) cloth. The filtrate was allowed to stand for 1 h to facilitate starch sedimentation and the top liquid was decanted and discarded. 200 ml of distilled water was added followed by centrifugation at 3,000 g for 10 min. The starch was air-dried on aluminium pans at room temperature for 24 - 36 h and stored in plastic air tight containers at room temperature. The extracted starch from each of the progeny families for a particular parent was bulked before analyses.

Determination of moisture content

Moisture content was determined according to (Benesi, 2005) with

modifications. 1.50 g of starch was dried in a forced air oven for 3 h at 105°C. The samples were transferred to a dessicator and allowed to cool to room temperature and the difference in the weight of starch was used to calculate the apparent moisture content.

Determination of protein and nitrogen content

The percentages of total nitrogen and protein were determined by Dumas combustion method in a Nitrogen/Protein analyser (Leco Model FP-528). 0.15g of the cassava starch sample was used and the total protein content was calculated using a protein conversion factor of 6.25.

Determination of starch content

The starch content was determined using a Megazyme total starch assay kit based on the AOAC method 996.11 by enzymatic hydrolysis of starch (0.1 g) using amylase/amyloglucosidases and quantification of glucose using glucose oxidase/peroxidase reagent.

Determination of amylose content

Amylose content was determined from 0.5 g starch (dry weight basis) using the Megazyme amylose/amylopectin assay kit by selective quantitative precipitation of amylopectin with concanavalin A (Con A), quantitative estimation of amylose on hydrolysis using amylase/amyloglucosidases and estimation of glucose by glucose oxidase/peroxidase assay.

Determination of total dietary fibre in extracted starch

Total dietary fibre was determined using the Megazyme available carbohydrate and dietary fibre assay kit based on the AOAC method 985.29 by deffating, drying, hydrolysis and deproteinisation of the 1.0 g of starch sample. The resultant solution was treated with ethanol (four times the volume of the sample) to precipitate the fibre and remove depolymerised proteins and glucose. The residue was filtered and washed with 78% ethanol followed by 95% ethanol and 70% acetone to remove any organic compounds left in the mixture. It was then dried in an air forced oven and weighed.

Determination of granule structure and size of cassava starch

Starch samples (starch powder) were mounted on SEM stubs with adhesive tape and coated with gold. Scanning electron micrographs were taken by a JOEL JSM-840 microscope (JOEL, Tokyo, Japan). The accelerating voltage was 5 KV and the magnification used was ×4, 000 and ×5, 000. The granule size (diameter) was obtained using the Image Tool software Version 3.0 for windows (UTHSCSA, 2002).

Pasting properties of starch

Starch pasting properties were evaluated using a Rapid Viscosity Analyser (RVA model 3D, New Port Scientific, Sydney, Australia). Starch (2.5 g, dry basis) was suspended in distilled water and the total weight adjusted to 28 g. The sample was equilibrated at 50°C for 1 min, heated 92°C in 7.5 min at a rate of 5.7°C per min, held at 92°C for 5 min, cooled to 50°C in 7.5 min at a rate of 5.7°C/min and held again at 50°C for 1 min. From the resulting pasting curve, temperature at initial viscosity increased (pasting temperature), peak viscosity (PV), time to peak viscosity (P_t), hot paste viscosity (HPV), breakdown viscosity (BV), final viscosity (FV) and setback viscosity (SV) were recorded by the rapid viscosity analyser.

Swelling powers of the starch molecules

The swelling power of the starch granules was determined according to Charles et al. (2004) at different temperatures ranging from 30 - 80°C. Swelling power was recorded as the ratio in weight of the wet sediment to the initial weight of dry starch.

Statistical data analysis

Quantitative data analysis was carried out using GENSTAT discovery Edition 3 (VSN International). Means were calculated for each of the progeny families and the analysis of variance (ANOVA) was used to test for the difference within and among the clones and parental lines at 5% level of significance ($p = 0.05$). Relationships among different starch characteristics were analyzed using correlation coefficient and regression analysis.

RESULTS AND DISCUSSION

Proximate analysis of cassava starch

Results for proximate analysis of cassava starch from the parents and their progenies are presented in Table 1. The average starch moisture content among the parental lines ranged from 14.04 to 16.66% as compared to the progenies in which it ranged from 13.78 to 15.37%. The extracted starch had low levels of protein on dry basis with averages ranging from 0.28 - 0.52% among the parents and from 0.28 - 0.35% among the progenies. Protein content values obtained were lower than the values reported by Rodríguez-Sandoval et al. (2008) and Ceballos et al. (2006). Protein effects on starch properties depend on its content with high protein negatively affecting the pasting properties (Moorthy, 2002). The dietary fibre ranged from 0.02 - 0.56% among the parental lines and 0.28 - 0.93% among the progenies with significant ($P < 0.05$) effects on a number of pasting properties such as breakdown viscosity, peak viscosity, hot paste viscosity, pasting temperature and peak time. Increase in dietary fibre results in reduction in peak viscosity and increase in the pasting temperature. On the other hand, the lipid content averaged between 0.12 - 0.38% among the parents and 0.19 - 0.38% among the progenies lying in the range suggested by Moorthy (2002).

Increased lipid content improves starch textural properties and leads to viscosity stability hence improving the quality properties of starch (Moorthy, 1985). The low levels of starch associated compounds indicate the easiness with which cassava starch can be extracted from the roots.

Starch content

The results for starch and amylose content are presented

Table 1. Proximate analyses of cassava starch (dry basis) from the parents and their progenies.

Parent cultivar	MC[1] (%)	MC[2] (%)	Protein[1] (%)	Protein[2]	Fibre[1] (%)	Fibre[2]	Lipid[1] (%)	Lipid[2] (%)
Bamunanika	16.49[a] ± 0.03	14.75[a] ± 0.04	0.35[a] ± 0.020	0.35[a] ± 0.004	0.37[a] ± 0.021	0.75[a] ± 0.017	0.38[a] ± 0.08	0.26[a] ± 0.08
Bao	16.47[a] ± 0.11	15.37[a] ± 0.19	0.52[b] ± 0.015	0.30[b] ± 0.012	0.37[a] ± 0.021	0.86[a] ± 0.017	0.22[a] ± 0.06	0.19[a] ± 0.08
Kakwale	14.62[b] ± 0.06	14.81[b] ± 0.38	0.29[a] ± .0003	0.29[b] ± 0.019	0.35[a] ± 0.014	0.28[b] ± 0.042	0.12[b] ± 0.11	0.38[a] ± 0.07
Nyaraboke	16.66[a] ± 2.00	14.91[a] ± 1.04	0.32[a] ± 0.007	0.32[b] ± 0.006	0.06[b] ± 0.014	0.69[a] ± 0.099	0.38[a] ± 0.06	0.28[a] ± 0.05
95/SE/00036	16.34[a] ± 0.24	13.78[a] ± 0.26	0.28[c] ± 0.009	0.31[b] ± 0.009	0.02[b] ± 0.007	0.59[a] ± 0.114	0.17[a] ± 0.08	0.28[a] ± 0.07
NASE 10	14.77[b] ± 1.44	15.31[b] ± 0.09	0.32[a] ± 0.007	0.31[b] ± 0.050	0.17[c] ± 0.000	0.33[b] ± 0.118	0.14[b] ± 0.09	0.34[a] ± 0.06
NASE 12	14.79[b] ± 0.76	14.08[a] ± 0.30	0.31[a] ± 0.012	0.28[b] ± 0.009	0.13[c] ± 0.021	0.58[a] ± 0.182	0.26[a] ± 0.11	0.35[a] ± 0.02
TME 5	14.04[c] ± 0.04	13.82[a] ± 0.25	0.31[a] ± 0.011	0.30[b] ± 0.004	0.56[d] ± 0.021	0.93[c] ± 0.171	0.37[a] ± 0.09	0.31[a] ± 0.03
TME 14	14.97[c] ± 0.12	14.97[a] ± 0.50	0.35[d] ± 0.011	0.33[a] ± 0.029	0.54[d] ± 0.028	0.49[d] ± 0.154	0.17[a] ± 0.08	0.22[a] ± 0.08

[1] Results for the parental lines; [2] Results for the progenies; [a] Mean values of triplicate analyses in a column with the same superscript are not significantly different at 5%. MC[1] = moisture content of the parents; MC[2] = moisture content of the progenies

in Table 2. Among the parental lines, the starch content averaged from 70.36 - 89.90% while it was between 73.48 - 93.85% among the progenies. Significant differences were observed among the parents and the progenies in terms of starch content with the TME and 95/SE/00036 showing significantly ($P < 0.05$) lower starch content amongst the parents and showing significantly ($P < 0.05$) higher starch contents in case of the progeny families.

Amylose content of cassava starch

Results for the amylose content in cassava starch are presented in Table 2. The amylose content among the parental lines ranged from 23.01 - 26.98% while among the progenies, it ranged from 19.69 - 26.63%. There were no significant ($P > 0.05$) differences observed in amylose contents of different parents. A similar observation was reported by Moorthy (2002). The amylose content did not have significant ($P>0.05$) effects on starch pasting properties although it was positively correlated to the pasting temperature and the peak time. The progenies however, showed significant ($P < 0.05$) differences with progenies of Nyaraboke showing significantly ($P < 0.05$) lower amylose content than the other families. Amylose content is important in almost all starch properties with low amylose contents leading to increased relative crystallinity of starch due to the reduced amorphous regions within the starch granule (Tukomane et al., 2007). Amylose content also affects the retrogradation properties of starch where high amylose starches have increased retrogradation tendencies caused by the aggregation of amylose which acts as nuclei during the process amylopectin retrogradation (Rodríguez-Sandoval et al., 2008). The influence of amylose on the pasting properties depends on its leaching out of the amylopectin network during heating into the solution affecting the starch's viscoelastic properties (Charles et al., 2004) . Increase in amylose content leads to increase in the pasting temperature (Novel-Cen and Betancur-Ancona, 2005) due to the prolonged escape of amylose out of the amylopectin network during the gelatinisation of starch leading to prolonged swelling of starch granules (Moorthy, 2002) hence increasing the temperature required to form a starch paste.

Starch granule structure and morphology

Results showing scanning electron micrographs for starch granule shapes are presented in Figure 1. The micrographs showed granules with varying shapes in both the parents and progenies with the granules being characteristically kettle-drum shaped/truncated and some shapes ranging from oval to polygonal and round. Different surface morphologies were observed in the different granules and these ranged from few rough surfaced to dominantly smooth surfaced granules. Some granules had surface pores or fissures. These are important in the hydrolysis of starch as they aid the release of amylose hence important in starch solution properties (Tukomane et al., 2007). The top surface of truncated granules was either convex, biconvex and in some cases with various convex pits presented. The granule size in the parental lines ranged from 8.14 - 10.77 μm and between 8.03 - 9.36 μm in the progenies (Table 3). Granule size had a trimodal range with small

Table 2. Amylose content and starch content of the parents and the F_1 progenies clones.

Parental cultivars	Starch content % (db)		Amylose %	
	Parent	Progenies	Parent	Progenies
Bamunanika	74.84[a]±2.54	75.12[a]±1.62	25.90[a]±0.25	24.51[a]±1.51
Bao	78.49[a]±1.80	75.09[a]±1.65	25.16[a]±0.59	22.77[b]±0.06
Kakwale	81.79[b]±0.13	80.94[b]±1.08	25.72[a]±0.08	24.04[a]±0.18
Nyaraboke	81.76[b]±0.96	88.56[c]±0.09	25.28[a]±1.98	19.69[c]±1.96
95/SE/00036	89.90[c]±1.03	93.85[d]±1.93	23.01[a]±1.05	26.63[d]±1.23
NASE 10	85.38[d]±1.11	73.92[a]±2.34	23.64[a]±0.03	20.49[c]±0.89
NASE 12	76.12[a]±3.43	76.43[a]±4.47	26.98[a]±0.68	23.21[a]±0.98
TME 5	77.27[a]±0.42	74.29[a]±1.39	24.60[a]±3.19	24.09[a]±1.58
TME 14	70.36[e]±0.40	73.48[a]±0.67	23.44[a]±2.63	26.04[d]±1.12

[a]Mean values of duplicate analyses in a column with the same superscript are not significantly different at 5%.

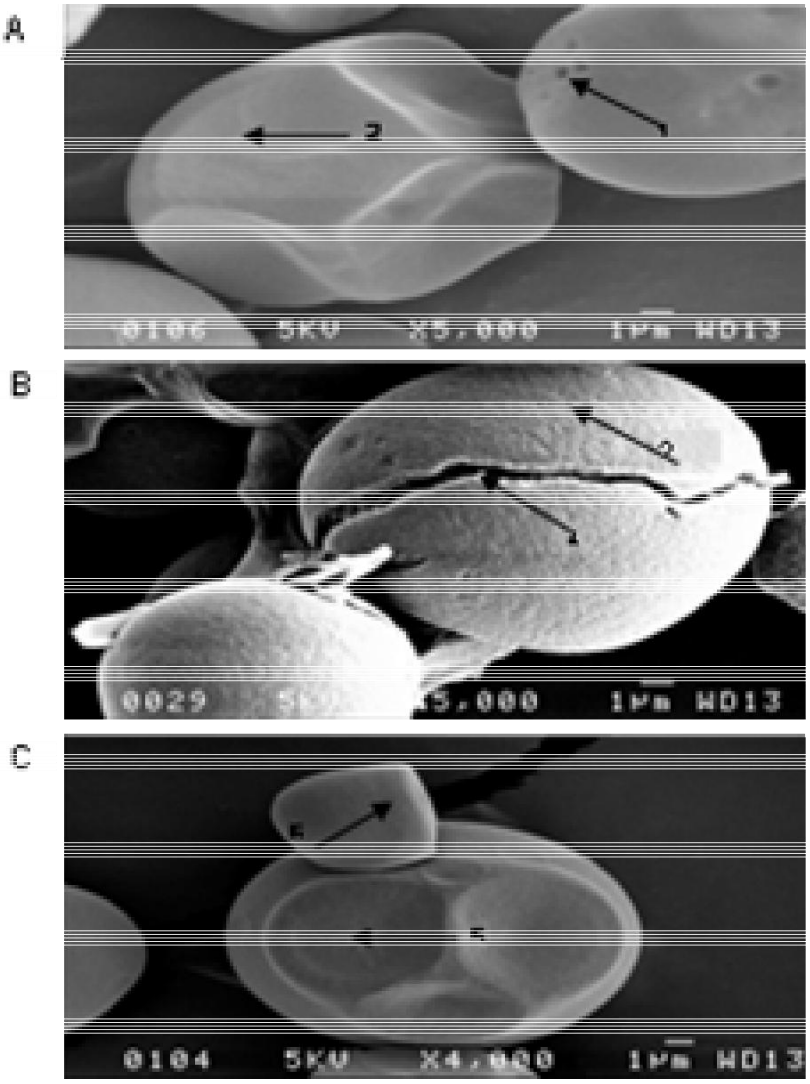

Figure 1. Structure of cassava starch granules showing the granule shapes and different surface morphologies A= TME 5 parent, B= Bao parent, C = Bamunanika parent. 1 = Surface pores on a smooth granule. 2 = Smooth surfaced granules, 3 = Rough surfaced granules 4 = Fissure in the granule 5 = Convex pits on the top surface of the granule, 6 = small granule on top of large granule.

Table 3. Granule size analysis across different parents and their progenies, size ranges and their trimodal distribution.

Variety/Family	Size[1]	Range[1]	Granule shape[1]	N	A%	B %	C%
Bamunanika	10.72[a]±3.12	1.0-19.5	truncated, polygonal, oval	108	11.11	65.28	23.61
Progenies	9.06[a]±3.09	2.0-16.0	truncated, polygonal	131	20.61	67.18	23.61
Bao	10.77[a]±3.19	5.0-18.5	truncated, polygonal	166	8.38	68.86	22.75
Progenies	8.06[a] ±2.86	1.5-14.5	truncated, polygonal	114	32.75	64.65	2.58
Kakwale	8.14[a] ±2.86	2.0-15.2	truncated, polygonal, oval	118	26.95	70.21	2.83
Progenies	8.97[a] ±3.07	2.9-15.4	truncated, polygonal oval	140	26.56	65.63	7.81
Nyaraboke	9.92[a] ±2.66	5.0-17.0	truncated, polygonal round	105	12.28	76.32	11.40
Progenies	8.03[a] ±2.90	1.8-14.8	truncated, polygonal	114	34.29	60.00	5.71
95/SE/00036	10.29[a] ±3.13	3.1-19.9	truncated, polygonal, oval	185	15.91	69.89	14.21
Progenies	9.36[a] ±3.30	2.5-18.9	truncated, polygonal, oval	107	24.29	65.42	10.28
NASE 10	8.33[a] ±3.26	1.4-18.8	truncated, polygonal	127	30.21	61.87	7.91
Progenies	9.35[a] ±3.21	1.4-16.7	truncated, polygonal	109	29.21	59.55	11.23
NASE 12	10.03[a] ±2.68	3.0-18.6	truncated, oval	98	7.84	82.35	9.80
Progenies	9.11[a]±2.49	2.4-14.8	truncated, oval	102	18.81	76.23	4.95
TME 5	8.51[a] ±3.08	1.7-15.2	truncated, oval rounded	108	32.28	59.84	7.84
Progenies	8.73[a] ±2.93	2.6-15.1	truncated, oval, rounded	107	29.59	61.23	9.18
TME 14	9.61[a] ±2.22	3.5-15.5	truncated, polygonal, oval	103	7.92	84.16	7.92
Progenies	8.97[a] ±2.72	2.1-16.2	truncated, polygonal, oval	122	21.95	69.11	8.94

[a] Mean values of n analyses in a column with the same superscript are not significantly different at 5%; N: number of granules observed/ measured in a particular size range and shape; Trimodal distribution shown as the percentage where A= small sized granules from 1-6.9 μm, B= medium sized granules of 7-12.9 μm, C= large granules of 13-20 μm.

with small granules ranging from 2-6 μm and composing of 7.8-34.3% among the parents and the progenies, middle sized granules ranging from 7-12 μm (59.6-84.2%) and large granules ranging from 13-20 μm (2.6-23.6%). The trimodal range observed may be attributed to the harvest time and the growing conditions for cassava (Sriroth et al., 1999) where granules of starch obtained from plants grown in the dry season has predominantly smaller granules. Due to the observed differences in size distri-butions among the progenies and their parents, variations were observed in their starch pasting proper-ties and swelling power. Most of the parents had a low percentage of small granules compared to the progenies. However, the percentage of middle sized granules was higher in most of the parents compared to their respective progenies. This could have resulted into the differences observed in the pasting characteristics of the progenies compared to the parents. Based on the granule morpho-logy and size variations, cassava starch can be produced to suit various uses such as in textile applications. In par-in the progenies it ranged between 170.79-226.54 RVU. The high average peak viscosity observed among cassava starches analysed reflect the low amylose content in cassava compared to wheat and maize starches (Zaidul et al., 2007). Starches with low amylose content gelatinize easily with consequent leaching out of amylose and rapid increases in viscosity. This is especially common in starches from potato and other tuber and root crops, which display high viscosities with large differences between the peak and final viscosities (Noda et al., 2006). In the parental lines, the average peak viscosity was low in local landraces compared to the introduced varieties with the exception of NASE 12 (Table 4). Low peak viscosity translates into good cooking properties (Moorthy, 2002) hence the farmers preference of local landraces especially Kakwale in this case. The hot paste viscosity (HPV) was generally lower applications. In particular the increased percentage of small granules among different progenies increases the potential for the use of this starch in the bio-ethanol industry (Ceballos et al., 2008). Starch granules are also important in the characterisation of different botanical sources of starch (Moorthy, 2002) and are a major focus in the modification of starch used in laundry (Varavinit et al., 2007).

Pasting properties of cassava starch

Results for cassava starch viscosity and pasting properties are shown in Table 4. The peak viscosity of the parental lines ranged from 253.01 - 344.96 RVU while in the parental lines (66.33 - 124.30 RVU) than in the proge-

Table 4. Rheological and pasting properties of cassava starch from nine parental varieties and their progenies.

Variety/Family	Peak (RVU)	HPV (RVU)	Break (RVU)	Final (RVU)	Setback (RVU)	PTi	Peak time (Min)
Bamunanika	290.21^{a}±7.01	73.33^{a}±5.66	216.88^{a}±1.35	156.57^{a}±1.84	73.67^{a}±6.01	66.93^{a}±0.74	5.44^{a}±0.05
Progenies	204.17^{b}±0.12	124.75^{b}±7.31	79.42^{b}±7.19	182.92^{b}±5.89	57.99^{b}±1.17	68.65^{b}±0.35	7.77^{b}±0.14
Bao	292.89^{a}±4.75	66.33^{a}±7.07	222.29^{a}±3.71	145.96^{c}±4.54	70.08^{a}±1.90	66.78^{a}±0.11	5.14^{c}±0.05
Progenies	170.79^{c}±0.4	81.75^{ca}±4.36	76.26^{b}±7.68	130.07^{d}±3.28	57.25^{b}±1.64	68.81^{b}±0.29	7.51^{b}±0.03
Kakwale	253.01^{d}±3.43	79.96^{c}±0.06c	168.56^{c}±2.98	193.36^{e}±0.06	63.71^{c}±1.58	70.4^{b}±1.27	5.97^{d}±0.05
Progenies	222.05^{e}±0.5	106.71^{d}±2.53	115.34^{d}±2.00	159.71^{a}±6.42	86.67^{d}±2.59	66.73^{a}±0.04	6.57^{e}±0.05
Nyaraboke	298.13^{a}±3.25	73.88 ^{a}±2.06	223.25^{a}±2.59	154.71^{a}±6.42	85.84^{d}±2.59	69.98^{b}±0.04	5.97^{d}±0.05
Progenies	226.54^{e}±0.41	94.84^{d}±0.12	129.7^{e}±3.37	172.79^{b}±6.19	73.46^{a}±3.13	66.73^{a}±0.04	7.50^{b}±0.14
95/SE/00036	336.55^{f}±0.18	80.34^{c}±0.23	256.21^{f}±0.41	162.75^{a}±1.41	82.42^{d}±1.65	63.28^{c}±0.04	4.24^{f}±0.04
Progenies	221.59^{e}±4.48	79.54^{c}±1.12	142.04^{g}±0.41	141.92^{c}±1.77	62.38^{c}±0.64	64.90^{d}±0.00	4.67^{g}±0.00
NASE 10	303.75^{a}±1.88	80.46^{c}±5.01	223.29^{a}±3.13	152.34^{a}±5.18	71.88^{a}±0.18	68.45^{b}±0.07	5.53^{h}±0.00
Progenies	221.46^{e}±0.05	97.67^{e}±0.19	120.34^{d}±4.37	159.63^{a}±2.03	67.28$_{e}$±0.51	65.80^{a}±0.35	5.13^{c}±0.00
TME 5	282.6^{a}±5.05	124.30^{b}±2.65	216.04^{a}±1.36	227.17^{f}±2.59	89.17^{d}±0.00	66.23^{a}±0.00	5.75^{i}±0.03
Progenies	195.55^{b}±1.95	127.34^{b}±7.66	93.34^{i}±2.35	178.67^{b}±2.60	76.81^{a}±2.66	68.05^{b}±0.00	6.90^{j}±0.24
TME 14	344.96^{h}±2.77	80.54^{c}±3.24	264.42^{j}±0.47	167.54^{a}±2.41	87.00^{d}±2.41	64.75^{d}±0.00	5.35^{k}±0.05
Progenies	203.17^{b}±5.66	99.25^{e}±3.29	103.92^{k}±2.36	165.42^{a}±6.72	66.08^{e}±3.54	68.45^{b}±0.00	6.70^{j}±0.04

^{a}Values with the same superscript in the column not significantly different at 5%. HPV= hot paste viscosity; PTi= pasting temperature; RVU= rapid viscosity units.

progenies (79.54 - 127.34 RVU) with significant (P< 0.05) differences observed among the parents and their progenies. Similar results were observed for the break down viscosity in the parental lines (168.56 - 264.42 RVU) and the progenies (56.13 - 142.04 RVU) while the final viscosity ranged from 145.96 - 227.17 RVU in the parental lines and 130.07 - 182.92 RVU in the progenies. The low final viscosities observed compared to the peak viscosities indicate the low tendency of cassava starch to retrograde (Moorthy, 2002). The set back viscosity was generally higher in the parents (63.71 - 89.17 RVU) than in the progenies (56.04 - 86.67 RVU). Starch viscosity is important in the characterisation of starch and the differences observed provides an opportunity for selection of cultivars from the F_1 progenies for industrial and food uses. The pasting temperature of starch from the different parental lines ranged from 63 - 69°C and was similar to that of the progenies where it ranged from 64.90 to 68.81. Cassava starch has low pasting temperature (average 68°C) hence, it forms pastes much easier compared to starches with high pasting temperatures such as potato (average 72°C) (Moorthy, 2002) and rice (average 69.5°C) (Cameron et al., 2007).This is due to the low stability of cassava starch granules on heating which makes them loose their molecular structure easily (Novelo-Cen and Betancur-Ancona, 2005). The peak time was low among the parental lines (4.24 - 5.97 min) compared to the progenies (4.67 - 7.77 min) hence their ability to form pastes much easier than the progenies. Significant (P < 0.05) differences were observed in the different pasting properties of the progenies with wider variations observed among them. Such differences can be attributed to the differences in the size distributions of starch granules (Table 3) and give more opportunity for selection of starch with different uses compared to the parents. The starch pasting curves for the different varieties and progenies are presented in Figures 2a and b. The results showed an outstanding feature for starch obtained from the progenies where the pasting curve had no clear peak with a 'shoulder' at attainment of peak viscosity suggesting differences in the crystalline nature of starch and the general structure of amylopectin component of starch in the different progenies compared to the different parents.

Swelling power of cassava starch

The results of starch swelling power at different temperatures are presented in Table 5. An average of 2 fold increase was observed with a 10°C change in temperature. At higher temperatures (>70°C), a sudden increase in swelling power was observed. This may be attributed to the disruption of starch granules at higher temperatures and consequent release of all the amylose from the amylopectin network (Charles et al., 2007).

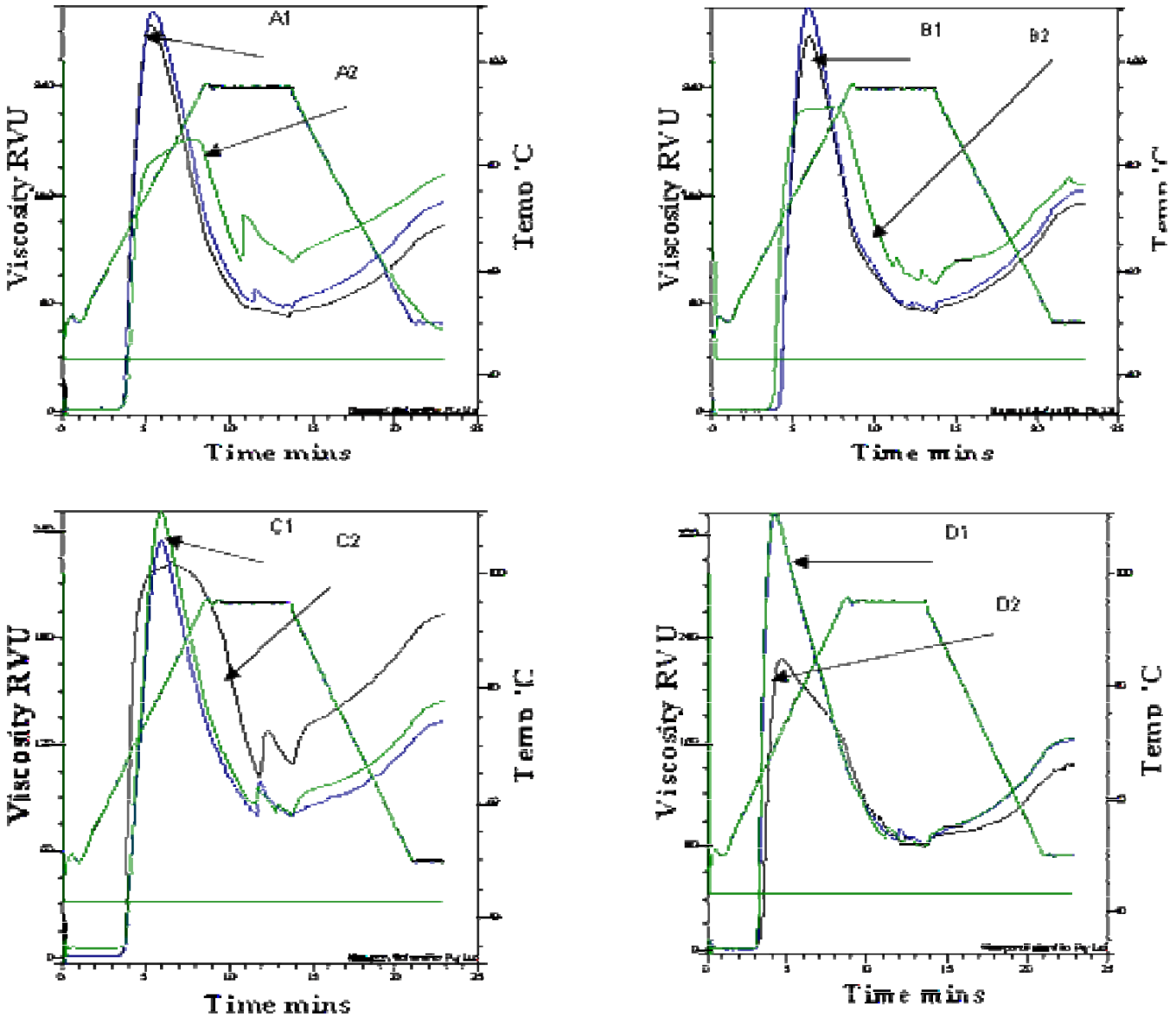

Figure 2a: Pasting profiles of different parents compared with F1 Families and other varieties. A=Bamunanika; B=Nyaraboke; C=Kakwale; D= 95/SE/00036. X1= Parent, X2= Progeny.

Significant (P< 0.05) differences were observed in swelling power at 30°C between the parents and progenies with the progenies showing an average high swelling power. At higher temperatures the differences generally disappeared. Uptake of water by starch granules results into progressive swelling as temperature increases (Charles et al., 2007). Swelling power is an important parameter especially in characterisation of starches from different botanical origins which display different swelling powers at a given temperature (Moorthy, 2002; Charles et al., 2007). It also affects both the eating quality of cassava roots and the use of starch in a number of industrial applications (Moorthy, 2002). High swelling power results into high digestibility and ability to use starch in solution suggesting improved dietary properties and the use of starch in a range of dietary applications.

Correlations among the physicochemical and functional properties of cassava starch

The results for the interrelationships between various starch properties are presented in Table 6. The amylose content was positively correlated to the starch content (r

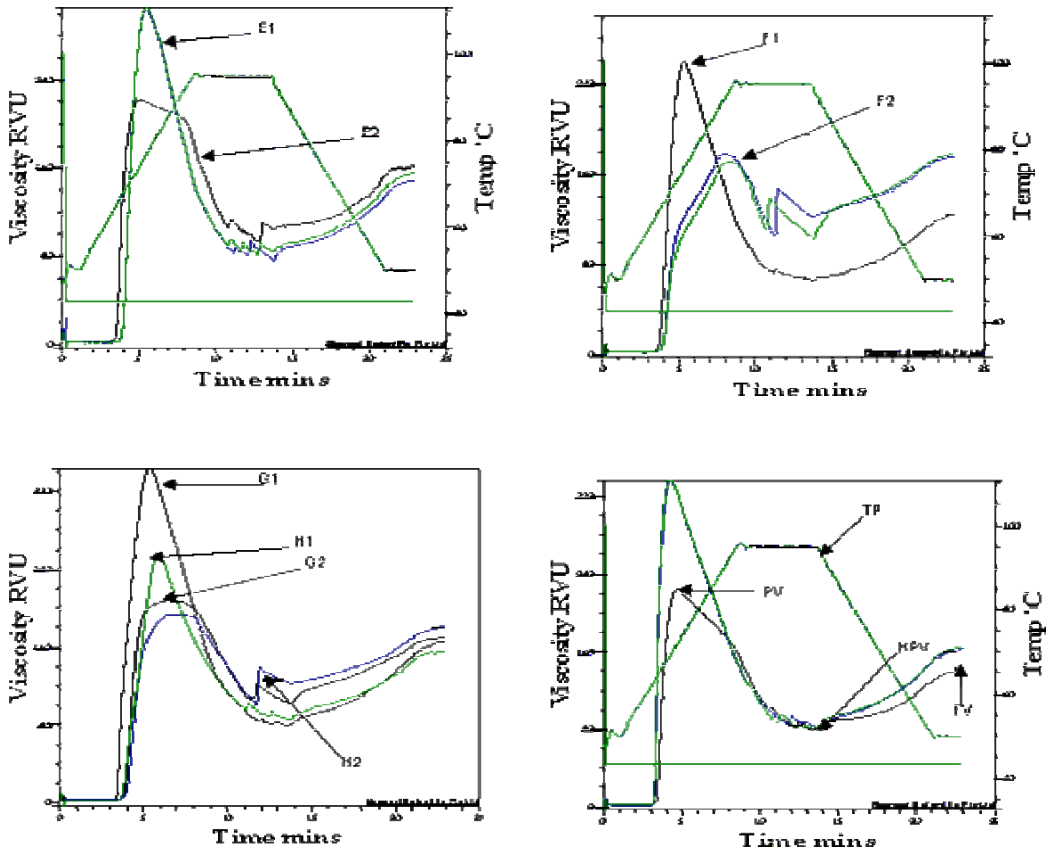

Figure 2b: Pasting profiles of different parents compared with F1 Families and other varieties.
E= NASE 12; F=NASE 10; G= TME 14; H= TME 5. X1= Parent, X2= Progeny. PV= Peak Viscosity, HPV = Hot Paste Viscosity or Trough Viscosity, FV= Final Viscosity, FV-HPV= Set back viscosity, PV-HPV = Break down viscosity TP = Temperature profile.

Table 5. Cassava starch swelling power at different temperatures.

Variety/Progenies	30°C	40°C	50°C	60°C	70°C	80°C
Bamunanika	1.52^{a} ± 0.22	2.63^{a} ± 0.71	5.95^{a} ± 0.28	7.87^{a} ± 0.36	10.21^{a} ± 0.57	16.16^{a} ± 0.75
Progenies	2.12^{b} ± 0.11	3.64^{a} ± 0.22	7.21^{b} ± 0.89	9.91^{b} ± 0.09	11.18^{a} ± 0.73	16.89^{a} ± 1.61
Bao	1.54^{a} ± 0.29	3.33^{a} ± 0.61	6.39^{a} ± 1.39	7.85^{a} ± 0.36	10.79^{a} ± 0.61	15.76^{a} ± 0.96
Progenies	2.73^{b} ± 0.51	3.64^{a} ± 0.52	6.79^{a} ± 0.42	9.09^{b} ± 0.14	12.24^{a} ± 1.43	15.05^{a} ± 0.09
Kakwale	1.32^{a} ± 0.19	3.74^{a} ± 0.37	6.39^{a} ± 0.31	8.72^{a} ± 0.34	11.61^{a} ± 0.10	15.66^{a} ± 0.55
Progenies	2.04^{b} ± 0.39	6.01^{b} ± 1.25	7.04^{a} ± 0.26	9.98^{b} ± 0.27	14.59^{b} ±1.44	18.59^{a} ± 2.48
Nyaraboke	1.68^{a} ± 0.45	3.59^{a} ± 0.65	6.21^{a} ± 0.68	8.73^{a} ± 0.34	12.11^{a} ± 0.25	16.32^{a} ± 0.74
Progenies	2.05^{b} ± 0.03	4.24^{b} ± 0.88	7.11^{a} ± 0.42	9.39^{b} ± 0.25	10.51^{a} ± 1.52	16.05^{a} ± 1.06
95/SE/00036	1.95^{a} ± 0.09	3.85^{a} ± 0.07	6.54^{a} ± 0.02	8.31^{a} ± 1.16	11.32^{a} ± 0.85	15.67^{a} ± 0.74
Progenies	1.94^{b} ± 0.11	4.54^{b} ± 0.96	5.62^{a} ± 1.47	9.75^{b} ± 0.62	12.78^{a} ± 1.88	15.15^{a} ± 1.37
NASE 10	1.57^{a} ± 0.18	3.10^{a} ± 0.06	5.97^{a} ± 0.23	9.11^{b} ± 0.25	12.62^{a} ± 0.98	17.14^{a} ± 1.37
Progenies	2.00^{b} ± 0.29	5.40^{b} ± 0.54	7.97^{a} ± 0.12	10.77^{b} ± 0.01	12.54^{a} ± 1.01	20.79^{b} ± 0.91
NASE 12	1.62^{a} ± 0.25	3.73^{a} ± 0.07	5.95^{a} ± 0.32	8.16^{a} ± 0.32	12.99^{a} ± 1.83	17.08^{a} ± 0.76
Progenies	2.36^{b} ± 0.01	4.00^{b} ± 0.52	6.74^{a} ± 0.46	9.92^{b} ± 0.31	13.29^{a} ± 1.61	18.01^{a} ± 2.99
TME 5	1.26^{a} ± 0.10	3.15^{a} ± 0.14	6.17^{a} ± 0.63	7.53^{a} ± 0.27	11.27^{a} ± 0.93	16.82^{a} ± 1.14
Progenies	1.92^{b} ± 0.57	6.31^{b} ± 1.16	7.46^{a} ± 0.26	9.11^{ab} ± 0.79	12.83^{a} ± 2.09	16.29^{a} ± 2.14
TME 14	1.27^{a} ± 0.18	3.18^{a} ± 0.08	5.95^{a} ± 0.31	8.59^{a} ± 0.37	10.38^{a} ± 1.85	17.33^{a} ± 0.93
Progenies	2.38^{b} ± 0.01	5.57^{b} ± 1.13	7.60^{a} ± 0.33	8.89^{a} ± 0.03	13.61^{a} ± 1.17	15.74^{a} ± 1.77

^{a}Mean values with the same superscript are not significantly different at 5%.

Table 6. Correlation matrix between the different starch parameters.

	Amy	Ash	BV	CF	FV	GS	Lpd	MC	PV	PT	Pt	Ptn	SP	SV	Sol	SC	HPV	WSM	
Amy	1.00																		
Ash	0.06	1.00																	
BV	-0.27*	0.13	1.00																
CF	0.32	0.25*	-0.38*	1.00															
FV	0.18	0.61*	-0.29*	0.08	1.00														
GS	-0.30*	0.46*	0.10	-0.49*	0.16	1.00													
Lpd	0.18	0.73*	0.09	-0.45*	0.45*	0.35*	1.00												
MC	-0.54*	-0.64*	-0.01	-0.28*	-0.29*	-0.35*	-0.37*	1.00											
PV	-0.20	0.32*	0.88*	-0.54*	0.10	0.24	0.35*	0.01	1.00										
PT	0.38*	0.53*	-0.62*	0.42*	0.51*	0.03	0.40*	-0.60*	-0.56*	1.00									
Pt	0.45*	-0.22	-0.73*	0.49*	0.44*	-0.60*	-0.21	0.17	-0.57*	0.38*	1.00								
Ptn	-0.28*	-0.09	0.27	-0.17	0.21	0.24	-0.38*	0.18	0.35*	-0.43*	-0.09	-0.09	1.00						
SP	-0.73*	-0.01	0.57*	-0.81*	-0.30*	0.36*	0.20	0.54*	0.59*	-0.63*	-0.66*	-0.66*	0.20	1.00					
SV	0.23	0.23	0.49*	-0.32*	0.14	-0.23	0.54*	-0.03	0.57*	-0.07	-0.16	-0.16	0.05	0.25	1.00				
Sol	-0.74*	0.18	0.24	0.08	0.26*	0.32*	-0.24	0.10	0.23	-0.11	-0.26*	-0.26*	0.58*	0.28*	-0.23	1.00			
SC	0.52*	0.31*	0.17	-0.05	-0.28*	0.17	0.23	-0.64*	0.04	0.14	-0.27*	-0.27*	-0.48*	-0.26*	-0.08	-0.55*	1.00		
HPV	0.35*	0.45*	-0.58*	0.18	0.87*	0.17	0.50*	-0.35*	-0.22	0.71*	0.49*	-0.01	-0.44*	0.10	-0.02	-0.24	0.71*	1.00	
WSM	0.10	0.25*	-0.47	0.32*	0.43*	-0.48*	0.33*	0.04	-0.39*	0.68*	0.55*	-0.44*	-0.29	0.24	-0.06	0.32*	0.45*	0.51*	1.00

*n= Significant correlations at 5%. BV= breakdown viscosity, CF= crude fibre, FV= final viscosity, GS= granule size, MC= moisture content, PV= peak viscosity, PT= peak temperature, Pt= peak time, SP= swelling power, SV= set back viscosity, Sol= Solubility, SC= starch content, HPV= hot paste viscosity, WSM= cold water soluble materials, Lpd = lipid content, Ptn = protein content.

= 0.522) and the peak time (r = 0.450) while it was negatively correlated to swelling power (r = -0.733) and moisture content (r = -0.536) suggesting its importance in starch solution and pasting properties. However, no significant relationships were observed between amylose content and other pasting parameters including peak and final viscosity. There were positive correlations between the ash content and peak time (r = 0.533), hot paste (r =0.451) and final viscosity (r = 0.607). This could be attributed to the presence of phosphorus and minerals such as calcium, which impart high viscosity to starch and increases its gel strength (Moorthy, 2002). The negative correlation between dietary fiber and peak viscosity (r = -0.544) explains the reductive effect of fiber on the viscosity of starch. Dietary fibre was also positively correlated to peak time (r = 0.486) and pasting temperature (r = 0.422) as expected since fibre acts as a barrier to the free swelling of starch granules hence increasing the pasting temperature and peak time during pasting (Moorthy, 2002). Thus the high swelling power observed in cassava starch is as a result of low fibre contents associated with it. Swelling power was negatively correlated to peak time (r = -0.659), pasting temperature (r = -0.629) and crude fibre (r = -0.805) suggesting the low peak time and low crude fibre associated with cassava starch which has a high swelling power (Charles et al., 2007), and positively correlated to peak viscosity (r = 0.588) explaining the increase in swelling power with increase in the pasting properties of starch (Rickard et al., 1991). On the other hand, cold water solubility was positively correlated to peak time (r = 0.549) and the pasting

temperature (r = 0.684).

ACKNOWLEDGEMENTS

This work was supported under the BIO-EARN program, with a grant from the Swedish International Cooperation Agency/Department for Research Cooperation (Sida/ SAREC).

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