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Physicochemical properties of bambarra groundnut starch and cassava starch blends

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The physicochemical properties of bambarra groundnut starch (BBS) and cassava starch (CS) were blended at different ratios (70BBS/30CS, 50BBS/50CS and 30BBS/70CS) and investigated. The minor components (lipids and proteins) of the starch granules were lowest for CS and highest for the blended starches. Apparent amylose (AAM) content of the starch blends was additive of their individual components. CS had the lowest AAM value (20.20%) and the 70BBS/30CS blend the highest value (41.53%). Swelling power (SP) was highest for CS at higher temperature and the SP of the blended starches was additive at 75 and 95°C. The solubility of the blended starches was additive at lower temperatures (55 and 65°C). The bulk density and dispersibility were non-additive and pH of the blends was additive of their individual components. With the exception of peak and breakdown viscosities, all the pasting parameters of the blends were additive of their individual components. CS had the highest peak (553.75 RVU) and breakdown (391.17 RVU) viscosities, but the lowest trough (162.58 RVU), final (274.63 RVU) and setback (112.05 RVU) viscosities. The 50BBS/50CS blend had the lowest breakdown viscosity (149.59 RVU) for thermal stability. Overall results indicate that blending native starches from different botanical sources improves their properties.

Key words: Bambara groundnut starch, wheat starch, control starches, pasting, dispersibility.

INTRODUCTION

The different botanical sources of starches are cereal, legume, root and tuber and unripe fruit (Ashogbon and Akintayo, 2014). The uniqueness and individuality of starches from different botanical origin had been 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 germination and growth had also affected the uniqueness of the starches. It is these differences in its entirety that accounted for the different applications of these starches in the food and non-food industries.

The industrial utilization of native starches is limited due to their inherent imperfect nature, such as water insolubility and their tendency to easily retrograde and

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undergo syneresis and therefore form unstable pastes and gels (Ashogbon and Akintayo, 2014). This deficiency of native starches is mitigated by physical and chemical modification, enzymatic and biotechnological modification, or their combinations. Furthermore, most native starches are restricted in their applications due to their instability under various temperatures, shears and pH conditions. With chemical modification in food, the introduction of chemicals (e.g. epichlorohydrin) that had tend out latter to be carcinogenic and banned is a problem (Ashogbon and Akintayo, 2014). Nowadays, market trends are towards natural food components, avoiding as much as possible any chemical treatments (Zhang et al., 2011).

There is therefore a need for an alternative. That alternative is the blending of native starches from different botanical sources. Blending of starches is safe, cheap and does not involve the introduction of chemicals or biological agents into the starches. Blending of starches is not entirely new. Potato starch had been previously blended with waxy maize starch (Park et al., 2009); waxy rice and corn starches blended with non-waxy corn, tapioca and potato starches (Lin et al., 2013); lima bean starch blended with cassava starch (Novelo-Cen and Betancur-Ancona, 2005); potato starch blended with maize starch (Zhang et al., 2011) and pigeon pea starch blended with rice starch (Baljeet et al., 2011).

Amylose (AM) and amylopectin (AP) are the two major components of starch granules. They are the main determinants of swelling power, solubility, pasting and gelatinization of the starches. The anti-swelling and anti-solubility role of the minor components (protein and lipids) had also been widely reported in the literature. The functionality of the two main components of starch differs significantly. AM has a high tendency to retrograde and produce tough gels and strong films (Ashogbon and Akintayo, 2014). In contrast, AP, when dispersed in water, is more stable and produces soft gels and weak films (Perez and Bertoft, 2010). According to Waterschoot et al. (2014), tremendous disparity in granule size and swelling power (SP) between blended starches lend to uneven moisture distribution during heating of starch suspension. The consequence is that the behavior of the mixture differ from what would be expected based on the behavior of the individual starches.

Bambarra groundnut (*Voandzeia substerranean*) like sword bean and pigeon pea is an underutilized legume. It is a drought tolerant and easy-to-cultivate legume (Sirivongpaisal, 2008). Bambarra groundnut starch (BBS) had been extensively studied (Sirivongpaisal, 2008). Except cassava (*Manihot esculenta*) and to a smaller extent sweet potato, starch from yam and other tuber crops have not been exploited for industrial applications because of difficulty in the extraction of pure starches (Otegbayo et al., 2013). Cassava starch (CS) had also been extensively studied (Ladeira et al., 2013).

There is paucity of work on the blending of BBS with CS, especially in the areas of bulk density, dispersibility, pH and potential applications of the blended starches. Therefore, the aim of the work is to study the physic-chemical properties of the control starches and their blends. Furthermore, the properties of the control starches will be compared to that of the blended starches and their potential applications emphasized.

MATERIALS AND METHODS

Bambarra groundnut seeds and cassava roots were purchased from a local market at Ikare, Ondo State, Nigeria. The seeds were screened to remove the defective ones. The roots were peeled and those with dark spots were eliminated. All other chemicals were of analytical reagent grade.

Starch isolation

Manually dehusked and dried bambarra groundnut was ground to a powdery form in a laboratory grinder. Starch was isolated from the powdery form by a procedure of Adebowale and Lawal (2002) as modified by Sirivongpaisal (2008). Isolation of native cassava starch was carried out using a method described by Benesi (2005).

Preparation of starch blends

Starch blends were prepared from the isolated control starches (BBS and CS) in three proportions (70BBS/30CS, 50BBS/50CS and 30BBS/70CS) (%, w/w). The starches were sieved and mixed in a laboratory blender.

Gross chemical compositions of control starches and their blends

Apparent amylose (AAM) content (%) was determined by colorimetric iodine assay index method, according to Juliano (1985). The moisture, protein, lipid and ash content in the starch samples were determined using procedure of AACC method (2000).

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. (1959).

Bulk density

This was determined by the method of Wang and Kinsella (1976) as recently modified by Ashogbon and Akintayo (2012).

Dispersibility

This was determined by the method described by Kulkarni et al. (1991) as modified by Akanbi et al. (2009).

Table 1. Gross chemical composition of the control starches and their blends.

Characteristic (%)	100BBS	70BBS/30CS	50BBS/50CS	30BBS/70CS	100CS
Moisture	11.00±0.02^{a}	11.52±0.10^{b}	11.95±0.20^{c}	12.36±0.01^{d}	12.65±0.30^{e}
Ash	0.05±0.02^{a}	0.30±0.01^{b}	0.21±0.10^{c}	0.12±0.40^{d}	0.20±0.30^{c}
Lipid	0.31±002^{a}	0.38±0.10^{b}	0.49±0.05^{c}	0.33±0.00^{a}	0.10±0.03^{d}
Protein	0.18±0.01^{a}	1.80±0.30^{b}	0.80±0.02^{c}	0.18±0.02^{a}	0.10±0.10^{d}
Amylose	37.31±0.10^{a}	41.53±0.02^{b}	36.26±0.01^{c}	33.23±0.10^{d}	20.20±0.01^{e}
Amylopectin	62.69±0.10^{a}	58.47±0.40^{b}	63.74±0.30^{c}	66.77±0.20^{d}	79.80±0.30^{e}
*AM/AP ratio	0.60±0.30^{a}	0.71±0.40^{b}	0.57±0.30^{c}	0.50±0.10^{d}	0.25±0.20^{e}

Uncommon superscripts along rows indicate statistically significant difference ($P<0.05$); *Amylose to amylopectin ratio.

pH

Starch samples (5 g) were weighed in triplicate into a beaker, mixed with 20 mL of distilled water. The resulting suspension was stirred for 5 min and left to settle for 10 min. The pH of the water phase was measured using a calibrated pH meter (Benesi, 2005).

Pasting properties

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

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.

RESULTS AND DISCUSSION

Gross chemical composition of starches and their blends

The gross chemical composition of BBS and CS and their blends are presented in Table 1. The low concentration of the minor components (ash, lipids and proteins) in the starch granules are indication of the purity of the isolated starches and their blends. The moisture content of the starches and their mixtures vary significantly ($P<0.05$), but fall within the commercially accepted range. The moisture content of the BBS was lower than that of CS.

Expectedly, as the proportion of BBS in the blends was increased, the moisture content decreased and vice versa for CS. The moisture content plays an important role in the perish-ability and rheological properties of starches.

The minor components of native starches generally vary according to their botanical origin. The legume starch (BBS) contains more lipids and proteins than the root starch (CS) (Table 1). The lipid content of CS was within the range reported for most root and tuber starches (0.10-1.14%) (Hoover, 2001), but the protein content was lower than that reported by Elevina et al. (2005). The lipid content of the blends was higher than that of the control starches. Furthermore, the protein content of the BBS and the blends were higher than that of the CS. The minor components (mainly lipids and proteins) are important because of their anti-swelling effect and influence on the pasting parameters.

The characteristic high apparent amylose (AAM) content of the legume starches was reflected in the BBS. BBS contained a higher proportion of AAM (37.31%) than CS (20.20%). Legume starches generally have higher AM content than non-legume starches (Hoover and Manuel, 1995; Gernat et al., 1990). Higher and lower values of AAM in legumes than that of BBS were widely reported in the literature. For example, Ratnayake et al. (2002) reported AAM values of 60-76% for wrinkled pea starches. In contrast, lower AAM values of 36.0, 34.4-35.5, 32.9-35.6 and 31.7-33.8% were indicated for kidney bean, chickpea, blackgram and mung bean starches, respectively (Chung et al., 2008; Nishinari, 2008). The AAM content of CS was within the range indicated for other root starches, like potato (20.0%) (Moorthy, 2002). Expectedly, as the proportion of BBS in the blends increased, the AAM content also increased and vice versa for CS. Higher AM content starches had been associated with the formation of harder and firmer gels (Novelo-Cen and Betancur-Ancona, 2005). Therefore, BBS and the blends (70BBS/30CS; 50BBS/50CS) with higher AAM contents will form harder gels when are dried as compared to the other starches.

The amylose content of starches is important, as it

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

Sample	Bulk density (g/mL)	Dispersibility (%)	pH
BBS	0.86±0.03^{a}	86.00±0.04^{a}	7.38±0.04^{a}
70BBS/30CS	0.88±0.01^{a}	86.02±0.05^{a}	7.32±0.01^{b}
50BBS/50CS	0.83±0.02^{a}	83.00±0.03^{b}	7.29±0.03^{b}
30BBS/70CS	0.87±0.01^{a}	87.00±0.06^{c}	7.21±0.05^{c}
CS	0.72±0.04^{b}	85.00±0.07^{d}	7.03±0.02^{d}

Uncommon superscript along columns indicate statistically significant difference ($P< 0.05$).

affects pasting, gelatinization, retrogradation, swelling power and enzymatic vulnerability of starches (Gerard et al., 2001; You and Izidorczyk, 2002). Higher AAM content of BBS and the blends with high proportion of BBS are desired in the manufacture of noodles. The association of high AP starches with high SP and high AM starches with high solubility had been widely reported in starch literature. CS had the highest AP value and as the ratio of CS in the blends was increased, the AP content increased and vice versa for BBS (Table 1). Therefore, CS and the blends with higher proportion of CS are expected to have higher swelling power and viscosity (Novelo-Cen and Betancur-Ancona, 2005). With the exception of CS, the AM/AP ratio of analyzed starches and their mixtures were >5, an indication of low content of AP in these starches (Jimenez-Hermandez et al., 2007).

Functional properties of BBS, CS and their blends

There is paucity of works in the literature on bulk density, dispersibility and pH of blended starches. The values of bulk densities, dispersibility and pH of the BBS, CS and their blends are presented in Table 2. There was no obvious trend (non-additive effect) in the bulk densities of the starch blends. The bulk density ranged from 0.83 to 0.88 g/mL. CS had the lowest bulk density and 70BBS/30CS blend the highest. Bulk density is a measure of the degree of coarseness of the starch sample. This signifies that the particles of the 70BBS/30CS mixture were the coarsest of the starch particles. It also implies that CS (0.72 g/mL) and the 50BBS/50CS blend (0.83 g/mL) were very smooth and could be useful in making face powder in the cosmetic industry.

The non-additive tendency of the starch blends in respect of dispersibility was obvious (Table 2). Dispersibility is a measure of the degree of reconstitution of starch flour in water. According to Kulkarni et al. (1991), the higher the dispersibility, the better the flour reconstitutes in water. There were significant differences ($P<0.05$) in dispersibility values of the control starches and their blends. Since the higher the dispersibility the better the starch flour reconstitutes, the value obtained for the 30BBS/70CS mixture was better than that of the other starches. The dispersibility value previously reported for rice starch (87.01%) (Ashogbon and Akintayo, 2012) was comparable to that of 30BBS/70CS blend in this study. Futhermore, all the dispersibility values (Table 2) observed in the present study were better than the 40.67% obtained by Akanbi et al. (2009) for breadfruit starch.

The pH values of control starches and their blends were not significantly different and slightly alkaline. Expectedly, as the proportion of the BBS in the starch blends was increased, the pH increased infinitesimally. pH is an important property in starch industrial applications, being generally used to indicate the acidic or alkaline properties of liquid media. Lower pH values (3.71-3.99) had been reported by Ahmed et al. (2007) for some cultivar of rice starches.

AP had being widely reported to be responsible for SP and AM for solubility. The significance and influences of proteins, lipids, native and induced amylose-lipid complexes on these two parameters were also emphasized. The effects of temperature on SP and WSI are presented in Figures 1 and 2, respectively. As the temperature was raised, the SP increase for CS at all temperatures investigated. The effects of temperature on BBS and other starch mixtures differ with respect to SP. The SP and WSI increased as the temperature was raised up to 65°C and subsequently decreased to 75°C (except for 30BBS/70CS) before astronomically increasing as the temperature was further increased. This decrease in SP and WSI at 75°C is likely due to the effects of residual proteins, lipids, native and temperature-induced complexes (Morrison et al., 1993). More amylose-lipid complexes might have been formed at 75°C, therefore swelling was inhibited and exudation of AM from starch granules that enhance solubility was also limited. Furthermore, denatured residual protein could have been deposited on the surface of the granules and further inhibited swelling and solubility (Olkku and Rha, 1978). These tendencies of complex formation and

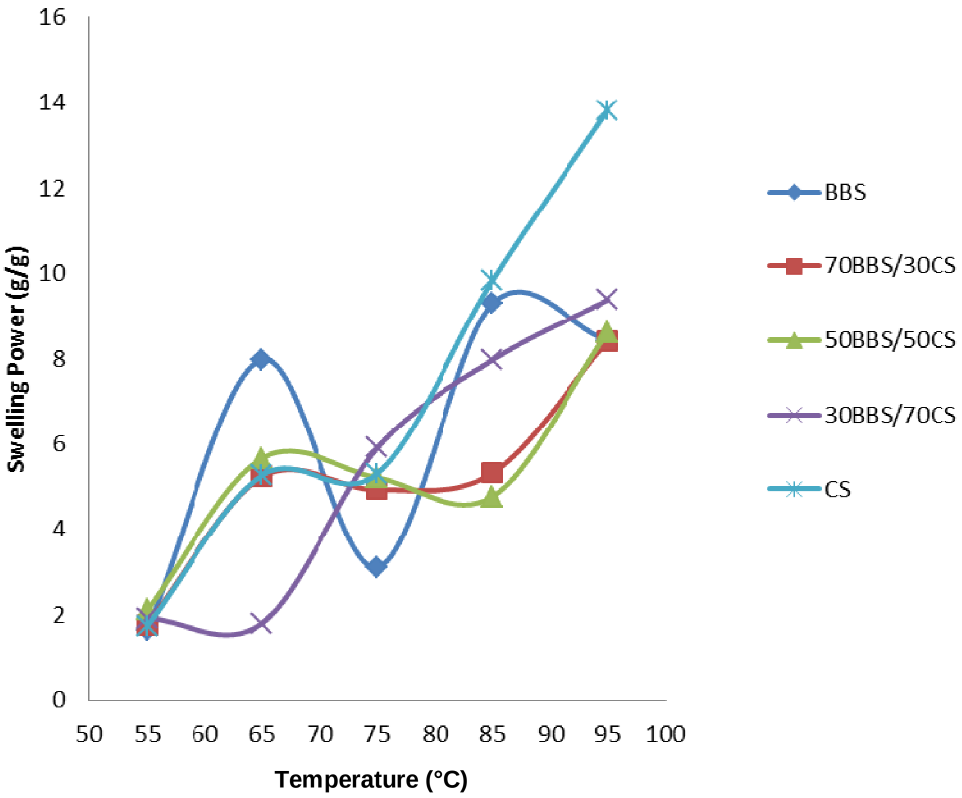

Figure 1. Effect of temperature on swelling power.

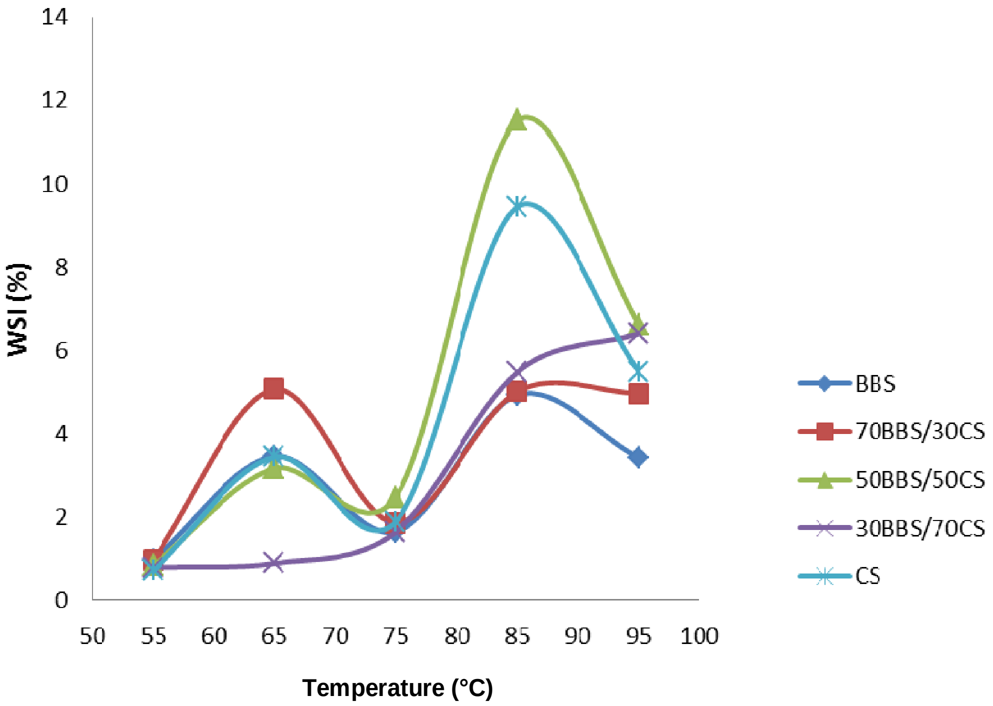

Figure 2. Effect of temperature on WSI.

Table 3. Pasting properties of control starches and their blends.

*P (RVU)	100BBS	70BBS/30CS	50BBS/50CS	30BBS/70CS	100CS
PV	432.38±0.20^a	416.21±0.30^b	362.34±0.20^c	360.38±0.20^d	553.75±0.10^e
TV	247.04±0.20^a	246.67±0.10^b	212.75±0.20^c	186.30±0.10^d	162.58±0.10^e
BV	185.34±0.30^a	169.54±0.20^b	149.59±0.20^c	174.08±0.30^d	391.17±0.10^e
FV	401.34±0.10^a	395.05±0.30^b	345.13±0.10^c	299.21±0.20^d	274.3±0.20^e
SV	154.29±0.20^a	148.38±0.10^b	132.38±0.10^c	112.92±0.20^d	112.05±0.30^e
Pt (Min)	4.73±0.30^a	5.24±0.20^b	5.33±0.10^c	4.90±0.10^d	3.34±0.20^e
PT (^{0}C)	84.13±0.20^a	95.25±0.10^b	94.95±0.10^c	70.28±0.20^d	69.98±0.30^e

Uncommon superscripts along rows indicate statistically significant difference ($P < 0.05$). *P stands for parameters.

protein deposition on the starch granules seem to have being disrupted at 85 and 95°C as the SP and solubility increased further at these temperatures. At 95°C, CS had the highest swelling power (due to possession of highest starch blends plummeted at 95°C, the SP and WSI increased. Highest SP of CS at 95°C may also be due to its weak internal structure (Pomeranz, 1991).

Pasting properties

The pasting parameters of the control starches (BBS and CS) and their blends are summarized in Table 3. There is always a direct proportionality relationship between peak viscosity (PV), swelling power (SP) and breakdown viscosity (BV). Higher amylopectin (AP) content is also associated with higher SP. CS with the highest AP content had the highest PV, BV and SP. It indicated that the CS easily swells and possessed weak intra-molecular and intermolecular forces between the polymeric molecules (mainly AM and AP) within its granules. Unexpectedly, the higher the proportion of CS in the starch blends, the lower the PV. Other anti-swelling minor components (lipids and protein) might be at play. The presence of native amylose-lipid complex, free AM serving as anti-swelling components and the formation of temperature-induced amylose-lipid complexes could be contributing factors.

Furthermore, denatured residual protein could adhere to the surface of starch granules and inhibit swelling (Olkku and Rha, 1978). CS due its higher PV, BV and weak internal structure might not be able to withstand high temperature and shear stress.

In terms of PV, the next higher value to CS is the BBS. In contrast to CS, the higher the proportion of BBS in the starch blends, the higher the PV. The starch blend (50BBS/50CS) will be able to with stand heat and shear stress than the other blends, including CS and BBS, because it possessed the lowest BV. Furthermore, the starch mixture (50BBS/50CS) due to its high thermal stability might be used in products requiring sterilization.

AP content). BBS and the blend (70BBS/30CS) have the lowest SP at 95°C because they have higher AM as compared to others. With the exception of the blend (50BBS/50CS) for WSI, as the proportion of BBS in the High values of BV and PV are manifested in high SP of the starch granules.

The characteristic high tendency of the legume starches to easily undergo retrogradation and syneresis was observed in BBS. This idiosyncrasy is due to their high AAM content with its linearity and associated randomly limited branching (Takeda et al., 1993). The higher the proportion of BBS in the starch blends, the higher the SV in the starch mixtures. In contrast, the higher the proportion of CS in the starch blends, the lower the SV values and also the lower the AAM content (Table 1). CS and 30BBS/70CS blend had the least tendency to retrograde. They can be used for making desserts, cake filling, sauces, soups and breads due to their low syneresis (Novelo-cen and Betancur-Ancona, 2005). The high AAM content and retrogradation of the legume starch (BBS) is desired in starches with potential in gluten-free pasta and noodles (Emmambux and Taylor, 2013). The high retrogradation of BBS (Table 3) due to its high AAM content is in absolute agreement with works in the literature (Gudmundsson, 1994) that constantly link high AAM concentration with the tendencies of syneresis, especially in legume starches (Ashogbon et al., 2011).

BBS showed the highest FV value and CS the least value. As the proportion of BBS in the starch mixtures was reduced, their FV values also diminished. This is to be expected, as a high AAM content is associated with the development of high FV values in starches (Miles et al., 1985). It was also observed that as the AAM content decreases, FV values also plummeted. These higher FV values exhibited by BBS and the blend (70BBS/30CS) indicate that their paste could more readily form a rigid gel. High FV starches are desired in many food products, especially soups, sauces and dressings; they can also be utilized in wet stage production of paper and the textile industry where high viscosity is needed (Moorthy, 2002). In contrast, the low FV starches, such as CS and

30BBS/70CS blend are necessary in the dry stage making of paper (Moorthy, 2002). The rather higher PV and FV values of the under-utilized legume (BBS) suggest that it could be utilized as thickening agent in food dispersions, where high viscosity is required (Jimenez-Hernandez et al., 2007). The high values of FV and SV are due to the presence of high concentration of AAM contents in the starches. This is true for BBS in this study. On the other hand, the higher PV and BV values of the CS, as compared to that of BBS and the other starch mixtures could be attributed to its higher AP content.

CS showed a lower PT as compared to that of BBS. As the ratio of the BBS in the starch mixtures was increased, their PT values also increased and vice versa for CS. This is an additive parameter. CS with the least PT (69.98°C) (Table 3) began to form paste faster than BBS and the blends. BBS had the highest TV value and CS the lowest, the TV values of the starch blends are in-between the individual starches. The importance of the TV is that it helps in the calculation of BV and SV.

Conclusions

With regards to the characteristic of the legumes, the bambarra groundnut starch (BBS) had a higher apparent amylose (AAM) content than the cassava starch (CS). As the proportion of BBS in the blends was increased, the AAM content also increased. Therefore, AAM content of the blends was additive of their individual components. The higher AAM content of the 70BBS/30CS blend was associated with the formation of hard and firm gels. While the bulk density and dispersibility were non-additive, in contrast, the pH of the starch blend was additive of their individual components. The fluctuation in swelling power (SP) and solubility of the blended starches as the temperature was increased, could be attributed to the differences in the quantity of anti-swelling and anti-solubility minor components (mainly lipids and proteins). Furthermore, the amylose and the amylose-lipid complexes inhibit SP. The SP of the blends was additive at 75 and 95°C, furthermore, the solubility was also additive at 55 and 65°C. At the other temperatures, the SP and solubility of the starch blends were non-additive of their individual components. The blend (50BBS/50CS) had the lowest breakdown viscosity and could be very useful in products requiring sterilization where high thermal stability is needed. The 30BBS/70CS blend with a low tendency to retrograde is significant in the food industry, especially in the making of soups, bread and desserts. Blending of native starches will be able to increase the usefulness of the under-utilized BBS in the food industry, by reducing its high retrogradation. Some of pasting parameters blends were additive (TV, FV, SV and PT) and others were non-additive (PV, BV and Pt) of their individual components. This study shows that the blending of native starches from different botanical sources improves their properties.

Conflict of interests

The authors did not declare any conflict of interests.

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