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Evaluation of proximate composition and pasting properties of high quality cassava flour (HQCF) from cassava genotypes (*Manihot esculenta Crantz*) of β-carotene-enriched roots

Emmanuel Oladeji Alamu [a], Bussie Maziya-Dixon [a,*], Alfred Gilbert Dixon [b]

[a] Food and Nutrition Sciences Laboratory, International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan, Oyo State, Nigeria
[b] Weed Science Management Project, International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan, Oyo State, Nigeria

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ABSTRACT

Cassava farmers are yet to fully exploit its full potential in terms of improvement of livelihood. Forty-five genotypes of cassava genotypes were processed into High Quality Cassava Flour (HQCF). These genotypes were planted in two sets, set 1 comprised 22 clones of β-carotene enriched roots and 3 check clones of white roots and set 2 comprised 18 clones and 2 check clones. The effects of variety on the proximate composition and pasting profile of the flour were investigated. The starch content ranged between 67.1 g/100 g (for 01/1663) and 82.4 g/100 g (for 30572) in set 1 and between 69.6 (01/1560) to 77.8 g/100 g (for Z97/0474) in set 2. Peak viscosity values ranged between 295.6 RVU (rapid visco unit) (30572) and 467.0 RVU (01/1115) across clones in set 1 while for set 2, it ranged from 271.9 RVU (for 01/1404) to 471.3 RVU (for 01/1417). Significant differences ($P < 0.05$) existed in the proximate composition and pasting properties of the flour from different cassava genotypes investigated. The high peak viscosity exhibited by most genotypes is indicative that the flour may be suitable for products requiring high gel strength and elasticity. The proximate composition compares competitively with values obtainable from conventional clones.

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a root crop cultivated and consumed as a staple in many regions of the developing world. Africa produced 157.7 MT of cassava in 2012 and Nigeria produced 53.0 MT, making it the most important root crop (FAOSTAT, 2015) and a major source of dietary calories. The importance of cassava to the livelihoods of many millions of poor people has made the commodity a target for interventions. Cassava is known to be grown in areas where mineral and vitamin deficiencies are widespread, especially in Africa. A marginal nutrient status increases the risk of morbidity and mortality. Therefore, improving the nutritional value of cassava could alleviate some aspects of hidden hunger, that is, subclinical nutrient deficiencies without overt clinical signs of malnutrition (Montagnac, Davis, & Tanumihardjo, 2009). This also depends on how traditional processing and food preparations will impact the nutritional value and physicochemical properties of cassava roots.

About 65% of cassava productions are for human consumptions, 25% is for industrial use and 10% is lost as waste (Fish & Trim, 1993). In Nigeria, more than 40% of cassava is currently processed, mainly into traditional food products. There are many opportunities to extend the traditional uses of cassava, especially processing into high quality cassava flour (HQCF). This product could be introduced it into a wide range of new food products, particularly in the rapidly urbanizing societies of the developing countries. Cassava is well known to be perishable and bulky and to overcome these limitations, it requires appropriate strategies and technology for post-harvest processing and utilization. Processing of fresh cassava roots provide a means of producing shelf-stable products (thereby reducing losses), adding value at a rural level, and reducing the bulk to be marketed (Dufour, O'Brien, & Best, 2002, p. 409). HQCF is popular in the food industry because of its special characteristics - clarity of appearance, low flavor overtones, and ideal viscosity. It has been tested as filler in comminuted meat products (Annor-Frempong, Annan-Prah, & Wiredu, 1996). Some newly tested applications of HQCF in recent years have been as weaning foods, as

* Corresponding author. International Institute of Tropical Agriculture (IITA), Carolyn House 26 Dingwall Road, Croydon CR9 3EE, England, United Kingdom.
E-mail address: b.dixon@cgiar.org (B. Maziya-Dixon).

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substrates in alcohol production, and for glucose syrup production (Adewusi, Orisadare, & Oke, 1992; Pontoh & Low, 1995). However, processing cassava root into food forms and raw materials such as flour, chips and pellets can extend the shelf life, facilitate trade and promote industrial use. Some authors have studied the chemical, functional and pasting properties of cassava starch and soy protein concentrate blends (Chinma, Ariahu, & Abu, 2013), tapioca grits from different cassava varieties and roasting methods (Adebowale, Sanni, & Onitilo, 2008) and cassava starch and mushroom flour blends intended for biofilm processing (Ojo, Ariahu, & Chinma, 2017). Chinma et al. (2013) reported that addition of varying levels of soy protein concentrates to cassava starch led to increase in protein (from 0.32 to 79.03 g/100 g), ash (from 0.45 to 2.67 g/100 g) and fat (from 0.17 to 0.98 g/100 g) contents while crude fiber, carbohydrate and amylose contents decreased from (1.19–0.38 g/100 g, 90.77 to 57.01 g/100 g and 29.45 to 23.04 g/100 g) respectively. Adebowale et al. (20008) reported amylose content of the tapioca grits to range between 22.95 g/100 g and 24.30 g/100 g, and the protein and fat content of the tapioca grits ranged from 0.23 to 0.26 g/100 g and from 0.12 to 0.25 g/100 g respectively. However, Ojo et al. (2017) recorded the proximate composition for the starch-mushroom blend to range from 8.79 to 9.35 g/100 g, 0.55–26.23 g/100 g, 0.34–2.01 g/100 g, 0.32–8.24 g/100 g and 0.10–17.86 g/100 g for moisture, protein, fat and ash respectively while Carbohydrate ranged from 36.31 to 89.62 g/100 g and amylose contents 18.47–25.35 g/100 g. All these studies used white cassava varieties and none has reported to use yellow root cassava varieties. However, there is scanty information on the proximate composition and pasting properties of HQCF from cassava genotypes (Manihot esculenta Crantz) of β-carotene-enriched roots.

Processing cassava can affect the nutritional value of cassava roots through modification and losses in nutrients of high value and cause changes to the physicochemical properties. This study attempts to evaluate the proximate composition and pasting properties of HQCF from cassava genotypes of β-carotene-enriched roots with a view to providing information that will guide breeding programmes and end use.

2. Materials and methods

2.1. Cassava roots

A total of 45 yellow cassava genotypes were grown in 2003/04 cropping season in replicated field trials (Randomized Complete Block Design) at the research farm of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. The 45 genotypes were planted in 2 sets. Set 1 comprised 22 clones with β-carotene enriched roots and three check clones with white roots (30572, TME 1, and 91/02324), set 2 comprise 18 clones with β-carotene enriched roots and two check genotypes with white roots (30572 and 91/02324). Cassava breeders have tried to improve the nutritional value and physicochemical properties of cassava by cross-breeding wild-type varieties. The two sets were different from each other by the source (parent lines with different quality traits) used for their breeding crosses, which could possibly dictate the chemical properties of the processed products from the genotypes. Both sets of genotypes were planted during the raining season in July and grown under rain fed conditions in a replicated complete block design with four replicates. No fertilizers or herbicides were applied during the experiment. Hand weeding was done when necessary. Harvesting was done at 12 months after planting (MAP). Only the two middle rows were harvested per plot and all processed cassava roots were collected from 2 replicates of the 4 replicates in the design. The processing of the roots was started within 60 min but completed within 24 h of harvesting.

2.2. Methods

2.2.1. Preparation of high quality cassava flour (HQCF)

Ten (10) kg of freshly harvested cassava roots were peeled, washed, grated, dewatered, and sieved. The resulting sieved mash was oven-dried at 40 °C and milled (sieve size, 0.5 mm). The processing and chemical analyses were done in 2 replications.

2.2.2. Determination of proximate composition

2.2.2.1. Moisture content determination. This was determined using AOAC method (1990). The sample was dried at 100–105 °C for 24 h in a draft air Fisher Scientific IsotempR Oven model 655 F (Loughborough, United Kingdom). The loss in weight was recorded as moisture.

2.2.2.2. Ash content determination. This was determined by the method of AOAC (1990). The method involved burning off moisture and all organic constituents at 600 °C in a VULCAN™ furnace model 3–1750 (Cole-Parmer, IL 60061 United States). The weight of the residue after incineration was recorded as the Ash content.

2.2.2.3. Protein content determination. This was determined by Kjeldahl method using Kjeltec™ model 2300, as described in FOSS (2003). The method involved digestion of the sample at 420 °C for 1 h to liberate the organically-bound nitrogen in the form of ammonium sulphate. The ammonia in the digest (ammonium sulphate) was then distilled off into a boric acid receiver solution, and then titrated with standard Hydrochloric acid. A conversion factor of 6.25 was used to convert from total nitrogen to percentage crude protein.

2.2.2.4. Starch and sugar content determination. The method of Dubois, Gilles, Hamilton, Rebers, and Smith (1956) was used for the starch and sugar determination. This involved weighing of 0.2 g of the sample into a centrifuge tube with 1 ml of ethanol (0.789 g/ml), 2 ml of distilled water and 10 ml of hot ethanol. Then mixture was vortexed and centrifuged for 10 min at 2000 rpm using Sorvall centrifuge (Newtown, Conneticut, USA), model GLC-1. The supernatant was decanted into another centrifuge tube; this was used for sugar determination while the sediment was used for starch determination. Perchloric acid (7.5 ml) was added to the sediment and allowed to stand for 1 h; then 17.5 ml of distilled water was added to it and vortexed. An aliquot of 0.05 ml of the solution was pipetted into a test tube, 0.95 ml of distilled water, 0.5 ml of phenol, and 2.5 ml of H_2SO_4 were added and vortexed. The mixture was cooled at room temperature and the absorbance read on a spectrophotometer (Milton Roy Company, USA), model spectronic 601 already standardized at 490 nm wavelength. The absorbance of both starch and sugar was read at 490 nm.

2.2.2.5. Amylose content determination. This was determined using the method described by Williams, Wu, Tsai, and Bates (1958). This is a spectrophotometric method based on the formation of deep blue-coloured complex with iodine, the absorbance of which is read at 620 nm.

2.2.3. Determination of pasting properties

Pasting characteristics was determined with a Rapid Visco Analyser (RVA), (model RVA 3D+, Newport Scientific, Warriewood NSW, Australia). Peak viscosity, trough, breakdown, final viscosity, set back, peak time, and pasting temperature were read from the pasting profile with the aid of thermocline for windows software connected to a computer (Newport Scientific, 1998, p. 26).

2.3. Statistical analysis

The general linear model procedure (GLM) of SAS version 8e (SAS, 2001), was used for analysis of variance (ANOVA) at P < 0.05.

3. Results and discussions

The results of the proximate composition of HQCF from β-carotene enriched cassava genotypes are presented in Tables 1 and 2. In set 1, moisture content of the flour across clones ranged from 10.78 g/100 g (for 01/1335) to 12.72 g/100 g (for 01/331) and from 11.02 g/100 g (for 01/1404) to 12.23 g/100 g (for 00/0093) in set 2. Moisture content is of the factors that determine the shelf life of HQCF and low moisture observed for most of the genotypes confers higher shelf life on the flour and a good indication of microbial stability and may also contribute to reducing the tendency of staling in baked food products (Ogiehor & Ikenebomeh, 2006). Results from the literature showed that moisture content and storage period had significant effects on the proximate composition (Ogbonnaya & Hamza, 2015).

The Amylose content ranged from 17.42 g/100 g (for 01/1235) to 22.25 g/100 g (for 01/1224) in set 1 and from 15.71 g/100 g (for 01/1404) to 19.06 g/100 g (for 30572) in set 2. The amylose content of HQCF from β-carotene enriched cassava genotypes was considerably higher than that of the check clones in set 1 but it was considerably lower than in the check clones in set 2. This showed that amylose was genetically inherited, variation due to variety will be expected and clones in set 1 gained higher amylose genetically. The starch content ranged between 67.08 g/100 g (for 01/1663) and 82.42 g/100 g (for 30572) in set 1 and between 69.62 (01/1560) to 77.82 g/100 g (for Z97/0474) in set 2. Protein content ranged from 0.56 g/100 g (for 01/1213) to 1.17 g/100 g (for 91/2324) in set 1 and from 0.60 g/100 g (for 01/1560) to 1.26 g/100 g (for 91/2324) in set 2. The protein content across clone in set 1 is relatively lower than that of set 2. Sugar content of the HQCF across clones ranged from 1.71 g/100 g (for 01/1442) to 5.53 g/100 g (for 01/1331) in set 1. For set 2, it ranged from 2.04 g/100 g (for 99/7578) to 5.66 g/100 g (for 00/0028). Ash content for set 1 ranged between 0.77 g/100 g (for 01/1368) and 1.10 g/100 g (01/1273). Ash content across clones in set 2 ranged from 0.96 g/100 g (for 99/7578) to 1.43 g/100 g (for 01/1417). Thus, almost all the samples complied with the regulatory standard of not more than 1.5 g/100 g ash content (SON, 1988, pp. 188–189). There is no significant difference ($P > 0.05$) among the ash contents of the samples in set 1, while significant differences existed in the ash contents across clones in set 2 ($P < 0.05$). This established the effect of genetic material used for crosses and genetic differences among the cassava genotypes on the chemical properties of HQCF. Tables 3 and 4 show the pasting properties of HQCF from β-carotene enriched cassava genotypes 25 clones (set 1) and 20 clones (set 2). The pasting temperature ranged from 64.24 °C (for 01/1335) to 65.21 °C (for 01/1331) and 64.06 °C Z97/0474) to 64.83 °C (for 01/1231). For set 1 and 2 trials, there was significant difference existed in varietal effect (P < 0.005). When starch-based foods are heated in an aqueous environment, they undergo a series of changes known as gelatinization and pasting. These are two of the most important properties that influence quality and aesthetic considerations in the food industry, since they affect texture and digestibility as well as the end use of starchy foods. Pasting temperature gives an indication of the gelatinization time during processing. It is the temperature at which the first detectable increase in viscosity is measured and is an index characterized by the initial change due to the swelling of starch. Pasting

Table 1
Proximate Composition of HQCF from cassava genotypes of β-carotene enriched roots planted in a Uniform Yield Trial (Set 1, 25 clones) at Ibadan in 2003/04.

Clone	[a]Amylose (g/100 g)	Protein (g/100 g)	Sugar (g/100 g)	Starch (g/100 g)	Ash (g/100 g)
01/1115	20.7	0.72	5.21	78.4	0.96
01/1224	22.3	0.65	4.13	76.5	0.96
01/1235	17.4	0.56	3.58	76.2	0.93
01/1273	17.9	0.68	2.79	77.6	1.1
01/1277	21.2	0.69	2.1	74.4	0.82
01/1331	19.6	0.65	5.53	75.4	0.97
01/1335	20.2	0.64	3.88	78.0	1.08
01/1368	20.3	0.71	2.74	76.5	0.77
01/1371	20.7	0.64	3.24	73.2	1.03
01/1412	19.4	0.61	3.43	78.2	1.08
01/1413	19.8	0.73	2.64	75.5	1.01
01/1442	19.5	0.76	1.71	81.2	0.94
01/1610	20.9	0.68	1.89	71.4	0.91
01/1646	19.3	0.76	3.24	75.2	1.07
01/1649	20.2	0.74	2.23	71.9	1.04
01/1662	18.2	0.63	3.25	71.6	1.06
01/1663	19.9	0.78	3.49	67.1	0.97
90/01554	20.4	0.84	1.96	71.6	0.95
94/0006	19.9	0.87	3.4	79.7	0.94
94/0330	19.4	0.9	2.58	79.1	0.94
95/0379	20.3	0.95	1.8	72.3	0.99
98/2132	20.0	0.96	3.3	77.0	0.91
TME - 1 (Check)	20.3	0.87	3.79	70.5	0.87
30572 (Check)	19.1	0.89	3.27	82.4	0.84
91/02324 (Check)	19.4	1.17	2.25	79.8	0.74
Range	17.42–22.25	0.56–1.17	1.71–5.53	67.1–82.4	0.77–1.10
Mean	19.9	0.76	3.1	75.6	0.96
STDV	1	0.1	1	4	0.1
CV	19.38	5.45	3.18	20.29	10.06
***P* of Clone**	***	***	***	***	***

ns, not significant at P < 0.05; **, significant at P < 0.01; ***, significant at P < 0.001.
HOCF= High quality cassava flour; STDV = standard deviation; CV = coefficient of variation.
[a] Parameters were analysed in duplicate and expressed in g/100 g.

Table 2
Proximate Composition of HQCF from cassava genotypes of β-carotene enriched roots planted in a Uniform Yield Trial (Set 2, 20 clones) at Ibadan in 2003/04.

Clone	[a]Amylose (g/100 g)	Protein (g/100 g)	Sugar (g/100 g)	Starch (g/100 g)	Ash (g/100 g)
00/0028	17.0	0.8	5.66	72.0	1.21
00/0093	15.8	0.8	2.87	69.9	1.39
01/1172	16.1	0.8	2.5	72.6	1.06
01/1181	17.3	0.83	3.42	77.2	1.27
01/1206	15.9	0.63	2.41	73.3	1.23
01/1231	16.0	0.76	2.64	74.5	1.35
01/1296	17.1	0.72	2.54	76.5	1.27
01/1380	17.0	0.85	3.61	75.2	1.11
01/1404	15.7	0.7	3.69	76.8	1.17
01/1417	16.4	0.9	2.61	74.5	1.38
01/1423	17.5	0.66	2.26	76.2	1.21
01/1551	17.9	0.76	2.54	75.5	1.43
01/1560	17.4	0.6	3.07	69.6	1.24
01/1635	16.1	0.76	2.14	73.9	1.3
01/1659	18.6	0.85	3.9	75.7	1.2
99/2987	16.9	0.81	3.16	73.9	1.26
99/7578	16.7	0.73	2.04	70.0	0.96
Z97/0474	18.2	0.82	3.68	77.8	1.35
30572 (check)	19.1	0.81	3.04	75.7	1.39
91/02324 (Check)	18.2	1.26	3.27	71.3	1.43
Range	15.7–19.1	0.60–1.26	2.04–5.66	69.6–77.8	0.96–1.43
Mean	17.1	0.79	3.05	74.2	1.24
STDV	1	0.1	0.8	3	0.1
CV	17.5	5.89	3.69	29.6	9.96
***P* of Clone**	***	***	***	***	***

ns, not significant at P < 0.05; **, significant at P < 0.01; ***, significant at P < 0.001.
HOCF= High quality cassava flour; STDV = standard deviation; CV = coefficient of variation.
[a] Parameters were analysed in duplicate and expressed in g/100 g.

Table 3
Pasting Properties of HQCF from cassava genotypes of β-carotene enriched roots planted in a Uniform Yield Trial (Set 1, 25 clones) at Ibadan in 2003/04.

Clone	[a]Peak Viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback Viscosity (RVU)	Peak Time (min)	Pasting temperature (°C)
01/1115	467.04	174.61	257.71	240.01	65.41	3.73	64.35
01/1224	301.16	73.13	210.07	95.87	22.75	3.8	64.56
01/1235	375.29	94.6	235.54	128.53	33.93	3.62	64.55
01/1273	424.67	166.01	243.17	215.18	49.17	3.78	64.5
01/1277	354.82	117.32	207.08	151.46	34.14	3.68	64.41
01/1331	357.32	97.77	241.45	125.26	27.5	3.79	65.21
01/1335	393.31	131.18	246.65	179.15	47.97	3.77	64.24
01/1368	363.49	108.07	211.96	147.72	39.65	3.6	64.43
01/1371	357.52	104.29	223.47	137.22	32.93	3.67	64.33
01/1412	428.46	133.53	250.27	175.11	41.59	3.64	64.45
01/1413	395.07	115.22	228.57	156.21	40.99	3.58	64.27
01/1442	404.88	131.43	248.41	173.5	42.07	3.7	64.5
01/1610	340.7	73.24	224.35	96.11	22.88	3.58	64.76
01/1646	354.07	106.27	207.83	137.22	30.96	3.59	64.75
01/1649	354.15	92.82	212.79	114.65	21.84	3.54	64.53
01/1662	427.25	156.44	256.15	208.25	51.81	3.78	64.65
01/1663	406.93	150.03	249.97	200.04	50.01	3.86	64.48
90/01554	323.63	104.06	203.14	137.38	33.29	3.82	64.54
94/0006	401.88	131.83	199.31	176.78	44.95	3.51	64.36
94/0330	324.44	109.26	187.57	137.71	28.45	3.65	64.43
95/0379	316.69	100.93	177.57	131.22	30.29	3.64	64.9
98/2132	319.77	89.57	199.4	116.96	27.39	3.64	64.67
TME−1 (Check)	352.93	109.08	211.43	150.11	41.11	3.73	64.51
30572 (Check)	295.57	90.4	159.58	127.34	20.6	3.62	64.73
91/02324 (Check)	350.58	121.56	210.24	159.39	37.83	3.73	64.63
Range	295.57–467.04	73.13–174.61	159.58–257.71	95.87–240.01	20.60–65.41	3.51–3.86	64.24–65.21
Mean	367.66	115.31	220.15	152.74	36.78	3.68	64.55
STDEV	43.9	26.5	25.6	36.3	11.0	0.09	0.21
CV	8	4	9.	4	3	39	305
***P* of Clone**	***	***	***	***	***	***	**

ns, not significant at P < 0.05; **, significant at P < 0.01; ***, significant at P < 0.001.
HOCF= High quality cassava flour; RVU = Rapid Visco Unit; STDV = standard deviation; CV = coefficient of variation.
[a] Parameters were analysed in duplicate.

Table 4
Pasting Properties of HQCF from cassava genotypes of β-carotene enriched roots planted in a Uniform Yield Trial (Set 2, 20 clones) at Ibadan in 2003/04.

Clone	[a]Peak Viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback Viscosity (RVU)	Peak Time (min)	Pasting temperature (°C)
00/0028	401.9	148.2	231.8	221.3	73.1	3.74	64.3
00/0093	320.2	72.6	229.2	101.9	29.3	3.76	64.4
01/1172	328.2	110.8	196.7	147.3	36.5	3.78	64.5
01/1181	384.3	146.0	213.6	194.7	48.7	3.79	64.7
01/1206	331.2	95.2	196.3	135.0	39.8	3.6	64.3
01/1231	289.7	45.8	208.7	62.1	16.3	3.64	64.8
01/1296	396.6	155.3	234.0	219.9	64.6	3.87	64.6
01/1380	308.9	104.6	189.7	145.0	40.3	3.86	64.7
01/1404	271.9	13.2	200.6	27.3	14.0	3.57	64.6
01/1417	471.3	173.4	254.1	240.0	66.5	3.68	64.6
01/1423	342.8	106.9	218.3	137.0	30.1	3.69	64.6
01/1551	291.1	57.9	199.3	77.9	20.1	3.61	64.8
01/1560	357.5	109.4	206.4	151.4	42.0	3.62	64.4
01/1635	395.9	145.9	241.8	189.0	43.1	3.61	64.4
01/1659	388.8	146.3	212.5	193.0	46.8	3.77	64.5
99/2987	384.7	155.4	217.3	220.7	65.3	3.86	64.5
99/7578	347.0	111.3	208.1	149.0	37.7	3.72	64.6
Z97/0474	333.6	79.5	213.9	111.8	32.3	3.7	64.1
30572 (Check)	280.1	97.4	161.5	129.4	32.0	3.73	64.3
91/02324 (Check)	340.0	118.8	206.2	173.3	54.5	3.86	64.2
Range	271.9–471.3	13.2–173.4	161.5–254.1	27.3–239.9	14.0–73.0	3.57–3.87	64.1–64.8
Mean	348.7	110.3	211.7	152.2	41.9	6.96	64.49
STDEV	50.0	41.4	20.3	56.9	16.7	14.5	0.200
CV	7	3	10	3	3	0.5	342
***P* of Clone**	***	***	***	***	***	ns	ns

HOCF= High quality cassava flour; RVU = Rapid Visco Unit; STDV = standard deviation; CV = coefficient of variation.
ns, not significant at P < 0.05; **, significant at P < 0.01; ***, significant at P < 0.001.
[a] Parameters were analysed in duplicate.

temperature has been reported to relate to water binding capacity. A higher pasting temperature implies higher water binding capacity, higher gelatinization, and lower swelling property of starch due to a high degree of association between starch granules (Emiola & Delarosa, 1981; Numfor, Walter, & Schwartz, 1996). Pasting temperature also gives an indication of the minimum temperature for cooking a given sample. Thus, have implications for the suitability and suitability of other components in a food formula and indicate energy costs.

Peak viscosity reflects the ability of starch to swell freely before their physical breakdown (Sanni, Kosoko, Adebowale, & Adeoye, 2004). Peak viscosity values obtained in this study ranged between 295.57 RVU (30572) and 467.04 RVU (for 01/1115) across clones in set 1 while for set 2 it ranged from 271.85 RVU (for 01/1404) to 471.29 RVU (for 01/1417). Peak viscosity is often correlated with final product quality. It has been suggested that high peak viscosity contributes to good texture of paste, which basically depends on high viscosity and moderately high gel strength (Rosenthal, Nakamura, Espindola, & Jochimek, 1974). The relatively high peak viscosity exhibited by most of the clones is indicative that the flour may be suitable for products requiring high gel strength and elasticity. Though, higher viscosity values were obtained by Rosenthal et al. (1974) using four Brazilian cultivars of cassava, the lower viscosities recorded in this study might relate to the fact that we used flour, while the previous study worked on starch. The pasting characteristics reported for cassava starch all show that on attaining the gelatinization temperature, the starch granules undergo a relatively high degree of swelling, resulting in a high peak viscosity, which is followed by rapid paste breakdown (Rickard, Asaoka, & Blanshard., 1991). Peak viscosity is often correlated with the final product quality, and also provides an indication of the viscous load likely to be encountered during mixing.

During the hold period of a typical pasting test, the sample is subjected to a period of constant temperature (usually 95 °C) and mechanical shear stress. This further disrupts the starch granules and amylose molecules generally leach out into the solution and align in the direction of the shear. A gradual decrease of the paste viscosity during the hold period indicates thermal breakdown of starch and, thus, may be considered a measure of stability. The period is sometimes called shear thinning, holding strength, hot paste viscosity, or trough, due to the accompanied breakdown in viscosity. It is the minimum viscosity value in the constant temperature phase of the RVA profile and measures the ability of paste to withstand breakdown during cooling. Large values indicate little breakdown of sample starches. The rate of breakdown depends on the nature of the material, the temperature, and degree of mixing and shear applied to the mixture. The ability of a mixture to withstand this heating and shear stress is an important factor for many processes. Cross-linked starches are more resistant to breakdown. In set 1 trial, trough (or hot paste viscosity) values of the HQCF ranged between 73.13 RVU and 174.61 RVU with lowest values being recorded by 01/1224 and the highest by 01/1115. However, in set 2, the values ranged from 13.24 RVU (for 01/1404 to 173.42 RVU (for 01/1417). Breakdown viscosities were highest for clone 01/1115 in set 1 and clone 01/1417 in set 2. Values ranged between 159.58 RVU and 257.71 RVU in set 1 and from 161.46 RVU to 254.14 RVU in set 2.

Final viscosity is the change in the viscosity after holding cooked starch at 50 °C and it represents cooked starch stability. Values of final viscosity ranged from 95.87 RVU for clones 01/1224 to 240.01 RVU for clone 01/1115. For set 2, the highest final viscosity (239.95 RVU) was recorded by clone 01/1417, while clone 01/1405 exhibited the lowest final viscosity (27.28 RVU). Final viscosity is the most commonly used parameter to define the quality of a sample, as it indicates the ability of the material to form a viscous paste or gel after cooking and cooling as well the resistance of the paste to shear force during stirring.

The viscosity after cooling to 50 °C represents setback or viscosity of cooked paste. It is a stage where retrogradation or reordering of starch molecules occurs. Setback has been correlated with texture of various products. High setback is also associated with syneresis, or weeping, during freeze/thaw cycles. Lower setback was observed for the flour samples from 25 clones of β-carotene enriched cassava genotypes in set 1 and 20 clones in set 2. This indicates that the flours will exhibit a low tendency to undergo retrogradation during freeze/thaw cycles. Values of setback viscosities ranged from 20.60 RVU (for 30572) to 65.41 RVU (for 01/1115) in set 1 and 14.04 RVU (for 01/1404) to 73.07 RVU (for 00/0028) in 2. A high setback value indicates lower retrogradation tendency and vice versa (Tolmasquim, Corrêa, & Tolmasquim, 1971). A higher value is useful if the flour is to be used in domestic products such as fufu, which requires high viscosity and paste stability at low temperature (Oduro, Ellis, Dziedzoave, & Nimakoyeboah, 2000). The peak time, which is a measure of the cooking time, was within a very close range (Tables 3 and 4) for all clones investigated. The close range of the pasting time across clones is indicative of the fact that cooking time of the flour and the respective products will be within the same profile. The information obtained from the study on the physicochemical properties of HQCF offer the benefits of good chemical functionalities as important raw material for the manufacturing of various food products.

4. Conclusion

The proximate composition and pasting properties of the HQCF from most of β-carotene enriched cassava genotypes investigated compares competitively to values obtainable from conventional clones and complies with SON specifications. This implied that these HQCF could be a source of important raw material for edible films processing and may be suitable for products requiring high gel strength and elasticity. However, irrespective of these processing benefits, cassava roots are perishable and bulky with high postharvest deterioration. This post-harvest rapid deterioration and bulkiness of the fresh roots shortens the shelf-life of fresh root and impacts on its transportation and potential for its industrial use.

Conflict of interest

There is no conflict of interest among the authors.

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References

Adebowale, A. A., Sanni, L. O., & Onitilo, M. O. (2008). Chemical composition and pasting properties of tapioca grits from different cassava varieties and roasting methods. *African Journal of Food Science, 2*, 077–082.

Adewusi, S. R., Orisadare, B. O., & Oke, O. L. (1992). Studies on weaning diets in Nigeria: Two protein sources. *Plant Foods for Human Nutrition, 42*(2), 183–192.

Annor-Frempong, I. E., Annan-Prah, A., & Wiredu, R. (1996). Cassava as non- conventional filler in comminuted meat products. *Meat Science, 44*(3), 193–202.

AOAC. (1990). *Official methods of analysis* (15th ed.). Arlington, Viriginia, USA: Association of Official Analytical Chemists(AOAC).

Chinma, E. C., Ariahu, C. C., & Abu, J. O. (2013). Chemical composition, functional and pasting properties of cassava starch and soy protein concentrate blends. *Journal of Food Science Technology, 50*(6), 1179–1185.

Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Journal of Analytical Chemistry, 28*, 350–356.

* Dufour, D., O'Brien, G. M., & Best, R. (2002). *Cassava flour and starch: Progress in research and development*. Cali, CO: Centro Internacional de Agricultura Tropical (CIAT), Département des Systèmes Agroalimentaires et Ruraux (CIAT publication no. 271).

Emiola, L., & Delarosa, L. C. (1981). Physicochemical characteristics of yam starches. *Journal of Food Biochemistry, 5*, 115–130.

FAO. (2015). *Food and agriculture data* Accessed FAOSTAT http://www.faostat3.fao.org/download/Q/QC/E. (Accessed 12 July 2015).

* Fish, D. M., & Trim, D. S. (1993). A review of research in the drying of cassava. *Tropical Science, 33*(2), 191–203.

FOSS. (2003). *Manual for Kjeltec system 2300 distilling and titration unit*. 69, Slangerupgade, DK-3400, Hilleroed, Denmark: FOSS Analytical.

Montagnac, J. A., Christopher, R. D., & Tanumihardjo, S. A. (2009). Nutritional value of cassava for use as a staple food and recent advances for improvement. *Comprehensive Reviews in Food Science and Food Safety, 8*, 181–194.

Newport Scientific. (1998). *Applications manual for the rapid viscoTM analyzer using thermocline for windows*. Unit 1, 2 Apollo Street Warriewood, NSW 2102, Australia: Perten Instruments of Australia Pty Limited.

* Numfor, F. A., Walter, W. M., & Schwartz, S. J. (1996). Effect of Emulsifiers on the physical properties of Native and fermented cassava starches. *Journal of Agricultural and Food Chemistry, 44*, 2595–2599.

* Oduro, I., Ellis, W. O., Dziedzoave, N. T., & Nimakoyeboah, K. (2000). Quality of gari from selected processing zones in Ghana. *Food Control, 11*, 297–303.

Ogbonnaya, C., & Hamza, A. (2015). Effects of moisture content and storage period on proximate composition, microbial counts and total carotenoids of cassava flour. *IJISET - International Journal of Innovative Science, Engineering & Technology, 2*(11), 63–73.

Ogiehor, I., & Ikenebomeh, M. (2006). The effect of different packaging materials on the shelf stability of gari. *African Journal of Biotechnology, 5*, 741–745.

Ojo, M. O., Ariahu, C. C., & Chinma, E. C. (2017). Proximate, functional and pasting properties of cassava starch and mushroom (*pleurotus pulmonarius*) flour blends. *American Journal of Food Science and Technology, 5*(1), 11–18.

Pontoh, J., & Low, N. H. (1995). Glucose syrup production from indonesian palm and cassava starch. *Food Reserves International, 28*(4), 379–385.

Rickard, J. E., Asaoka, M., & Blanshard, J. M. V. (1991). The physicochemical properties of cassava starch. *Tropical Science, 31*, 189–207.

Rosenthal, F. R. T., Nakamura, T., Espindola, A. M. C., & Jochimek, M. R. (1974). Structure of starch granules. *Die Starke, 26*, 50–55.

* Sanni, L. O., Kosoko, S. B., Adebowale, A. A., & Adeoye, R. J. (2004). The influence of palm oil and chemical modification on the pasting and sensory properties of fufu flour. *International Journal of Food Properties, 7*(2), 229–237.

SAS. (2001). *Statistical Analysis software (SAS) systems for windows*. Cary. NC, USA: SAS Institute Inc.

SON. (1988). *Standard organization of Nigeria. Nigeria industrial standard (NIS) for gari*.

Tolmasquim, E., Corrêa, A. M. N., & Tolmasquim, S. T. (1971). New starches: Properties of five genotypes of cowpea starch. *Cereal Chemistry, 48*, 132–139.

Williams, V. R., Wu, W., Tsai, H. Y., & Bates, H. G. (1958). Varietal differences in amylose content of rice starch. *Journal of Agricultural and Food Chemistry, 6*, 47–48.