American Journal of Food and Nutrition, 2017, Vol. 5, No. 2, 62-68
Available online at http://pubs.sciepub.com/ajfn/5/2/3

DOI:10.12691/ajfn-5-2-3

Evaluation of Compositional and Some Physicochemical Properties of Bambara Groundnut and Cocoyam Starch Blends for Potential Industrial Applications

Adeleke Omodunbi Ashogbon*

Departmental of Chemical Sciences, Faculty of Science, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria
*Corresponding author: ashogbonadeleke@yahoo.com

Abstract Bambara groundnut starch (100BBS) and cocoyam starch (100CYS) were blended at three different ratios (70BBS/30CYS, 50BBS/50CYS and 30BBS/70CYS) (%, w/w) and their compositional and some physicochemical properties evaluated. The potential industrial applications of the starch blends were adduced from their physicochemical properties. Substitution of 100CYS with 100BBS led to decreases in lipid (from 0.31 to 0.06%), protein (0.12 to 0.06%) and apparent amylose (37.31 to 22.60%) contents and vice versa when more 100BBS was substituted into 100CYS. Swelling power (SP) (except at 55°C), water solubility index, bulk density (BD), dispersibility (DP), pH and pasting parameters (except peak viscosity and peak time) of the starch blends were non-additive of their individual components. Bulk density, DP and pH of the starch blends ranged from 0.79 to 0.85 g/ml, 81 to 86% and 7.38 to 7.52, respectively. The breakdown viscosity of the control starches was smaller compared to that of starch blends. Peak time of starch blends was intermediate to that of the control starches. The searches for starch blends with appropriate physicochemical properties for potential industrial applications were achieved. The 30BBS/70CYS blend with the lowest retrogradation (120.60RVU) could be utilized in refrigerated foods. Furthermore, the 70BBS/30CYS blend with the highest SP could find application in the pharmaceuticals as disintegrants. These findings indicate that blending of under-utilized 100BBS and 100CYS could result in starch blends with appropriate physicochemical properties for industrial applications.

Keywords: *Bambara groundnut starch, cocoyam starch, starch blends, pasting, dispersibility*

Cite This Article: Adeleke Omodunbi Ashogbon, "Evaluation of Compositional and Some Physicochemical Properties of Bambara Groundnut and Cocoyam Starch Blends for Potential Industrial Applications." *American Journal of Food and Nutrition*, vol. 5, no. 2 (2017): 62-68. doi: 10.12691/ajfn-5-2-3.

1. Introduction

The importance of starches lies in their abundant availability, cheapness, renewability, biodegradability and non-toxic nature. The significance of starch is the ease with which the physicochemical properties can be altered with different kind of modifications [1]. The uniqueness and individuality of starches from different botanical origin was widely attributed to differences in morphology, amylose/amylopectin ratio and soil type during growth. The mechanism of the physiology of starch component synthesis during plant growth had also affected the uniqueness of the starches [2]. It is these differences in its entirety that accounted for the diverse applications of these starches in the food and non-food industries.

The industrial utilization of native starches is limited due to inherent high rate of retrogradation, insolubility in water and fluctuation in viscosity during thermal processing [3]. Furthermore, instability of pastes and gels under various temperatures, shears and pH conditions also restricted the commercial applications of native starches. This limitation of native starches can be circumvented by physical and chemical modification, enzymatic and biotechnological modification, or their combinations. All these modifications can increase the cost of starch by five to six folds [4]. Nowadays, market trends are towards natural food components, avoiding as much as possible any chemical treatment [5]. Chemical and physical modifications of starches are costly and frequently employ treatments with hazardous chemicals [6].

Blending of starches from different botanical origin has come as a good alternative. It is cheap and does not involve the addition of chemicals or biological agents into the starches. Starch blends are not additives and therefore the quantities utilized are not subject to regulation [7]. Blending of starches is not an entirely new process. Bambara groundnut starch (100BBS) had been previously blended with cassava starch [2]; cocoyam starch (100CYS) blended with wheat starch [8]; and sweat potato starch blended with wheat starch [9].

The pasting properties, swelling power (SP) and amylose content are some of the important parameters for determining the potential applications of starches in the industry. Knowledge of pasting properties is a significant indicator of the processing quality of foods and their components and aids a processor in optimizing ingredient concentrations and temperature-pressure-shear limits to achieve a desired product [10]. Furthermore, the pasting properties are used in assessing the suitability of starch as a functional ingredient in food and other industrial products [11]. For starch blends, pasting properties are non-additive when the characteristics of the blend cannot be predicted from those of the individual starches [12,13].

It had been widely reported that the physicochemical properties of starch blend could be either additive or non-additive depending on the botanical origin, amylose (AM) content, starch-to-water ratio and ratio of starches in the blend [14]. The same researchers adduced that tremendous disparity in granule size SP between blended starches leads to uneven moisture distribution during heating of starch suspension. The consequence is that the behavior of the blend differ from what would be expected based on the behavior of the individual starches. Amylose and amylopectin (AP), are the major components of the starch granule. They play an important role in the determination of SP, solubility, pasting and gelatinization of the starches. The role of the anti-swelling and anti-solubility minor components (mainly lipids and proteins) of starch had been widely reported [15]. The functionality of the two main components of starch differs significantly. Amylose has a high tendency to retrograde and produce tough gels and strong films [3]. In contrast, AP, when dispersed in water, is more stable and produces soft gels and weak films [16].

Bambara groundnut (*Voandzeia substerranean*) like sword bean and pigeon pea is an underutilized legume. It is a drought tolerant and easy-to-cultivate legume [17]. Bambara groundnut starch (100BBS) had been extensively studied [17]. Cocoyam *(Xanthosoma sagittifolium)* belongs to the family Aracea and it is the sixth most important root and tuber crops world-wide [18]. The high carbohydrate content of cocoyam and its wide availability in the tropical countries makes it a very good source of starch for domestic and industrial applications [19]. It is an underutilized tuber when compared to cassava and potato in terms of industrial applications. Cocoyam starch (100CYS) had also been extensively studied [20]. It was observed that there are limited works on blending of 100BBS and 100CYS. The available works were especially lacking in the areas of bulk density, dispersibility, pH and potential industrial applications of the starch blends. Therefore, the aim of this work is to study the physicochemical properties of these starch blends in different ratios.

2. Materials and Methods

2.1. Materials

Bambara groundnut seeds and new cocoyam tubers were purchased from a local market at Igbokoda, Ondo State, Nigeria. The seeds were screened to remove the defective ones. The tubers were peeled and those with dark spots were eliminated. All chemicals were of analytical reagent grade.

2.2. Starch Extraction

Manually de-husked and dried bambara groundnut seeds were ground to a powdery form in a laboratory grinder. Starch was extracted from the powdery form by a procedure of Adebowale and Lawal [21] as modified by Sirivongpaisal [17]. Starch was extracted from new cocoyam tubers by a method previously described by Lawal [19]. In brief, the tubers were peeled, washed, grated and sieved (Lab. Test Sieve Int. UK. Aperture: 600 MIC). The sieved slurry was stirred with distilled water and allowed to stand for 2 hr. The supernatant of the starch solution was decanted and the sediment prime starch dried in the laboratory ovum (N505F, YOGOII, Genlab Widnes, England) at 40°C for 48 hr.

2.3. Preparation of the Starch Blends

The method of Zhang et al. [5] was adopted to ensure homogeneity of the starch blends. The blends were prepared from the extracted native starches (100BBS and 100CYS) in three proportions (70BBS/30CYS, 50BBS/50CYS and 30BBS/70CYS) (%, w/w). The starches were sieved and mixed in a laboratory blender [Marlex Electroline by KIL, Unit 3, Debhel, Daman (UT))].

2.4. Chemical Compositions of 100BBS, 100CYS and Their Blends

Apparent amylose (AAM) content (%) was determined by a colorimetric iodine assay index method, according to Juliano [22]. The moisture, protein, lipid, and ash contents in the starch samples were determined using procedure of AACC method [23].

2.5. Swelling Power and Solubility

Swelling power (SP) and water solubility index (WSI) determinations were carried out in the temperature range 55-95°C at 10°C intervals using the method of Leach et al. [24].

2.6. Bulk Density

This was determined by the method of Wang and Kinsella [25] as modified by Ashogbon and Akintayo [26].

2.7. Dispersibility

This was determined by the method described by Kulkarni et al. [27] as modified by Akanbi et al. [28].

2.8. pH

Starch samples (5g) were weighed in triplicate into a beaker, mixed with 20 ml of distilled water. The resulting suspension stirred for 5 min and left to settle for 10 min. The pH of the supernatant was measured using a calibrated pH meter [29].

2.9. Pasting Properties

The pasting properties of the control starches and their blends were evaluated using a Rapid Visco Analyzer (Newport Scientific, RVA Super 3, Switzerland). Starch suspensions (9%, w/w, dry weight basis; 28g total weight) were equilibrated at 30°C for 1min, heated at 95°C for 5.5min, at a rate of 6°C /min, held at 95°C for 5.5min, cooled down to 50°C at a rate of 6°C/min and finally held at 50°C for 2 min. Parameters recorded were pasting temperature (PT), peak viscosity (PV), trough viscosity (TV), final viscosity (FV), and peak time (Pt). Breakdown viscosity (BV) was calculated as the difference between PV and TV, while setback viscosity (SV) was determined as the FV minus TV. All determinations were performed in triplicate and expressed in rapid viscosity unit (RVU).

2.10. Statistical Analysis

Experimental data were analyzed statistically using Microsoft Excel and SPSS V. 12 .0. The least significant difference at the 5% probability level (P<0.05) was calculated for each parameter.

3. Results and Discussion

3.1. Chemical Composition of Control Starches and Their Blends

The moisture content (MC) of the control starches and their blends was within the commercially accepted range for stable shell life (less than 14.0% MC; [30]). The substitution of 100CYS with 100BBS (an increase in the blend of 100CYS) led to an increase in the MC (from 11.52 to 12.38%), ash (from 0.12 to 0.26%) contents while there was decrease in lipid (from 0.31 to 0.06%), protein (from 0.12 to 0.06%) and AAM (from 29.92 to 22.60%) contents (Table 1). As the substitution of 100CYS for 100BBS in the starch blends was increased, the moisture and ash contents also increased. Therefore the moisture and ash contents of the starch blends were additive (as expected) of their individual components.

As the substitution of the 100CYS with the 100BBS increased, the AAM concentration of the starch blends decreased. This is expected, as the characteristic high AAM content of the legume starch (100BBS) decreases. The higher AAM on 100BBS and the 70BBS/30CYS blend could be desired in the making of noodles [2]. Furthermore, these high AAM starch and blend could be potentially useful for making sweets [1], additive products, paper and resistant starch [31]. High amylose starches due to their strong gelation properties and helical linear polymer structure are significant film-filming materials [22].

There are three types of amylose-starches: high AM-starches, intermediate AM-starches and low AM-starches (the amylose is not low enough to call the starch waxy). Each of those AM- starches have different applications in the food and non-food industries. Blending of starches from different botanical origins change the AM contents of the blends and each of them find different applications in the industries.

3.2. Functional Properties of Control Starches and Their Blends

The bulk density (BD), dispersibility (DP) and pH of the starch blends were non-additive of their individual components (Table 2). As the proportion of 100CYS incorporated into the starch blends increased the BD fluctuated insignificantly. Among the blends, the changes in their BD was statistically insignificant (P<0.05) as the substituted 100CYS in the blends increased. The BD of the starch blends was intermediate to that of the control starches. 100BBS was the coarsest. In contrast, the 100CYS was the smoothest in terms of particle size and could be potentially useful in the cosmetic industry for making face powder. The reduced bulk density of the blend (50BBS/50CYS) compared to others, although not statistically significant, could be of economic advantage during packaging, transportation and distribution of the starch blend products [32].

Table 1. Chemical composition of control starches and their blends

Parameter (%)	100BBS	70BBS/30CYS	50BBS/50CYS	30BBS/70CYS	100CYS
MC	11.74±0.12^{a}	11.52±0.04^{b}	11.64±0.03^{a}	12.38±0.05^{c}	12.84±0.02^{d}
Ash	0.05±0.16^{a}	0.12±0.01^{a}	0.22±0.03^{a,b}	0.26±0.00^{b}	0.29±0.02^{b}
Lipid	0.31±0.11^{a}	0.31±0.02^{a}	0.06±0.00^{b}	0.06±0.01^{b}	0.08±0.03^{b}
Protein	0.12±0.01^{a}	0.12±0.00^{a}	0.12±0.01^{a}	0.06±0.02^{a}	0.06±0.00^{a}
AM	37.31±0.20^{a}	29.92±0.20^{b}	25.53±0.30^{c}	22.60±0.22^{d}	22.60±0.30^{d}
AP	62.69±0.10^{a}	70.08±0.03^{b}	74.47±0.10^{c}	77.34±0.13^{d}	77.40±0.10^{d}
AM/AP	0.60±0.02^{a}	0.43±0.10^{b}	0.34±0.12^{b}	0.29±0.02^{b}	0.29±0.03^{b}

Different superscripts along rows indicate statistically significant difference (P<0.05). *Amylose to amylopectin ratio. MC = Moisture content.

Table 2. Bulk density, dispersibility and pH of control starches and their blends

Sample	BD (g/ml)	DP (%)	pH
100BBS	0.95±0.03^{a}	88.5±0.05^{a}	7.50±0.03^{a}
70BBS/30CYS	0.85±0.01^{b}	83.0±0.03^{b}	7.52±0.01^{a}
50BBS/50CYS	0.79±0.02^{b}	86.0±0.04^{b}	7.38±0.02^{a}
30BBS/70CYS	0.81±0.01^{b}	81.0±0.02^{b}	7.41±0.01^{a}
100CYS	0.60±0.02^{c}	74.0±0.06^{c}	7.84±0.04^{b}

Different superscripts along columns indicate statistically significant difference (P<0.05).

The DP percentage of the starch blends was non-additive of their individual components. The higher DP of the 100BBS was more favored in terms of potential industrial applications than the lower value of 100CYS (74.0%) (Table 2). All the blends possessed intermediate DP in-between the control starches. The DP in this study was better and higher than that obtained by Akanbi et al. [28] for breadfruit starch (40.67%) and Abu et al. [32] for starch blends of Irish potato and pigeon pea.

The pH of the starch blends was not significantly different ($P<0.05$). As more 100CYS was incorporated into the starch blends, the pH values fluctuate infinitesimally and these changes are statistically insignificant. The pH of the starch blends was slightly alkaline and non-additive of its individual components. Blending had minimal effect on the pH of the blends. Other previously conducted studies had similar or different pH values than that observed in this study. For example, starch blends of bambara groundnut and cassava had pH values in the range (7.21-7.32) [2] and cocoyam and wheat with pH values of 2.9 to 3.7 [8], respectively.

AP had been widely documented to be responsible for SP and AM for solubility of various starches. When thermally agitated, starch granules swell and eventually ruptured. The exudation of AM from the ruptured starch granules is directly responsible for the solubility of starches. The influences of proteins, lipids, native and temperature-induced AM-complexes [33] on these parameters (AM and AP) were also emphasized. The SP and WSI of the control starches and their blends were heated from 55 to 95°C at 10°C interval are summarized in Figure 1 and Figure 2, respectively. At all the temperatures (65-95°C) investigated, except at 55°C, the SP of the starch blends was non-additive of their individual components. As the proportion of 100BBS in the blends was increased with increasing temperature, the SP of the blends was also raised, though not too pronounced for 50BBS/50CYS. The 70BBS/30CYS had the highest SP, at higher temperature, probably due to its weak internal structure (Figure 1; [34]). From this study, it was observed that AP is not the factor responsible for the manifestation of high SP of starch granules. Other factors like bond strength of starch chains, the nature of linkage between the main starch polymers and the presence of the minor components (mainly proteins and lipids) must be taken into consideration. It is noted that the 70BBS/30CYS blend having the highest SP does not possessed the highest AP content. The characteristic restricted SP associated with the legume starches was reflected by 100BBS in this study. The blend (50BBS/50CYS) and the control starch (100BBS) with the lowest SPs have large disparity in AM content between them. The 70BBS/30CYS blend with the highest SP could found application as binder or extender in the industry. Furthermore, it could be utilized in the pharmaceutical industry as disintegrants [35].

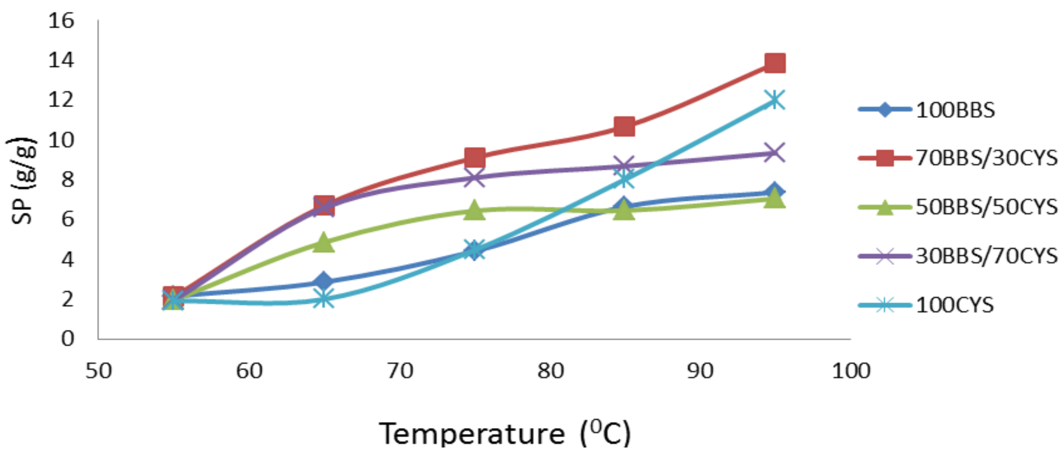

Figure 1. SP of control starches and their blends

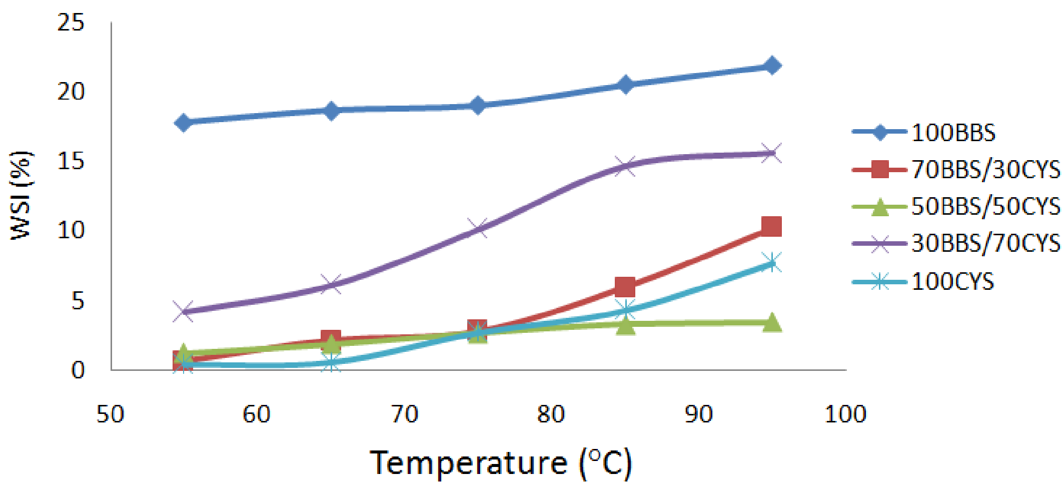

Figure 2. WSI of control starches and their blends

The WSI of the control starches and their blends increases as the temperature was increased (Figure 1). The exceptional high solubility of the 100BBS and the 30BBS/70CYS should be noted. This behavior of 100BBS could be attributed its having the highest AM content. In contrast, the high solubility of the 30BBS/70CYS blend could be ascribed to sometime inherent in the nature of the blend that promoted easy exudation of AM from the granules and therefore enhance solubility. Although the concept of high AM been responsible for the solubility of starches was applicable to 100BBS. It is obviously not applicable to the starch blends and 100CYS.

3.3. Pasting Properties of the Control Starches and Their Blends

Only few of the pasting parameters of the starch blends were additive (PV and Pt), while the others were non-additive of their individual components (Table 3). Just like in the study of pasting properties of starch blends from various plant sources, most of the pasting parameters are non-additive of their individual components [5]. As the proportion of 100CYS in the blends was increased, the PV values also raised. The 30BBS/70CYS blend had the highest PV and BV values. This indicated that the blend granules can easily swell and get fragmented when thermally and mechanically agitated. It also portrays the likely weak internal structure of the granules of the 30BBS/70CYS blend [34]. The polymeric molecules (AM and AP) within the starch blend granules are probably held by weak intermolecular and intra-molecular forces. This high SP and viscosity can be ascribed to the low AAM concentration (high AP concentration) of the 30BBS/70CYS blend (Table 1). The highest PV, BV and SP values of the 30BBS/70CYS blend resulted in a lowest SV value than those of the other blends and control starches (Table 3). The results of the pasting behaviors of the 30BBS/70CYS blend indicated that a lower AAM content was connected with the manifestation of higher PV [36]. The high PV displayed by the 30BBS/70CYS blend implies that it could be suitable for products needing high gel strength and elasticity [37].

The 100BBS with the lowest PV and BV values should be the most resistant to granular fragmentation when thermally and mechanically agitated. Among the starch blends, the 50BBS/50CYS blend with the least BV will not be easily fragmented by attrition, thermal and mechanical agitation. This means that the granules of the 100BBS and the 50BBS/50CYS blend were more compacted and the polymeric molecules better tightly held together by stronger forces than the other blends and 100CYS. The granules were rigid and do not easily swell. Furthermore, the granules of 100BBS and 50BBS/50CYS blend were probably denser or more crystalline when compared to the granules of the other blends and 100CYS [36]. These exceptional low values of PV and BV of the 100BBS could be ascribed to its characteristic high AAM concentration (low AP content) (Table 1).

The lowest values of FV and SV of the 30BBS/70CYS blend were expected due to its low AAM content. It is this low AAM concentration that had being implicated in the manifestation of low FV and SV values. It indicated that the 30BBS/70CYS blend possessed low syneresis and retrogradation and could be potentially useful in the food industry. Because of its least tendency to retrograde, the 30BBS/70CYS blend could be desired in refrigerated foods and also in cake filling, desserts, sauces and soups [7]. In disparity, the high retrogradation (161.54RVU) of the 50BBS/50CYS blend could be potentially utilized in gluten-free pasta and noodles [38]. The characteristic high AAM (37.31%) concentration (Table 1) and retrogradation (252.13RVU) of the legume starches were also observed in 100BBS. The latter is not suitable for usage in refrigerated food.

The FV values of the starch blends ranged from 340.50 (30BBS/70CYS) to 423.83RVU (50BBS/50CYS) and were non-additive of their individual components. Since the 50BBS/50CYS blend had the highest FV value, it indicated that the 100BBS and 100CYS contributed equally to the manifestation of higher FV value. The highest FV value of the 50BBS/50CYS blend could be desired in the textile industry and wet stage paper production where high viscosity is needed [39]. In contrast, the lowest FV value of the 30BBS/70CYS blend can be utilized in the dry stage paper-making where low viscosity starches are preferred [39].

The Pt of the starch blends was additive and PT was non-additive of their individual components. As the proportion of the 100CYS in the starch blends increased, the Pt values plummeted. This indicated that as more 100CYS was substituted into the blends, the cooking time decreases. This could be of some advantage to the food industry as time and energy will be conserved. The least PT value of the 30BBS/70CYS blend indicates that it began to form paste earlier compared to the other blends and control starches. The least PT value of the 30BBS/70CYS blend will be preferred in some food industries because of the reduced energy cost of production. In contrast, the highest PT value of the 50BBS/50CYS blend could be desired in canned and sterilized foods processed at high temperatures. This highest PT value of the 50BBS/50CYS blend could be attributed to the strong association between starch granules (Numfor et al., 1996). It is also worth-noting that 100BBS and 100CYS contributed equally to the manifestation of high PT value of the 50BBS/50CYS blend. The TV values of the starch blends ranged from 219.71 to 262.29RVU and vary significantly (P<0.05). The significance of the TV values is that, they aid in the computation of the BV and SV values.

Table 3. Pasting Properties of Control Starches and their Blends

Sample	PV	TV	BV	FV	SV	Pt (min)	PT (°C)
100BBS	176.96± 0.01^a	148.25±0.03^a	28.71±0.00^a	400.38±0.02^a	252.13±0.04^a	6.1±0.01^a	82.45±0.05^a
70BBS/30CYS	503.25±0.03^b	237.59±0.01^b	265.67±0.02^b	366.59±0.00^b	129.00±0.02b	4.70±0.00^b	74.78±0.02^b
50BBS/50CYS	506.08± 0.04^c	262.29±0.02^c	243.79±0.01^c	423.83±0.03^c	161.54±0.00c	4.64±0.01^b	86.43±0.00^c
30BBS/70CYS	507.09± 0.02^d	219.71±0.04^d	287.38±0.04^d	340.50±0.01^d	120.80±0.03d	4.47±0.02^c	73.15±0.03^d
100CYS	480.63± 0.00^e	245.75±0.01^e	234.88±0.03^e	368.38±0.04^e	123.75±0.01e	4.30±0.00^d	82.53±0.01^e

Different superscripts along columns indicate statistically significant difference (P<0.05). The viscosities are expressed in rapid viscosity unit (RVU).

4. Conclusions

This work is about a search for a starch blend from bambara groundnut starch and cocoyam starch with the appropriate physicochemical properties for potential industrial applications. 30BBS/70CYS and 50BBS/50CYS blends represent such possibilities. The 30BBS/70CYS blend with the highest peak, breakdown and least setback viscosity values could be potentially utilized in refrigerated foods and pharmaceutical as disintegrants. In contrast, the 50BBS/50CYS blend with the lowest breakdown viscosity value can found application in sterilization operations in the food industry, especially in canned foods. Furthermore, the 70BBS/30CYS blend with the highest amylose concentration will be preferred in the making of noodles. These findings indicate that blending native starches from different botanical sources improves their physicochemical properties for appropriate industrial utilization without the need for costly starch modification.

Conflict of Interest

The authors have declared no conflict of interest.

References

[1] Jobling, S., "Improving starch for food and industrial applications," Current Opinion in Plant Biology, 7. 210-218. 2004.

[2] Ashogbon, A. O., "Physicochemical properties of bambara groundnut starch and cassava cassava starch blends," African Journal Food Science, 8(6): 322-329. 2014a.

[3] Ashogbon, A. O., and Akintayo, E. T., "Recent trend in the physical and chemical modification of starches from different botanical sources: A review," Starch/Starke, 66. 41-57. 2014.

[4] Bello-Perez, L. A., Meza-Leon, K., Contreras-Ramos, S., and Paredes-Lopez, O., "Functi-onal properties of Corn, banana and potato starch blends," Acta Cientifica Venezola-na, 52. 62-67. 2001.

[5] Zhang, Y., Gu, Z., Hong, Y., Li, Z., and Cheng, L., "Pasting and rheological properties of potato starch and maize starch mixtures," Starch/Starke, 63(1). 11-16. 2011.

[6] Santelia, D., and Zeeman, S. C., "Progress in Arabidopsis starch research and potential biotechnological applications," Current Opinion in Biotechnology, 22. 271-280. 2011.

[7] Novelo-Cen, L., and Betancur-Ancona, D., "Chemical and functional properties of *Phaseolus lunatus* and *Manihot esculenta* starch blends," Starch/Starke, 57. 431-441. 2005.

[8] Ashogbon, A. O., "Chemical and functional properties of cocoyam starch and wheat starch blends," International Journal of Biotechnology and Food Science, 2(5). 94-101. 2014b.

[9] Zhu, F., and Cooke, H., "Gelatinization, pasting and gelling properties of sweet potato and wheat starch blends," Cereal Chemistry, 88(3). 302-309. 2011.

[10] Dang, J. M. C., and Copeland, L., "Studies of the fracture surface of rice grains using environmental scanning electron microscopy," Journal of Science and Food Agriculture, 84. 707-713. 2004.

[11] Wani, A. A., Singh, P., Shah, M. A., Schweiggert-Weisz, U., Gul, K., and Wani, I., "Rice starch diversity: Effects on structural, morphological, thermal, and physicochemical properties-A review," Comprehensive Reviews in Food Science and Food Safety, 11. 417-436. 2012.

[12] Puncha-arnon, S., Pathipanawat, W., Puttanlek, C., Rungsardthong, V., and Uttapap, D., "Effects of relative granule size and gelatinization temperature on paste and gel properties of starch blends," Food Research International, 41(5). 552-561. 2008.

[13] Yao, Y., Zhang, J., and Ding, X., "Retrogradation of starch mixtures containing rice Starch," Journal of Food Science, 68(1). 260-265. 2003.

[14] Waterschoot, J., Gomand, S. V., Fierens E, and Delcour, J. A., "Starch blends and their physicochemical properties," Starch/Starke, 67. 1-13. 2015.

[15] Debet, M. R., and Gidley, M. J., "Three classes of starch granule swelling: influence of surface proteins and lipids. Carbohydrate Polymer, 60. 139-154. 2006.

[16] Perez, S., and Bertoft, E., "The molecular structure of starch components and their contribution to the architecture of starch granules. A comprehensive review," Starch/Starke 62: 389-420. 2010.

[17] Sirivongpaisal, P., "Structure and functional properties of starch and flour of bambara Groundnut," Songklanakarin Journal Science and Technology, 30(1). 51-56. 2008.

[18] Jennings, D. L., "Starch crops. In: CRC Handbook of plant science in Agriculture. Vol. II," (Eds. B. R. Christe). CRC Press, Inc. Boca Raton, Florida, USA. PP. 37-143. 1987.

[19] Lawal, O. S., "Composition, physicochemical properties and retrogradation characteristi cs of native, oxidized, acetylated and acid-thinned new cocoyam (*Xanthosoma sagittifolium*) starch," Food Chemistry, 87. 205-218. 2004.

[20] Nwokocha, L. M., Aviera, N. A., Senan, C., and Williams, P. A., "A comparative study of some properties of cassava and cocoyam starches," Carbohydrate Polymer, 76. 362-367. 2009.

[21] Adebowale, K. O., and Lawal, O. S., "Effect of annealing and heat moisture conditioning on the physicochemical characteristics of bambara groundnut (*Voandzeia subterranean*) starch and flour," Food Chemistry, 78. 305-311. 2002.

[22] Juliano, B. O., "Criteria and test for rice grain qualities. Rice Science and Technology," St. Paul, MN: AACC, pp. 443-524. 1985.

[23] American Association of Cereal Chemists. Approved of the AACC, 10th edition. The Association: St. Paul, MN, 2000.

[24] Leach, H. W., McCowen, L. D., and Schoch, T. J., "Structure of the starch granule. 1. Swelling and solubility patterns of various starches," Cereal Chemistry, 36. 534-544. 1959.

[25] Wang, J. C., and Kinsella, J. E., "Functional properties of novel proteins: alfalfa leaf protein," Journal Food Science, 41. 286-289. 1976.

[26] Ashogbon, A. O., and Akintayo, E. T., "Morphological, functional and pasting propertties of starches separated from rice cultivars grown in Nigeria," International Food Research Journal, 19(1). 665-671. 2012.

[27] Kulkarni, K. D., Kulkarni, D. N., and Ingle, U. M., "Sorghum malt-based weaning formulations: preparation functional properties and nutritive value. Food Nutrition Bulletin, 13(4). 322-327. 1991.

[28] Akanbi, T. O., Nazamid, S., and Adebowale, A. A., "Functional and pasting properties of a tropical breadfruit (*Artocarpus altilis*) starch from Ile-Ife, Osun State, Nigeria," International Food Research Journal, 16. 151-157. 2009.

[29] Benesi, I. R., "Characterization of Malawian cassava germplasm for diversity, starch extraction and its native and modified properties. Bloemfontain: PhD Thesis, Department of Plant Science, University of the Free State, South Africa. 2005.

[30] Juliano, B. O., and Villareal, C.P., "Grain quality evaluation of world rices," International Rice Research Institution, Los Banos , Philippines. 1993.

[31] Bird, A. R., Brown, I. L., and Topping, D. L., "Starches, resistant starches, the gut microflora and human health," Current Issues of Interest in Microbiology, 1. 25-37. 2000.

[32] Abu, J. O., Enyinnaya, C. C., James, S., and Okeleke E., "Quality evaluation of stiff porridges prepared from Irish potato (*Solanum tuberosum*) and pigeon pea (*Cajanus cajan*) starch ble-nds," Journal Food Science and Technology, 49(3). 394-355. 2012.

[33] Morrison, W. R., Tester, R. F., Snape, C. E., Law, R., and Gidley, M. J., "Swelling and gelatinization of cereal starches. IV. Some effects of lipid-complexed amylose and free amylose in waxy and normal barley starches," Cereal Chemistry, 90(4). 385-391. 1993.

[34] Pomeranz, Y., "Functional Properties of Food Components," Academic Press, New York, pp. 24-77. 1991.

[35] Otegbayo, B., Oguniyan, D., and Akinwumi O., "Physicochemical and functional characterization of yam starch for potential industrial applications," Starch/Starke, 65. 1-16. 2013.

[36] Zaidul, I. S. M., Yamauchi, H., Kim, S. J., Hashimoto, N., Noda, T., "RVA study of mixtures of wheat flour and potato starches with different phosphorus content," Food Chemistry, 102. 1105-1111. 2007.

[37] Adebowale, K. O., Olu-Owolabi, B. I., Olayinka, O. O., and Lawal, O. S., "Effect of heat Moisture treatment and annealing on physicochemical properties of red sorghum starch," African Journal of Biotechnology, 4(9). 928-933. 2005.

[38] Emmambux, M. N. and Taylor, J. R. N., "Morphology, physical, chemical and functional properties of starches from cereals, legumes and tubers cultivated in Africa: A review," Starch/Starke, 65. 715-729. 2013.

[39] Moorthy, S. N., "Physicochemical and functional properties of tropical tuber starches: A review," Starke/Starch, 54. 559-592. 2002.

[40] Numfor, F. A., Walter, W. M., and Schwarty, S. J., "Effect of emulsifiers on the physical Properties of native and fermented cassava starches," Journal of Agriculture and Food Chemistry, 44. 2595-2599. 1996.