African Crop Science Journal, Vol. 31, No. 2, pp. 201 - 214 ISSN 1021-9730/2023 $4.00

DOI: https://dx.doi.org/10.4314/acsj.v31i2.6

EVALUATION OF THE INDUSTRIAL POTENTIAL OF CASSAVA BASED ON PASTING PROPERTIES OF CASSAVA FLOUR FROM UGANDAN ELITE VARIETIES

E. NUWAMANYA[1,2], M. KANAABI[12], A. KATUNGISA[2], N. MUHUMUZA[1,2], I. LYATUMI[2], W. ESUMA[2], R. KAWUKI[2], Y. BAGUMA[2] and E. ATWIJUKIRE[3]

[1]Department of Agricultural Production, Makerere University, P. O. Box 7062, Kampala, Uganda
[2]National Crops Resources Research Institute, P. O. Box 7084, Kampala, Uganda
[3] National Coffee Research Institute, P. O. Box 185, Mukono, Uganda
Corresponding author: Ephraim.nuwamanya@mak.ac.ug

(*Received 11 January 2023; accepted 4 February 2023*)

ABSTRACT

The importance of cassava (*Manihot esculenta* Crantz) as a source of bio-polymers and as an industrial crop is based on its adaptability for various end-uses and high productivity potential. Cassava's transformation from its traditional uses, therefore, calls for application of targeted varieties with industrial specifications. Even cassava-based products require understanding of the variety based attributes. However, lack of information about cassava variety traits has limited targeting of different varieties or products for specific industrial uses. The objective of this study was to profile the released Ugandan cassava varieties for biochemical composition and critical industrial attributes. Dry matter content ranged from 30 to 38%, but was not a significantly different (P>0.05) variable among the cassava varieties. Starch yield to dry matter ratio ranged from 0.617 to 0.831, representing 61.7-83.1% starch recovery from different varieties. Flour pasting properties showed significant differences (P<0.05), especially in the time to attain peak viscosity and the time at which the initial rise in viscosity due to pasting was achieved. Pasting temperatures of the flour also ranged from 69-74°C and were within the recommended range for cassava based industrial products. Flour showed significant differences when the paste was cooled, especially for the setback (245-1410 cP) and final viscosities (3522-6730 cP). Pasting properties showed that Ugandan cassava varieties can be categorised into three distinct groups, and hence differ in suitability for various cassava flour-based applications. The observations from this study are important in developing a realistic variety use strategy, especially for niche industries. The observed variabilities can be used in two different ways; (i) selections in the current germplasm for a variety(ies) for specific industrial applications, and (ii) hybridisations within this existing germplasm and subsequent selection of new varieties with industry specific characteristics.

Key Words: Cassava, dry matter, pasting, starch

RÉSUMÉ

L'importance du manioc (*Manihot esculenta* Crantz) en tant que source de biopolymères et en tant que culture industrielle repose sur sa capacité d'adaptation à diverses utilisations finales et son potentiel de productivité élevé. La transformation du manioc de ses utilisations traditionnelles nécessite donc l'application de variétés ciblées avec des spécifications industrielles. Même les produits à base de manioc nécessitent une compréhension des attributs variétaux. Cependant, le manque d'informations sur les caractéristiques des variétés de manioc a limité le ciblage des différentes variétés ou produits à des fins industrielles spécifiques. L'objectif de cette étude était de profiler les variétés de manioc ougandaises publiées pour la composition biochimique et les attributs industriels critiques. La teneur en matière sèche variait de 30 à 38 %, mais n'était pas une variable significativement différente (P>0,05) parmi les variétés de manioc. Le rapport rendement en amidon sur matière sèche variait de 0,617 à 0,831, ce qui représente une récupération d'amidon de 61,7 à 83,1 % à partir de différentes variétés. Les propriétés d'empâtage de la farine ont montré des différences significatives (P < 0,05), en particulier en ce qui concerne le temps nécessaire pour atteindre la viscosité maximale et le moment auquel l'augmentation initiale de la viscosité due à l'empâtage a été atteinte. Les températures d'empâtage de la farine variaient également de 69 à 74 °C et se situaient dans le rang recommandé pour les produits industriels à base de manioc. La farine a montré des différences significatives lorsque la pâte a été refroidie, en particulier pour le recul (245-1410 cP) et les viscosités finales (3522-6730 cP). Les propriétés d'enrobage ont montré que les variétés de manioc ougandaises peuvent être classées en trois groupes distincts, et diffèrent donc par leur aptitude à diverses applications à base de farine de manioc. Les observations de cette étude sont importantes pour l'élaboration d'une stratégie réaliste d'utilisation des variétés, en particulier pour les industries de niche. Les variabilités observées peuvent être utilisées de deux manières différentes ; (i) sélections dans le germoplasme actuel pour une ou plusieurs variétés pour des applications industrielles spécifiques, et (ii) hybridations au sein de ce germoplasme existant et sélection ultérieure de nouvelles variétés avec des caractéristiques spécifiques à l'industrie.

Mots Clés: Manioc, matière sèche, empâtage, amidon

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is important in sub-Saharan Africa as a livelihood crop for millions of farmers, processors and traders (Abass *et al.*, 2013). Cassava production trends have increased with adoption of new varieties as the main driver for the increasing production (Buyinza and Kitinoja, 2018). In Uganda, most of the cassava produced is consumed locally, although there has been increase in industrial demand, especially in flour, brewery and confectionaries (Waigumba *et al.*, 2016). In some cases, cassava is used to replace proportions of raw materials in the production processes as a cost cutting measure or in the production of affordable products (Kleih *et al.*, 2012).

Because of such developments, interest in cassava for business is fast growing. Different players involved in production of "industrial cassava" have also emerged, with interest in various products, ranging from high quality cassava flour (HQCF), cassava pellets, chips and other cassava flour or cassava chips variants (Waigumba *et al.*, 2016).

The growing interest has led to the revision of East African Standards (EAS, 2010) for cassava and based products, with emphasis on products that meet industrial requirements. It has also led to the demand for varieties that can easily be processed to meet such requirements and specifications.

Industrial players have also been demanding for cassava varieties that meet the requirements in such specifications, with emphasis on yield and process-ability attributes.

Specifications for industrial based cassava products demand for understanding of the variety based attributes. Apart from measurable industrial and product quality characteristics such as starch, fiber and moisture contents, other inherent attributes such as pasting properties and solution properties also need to be known. For example, the 2012 EAS standard indicates that the pasting temperature for HQCF should be less than 75 °C. However, dissimilarities in many of the industrial and specific end user traits have been reported to be variety dependent (Omodamiro *et al*., 2007; Ikegwu *et al.,* 2009). Even then, flour has become the primary tradable product of cassava (Ayetigbo *et al*., 2018) although little has been done to understand its relevant properties. Therefore, recommendations for specific variety usage cannot be made presently. Thus, the specific requirement and the lack of knowledge about flour properties calls for understanding of the attributes of available cassava varieties before they can be exploited for industrial use. The objective of this study was to provide relevant information on the pasting and solution properties of flour from cassava varieties released in Uganda in the period 1990-2018.

MATERIALS AND METHODS

Cassava varieties. The study focused on eighteen improved and released cassava varieties in Uganda. It was established in plots in a randomised complete block design (RCBD) with 3 replications at the National Crops Resources Research Institute (NaCRRI), Namulonge located within the Lake Victoria crescent at 32°37’36.0’’E and 0°31’13.7’’N, and at 1134 M above sea level. These varieties were the most common among farmers although their distribution depended on farmer preference, susceptibility to diseases and pests and availability of seed (Buyinza and Kitinoja, 2018). Being grown in different areas also implies that the varieties are currently being used to produce industrial based cassava flours.

At maturity (about 12 months after planting), three plants were harvested from each plot and two medium sized roots (1-1.5 kg) each were selected from each plant. The roots were pooled together to form six roots, representing a single plot. The pooled roots were taken to the sample preparation platform in the laboratory, washed using potable water, peeled and aggregated for sample preparation.

Sample preparation. The roots were peeled, washed under running water and wiped with a paper towel. The roots were then cut longitudinally into two equal halves. The different halves from all the plants per plot, were then aggregated. One portion of the first half was used to prepare samples for dry matter determination; while the remaining portion on the other half was used in preparation of flour. A portion of the other half was used to determine starch yield; while the remaining portion from this half was used to prepare flour for analysis. The portions for flour preparation were grated to enhance drying. The grates were later dried in the oven (Leader engineering, Cheshire, England) at 50°C and thereafter milled into flour using a laboratory mill (Wiley® Mini-Mill).

Cassava root dry matter content. The root halves used for dry matter determination were cut into small pieces of approximately 2 by 4 centimeters. From these, 200 g were taken using an electronic balance (ME204/Mettler Toledo) and placed on a pre-weighed dry matter determination plate.

The plates were placed in an air forced oven for 48 hours at 105 °C, after which they were reweighed. Further drying was done to ensure constant dry weight and thereafter, the dried pieces were placed in silica gel container and reweighed. Dry matter was determined using Equation 1.

$$DMC = \frac{W2}{W1} \times 100 \quad \text{.............. Equation 1}$$

Where:

W_1= Weight of the chopped cassava sample before drying;
W_2= Weight of the cassava sample after drying

Root starch yield. Halves of selected cassava were piled together and sliced into small (approximately 5 by 5 cm^3) cubes, using a table knife. Fresh root starch yield was then determined according to Atwijukire *et al.* (2019) with calculation for starch yield (%) as a ratio of the dry starch weight to fresh root sample weight multiplied by 100 (Equation 2).

$$RSY = \frac{DSW}{FRW} \times 100 \quad \text{.................. Equation 2}$$

Where:

RSY = root starch yield,
DSW = weight of dried starch after extraction and drying;
FRW= weight of the peeled cassava root sample before extraction

Flour water binding capacity. The water binding capacity was determined by adding one gramme of flour sample into a pre-weighed 15 ml falcon tube. Distilled water (10 ml) was added to the sample and mixed thoroughly using a vortex machine.

To allow the flour to bind water molecules to saturation, the sample was allowed to stay for 30 mins at room temperature and then centrifuged at 5000 x g for 30 minutes. The supernatant was discarded and the new weight of the falcon tube taken. Water binding capacity was calculated as the weight of water absorbed per gramme of flour.

Flour swelling capacity. Swelling power of starch was determined according to van Hung *et al.* (2007), by dispersing one gramme of flour sample in 25 ml of distilled water in a pre-weighed falcon tube. The slurries were heated in a thermostatically controlled water bath (GP20/Thermo Precision) at 60 and 80 °C for 30 minutes, with periodic shaking after 5 min. After heating, slurries were allowed to cool at room temperature and centrifuged at 3000 rpm for 10 minutes to separate gel and supernatant. The supernatant was drained off and the gel was weighed and swelling power determined by division (Equation 3).

$$\text{Swelling Power} = \frac{W2}{W1} \quad \text{..................................... Equation 3}$$

Where:

W1 = initial weight of flour sample, and
W2 = weight of the gel after heating at either 60 or 80 °C.

Flour pasting properties. Flour pasting properties were determined using a Rapid Visco-Analyser (RVA-4500, Perten Instruments, Australia) and the Thermocline for Windows Software, using standard profile 1. Flour (3 g) was transfered into an RVA canister and a volume equivalent to 25 ml of distilled water added. The RVA test profile was held constant at 50 °C, 960 rpm mixing speed for 10 seconds. The mixing speed was then decreased to 160 rpm and the temperature held at 50 °C for an extra 50 seconds. The temperature was then steadily increased to 95 °C within 4 minutes and held constant at 95 °C for 2.5 minutes and then steadily decreased back to 50 °C in nearly 4 minutes.

The final viscosity was recorded after 13 minutes. From the resulting pasting curve, industrially relevant parameters, including flour viscous load on pasting, flour ability to withstand heating and shear stress, time to attain peak viscosity, flour process-ability temperature, the degree of re-association of pasted flour during cooling and tendency to form a paste/gel after cooking were recorded.

Data analysis. Summary statistics were generated using R statistical software (R Core

Team, 2017). Data were further subjected to analysis of variance (ANOVA) to test for significance of observed differences in measured parameters at $\alpha = 0.05$ significance level. Correlation analysis was performed to test for the nature of the linear relationship between varieties based on their pasting properties at $\alpha = 0.01$ significant level.

RESULTS AND DISCUSSION

Dry matter content. Among the tested varieties of cassava, dry matter content (DMC) ranged between 30-38%, but did not significantly (P>0.05) vary among the varieties. Greater than average DMC (>35 %) were observed in the recently released varieties, including NAROCASS 1, NAROCASS 2, NASE 13, NASE15, NASE 18 and NASE 19 (Esuma *et al.,* 2016). Other varieties released earlier with higher DMC included NASE 3 and NASE 10 (Table 1).

In cassava, the root DMC is mainly composed of starch and henceforth variations in DMC determine the application of a variety to different uses (Nuwamanya *et al.*, 2010). There is potential for relevance of improved cassava varieties in both industrial and food based applications. Most such varieties have high adoption rates, showing the preference for high DMC by farmers.

The influence of high dry matter on application of cassava industrially is in specific reference to the influence of starch, the major contributor to dry matter in cassava roots (up to 90%) and its influence on starch properties

TABLE 1. Properties of cassava roots and solution properties of cassava flour for varieties popularly grown in Uganda

Variety	Dry matter (%)	Starch yield (%)	WBC[a] ($g\ g^{-1}$)	SP60[b] ($g\ g^{-1}$)	SP80[c] ($g\ g^{-1}$)
NASE 1	35.40a	28.44a	1.24c	3.47a	10.02b
NASE 2	31.68b	26.98a	1.22c	3.67a	9.01ab
NASE 3	35.85a	28.31a	1.17b	3.66a	8.45a
NASE 4	34.40a	28.14a	1.16b	3.64a	8.47a
NASE 5	30.10c	26.58a	1.21c	3.73a	8.91ab
NASE 7	35.37a	28.36a	1.27d	3.66a	9.41ab
NASE 9	36.73d	28.89a	1.21c	3.73a	8.49a
NASE 10	38.95e	30.15b	1.29d	3.81a	9.39ab
NASE 11	33.35ab	27.95a	1.20bc	3.65a	8.54a
NASE 12	32.83bc	27.17a	1.29d	3.50a	9.29b
NASE 13	38.75e	29.51ab	1.29d	3.60a	9.29b
NASE 14	32.80bc	27.23a	1.18b	3.37a	8.48a
NASE 15	37.72e	29.45ab	1.23c	3.69a	8.80a
NASE 16	31.20c	26.75a	1.27d	3.93ac	9.13a
NASE 18	35.23a	28.32a	1.23c	3.35a	10.42c
NASE 19	36.33a	28.70a	1.02a	3.12b	9.91c
NAROCASS 1	35.05a	27.85a	1.29d	3.61a	9.53bc
NAROCASS 2	38.38e	29.71a	1.08a	4.07c	10.31c
Average	35.01	28.25	1.21	3.63	9.21
CV (%)	1.37	1.4	6.60	4.97	4.48

Mean values and standard deviations are from triplicate determinations. Note: [a]Water Binding Capacity, [b]Swelling Power at 60 °C, [c]Swelling Power at 80 °C such as swelling and water absorption/binding capacities (Sriroth *et al*., 1999). Owing to the high average DMC for improved varieties, industries involved in bulk processing of starch and fiber can employ varieties such as NASE 3, NASE 10, NASE 13, NASE 19 and NAROCASS 2 in processing.

Root starch yield. Starch yield was on average between 25 and 30% root fresh weight (Table 1). Cassava root starch yield describes the amount of available starch for a unit mass of fresh root on extraction. High starch yield was observed in NASE 10, NASE 13 and NASE 15 and NAROCASS 2, although these were not significantly different (P>0.05) from varieties with low starch yields such as NASE 2 and NASE 16 (Table 1). Since starch yield describes the amount of carbohydrate stored by a particular variety, varieties with high starch yield are amenable for starch production (Atwijukire *et al.,* 2019).

Starch yield to root dry matter ratio. Starch yield to dry matter ratio ranged from 0.76 in NASE 13 to 0.88 in NASE 5, representing 76.0-88.3% starch recovery from different varieties. High starch recovery from the roots is an important industrial parameter (Fig. 1).

Varieties with high starch recovery above 80% of the DMC such as NASE 2, NASE 4, NASE 5, NASE 11,NASE 12, NASE 14 and NASE 16 could be preferred in industrial applications of cassava, such as starch or food processing or textile. Such varieties do not necessarily have high DMCs and may not be preferred due to their low yield potential. However, these varieties are critical for industrial applications of cassava that require high pure starch outputs.

The ratio of starch yield to DMC shows the amount of extractable starch per unit mass of the root. It is an indicator of the amount of available pure starch, regardless of the fresh root yield of a particular variety. Varieties with

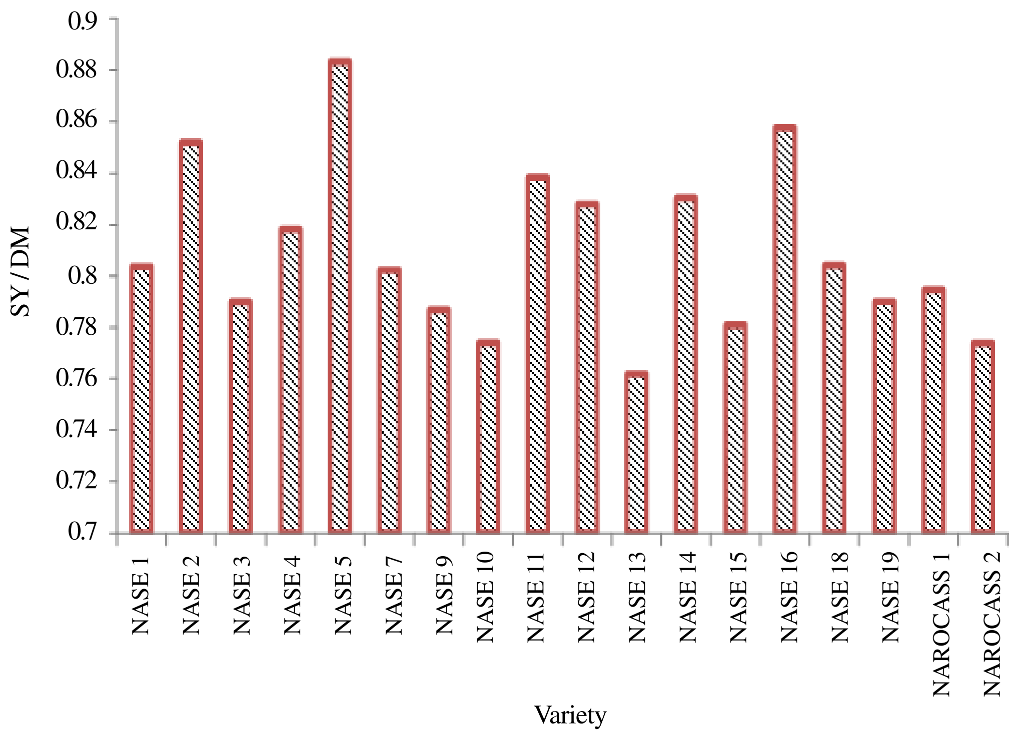

Figure 1. Starch yield to dry matter ratio (SY/DM) for different varieties commonly grown in Uganda.

a high starch yield to dry matter ratio are, therefore, relevant in industries that utilise starch as their primary raw material for processing such as the food industries.

Water binding capacity. Water binding capacity (WBC) ranged from 1-1.3 g g^{-1} of flour dissolved in water, and was significantly different ($P<0.05$) among the varieties (Table 1). The highest degree of water binding was observed in NASE 10 and NASE 12 (1.29); while the lowest was observed in NASE 19 and NAROCASS 2 (1.02 and 1.07). Differences in water absorption among the varieties of cassava tested are an indicator of variations in the way the granular molecules in the flour relate with the water. These granular interfaces are mainly influenced by the starch content of the flour; and hence, will determine preference for flour in different application. For instance, in the confectionery industry, flours that bind water strongly may be preferred due to their ability to form firm dough.

Swelling power. On heating, cassava flour swells, this is quantified as the extent of flour expansion during swelling. Higher expansion at this temperature was observed with NAROCASS 1, NASE 10 and NASE 16 (approximately 4.0 g g^{-1}); while lower expansion was observed for NASE 19 (Table 1). The low swelling power in NASE 19 was consistent with results observed for water binding capacity (Table 1).

On heating at 80 °C, a higher of expansion of cassava flour molecules was observed, with the highest expansion rates observed for NAROCASS 2 and NASE 18 a (10.30 and 10.4 g g^{-1}, respectively. However, lower expansion was observed at 80 °C for varieties NASE 3, NASE 4 and NASE 14 (Table 1).

The observations on swelling power are related to the amount of starch available per unit gramme of flour, where higher swelling was observed with increase in the amount of available starch. However, the interaction of fiber and starch in flour during heating also plays a significant role in flour expansion (Li *et al.*, 2016). Such interactions need to be further studied to understand the relevance of these varieties in applications of cassava that are highly dependent on cassava flour.

The change in behaviour of flour during heating at different temperatures was observed which shows that the processing temperature does affect the functionality of flour and its relevance in particular applications as observed by Iwe *et al.* (2017).

The ability of starch to form hydrogen bonds with water during heating, allows for the expansion of starch granules (Nuwamanya *et al.*, 2010). The extent of such an expansion defines the swelling power of starch; an important criterion in utilistion of starch in industry, since it influences the amount of product, per weight of starch used. Swelling power is dependent on the interface between the starch chains in amorphous and crystalline regions, and hence is starch type dependent (Shogren and Biswas, 2006).

Pasting properties. Flour paste viscosity determination is important in understanding the heating/cooking, eating and processing quality of flour. Variability in pasting properties is a function of variations in genetic nature of cassava. These variations inform the application of flour from different varieties in different uses.

A cassava pasting curve was observed with differences among the test varieties, at different times during pasting (Fig. 2). Significant ($P<0.05$) differences were observed in the peak area, time to attain peak viscosity and time at which initial rise in viscosity due to pasting was achieved. During the holding stage at 90 °C and the subsequent 50 °C, significant differences were also observed.

Due to these differences, the varieties were divided into three main groups based on the period at which initial viscosity increments were observed, and during holding at 90 °C

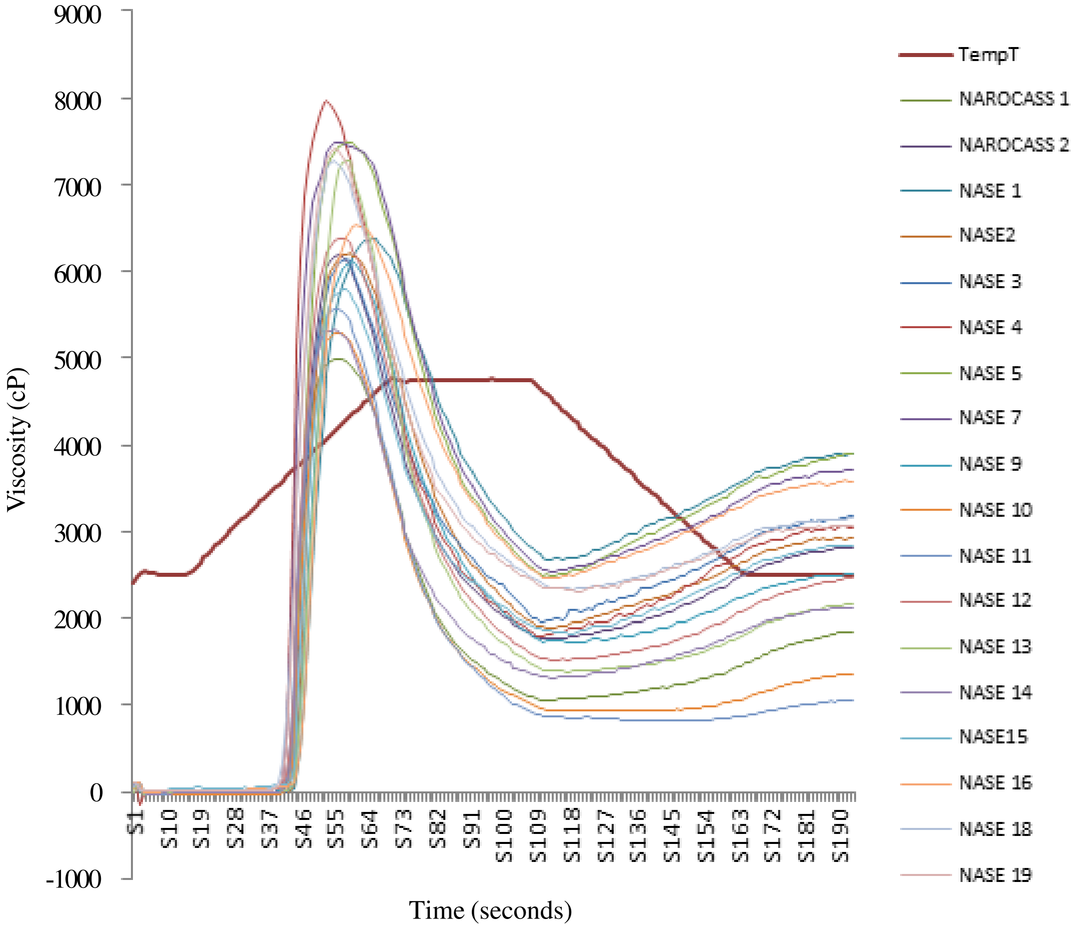

Figure 2. Typical cassava pasting curves showing differences observed in the different varieties studied. Note: the temperature scale has been transformed 50 times to fit scale.

and 50°C. Initially on pasting, flour from NASE 4, NASE 7, NASE 18 and NASE 19 (labelled as A; Fig. 3 -1)) attained increment in viscosity during pasting. These varieties also had higher viscosity at this point compared to other varieties. The second set included varieties that increased their viscosity later during pasting. These varieties included NASE 13, NASE 9, NASE 2, NASE 16 and NASE 1 and are labelled C. The rest of the varieties had medium increment in viscosity at onset of heating.

During holding at 90 °C, it was also observed that the varieties could distinctly be categorised into three main groups. The groups include varieties with higher viscosity values (6000-7000 cP) at the start of the holding phase (Group A), those with medium viscosity (4500-5500 cP) labelled as (Group B) and those with low viscosity (3700-4000) or group C (Fig. 3-II).

The groups were distinct in their pasting behavior, attributable to differences in their flour structure and composition as suggested by Wang *et al.* (2015). Rlated observations were made during holding at 50 °C and at the end of the pasting period (Fig. 3-III). This showed the change in structure and possible interactions between the different molecules in flour from these varieties that could have resulted into differences in behavior. In addition, these varieties still maintained lower

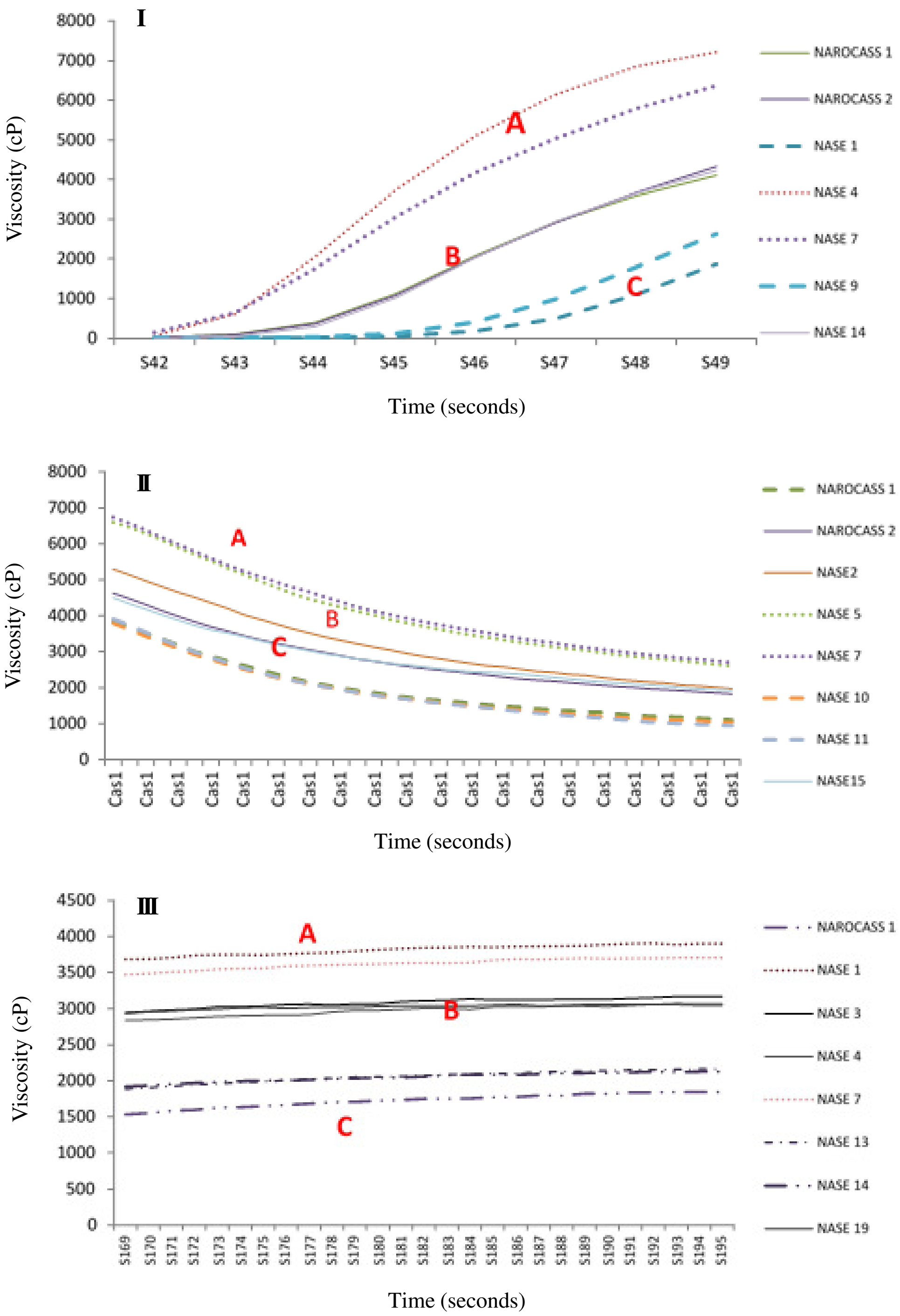

Figure 3. I = Behaviour of the pasting curves at onset of pasting with heating from 72-78 °C. Note the increase in viscosity as temperatures and time increases for variety groups A, B, and C denote such differences; II = 3: Holding at 90 °C and progression of the pasting curve showing behavior of group A,B and C varieties during the cooling phase. III = Holding at 50 °C and progression of the pasting curve showing behavior of group A, B and C varieties during the holding phase.

viscosities as earlier observed at different pasting periods. However, groups A and B maintained close resemblance in behavior, showing similarity in structure and composition of these varieties during holding. Similar observations were made by Iwe *et al.* (2017) on composite cassava flours produced from cassava and cereal crops with similiarity in pastes influenced by cassava

Flour viscous load on pasting. From the present study, the flour viscous load on pasting varied significantly (P<0.05) among the test materials used (Table 2). High viscous loads were observed for variety NASE 4 at 8367 cP while variety NAROCASS 1 had the lowest (4989 cP). Accordingly, the varieties were divided into three main groups. The first group included varieties with low viscous loads on pasting (below 6000 cP) such as NASE 11, NASE 14, NAROCASS 1, NASE 3, NASE 10 and NASE 15. The other group included varieties with viscous loads ranging from 6000-7000 cP such as NASE 12, NAROCASS 2, NASE 1, NASE 9, NASE 16 and NASE 2. Higher viscous loads were observed for varieties with more than 7000 cP which included NASE 13, NASE 5, NASE 7, NASE 19, and NASE 18.

The flour viscous load on pasting is defined by the peak viscosity or the water holding capacity of the flour during heating and, hence, influences the final product quality .The viscous load on pasting represents the equilibrium between granule swelling and rapture during the flour pasting process (Pongsawatmanit *et al.*, 2002). Therefore, varieties with high viscous load observed in this study had high paste stability; while those with low peak viscosities showed an earlier rapturing of the granules and release of the granule contents during processing. This is important in the selection of varieties fit for particular processing conditions where ability

TABLE 2. Pasting properties of cassava flour across the different varieties grown in Uganda

Variety	Peak viscosity	Trough viscosity	Breakdown viscosity	Final viscosity	Setback viscosity	Peak time	Pasting temp
NAROCASS 1	4989^{c}	1001.1^{p}	3988.4^{o}	1413.4^{bcd}	412.1^{ef}	3.83^{ab}	71.0^{ab}
NAROCASS 2	6202.1^{abc}	1761.5^{k}	4440.5^{i}	2818.5^{abcd}	1057.2^{abcd}	3.8^{b}	71.38^{ab}
NASE 1	6399.5^{abc}	2666.0^{a}	3733.5^{q}	3898.5^{a}	1232.5^{ab}	4.33^{a}	66.25^{b}
NASE 2	6217.1^{abc}	1885^{h}	4332.2^{l}	2919.2^{abc}	1034.3^{bcd}	3.97^{ab}	72.65^{ab}
NASE 3	5364.5^{bc}	1842.3^{i}	3522.5^{r}	2921.5^{abc}	1079.5^{abcd}	4.07^{ab}	73.38^{a}
NASE 4	8637.0^{a}	1907^{g}	6730.2^{a}	3222^{ab}	1315.4^{ab}	3.6^{b}	71.45^{ab}
NASE 5	7489.2^{ab}	2487.1^{c}	5002.1^{d}	3896.5^{a}	1409.5^{a}	3.93^{ab}	71.40^{ab}
NASE 7	7480.5^{ab}	2529.5^{b}	4951.1^{e}	3704.6^{a}	1174.5^{abc}	3.77^{b}	70.20^{ab}
NASE 9	6131^{abc}	1717^{l}	4414.1^{j}	2500.3^{abcd}	783.3^{cde}	4.03^{ab}	73.50^{a}
NASE_10	5294^{bc}	923.5^{q}	4370.5^{k}	1362.5^{cd}	439.2^{ef}	3.77^{b}	72.23^{ab}
NASE_11	5570.5^{bc}	808.1^{r}	4762.5^{h}	1053.5^{d}	245.5^{f}	3.77^{b}	71.0^{ab}
NASE_12	6396.5^{abc}	1518^{m}	4878.5^{g}	2458.1^{abcd}	940.2^{bcd}	3.87^{b}	71.0^{ab}
NASE_13	7316.5^{ab}	1383.5^{n}	5933^{b}	2164.3^{abcd}	780.5^{cde}	3.93^{ab}	72.63^{ab}
NASE_14	5334.5^{bc}	1303.3^{o}	4031.5^{n}	2125.5^{abcd}	822.5^{cde}	3.7^{b}	71.78^{ab}
NASE_15	5799.5^{bc}	1818.1^{j}	3981.5^{p}	2839.5^{abcd}	1021.5^{bcd}	3.9^{ab}	67.8^{b}
NASE_16	6542^{abc}	2452.1^{d}	4090.2^{m}	3583.5^{a}	1131.5^{abcd}	4.13^{ab}	73.13^{a}
NASE_18	7270.1^{abc}	2329.5^{e}	4940.5^{f}	3146.5^{ab}	817.4^{cde}	3.7^{b}	69.8^{ab}
NASE_19	7418^{ab}	2299.4^{f}	5119^{c}	3067.3^{abc}	768.6^{de}	3.77^{b}	70.2^{ab}

Note: Values with the same superscript in a column are not significantly different at P<0.05

to maintain a high viscous load is relevant in strenuous processing under high temperatures, such as during food processing or baking. On the other hand, varieties with low viscous load can be adapted for industrial processes that do not necessarily require high paste stability, such as formulation of microbial nutrient media. Notably, differences in peak viscosities and high peak viscosity compared to other starch sources represent a wide range of granule sizes among the varieties (Niba *et al*., 2002; Mishra and Rai, 2006). This characteristic influences granule disintegration and hence the stability of the paste. Such inherent differences show the diversity in function of the different varieties.

Flour ability to withstand heating and shear stress. Significant variations ($P<0.05$) were observed in cassava flour trough viscosity ranging from 800 cP in NASE 11 to 2600 cP in NASE 1 (Table 2). The trough viscosity describes the ability of the sample to withstand heating and shear stress. This viscosity is dependent on the temperature and degree of mixing during the heating process (Iwe *et al*., 2017). Varieties with lower tolerance to shear stress and high temperature included those with trough viscosity (below 1000 cP) such as NASE 11, NAROCASS 1 and NASE 10; while those with higher tolerances to shear stress and temperature, hence higher trough viscosity (>2000 cP) included NASE 5, NASE 1, NASE 7, NASE 16, NASE 19 and NASE 18.

Varieties with low trough viscosity easily undergo molecular and structural changes leading to increased amylose leaching (Patel *et al*., 2005). For cassava, these properties may enhance the functional application of flour in baking given their influences on product firming and product shelf-life.

Time and ease of formation of the paste. Significant variability was observed in the ease and time (peak time) taken to form pastes from different cassava varieties (Table 2). The time taken by cassava flours to attain the highest viscous load ranged from 3.5-4.4 minutes, with the highest observed for variety NASE 1; while the lowest was observed for NASE 4. Specific variability ($P<0.05$) depending on this parameter was observed with most of the varieties having peak times averaging four minutes (Table 2). Flour with low pasting time forms pastes much easier compared to that with high pasting time. This property is related to the amount of energy required to form a paste which also affects the cooking properties of the flour. Therefore, flours with low pasting temperatures and time would be preferred for industrial processing due to lower energy requirements and hence low production cost (Paes *et al*., 2008)

Flour process-ability temperature. Flour samples from the cassava varieties used in this study had pasting temperature ranging from 63-74 °C (Table 2), which was lower than the provided upper limit in the East African standard of 75 °C (EAS740, 2010)). This revealed the lower gelatinisation temperature of cassava starch granules, which translates into shorter cooking time, hence the relevancy of cassava flour in foods that are heat labile where shorter cooking times improves the availability of heat labile nutrients. Pasting temperature, which is also related to paste stability, gives an indication of the strength of associative forces within the flour based starch granules (Cornejo-Ramírez *et al*., 2018) and is an indication of the energy demands for processing flour. As such, specific shorter cooking temperatures were observed for NASE 1, NASE 15 and NASE 18. Varieties with longer cooking times can be applied in high temperature and shear processes such as the use of starch in drilling (Nasiri *et al.,* 2018).

Degree of re-association of pasted flour. The degree of association of flour molecules during cooling, also known as the setback viscosity varied significantly in different varieties with the lowest recorded in NASE 11 at 245.5 cP; while the highest recorded was in NASE 5 at 1409.5 cP (Table 2). This describes the tendency of flour to retrograde after cooling (Wang *et al.*, 2015). Varieties with low tendency to retrograde included NASE 11, NASE 10 and NAROCASS 1. However, varieties NASE 5, NASE 4, NASE 1, NASE 7 and NASE 16 had a higher tendency to retrograde.

Retrogradation has negative effects on the sensorial and storage quality of flour products due to altered starch structure that affects sensory perception (Wang *et al.*, 2015). Such changes limit the usability of the product; hence limiting its application and acceptability. Therefore, the range of variation in this property showed that varieties with low tendency to retrograde can be earmarked for use in food applications. However, the strong textural properties of flour from varieties with high setback viscosity are also critical in application that requires high textural characteristics.

Tendency to form paste/gel after cooking. The final viscosity, a parameter that determines flour ability to form a gel after cooking and cooling, also varied significantly among the varieties tested in this study. It ranged from 1053.5 cP in NASE 11 to 3896 cP in NASE 5 and NASE 1 (Table 2). This parameter is related to the tendency of the flour to retrograde where samples with low final viscosity and high peak viscosity have lower tendency to retrograde (Cameron *et al.*, 2007). Varieties that produced flour with low final viscosity included NASE 11, NASE 10 and NAROCASS 1; although their corresponding peak viscosities were lower ranging between 5000-5600 cP. Varieties with higher final viscosities (>3000 cP) included NASE 5, NASE 4, NASE 1, NASE 7 and NASE 16 and had correspondingly higher peak viscosities ranging between 7000-8700 cP, than compared to other varieties. This shows the limitations of cassava flour in application much as the amenability of modification to different flour and starch based derivatives is quite high.

Replacement of old varieties with new varieties. Based on the pasting properties, the relationship between different varieties based on their similarities and differences was established for the cassava varieties used in this study. It was observed that most of the newly released varieties such as NAROCASS 1, NAROCASS 2, NASE 19 and NASE 18 had similar pasting properties. These varieties were also similar to varieties such as NASE 14 and NASE 12, NASE 10 and NASE 3. Such strong similarities point to the fact that these varieties can easily replace varieties bred earlier which had important industrial properties. In particular, NASE 15 had similar properties with earlier bred varieties such as NASE 2, NASE 3 and NASE 5, though it had higher dry matter and starch yield contents (Table1). This shows that improvements in industry application of cassava in Uganda are being achieved with the current breeding strategies.

CONCLUSION

The importance of cassava as a source of biopolymer in sub-Saharan Africa continues to rise due to its adaptability for different purposes. Cassava has already been transitioned from its traditional use as energy-source food to more sophisticated food and non-food industrial applications. Observations in this study showed that the current cassava varieties cannot fully satisfy the industrial demand. Therefore, it is important that a realistic variety replacement strategy for industrial based traits be developed. In the current bid to breed for industrial varieties, it is imperative to note that the observed variabilities in this study can be used in two different ways; (i). Selections can be made in the current germplasm and a variety (-ies) targeted to specific industrial applications. (ii) Hybridisations within this existing germplasm and subsequent selection will arise into new varieties with industrial specific characteristics.

ACKNOWLEDGEMENT

The authors acknowledge the support of the Root Crops Programme at the National Crops Resources Research Institute (NaCRRI) of the National Agricultural Research Organisation. We also acknowledge the adjoining financial support of the Next generation Cassava breeding project through funds from the Bill and Melinda gates Foundation and the Department for International Development of the United Kingdom (Grant number OPP1048542).

REFERENCES

Abass, A.B., Mlingi, N., Ranaivoson, R., Zulu, M., Mukuka, I., Abele, S. and Cromme, N. 2013. Potential for commercial production and marketing of cassava: Experiences from the small-scale cassava processing project in East and Southern Africa. *Journal of Stored Products Research* 24(2):1-5.

Atwijukire, E., Hawumba, J. F., Baguma, Y., Wembabazi, E., Esuma, W., Kawuki, R. S. and Nuwamanya, E. 2019. Starch quality traits of improved provitamin A cassava (*Manihot esculenta* Crantz). *Heliyon* 5(2):e01215.

Ayetigbo, O., Latif, S., Abass, A. and Müller, J. 2018. Comparing characteristics of root, flour and starch of biofortified yellow-flesh and white-flesh cassava variants, and sustainability considerations: A review. *Sustainability* 10(9):308-309.

Buyinza, T. and Kitinoja, L. 2018. Commodity systems assessment of cassava in Uganda. *PEF White Paper* 18(01):1-28

Cameron, D.K., Wang, Y.J. and Moldenhauer, K.A. 2007. Comparison of starch physicochemical properties from medium-grain rice cultivars grown in California and Arkansas. *Starch Stärke* 59(12):600-608.

Cornejo-Ramírez, Y. I., Martínez-Cruz, O., Del Toro-Sánchez, C. L., Wong-Corral, F.J., Borboa-Flores, J. and Cinco-Moroyoqui, F.J. 2018. The structural characteristics of starches and their functional properties. *CyTA-Journal of Food* 16(1):1003-1017.

East African Standard. 2010. Food grade cassava starch - Specification. EAS 742:2010/ICS 67.080.20. *East African Community* 1(1):3-10.

Esuma, W., Kawuki, R.S., Herselman, L. and Labuschagne, M.T. 2016. Stability and genotype by environment interaction of provitamin A carotenoid and dry matter content in cassava in Uganda. *Breeding Science* 66(3):434-443.

Ikegwu, O.J., Nwobasi, V.N., Odoh, M.O. and Oledinma, N.U. 2009. Evaluation of the pasting and some functional properties of starch isolated from some improved cassava varieties in Nigeria. *African Journal of Biotechnology* 8(10):2310-2315.

Iwe, M.O., Michael, N., Madu, N.E., Obasi, N.E., Onwuka, G.I., Nwabueze, T.U. and Onuh, J.O. 2017. Physicochemical and pasting properties high quality cassava flour (HQCF) and wheat flour blends. *Agrotechnology* 6(2):1-8.

Kleih, U., Phillips, D., Jagwe, J., Kirya, M. and Innovations, A. 2012. Cassava market and value chain analysis Uganda case study. *N*atural Resources Institute (NRI) and Africa Innovations Institute (AII). URL http://cava. nri. org/images/documents/ publications/UgandaCassavaMarketStudy-FinalJuly2012_anonymised-version2. pdf .

Li, T., Fan, J., Chen, W., Shu, J., Qian, X., Wei, H., Wang, Q. and Shen, J. 2016. Coaggregation of mineral filler particles and starch granules as a basis for improving filler-fiber interaction in paper production. *Carbohydrate Polymers* 149:20-27.

Mishra, S. and Rai, T. 2006. Morphology and functional properties of corn, potato and tapioca starches. *Food hydrocolloids* 20(5):557-566.

Nasiri, A., Shahrabi, M.J.A., Nik, M.A.S., Heidari, H. and Valizadeh, M., 2018. Influence of monoethanolamine on thermal stability of starch in water based drilling fluid system. *Petroleum Exploration and Development* 45(1):167-171.

Niba, L.L., Bokanga, M.M., Jackson, F.L., Schlimme, D.S. and Li, B.W. 2002. Physicochemical properties and starch granular characteristics of flour from various *Manihot esculenta* (cassava) genotypes. *Journal of Food Science* 67(5): 1701-1705.

Nuwamanya, E., Baguma, Y., Emmambux, M.N., Taylor, J.R.N. and Rubaihayo, P. 2010. Physicochemical and functional characteristics of cassava starch in Ugandan varieties and their progenies. *Journal of Plant Breeding and Crop Science* 6(4):001-011.

Omodamiro, R.M., Iwe, M.O. and Ukpabi, U.J. 2007. Pasting and functional properties of lafun and starch processed from some improved cassava genotypes in Nigeria. *Nigerian Food Journal* 25(2). doi: 10.4314/ nifoj.v25i2.50849

Paes, S.S., Yakimets, I. and Mitchell, J.R. 2008. Influence of gelatinization process on functional properties of cassava starch films. *Food Hydrocolloids* 22(5):788-797.

Patel, B.K., Waniska, R.D. and Seetharaman, K. 2005. Impact of different baking processes on bread firmness and starch properties in breadcrumb. *Journal of Cereal Science* 42(2):173-184.

Pongsawatmanit, R., Thanasukarn, P. and Ikeda, S. 2002. Effect of sucrose on RVA viscosity parameters, water activity and freezable water fraction of cassava starch suspensions. *Science Asia* 28(2):129-134.

Shogren, R.L. and Biswas, A. 2006. Preparation of water-soluble and water-swellable starch acetates using microwave heating. *Carbohydrate Polymers* 64(1):16-21.

Sriroth, K., Santisopasri, V., Petchalanuwat, C., Kurotjanawong, K., Piyachomkwan, K. and Oates, C.G. 1999. Cassava starch granule structure–function properties: influence of time and conditions at harvest on four cultivars of cassava starch. *Carbohydrate Polymers* 38(2):161-170.

Van Hung, P., Maeda, T. and Morita, N. 2007. Dough and bread qualities of flours with whole waxy wheat flour substitution. *Food Research International* 40(2):273-279.

Waigumba, S.P., Nyamutoka, P., Wanda, K., Abass, A, Kwagala, I., Menya, G., Acheng, S., Nuwamanya, E., Matovu, M., Kaliisa, R. and Muyinza, H. 2016. Technical Report: Market opportunities and value chain analysis of fresh cassava roots in Uganda. *www.rtb.cgiar.or/endure/technical report.* 43pp.

Wang, S., Wang, J., Zhang, W., Li, C., Yu, J. and Wang. S. 2015. Molecular order and functional properties of starches from three waxy wheat varieties grown in China. *Food Chemistry* 181:43-50.