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Research Paper

Chemical and functional properties of cocoyam starch and wheat starch blends

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Abstract. Chemical and functional characteristics were determined for cocoyam starch (100CYS) and wheat starch (100WS) and blends of these two starches at different proportions (70CYS/30WS, 50CYS/50WS and 30CYS/70WS) (%, w/w). The minor components of starch were higher in the WS when compared to 100CYS and the blends. The lowest apparent amylose (AAM) content was in 100CYS (22.60%) and the starch blends had higher AAM values than the control starches. The swelling power of the blends was additive of their individual components at 55, 75 and 95°C but non-additive at 65 and 85°C. The solubility of the blends was non-additive except at 75°C. Bulk density (BD), dispersibility (DB) and pH of the blends were additive of their individual components. BD was highest for the 70CYS/30WS blend (0.87 g/cm^3) and lowest for 100WS (0.67 g/cm^3). In contrast, DB was highest for 100WS (90.00%) and lowest for the 100CYS (83.00%). With the exception of pasting temperature and peak time, all the other pasting parameters of the blends were non-additive of their individual components. The 50CYS/50WS blend had the highest peak, trough, breakdown and final viscosities. In contrast, 100WS had the lowest peak (254.90 RVU), breakdown (52.90 RVU) and setback (97.00 RVU) viscosities. Overall results indicate that new chemical and functional properties can be generated by blending native starches of different plant origin.

Keywords: Cocoyam starch, wheat starch, control starch, blends.

INTRODUCTION

Physical, chemical, enzymatic and biotechnological modification of native starches from different botanical origin had been in existence for some time in order to ameliorate the deficiency inherent in them. Native starches are limited in industrial applications due to their insolubility and proneness to retrogradation. Furthermore, instability of pastes and gels under various temperatures, shears and pH conditions also restricted the commercial applications of native starches (Ashogbon and Akintayo, 2013).

Blending of starches from different botanical origin has come as a good alternative. It is safe, cheap and does not involve the addition of chemicals or biological agents into the starches. Blending of starches is not an entirely new process. Sweet potato starch had been previously blended with wheat starch (Zhu and Corke, 2011); rice starch blended with pigeon pea starch (Yadav et al., 2011); Irish potato starch blended with pigeon pea starch (Abu et al., 2012) and potato starch blended with maize starch (Zhang 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 (proteins and lipids) had also been widely reported in the literature (Debet and Gidley, 2006). 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, 2013). 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 leads to uneven moisture distribution during heating of starch suspension. The consequence is that the behavior of the mixture differs from what would be expected based on the behavior of the individual starches.

Cocoyam (*Xanthosoma sagittifolium*) belongs to the family Aracea and it is the sixth most important root and tuber crops world-wide (Jennings, 1987). 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 (Lawal, 2004). It is a highly under-utilized tuber when compared to cassava and potato in terms of industrial applications. Cocoyam starch (100CYS) had been extensively studied (Lawal, 2004).

The uniqueness of wheat (*Triticuma estivum* L.) lies in its two principal macromolecular components (gluten and starch) (Maningat and Seib, 2010). The dough-forming ability of wheat flours to make bread is due to the gluten, which is unmatched by any other proteins of plant, animal, or microbial origin (Gianibelli et al., 2001). Wheat starch (100WS) had also been extensively studied (Kim et al., 2003). There is paucity of work on the blending of 100CYS and 100WS, especially in the areas of bulk density, dispersibility, pH and potential applications of the blended starches. Therefore, the aim of this work is to study the chemical, functional and pasting properties of the control starches and their blends. Furthermore, the properties of the control starches will be compared to that of the blended starches (in different ratio) and their potential applications emphasized.

MATERIALS AND METHODS

Materials

New cocoyam tubers and wheat grains were purchased from a local market at Ikare, Ondo State, Nigeria. The defective tubers were separated and discarded. The grains were screened and sieved to remove defective ones and eliminate dust particles. Chemicals utilized were of analytical reagent grade and were purchased at Finlab, Ikeja, Lagos.

Starch isolation

Starch was isolated from new cocoyam tubers by a method previously described by Lawal (2004). Isolation of native wheat starch was carried out by a method previously reported by Finnie et al. (2010). Isolated starches were called 100CYS and 100WS (%, w/w).

Preparation of starch blends

Starch blends were prepared from the isolated starches (100CYS and 100WS) in three proportions (70CYS/30WS, 50CYS/50WS and 30CYS/70WS) (%, 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 of 55 to 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).

pH

Starch samples (5 g) 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 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 ViscoAnalyzer (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),

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

C (%)	100CYS	70CYS/30WS	50CYS/50WS	30CYS/70W	100WS
Moisture	12.62±0.02[a]	11.70±0.10[b]	11.85±0.20[c]	12.65±0.01[a]	10.35±0.30[d]
Ash	0.15±0.02[a]	0.30±0.10[b]	0.22±0.10[c]	0.12±0.40[a]	0.40±0.30[d]
Lipid	0.08±0.02[a]	0.45±0.10[b]	0.06±0.05[a]	0.40±0.00[b]	0.70±0.03[d]
Protein	0.09±0.10[a]	0.18±0.30[b]	0.07±0.02[a]	0.18±0.20[b]	0.45±0.10[c]
AM	22.60±0.10[a]	38.57±0.40[b]	30.99±0.30[c]	44.00±0.20[d]	27.69±0.30[e]
AP	77.40±0.10[a]	61.43±0.02[b]	69.01±0.01[c]	56.00±0.10[d]	72.31±0.01[e]
*AM/AP	0.29±0.30[a]	0.63±0.40[b]	0.45±0.30[c]	0.79±0.10[d]	0.38±0.20[e]

Uncommon superscripts along rows indicate statistically significant difference (P < 0.05).*Amylose to amylopectin ratio. C stands for composition.

final viscosity (FV), and peak time (Pt). Breakdown viscosity (BV) was calculated as the difference between PV minus MV, while setback viscosity (SV) was determined as the FV minus MV. All determinations were performed in triplicate and expressed in rapid viscosity units (RVU).

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 control starches and their blends

The gross chemical composition of the control starches and their blends are summarized in Table 1. The moisture content of the control starches and their blends fall within the commercially accepted range. This accepted range concurs with the established goal necessary to reach a stable shelf life (less than 14.00% moisture content; Juliano and Villareal, 1993). The moisture content plays an important role in the flow and other rheological properties of the starches. The moisture content of 100CYS was higher than that of 100WS. It was observed in Table 1 that 100WS for the manifestation of higher moisture content in the blends than 100CYS.

The low concentration of the minor constituents in the control starches and their blends was an indication of their purity. 100WS had a higher concentration of the minor components (ash, protein and lipid) than 100CYS. This higher concentration ofminor components (especially lipids and proteins) will be manifested in restricted swelling and pasting parameters.

The protein and lipid content of 100WS fall within the range previously reported (Vansteelandt and Delcour, 1999; Swinkels, 1985). Like in all root and tuber starches, the minor components of the 100CYS were infinitesimal and believed to have no effect on SP and the pasting parameters. The protein and lipid content of 100CYS fall within the range reported by Lawal (2004). The 70CYS/30WS blend had a higher concentration of the minor components of starch than the other blends. Unexpectedly, it was observed that 100CYS had a higher influence in the manifestation of minor constituents than the 100WS (Table 1).

AAM content of the control starches and their blends differed significantly (P < 0.05). The AAM content in the control starches was lower than that of the blended starches. The 100WS contained a higher proportion of AAM (27.69%) than 100CYS (22.60%). The AAM content of 100CYS (22.60%) was higher than the 17.3 and 20.00% reported for cassava starch (Novelo-Cen and Betancur-Ancona, 2005) and potato starch (Moorthy, 2002), respectively. In contrast, the AAM content of 100CYS was lower than 24.6 and 25.4% reported for white and red cocoyam starches, respectively (Lauzon et al., 1995). The AAM content of the 100WS falls within the range (17.00 to 29.00%) reported for some cultivar of wheat starches (Vansteelandt and Delcour, 1999).

The amylose content of starches is important, as it affects pasting, gelatinization, retrogradation, swelling power and enzymatic vulnerability of starches to digestion (Gerard et al., 2001; You and Izydorczyk, 2002). The 30CYS/70WS blend had the highest AAM content and this indicates that 100WS was more significant in the manifestation of higher AAM in the blends than 100CYS. Higher AAM content of 30CYS/70WS and 70CYS/30WS blends are desired in the manufacture of noodles. If minor components of starches were infinitesimal as in most root and tuber starches, the effects of AP and AM on SP and solubility, respectively will be better evaluated. The AM/AP ratio of the control starches and their blends are either >0.5 or <0.5. When the AM/AP ratio is <0.5 (control starches and 50CYS/50WS blend), it indicates high AP starches (Jimenez-Hernandez et al., 2007). In contrast, 70CYS/30WS and 30CYS/70WS blends had AM/AP ratio that is >0.5, an indication of lower AP content in these blends.

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

Sample	Bulk density (g/ml)	Dispersibility (%)	pH
100CYS	0.80±0.03[a]	83.00±0.04[a]	6.5±0.04[a]
70CYS/30WS	0.87±0.01[b]	84.00±0.05[b]	3.72±0.01[b]
50CYS/50WS	0.86±0.02[c]	85.00±0.03[c]	3.11±0.03[c]
30CYS/70WS	0.84±0.01[d]	87.00±0.06[d]	2.90±0.05[d]
100WS	0.67±0.04[e]	90.00±0.02[e]	4.40±0.02[e]

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

Functional properties of control starches and their blends

There is a paucity of work in the literature on bulk density, dispersibility and pH of blended starches. The values for bulk density, dispersibility and pH of the control starches and their blends are shown in Table 2. Bulk density is a measure of the degree of coarseness of the starch sample. 100WS had the least bulk density. As the proportion of 100WS in the blends was increased, the bulk density decreases and vice versa for 100CYS. The control starches had lower bulk densities than the starch blends. The 70CYS/30WS blend was the coarsest and 100WS was the smoothest. Therefore, the 100WS fine particles could be used as face powder in the cosmetic industry.

The 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. 100WS had the highest percentage dispersibility value and 100CYS the least. As the proportion of 100WS in the blends was increased, the percentage dispersibility also increased and vice versa for 100CYS. Since the higher the dispersibility the better the starch flour reconstitutes, the value for 100WS and that obtained for the 30CYS/70WS mixture are better than that of the other starches.The dispersibility value previously reported for the rice starch (87.01%) (Ashogbon and Akintayo, 2012) was comparable to that of the 30CYS/70WS blend (Table 2). Percentage dispersibility of 100WS (90.00%) is better than those stated above. Furthermore, all the dispersibility values (Table 2) observed in this study were better than the 40.67% obtained by Akanbi et al. (2009) for breadfruit starch.

pH is an important property in starch industrial applications, being generally used to indicate the acidic or alkaline properties of liquid media. The pH of the control starches and their blends were generally low. 100WS had a pH of 4.40 and 100CYS the highest pH value of 6.5. The pH values of the blended starches were in between that of the control starches. Low acidic pH values as those obtained here had been previously reported for some cultivars of rice starches (pH 3.71 to 3.99) (Ahmed et al., 2007).

AP had been widely reported to be responsible for SP and AM for solubility. The influences of proteins, lipids, native and temperature-induced amylose-lipid complexes (Morrison et al., 1993) on these parameters were also emphasized. The swelling power (SP) and the water solubility index (WSI) of the control starches and their blends, heated from 55 to 95°C at 10°C interval were summarized in Figures 1 and 2, respectively. The 70CYS/30WS and 50CYS/50WS blends have the highest swelling power at 95°C. At 55 and 75°C, when the proportion of 100WS in the starch blends was increased, the SP decreased and vice versa at 95°C (Figure 1). For the control starches, the SP of 100CYS was lower and higher than that of 100WS at lower and higher temperature, respectively. The direct proportionality relationship between AP and SW was not observed in this study. For instance, the 100CYS with the highest AP content did not have the highest SP at any of the investigated temperatures when compared to the other starch and blends. The effects of temperature on SP were obviously modified by the different quantity of the minor constituents in the control starches and their blends.

As the temperature of the 100WS was increased, the solubility also increased. The low solubility of the 100WS was expected due to its low AAM content. The solubility of the 100WS was lower than that of the blends at higher temperatures, due to the higher AAM content of the blends. The relationship between the 100WS proportion in the blends and the solubility of the blends were not proportionate. At 75°C, as the proportion of the 100CYS in the starch blends was increased, the solubility also decreased. SP and solubility of starches provided evidence of interactions between water molecules, and starch chains in amorphous and crystalline domains (Ratnayake et al., 2002). The higher solubility of the starch blends compared to the control starches was due to their higher AAM content.

Starches that swell rapidly on heating tend to be shear sensitive and contain less protein and lipid than starches displaying more restricted swelling (Debet and Gidley, 2006). The higher SP of 70CYS/30WS and 50CYS/50WS blends especially at 95°C make them potentially suitable as additive in sausage-type meat products, as this property

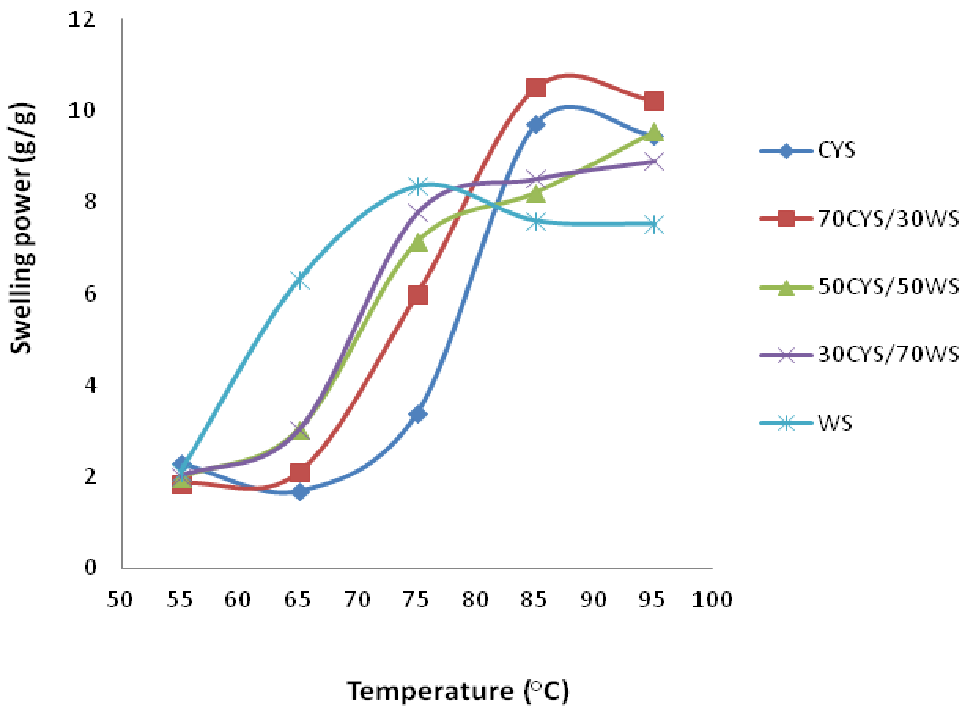

Figure 1. Effect of temperature on swelling power.

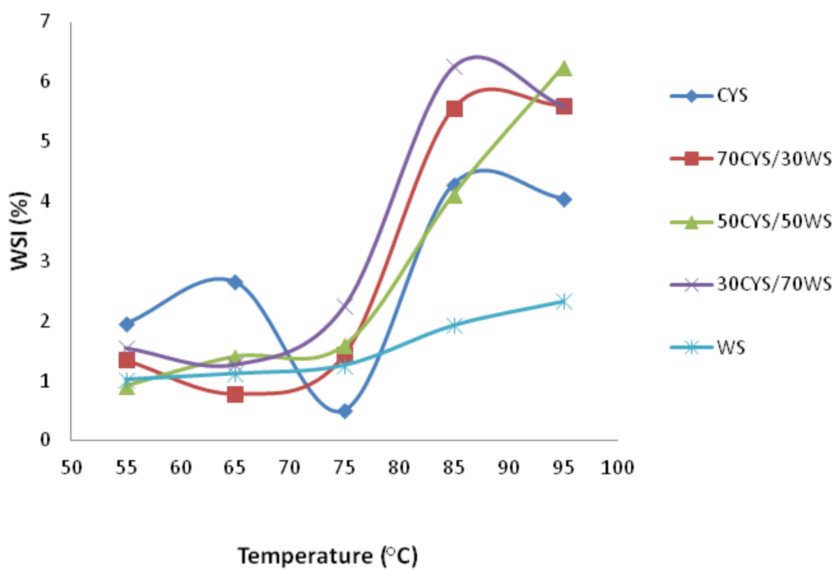

Figure 2. Effect of temperature on WSI.

is essential for proper texture in these foods (Carballo et al., 1995).

Pasting properties of control starches and their blends

The pasting parameters of the control starches (100CYS and 100WS) and their blends were presented in Table 3. PV indicates the SP and the strength of the forces holding together the polymeric molecules within the starch granules. The PV of the 50CYS/50WS blend was the highest, followed closely by 100CYS and 100WS possessed the smallest PV. This indicates that the 50CYS/50WS blend had the weakest intra-molecular and intermolecular bond holding the molecules together. Therefore, the granules easily get distended when thermally agitated. The rigid nature of the 100WS granules

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

P (RVU)	100CYS	70CYS/30WS	50CYS/50WS	30CYS/70WS	100WS
PV	499.25±0.20[a]	464.92±0.30[b]	559.00±0.20[c]	342.75±0.20[d]	254.90±0.10[e]
TV	233.10±0.10[a]	199.25±0.10[b]	250.33±0.20[c]	143.92±0.10[d]	202.00±0.20[e]
BV	266.15±0.10[a]	265.67±0.30[b]	308.67±0.20[c]	198.83±0.20[d]	52.90±0.30[e]
FV	353.70±0.10[a]	331.50±0.30[b]	428.92±0.10[c]	296.67±0.20[d]	299.60±0.30[e]
SV	120.60±0.30[a]	132.25±0.20[b]	178.59±0.10[c]	152.75±0.10[d]	97.00±0.20[e]
Pt (Min)	4.30±0.30[a]	4.13±0.20[b]	4.87±0.10[c]	5.00±0.10[d]	6.90±0.20[e]
PT (°C)	81.45±0.30[a]	80.00±0.20[b]	82.45±0.10[c]	84.10±0.10[d]	88.20±0.20e

Uncommon superscripts along rows indicate statistically significant difference (P < 0.05). P stands for parameters and RVU for rapid viscosity units.

was displayed by its small PV value (254.90 RVU) (Table 3). The 70CYS/30WS and 30CYS/70WS blends had PV values of 464.92 and 343.75RVU, respectively. This simply means that the 100CYS contribute to the manifestation of higher PV values than 100WS. Putting the 50CYS/50WS blend aside, as the proportion of 100CYS in the starch blends was increased, the PV also increased and vice versa for 100WS.

The unique nature of the 50CYS/50WS blend is worth-noting. It had the highest values of PV, TV, BV, FV, and SV. The 50CYS/50WS blend had higher AP than the other starch blends. Despite its lower AP than the control starches, its higher PV value could be attributed to its lower minor components. BV is the measure of the degree of susceptibility of the starch granules to shear stress and thermal agitation. BV value was highest for the 50CYS/50WS blend and lowest for 100WS. This simply means that the 100WS is very stable when thermally agitated and 50CYS/50WS mixture is very weak and the granules easily rupture when subjected to high shear stress and heat. Putting the 50CYS/50WS blend aside, as the proportion of 100WS in the starch blends was increased, the BV value decreased. The 100CYS therefore had more impact on the manifestation of higher BV values in the blends than 100WS. The high thermal stability of 100WS and the 30CYS/70WS blend could be useful in products that require sterilization, as in baby food and food for the elderly (Novelo-Cen and Betancur-Ancona, 2005).

The low retrogrodation tendency associated with the cereal starches (100WS) was expected.The highest value of SV was obtained for the 50CYS/50WS blend. The SV value for the 70CYS/30WS blend was 132.25 RVU and that for the 30CYS/70WS blend was 152.75 RVA. This clearly indicates that the 100WS was more important in the formation of higher SV blends than 100CYS. The association of higher AAM content with higher retrogadation rate had not been obvious in this study. It is not even manifested in the control starches, it is possible that other factors like the minor constitutes of starches are at play. Furthermore, the control starches and their blends might have short chain AM molecules and not too highly branch AP molecules. Apart from long chain AM molecules, non-random highly branched AP molecules had also been reported to enhance retrogradation (Bello-Perez et al., 2001; Jane and Chen, 1992).

Lower retrogradation values of the control starches could be useful in refrigerated foods and also in soups, sauces, desserts and cake filling (Novelo-Cen and Betancur-Ancona, 2005). In contrast, the high retrogradation and AAM starch mixtures are desired in starches with potential in gluten-free pasta and noodles (Emmambux and Taylor, 2013).

FV values for the control starches and their blends ranged from 296.67 to 428.92 RVU and they vary significantly (P < 0.05). With the exception of the 50CYS/50WS blend that had the highest FV value, high proportion of 100CYS in the blend (70CYS/30WS) tends to enhance high FV value than the 100WS (Table 3). This is expected because 100CYS had a high FV value than 100WS. The higher FV values of 100CYS and 50CYS/50WS blend are desired in many food products (soups and sauces); they can also be utilized in the textile industry and wet stage paper production where high viscosity is needed (Moorthy, 2002). In contrast, the lower FV starches (100WS and 30CYS/70WS blend) are significant in the dry stage paper-making were low viscosity starches are preferred (Moorthy, 2002).

100WS showed the highest PT value and 70CYS/30WS blend the lowest PT. Expectedly, as the proportion of 100WS in the blends was increased, the PT values also increased. The least PT value of the 70CYS/30WS blend indicates that it began to form paste earlier than the control starches and the other blends. The lower PT value starches are preferred in some food industries because of their reduced energy cost during production. The TV values of the control starches and their blends ranged from 143.92 to 250.33RVU and vary significantly (P < 0.05). The significance of the TV is that, it aids in the computation of BV and SV values.

CONCLUSION

Despite the higher moisture content (MC) of cocoyam starch (100CYS) than wheat starch (100WS), it was observed that 100WS was more important in the manifestation of higher moisture content in the blends. Therefore, MC of the blends was non-additive of their individual components. The higher apparent amylose (AAM) content of the blended starches compared to the control starches had tremendous impact on swelling power, solubility and the pasting parameters. The higher AAM blended starches (70CYS/30WS and 30CYS/70WS) could be very significant in the making of noodles. The AAM content of the blended starches was non-additive of their individual components in this study.

The functional properties of the blended starches like bulk density, percentage dispersibility and pH were additive of their individual components. The direct proportionality relationship between amylopectin and swelling power was not obvious in this study. For example, the 100CYS with the highest AP content did not possess the highest SP at any of the investigated temperatures when compared to 100WS and the blends. This is likely due to the different quantity of the minor components, the native and temperature-induced amylose-lipid complexes in the control starches and the blends. The higher SP of some blends (70CYS/30WS and 50CYS/50WS) especially at 95°C makes them potentially better than the control starches as additive in sausage-type meat products, as the property is essential for proper texture in these foods. With the exception of peak time and pasting temperature, all the other pasting parameters of the blends are non-additive of their individual components. The SP was additive at 75 and 95°C, furthermore, the solubility of the blends was only additive at 75°C. This study shows that blending of native starches with different chemical and functional properties may lead to systems that can be utilized for new industrial applications based on their swelling and pasting properties.

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