

Effect of varieties on the functional and pasting properties of biofortified cassava root starches

W. Awoyale · L. O. Sanni · T. A. Shittu ·
M. O. Adegunwa

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Abstract The effect of varieties on the functional and pasting properties of biofortified cassava root starches (BfCRS) was investigated. Dried starches were produced from three biofortified cassava roots (TMS01/1371, TMS01/1368 and TMS06/1630), and their functional and pasting properties were evaluated. The result revealed that significant ($P \leq 0.001$) variations exist in all the starch properties. The water absorption capacity (WAC) ranged from 75.86 to 86.50 %, dispersibility 80.00–86.00 %, swelling power (SWP) 6.27–9.59 %, solubility index (SI) 1.30–1.90 %, bulk density (BD) 69.52–70.32 % and least gelation concentration (LGC) 4.01–4.06 %. TMS01/1371 BfCRS had the highest BD and WAC; TMS01/1368 BfCRS had the highest SWP, SI and LGC while TMS06/1630 BfCRS had the highest dispersibility and amylose contents. The starch from TMS01/1371 had the highest peak, trough and final viscosities, and peak time; TMS01/

1368 had the highest breakdown viscosity and TMS06/1630 was high in setback viscosity and pasting temperature. Therefore, any of the BfCRS could be used for food formulations depending on the quality desired in the final product.

Keywords Biofortified · Cassava root starch · Functional properties · Pasting properties

Introduction

The yellow flesh colour found in some cassava varieties is associated with the density of micronutrients, such as β -carotene [1] incorporated through the process of biofortification. Biofortified cassava root (BfCR) has been at the centre-stage in breeding for enhanced micronutrients, because of the use of cassava as a staple in most of the poverty-stricken Africa countries, specifically sub-Sahara Africa [2]. Yellow *gari*, powdered *fufu*, chips and high quality cassava flour has been produced from BfCR [3], with no information presently on the extracted starch properties.

Starch is the commonest form of carbohydrate stored in plant and the largest source of energy in human diet. Its array of functional properties makes it a flexible ingredient with compatible attributes for innumerable edible and non-edible industrial applications [4]. Starch and starch products are used in many foods and non-foods industry and as chemical raw materials for many other purposes, as in plastics and the tanning of leather. Non-food use of starches—such as coating, sizing and adhesives—accounts for about 75 % of the output of the commercial starch industry [5] based on its functionality. In many applications, there is competition not only among

W. Awoyale (✉)
Department of Food, Agriculture and Bioengineering, Kwara State University Malete, PMB 1530, Ilorin, Kwara State, Nigeria
e-mail: wawoyale0101@gmail.com;
wasu.awoyale@kwasu.edu.ng

L. O. Sanni · T. A. Shittu
Department of Food Science and Technology, Federal University of Agriculture Abeokuta, PMB 2240, Abeokuta, Ogun State, Nigeria
e-mail: lateef_2@yahoo.com; lateefsanni5@gmail.com

T. A. Shittu
e-mail: staofeek0904@yahoo.com

M. O. Adegunwa
Department of Hospitality and Tourism, Federal University of Agriculture Abeokuta, PMB 2240, Abeokuta, Ogun State, Nigeria
e-mail: nikytilo@yahoo.com

starches from various sources but also between starches and many other products.

The performance of a given starch in any application is governed by its physicochemical properties, of which pasting properties is very important. Starches from different sources are known to differ in their physical, functional and physicochemical properties [6]. These differences are believed to arise from difference in amylose/amylopectin ratio in the starch granule, the characteristics of each fraction in terms of molecular weight, length/degree of branching and the physical manner in which these constituents are arranged within the starch granules, and the presence of naturally occurring non-carbohydrate impurities [7]. The physicochemical properties of starch are therefore an important consideration because they determine the use of any starch. However, information on the functional and pasting properties of starches extracted from BfCR is scarce. Therefore, the main objective of this study was to evaluate the effect of varieties on the functional and pasting properties of biofortified cassava root starch (BfCRS) so as to provide important information for possible use in food applications.

Materials and methods

All the three BfCRs used in this work are of the Tropical Maniot Selection (TMS), obtained from the cassava farm of the International Institute of Tropical Agriculture (IITA), Ikenne, Ogun State, Nigeria. These are TMS01/1368, TMS01/1371 and TMS06/1630. These cassava varieties were harvested at 12 months of maturity during the dry season.

Production of biofortified cassava root starch

Biofortified cassava root starch (BfCRS) was produced using the traditional method of starch extraction as described by Oyewole and Obieze [8] with some modifications. Freshly harvested BfCRs were peeled, washed in water and grated with an electric motor powered mechanical grater. The resultant pulp was immediately sieved through a muslin cloth and suspended in water. This separates the fibrous and other coarse root material from the starch pulp. The starch pulp was allowed to settle for 4–6 h before decanting. The supernatant containing a mixture of yellow carotenoid and starch was decanted into a bowl and the thick sediment is the wet starch. The wet starch was reconstituted in water for washing twice, allowed to settle, decanted and then mixed with the yellow carotenoid/starch mixture, pressed and dried using a convectional cabinet dryer (model, manufacturer) at 45 ± 5 °C for 18 h. It was then allowed to cool to room

temperature, milled, and packed in polythene nylon prior to further investigations (Fig. 1).

Bulk density

The bulk density (BD) of the BfCRS was determined using the method of AOAC [9]. 7 g of the flours was weighed into a 50 ml graduated measuring cylinder. The cylinder was tapped gently against the palm of the hand until a constant volume was obtained.

$$BD = (\text{Weight of sample}) / (\text{Volume of sample after tapping}) \times 100$$

Water absorption capacity

Water absorption capacity (WAC) of the BfCRS was determined using the method described by Beuchat [10]. A sample (1 g) each was mixed with 10 ml of distilled water and blended for 30 s. It was allowed to stand for 30 min and centrifuged at 3,500 rpm for 30 min at room temperature. The supernatant was decanted and weight of water absorbed by the flour was calculated and expressed as WAC.

Swelling power

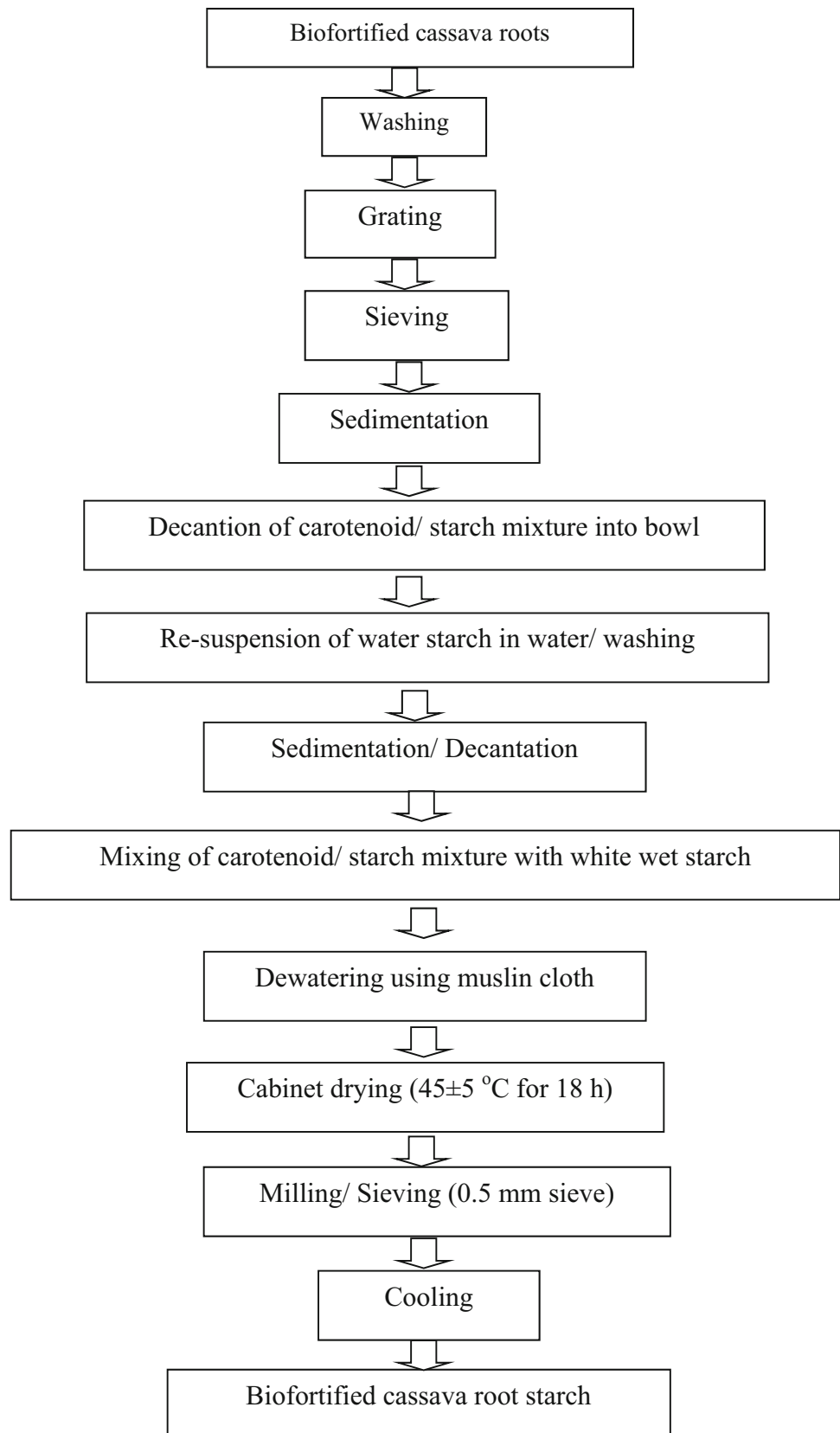
The method described by Leach et al. [11] with modification for small samples, was used for the determination of the BfCRS swelling power (SWP). A sample of 0.1 g was weighed into a weighed test tube into which 10 ml of distilled water was added and heated in a water bath at temperature of 60 °C for 30 min. This was continually shaken within the heating period. At the end, the test-tube was centrifuge at 2,200 rpm for 15 min in order to facilitate the removal of the supernatant, which was then carefully decanted and the weight of the starch paste taken.

$$SWP = (\text{Weight of starch paste}) / (\text{Weight of dry starch sample}) \times 100$$

Solubility index

The solubility index (SI) of the starches was evaluated by weighing 1 g of sample in 20 ml of distilled water in a test tube. This was subjected to heating in water bath at a temperature of 60 °C for 30 min. At the end of heating, it was subjected to centrifugation at 2,500 rpm for 20 min, 10 ml of the supernatant was decanted and dried to constant weight, and the solubility expressed as the percent by weight of dissolved starch from a heated solution [12].

Fig. 1 Flow chart for the production of biofortified cassava root starch (Modified from Oyewole and Obieze) [8]



$$SI = (\text{Weight of soluble})/(\text{Weight of sample}) \times 100$$

Least gelation concentration

The method of Coffman and Gracia [13] was used in the determination of the least gelation concentration (LGC). Appropriate sample suspensions was weighed into 5 ml distilled water each to make 2–20 % (w/v) suspension. The test tubes containing these suspensions were heated for 1 h in boiling water (bath) followed by rapid cooling under running tap water. The test tubes were further cooled for an hour under running water and the LGC was determined as the concentration when the sample from the inverted test tube did not fall or slip.

Dispersibility

This was determined by the method describe by Kulkarni et al. [14]. Samples were weighed (10 g each) into 100 ml measuring cylinder and distilled water added to reach a volume of 100 ml. The set up was stirred vigorously and allowed to settle for 3 h. The volume of settled particles was recorded and subtracted from 100. The difference was then reported as percentage dispersibility.

Amylose content

This was determined according to the method described by Williams et al. [15]. 0.1 g of flour sample was weighed into a test tube. To this, 1 ml of 95 % ethanol and 9 ml 1 N NaOH was carefully added and vortexed with the mouth of the test tube covered. The samples was heated for 10 min in a boiling water bath to gelatinize the starch, and then allowed to cool to room temperature. 10 times dilution of the extract was made by taking 1 ml of the extract and make up to 10 ml with 9 ml of water. From the diluents, an aliquot of 0.5 ml was taken for analysis. To this, 0.1 ml of acetic acid solution, and 0.2 ml of iodine solution was added. The volume was then made up to 10 ml with 9.2 ml of distilled water. The test mixture was left for 20 min. for color development after which it was vortexed and the absorbance read at 620 nm.

Calculation was done using this equation:

$$\% \text{Amylose of sample} = \frac{\% \text{ amylose of standard} \times \text{Absorbance of sample}}{\text{Absorbance of standard}}$$

Pasting properties

The pasting characteristics of the BfCRS samples was determined using a Rapid Visco Analyzer (RVA) (Model RVA-4C, Newport Scientific, Warriewood, Australia) interfaced with a personal computer equipped with the Thermocline Software supplied by same manufacturer [16]. Each starch samples (3 g of moisture content less than 12 %) was weighed into a canister and made into slurry by adding 25 ml of distil water. This canister (covered with a stirrer) was inserted into the RVA. The heating and cooling cycles was programmed in the following manner. The slurry was held at 50 °C for 1 min, heated to 95 °C within 3 min and then held at 95 °C for 2 min. It was subsequently cooled to 50 °C within 3 min and then held at 50 °C for 2 min, while maintaining a rotation speed of 160 rpm. The viscosity was expressed as rapid viscosity units (RVU). The parameters that was determined automatically by the instrument are peak viscosity (the maximum viscosity during pasting), breakdown viscosity (the difference between the peak viscosity and the minimum viscosity during pasting), setback viscosity (the difference between the maximum viscosity during cooling and the minimum viscosity during pasting), final viscosity (the viscosity at the end of the RVA run), pasting temperature (°C) (the temperature at which there is a sharp increase in viscosity of flour suspension after the commencement of heating) and peak time (min) (time taken for the paste to reach the peak viscosity).

Data analysis

All analyses were carried out in triplicates and subjected to one way analysis of variance (ANOVA) using statistical analysis system (SAS) package (version 9.1, SAS Institute, Inc., Cary, NC) [17]. Means were separated using fisher's protected least significant difference test. Pearson correlation analysis was done using Statistical Package for Social Sciences (SPSS-version 17).

Results and discussions

Table 1 showed the functional and physicochemical properties of biofortified cassava root starches (BfCRS). The swelling power (SWP) of the BfCRS ranged from 6.27 to 9.59 %, and the solubility index (SI) ranged between 1.03 and 1.90 %. TMS01/1368 BfCRS had the highest SWP and SI, while that of TMS01/1371 and TMS06/1630 had the lowest respectively (Table 1). SWP and SI provide

Table 1 Functional and physicochemical properties of biofortified cassava root starches

Samples	SWP (%)	SI (%)	BD (%)	WAC (%)	Dispersibility (%)	LGC (%)	Amylose (%)
TMS01/1371 BfCRS	6.27 (0.05) ^c	1.80 (0.00) ^b	70.32 (0.00) ^a	86.50 (0.01) ^a	80.00 (0.00) ^c	4.01 (0.03) ^b	21.93 (0.28) ^b
TMS01/1368 BfCRS	9.59 (1.11) ^a	1.90 (0.10) ^a	70.25 (0.00) ^a	75.86 (0.00) ^b	84.50 (0.50) ^b	4.06 (0.04) ^a	21.00 (0.11) ^c
TMS06/1630 BfCRS	6.51 (0.10) ^b	1.30 (0.44) ^c	69.52 (0.00) ^b	76.32 (0.02) ^b	86.00 (0.00) ^a	4.03 (0.03) ^b	24.80 (0.30) ^a
Mean	7.46	1.67	70.03	79.56	83.50	4.03	22.58
<i>P</i> level	***	***	***	***	***	***	***

SWP swelling power, SI solubility index, BD bulk density, WAC water absorption capacity, LGC least gelation concentration, ND Not determined, () standard deviation, BfCRS biofortified cassava root starch

*** $P \leq 0.001$, means with different letters on the same column are significantly different at $P \leq 0.05$

evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains [18]. The bonding forces within the granules, granule size distribution, granule morphology and amylose/amylopectin ratio influence the extent of this interaction [19]. Consequently, the lower SWP obtained in TMS01/1371 BfCRS might suggest a more highly ordered arrangement in its granules than that of TMS01/1368 with the highest SWP. Nevertheless, the SWP obtained in this work for TMS01/1368 BfCRS was within the range reported by Onitilo et al. [20] and Eke et al. [21] but lower to that of Kay [22] for dried white-fleshed cassava root starches (WfCRS). This could be due to varietal differences. Furthermore, TMS06/1630 BfCRS might consists of highly associated starch granules with an extensive and strongly bonded micellar structure due to its lower SI, while that of TMS01/1368 may be made up of weak associated forces due to its high SI [19]. However, the SI of the all the BfCRS agreed with the values reported by Onitilo et al. [20] but lower than those reported by Eke et al. [21] for WfCRS. This could be attributed to difference in variety.

The bulk density (BD) of the BfCRS was higher in TMS01/1371 (70.32 %) and lower in TMS06/1630 (69.52 %) (Table 1). Low BD food has been reported by Ikujenlola [23] to be desired where packaging is a serious problem; hence, TMS06/1630 BfCRS might require the least packaging material because of its BD. The BD of WfCRS reported by Agunbiade and Ighodalo [24] was higher compared to that of this study. This may be attributed to varietal differences. This study also revealed that the higher the BD, the higher the time required to form a paste. This is because a significant ($P \leq 0.01$) positive correlation ($r = 1.00$) exist between the BD of the BfCRS and the time it takes to form a paste (peak time) (Table 2).

Literature had shown that water absorption capacity (WAC) of starchy foods is closely related to starch granular integrity [25]. The WAC of the BfCRS ranged from 75.86 % (TMS01/1368 BfCRS) to 86.50 % (TMS01/1371 BfCRS) (Table 1). These values were higher compared to that reported by Ikegwu et al. [26] but lower than values

reported by Onitilo et al. [20] for WfCRS. The observed differences in water absorbed by the starches may be due to the starch granular properties and integrity [25]. Additionally, a negative but significant correlation ($P \leq 0.05$, $r = -1.00$) exist between the WAC and the breakdown viscosity of the BfCRS (Table 2). This implied that BfCRS paste from TMS01/1371 with the highest WAC might not be cohesive in nature. Dispersibility is a measure of the reconstitutability of starch or starch blends in water. The higher the dispersibility the better the starch reconstitutes in water [15]. This indicates that TMS06/1630 BfCRS with the highest dispersibility might reconstitute easily and form a fine paste without lumps for product like custard powder. However, since the values of dispersibility are relatively high for all the BfCRS (80–86 %) (Table 1), they may reconstitute easily to give a fine consistent paste without lump formation [15]. Consequently, reducing energy use for stirring to enhance dispersibility during preparation of food product like custard powder. Additionally, percentage dispersibility of the BfCRS was in agreement with the result obtained by other researchers for the dispersibility of WfCRS [20].

Starch granule is made up of straight chain of glucose (amylose) and the branched chain (amylopectin). Amylose is the linear component that imparts a definite characteristic to starch and, therefore, its content is an important criterion in starch quality [27]. The amylose content determines, largely the stability of viscous solution formed, when starch is heated. The amylose content of the BfCRS ranged from 21 to 24.80 %; TMS06/1630 BfCRS had the highest value while that of TMS01/1371 had the lowest (Table 1). The differences in the amylose contents of all the BfCRS of this work compared to that of WfCRS reported by various workers [20, 21, 26] may be attributed to varietal difference. The observed LGC of the BfCRS (4.01–4.06 %) (Table 1) was within the range of values reported by Onitilo et al. [20] for WfCRS. LGC can be described as a measure of the minimum amount of starch or blends of starch that is needed to form a gel in a given volume of water. The higher the LGC, the higher the amount of the

Table 2 Pasting properties of biofortified cassava root starches

Samples	Peak viscosity (RVU)	Trough (RVU)	Break down (RVU)	Final viscosity (RVU)	Set back (RVU)	Peak time (min)	Pasting temperature (°C)
TMS01/1371 BfCRS	418.74 (0.01) ^a	304.67 (0.01) ^a	114.08 (0.01) ^c	356.08 (0.01) ^a	51.41 (0.01) ^b	4.68 (0.03) ^a	75.83 (0.05) ^b
TMS01/1368 BfCRS	349.75 (0.01) ^c	197.50 (0.01) ^c	152.25 (0.01) ^a	241.92 (0.01) ^c	44.42 (0.01) ^c	4.66 (0.01) ^a	75.65 (0.01) ^c
TMS06/1630 BfCRS	377.92(0.00) ^b	228.17(0.01) ^b	149.75 (0.01) ^b	293.33 (0.01) ^b	65.16 (0.01) ^a	4.45 (0.05) ^b	78.80 (0.01) ^a
Mean	382.14	243.45	138.69	297.11	53.66	4.60	76.76
<i>P</i> level	***	***	***	***	***	***	***

Means with different superscript on the same column are significantly different at $P \leq 0.05$ () standard deviation, *RVU* rapid visco unit, *BfCRS* biofortified cassava root starch

*** $P \leq 0.001$

starch needed to form a gel [28]. Lower LGC will definitely have a favourable economic impact on use, since this implies that less starch is required to make food gels. Thus, small quantity of all the BfCRS might be required to form a gel in food formulations like custard powder.

The pasting properties of the BfCRS are shown in Table 3. Determination of the pasting properties of the BfCRS is important to predict the cooling behaviour of its reconstituted slurry when applied to food formulations. The temperature at the onset of any rise in viscosity is referred to as the pasting temperature (PTp) [29]. Therefore the PTp is a measure of the minimum temperature required to cook a given food sample, which can have implications for the stability of other components in a formulation and indicate energy costs. The PTp of all the BfCRS ranged between 75.65 and 78.80 °C. TMS06/1630 BfCRS had the highest value while TMS01/1368 BfCRS had the lowest (Table 3). This value was higher than the value reported by Onitilo et al. [20] for WfCRS. However, food product from these BfCRS might be cooked below the temperature of boiling water, and thus conserve energy used for cooking. The peak time (PTm) on the other hand is a measure of the cooking time [28]; hence, all the BfCRS may be cooked for <4.7 min (Table 3). Furthermore, peak viscosity (PV) is the maximum viscosity developed during or soon after the heating portion, which indicates the water binding capacity of the starch or mixture [26]. It has been suggested that high PV contributes to good texture of paste, which depends on moderately high gel strength [30]. This study revealed that TMS01/1371 BfCRS with the highest PV (418.74 RVU) might be used for food formulations that require good paste with moderately high gel strength, compared with that of TMS01/1368 (349.75 RVU) (Table 3). However, the observed PV of the BfCRS was within the range of values reported by Onitilo et al. [20] for WfCRS. The breakdown viscosity (BDV) was higher in TMS01/1368 BfCRS (152.25 RVU) and lower in that of TMS01/1371 (114.08 RVU) (Table 3). Eliasson [31] reported that BDV is not desirable since it leads to uneven

viscosity and results in the cohesive nature of the starch paste. Hence, TMS01/1368 BfCRS might form an uneven viscosity with cohesive starch paste compared to that of TMS01/1371, because of its high BDV. Similar results for the BfCRS BDV was reported by Nuwamanya et al. [32] and lower range reported by Ikegwu et al. [26] for WfCRS.

The BfCRS with the highest final viscosity (FV) was TMS01/1371 BfCRS (356.08 RVU) while the lowest was that of TMS01/1368 (241.92 RVU) (Table 3). The FV is the most commonly used parameter to determine a particular starch-based sample quality as it indicates the ability of the material to form gel after cooking [33]. In addition, the low FV observed for all the BfCRS compared to the PV indicate their low tendency to retrograde [34]. Values of the BfCRS FV reported in this work were in range as reported by other workers for WfCRS [25, 41]. The viscosity of cooked paste or setback viscosity (SBV) of the BfCRS ranged from 44.42 to 65.16 RVU; TMS06/1630 BfCRS had the highest value while TMS01/1368 BfCRS had the least (Table 3). The SBV is a stage where retrogradation or re-ordering of starch molecules occurs [35]. Sanni et al. [36] also stated that lower SBV during the cooling of the paste indicates greater resistance to retrogradation. Consequently, TMS01/1368 BfCRS might retrograde slowly after cooking compared to that from TMS06/1630 with higher SBV.

Conclusion

This study shows that significant variations exist in all the functional and physicochemical properties of the all the biofortified cassava root starches analyzed. The starch from TMS01/1371 had the highest bulk density, water absorption capacity, peak, trough and final viscosities, and peak time; TMS01/1368 had the highest swelling power, solubility index, least gelation concentration, breakdown viscosity while TMS06/1630 was high in dispersibility, amylose, setback viscosity and pasting temperature.

Table 3 Pearson correlation between the functional and physicochemical properties of biofortified cassava root starch

Parameters	SWP	SI	BD	WAC	Dispersibility	LGC	Amylose	PV	TV	BDV	FV	SBV	Peak time	Pasting temperature
SWP	1.00													
SI	0.58	1.00												
BD	0.37	0.97	1.00											
WAC	-0.59	0.32	0.54	1.00										
Dispersibility	0.34	-0.57	-0.75	-0.96	1.00									
LGC	0.94	0.27	0.04	-0.83	0.64	1.00								
Amylose	-0.64	-1.00	-0.95	-0.25	0.51	-0.35	1.00							
PV	-0.85	-0.05	0.18	0.93	-0.79	-0.98	0.13	1.00						
TV	-0.76	0.09	0.32	0.97	-0.87	-0.94	-0.01	0.99	1.00					
BDV	0.60	-0.30	-0.52	-1.00*	0.96	0.84	0.23	-0.94	-0.98	1.00				
FV	-0.87	-0.10	0.14	0.91	-0.76	-0.99	0.18	1.00*	0.98	-0.92	1.00			
SBV	-0.72	-0.98	-0.91	-0.15	0.42	-0.44	1.00	0.23	0.10	0.13	0.28	1.00		
Peak time	0.37	0.97	1.00***	0.54	-0.75	0.04	-0.95	0.18	0.32	-0.52	0.14	-0.92	1.00	
Pasting temperature	-0.49	-0.99	-0.99	-0.42	0.66	-0.17	0.98	-0.06	-0.19	0.40	-0.01	0.96	-0.99	1.00

SWP swelling power, SI solubility index, BD bulk density, WAC water absorption capacity, LGC least gelation concentration, PV peak viscosity, TV trough viscosity, BDV breakdown viscosity, FV final viscosity, SBV setback viscosity

** $P \leq 0.01$; * $P \leq 0.05$

Therefore, the functionality of any of the biofortified cassava root starch in food formulations depend on the cassava variety used.

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Conflict of interest No conflict of interest.

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