Physicochemical properties of microwaved starch blends from cocoyam (*Xanthosoma sagittifolium*) and pigeon pea (*Cajanus cajan*) for industrial applications

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Abstract

The extracted cocoyam starch (100CYS) and pigeon pea starch (100PPS) were blended in three ratios (70CYS/30PPS, 50CYS/50PPS and 30CYS/70PPS) (% w/w) and microwaved. The aim was to alter the compositional and some physicochemical properties of the starches to enhance their functionality for industrial applications. The microwave-irradiated starch samples resulted in decrease in moisture, lipid and ash contents of the modified starch samples but an increase in the protein content. The apparent amylose (AAM) content of the modified control starches increased and that of the treated starch blends (SBs) decreased upon microwave (MW) radiation. For the MW-irradiated SBs, the values of bulk density, dispersibility, water absorption capacity and pH were in the range 0.75-0.83g/mL, 82.0-86.0%, 75.00-91.38% and 6.7-7.2, respectively. MW modification increased the swelling power (SP) of the modified SBs (M50CYS/PPS, M70CYS/30PPS) but decreased the SP of the remaining starch samples. Apart from M100PPS, MW irradiation resulted in increase in water solubility index of the remaining modified starch samples (starch blends and 100CYS). The MW-irradiated control starches decreased for peak, trough, final and setback viscosities. In contrast, these pasting viscosity parameters increased when SBs were MW-modified. With the exception of the 50CYS/50PPS blend, MW radiation lowered the breakdown viscosity of modified control starches and starch blends, whereas the pasting temperatures of the studied starches increased.

Keywords: Cocoyam starch, pigeon pea starch, physicochemical properties, microwave modification, starch blends

Introduction

The uniqueness of starch is undeniable among the polysaccharides. It is the second most abundant organic compound, apart from cellulose in the biosphere. Furthermore, starch is the most significant carbohydrate in the human diet [1]. It accounts for 30-40% of daily energy intake [2]. The source of starch is the plant kingdom; it is mostly obtained from cereal, root and tuber, legume and green fruits [3]. Starch is the only polymer that had the tendency to gelatinize among the natural and synthetic polymers. It is a condensation polymer and the presence of ubiquitous hydroxyl groups facilitates chemical modification. Amylose (AM) and amylopectin (AP) are the two polymers that build up the starch granules [4].

The search for starch with the appropriate physicochemical and functional properties for industrial applications is increasing daily. The limitations of native starches (NSs) due to inherent insolubility in water and tendency to easily retrograde are popularly acknowledged. In addition, NSs has many weaknesses such as narrow peak viscosity range, poor process tolerance, low shear stress resistance, thermal decomposition and cooked starches will formed a weak, cohesive and rubbery paste [5]. In view of consumers increasing request for safe and non-additive foods, there is a growing interest
for physically modified starch over chemically or enzymatically modified starches because starch functionality can be improved without introducing any foreign substances [6]. Physical modification is simple, cheap and safe because it requires no chemicals or biological agents [3]. Starch blending and microwave heating are examples of physical modification.

Starch blends are not additives and the quantity utilized is not regulated. Blending of starches from different botanical sources is not an entirely new process. Sweet potato starch had been previously blended with wheat starch [7]; Irish potato starch blended with pigeon pea starch [8]; cocoyam starch blended with wheat starch [9] and bambara groundnut starch blended with cassava starch [10].

Microwave (MW) irradiation is non-ionizing and one of the physical modification methods that can treat starch and alter its functionality [11]. The impacts of MW interaction with matter depended on the MW energy which is delivered directly to the material through molecular interaction with the electromagnetic field [11]. When MW radiation is incident on matter, some of the energy is reflected and others transmitted. It is part of the transmitted energy that is absorbed which is useful for interaction with starch molecules. It is the absorbed energy that is later converted to heat when starch molecules are penetrated by MW irradiation. There are many documented studies based on the interaction of MWs with starch [12-15]. Generally, MWs could bring about rearrangement of intra- and intermolecular structure and consequent alterations in physicochemical and functional properties of starches from various botanical sources depending on starch type and experimental treatment parameters [11].

Cocoyam (Xanthosoma sagittifolium) belongs to the Aracca family and it is the sixth most important root and tuber crops world-wide [16]. The high carbohydrate content of cocoyam and its wide availability in the tropical countries make it a very good source of starch for domestic and industrial applications [17]. It is a highly under-utilized tuber when compared to cassava and potato in terms of industrial application. Cocoyam starch had been extensively studied [18-20]. Legumes are an excellent source of carbohydrate and provide an inexpensive source of protein [21]. Pigeon pea (Cajanus cajan) is a widely cultivated legume in Nigeria, India, Hawaii and the Dominican Republic. From an industrial point of view, it is an underutilized legume. The starch extracted from pigeon pea had been extensively studied [8, 22].

Some generalizations from previous works on MW irradiated starches are worth-noting: alterations in physicochemical properties of cereal starches impacted by MW irradiation were less marked than for root and tuber starches [23, 24]; for tuber starches, a strong correlation existed between the moisture content and the extent of alterations [23]; the most noticeable alteration effected by microwaving was the conversion of potato starch crystal structure from type B to type A [23].

Much work has been done on individual native starches and starch blends (SB) [8-10], but paucity of researches on microwaved starch blends (MSB). Therefore, the aim of this work is to study the compositional and some physicochemical properties of microwave treated starch blends for potential industrial applications.

**Materials and Methods**

**Materials**

Cocoyam tubers (Figure 1) and pigeon pea seeds (Figure 2) 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.
Starch isolation

The cocoyam starch (100CYS) was extracted by a method previously documented by Ogunmolasuyi et al. [18] and Ukom et al. [19]. The cocoyam tubers were peeled, thoroughly washed and cut into pieces and subsequently crushed in a laboratory blender. The starch slurry was mixed with appropriate volume of distilled water and filtered. The filtrate was allowed to stand for the formation of clear supernatant and starch sediment. Subsequently, the supernatant was decanted off and the sediment re-suspended in distilled water. These processes re-suspension and decantation continued to obtain white prime starch, which was dried in an oven (N505F, YOGO11, Genlab Widnes, England) at 40 °C for 48 hours.

Isolation of native pigeon pea starch (100PPS) was carried out by a method described by Singh et al. [25]. Pigeon pea seeds were steeped in 0.1 % sodium hydroxide solution for 2 h. The coat was manually removed and the inner endosperm blended for 5 min at slow rotation using a laboratory blender. The slurry was diluted with distilled water and sieved using a muslin cloth with retained fiber. The fiber was rewashed with distilled water to remove adhering starch. The extracted starch was allowed to stand for 1 h. The supernatant was decanted and distilled water added to the starch residue. Repeated dilution and decantation were carried out until the pH was neutral. The starch residue was collected and dried in an electric oven at 40 °C for 48 h.

Preparation of the starch blends

The method of Zhang et al. [26] was adopted to ensure homogeneity of the starch blends. The blends were prepared from the isolated native starches (100CYS and 100PPS) in three proportions (70CYS/30PPS, 50CYS/50PPS and 30CYS/70PPS) (%. w/w). The starches were mixed in a laboratory blender and subsequently sieved.

Microwave irradiation of starch samples

The control starches (100CYS, 100PPS) and their blends (70CYS/30PPS, 50CYS/50PPS and 30CYS/70PPS) were adjusted to 20% moisture by the addition of appropriate quantity of distilled water to the starch samples of known moisture contents. The moistened starch samples were placed in glass beakers and sealed with perforated polyethylene foil designed for the MW oven (Scanfrost Model SF 17N, China) emitting a 2450MHz MW frequency and 0.5W/g MW energy [24] for 60 min.

Gross chemical compositions of starch samples

Apparent amylose (AAM) content (%) was determined by a colorimetric iodine assay index method, according to Juliano [27]. The moisture, protein, lipid, and ash contents in the starch
samples were determined using procedure of AACC method [28].

**Determination of some functional properties**

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. [29]. Bulk density was determined by the method of Wang and Kinsella [30] as recently modified by Ashogbon and Akintayo [31]. The percentage dispersibility was determined by the method described by Kulkarni et al. [32] as modified by Akanbi et al. [33]. The determination of water absorption capacity (WAC) was carried out using the method described by Sosulski [34]. 1g of the starch flour was added to 15mL of distilled water in a pre-weighed 25mL centrifuge tube. The tube was agitated on a vortex mixer for 2 min; the clear supernatant was decanted and discarded. The adhering drops of water were removed and the tube was re-weighed. The WAC was expressed as the weight of water bound by 100 g of dry flour. In the determination of the pH, the Starch samples (5g) were weighed in triplicate into three beakers, 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 supernatant was measured using a calibrated pH meter [35].

**Pasting properties**

The pasting properties of the starch samples 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) and final viscosity (FV). 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).

**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 starch samples**

The moisture, lipid and ash contents of the starch samples decreased after being subjected to MW irradiation. In disparity, the protein contents of the starch samples increased due to MW modification.

The decrease in moisture content of all the starch samples (control starches and their SBs) due to MW irradiation was attributed to leaching of water out of the starch granules and its subsequent evaporation due to MW heating. Similar reduction in the moisture content of lentil starch [36] and canna starch [37] has been previously documented. Other studies in moisture content contraction due to MW treatment involves wheat flour and potato starch [38, 39]. The quantity of moisture content reduction in all these studies differs because they were subjected to various MW parameters.
Table 1. Gross chemical composition of Starch samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture (%)</th>
<th>Protein (%)</th>
<th>Lipid (%)</th>
<th>Ash (%)</th>
<th>Amylose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100CYS</td>
<td>8.06±0.02(^a)</td>
<td>0.16±0.02(^a)</td>
<td>0.23±0.01(^a)</td>
<td>1.30±0.02(^a)</td>
<td>24.83±0.14(^a)</td>
</tr>
<tr>
<td>M100CYS</td>
<td>5.60±0.43(^b)</td>
<td>0.28±0.02(^b)</td>
<td>0.86±0.00(^b)</td>
<td>1.08±0.01(^b)</td>
<td>25.08±0.43(^b)</td>
</tr>
<tr>
<td>100PPS</td>
<td>6.72±0.01(^c)</td>
<td>0.12±0.15(^c)</td>
<td>0.31±0.01(^c)</td>
<td>1.19±0.01(^c)</td>
<td>29.27±0.28(^c)</td>
</tr>
<tr>
<td>M100PPS</td>
<td>4.78±0.02(^d)</td>
<td>0.35±0.01(^d)</td>
<td>1.00±0.02(^d)</td>
<td>0.95±0.15(^d)</td>
<td>29.99±0.07(^d)</td>
</tr>
<tr>
<td>70CYS/30PPS</td>
<td>11.06±0.02(^f)</td>
<td>1.61±0.03(^f)</td>
<td>0.96±0.00(^f)</td>
<td>1.21±0.01(^f)</td>
<td>33.68±0.57(^f)</td>
</tr>
<tr>
<td>M70CYS/30PPS</td>
<td>8.25±0.05(^i)</td>
<td>2.00±0.21(^i)</td>
<td>0.96±0.04(^i)</td>
<td>1.06±0.04(^i)</td>
<td>33.01±0.14(^i)</td>
</tr>
<tr>
<td>50CYS/50PPS</td>
<td>8.85±0.03(^f)</td>
<td>1.25±0.12(^f)</td>
<td>0.93±0.01(^f)</td>
<td>1.26±0.13(^f)</td>
<td>32.00±0.07(^f)</td>
</tr>
<tr>
<td>M50CYS/50PPS</td>
<td>5.02±0.01(^h)</td>
<td>1.35±0.29(^h)</td>
<td>0.92±0.09(^h)</td>
<td>1.09±0.02(^h)</td>
<td>31.24±0.14(^h)</td>
</tr>
<tr>
<td>30CYS/70PPS</td>
<td>8.76±0.02(^i)</td>
<td>1.58±0.12(^i)</td>
<td>0.97±0.01(^i)</td>
<td>1.23±0.02(^i)</td>
<td>27.07±0.45(^i)</td>
</tr>
<tr>
<td>M30CYS/70PPS</td>
<td>7.16±0.02(^j)</td>
<td>1.99±0.23(^j)</td>
<td>0.92±0.07(^j)</td>
<td>1.05±0.06(^j)</td>
<td>26.50±0.07(^j)</td>
</tr>
</tbody>
</table>

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

The ash content of starches consists mainly of sodium, potassium, calcium, magnesium and phosphorus [40]. These residual elemental compositions vary depending on the starch type and soil type on which the source plant was planted. Lares and Perez [37] have previously reported diminution in the ash content of MW-irradiated canna starches. The contraction in the ash content in this work, some of them statistically significant and others insignificant (P<0.05) could be ascribed to the migration of water soluble minerals from starch into water and subsequent lost through evaporation as a result of MW treatment [37]. It is obvious that the residual salts in the MW-treated starches could be due to the presence of insoluble metallic salts. Other results in the literature where MW-irradiated starches have resulted in increment of ash content [36] could be attributed to the presence of insoluble salts in the water source used for dilution of the starches.

The contraction and increment in the lipid and protein contents of the modified starch samples could also be elucidated. The decrease in the lipid content of MW-modified starch samples could be ascribed to the enabling environment for the combination of free lipids with AM to form more AM-lipid complexes. This kind of scenario provided for the reduction of not only the free lipids but also the free AM content. The low lipid content is indicative that products made from them will not be easily vulnerable to rancidity [33]. The increment in the protein content of the starch samples could be attributed to the leaching of internal protein [41] or the display of additive tendency of the protein content of the individual starches that constitute the blend, most especially for the legume (100PPS) known to contain conjugate protein which is difficult to remove during starch extraction [42]. The linear and randomly limited branching of the AM structure is very important because of
their influence on swelling, gelatinization, retrogradation, pasting properties and enzymatic susceptibility of starches to digestion [43, 44]. The generally higher AM content of the legume starches (100PPS) than the root and tuber starches (100CYS) was displayed in this work (Table 1). The AM content of 100PPS was significantly (P<0.05) higher than that of 100CYS. The AM content of 100CYS fell within the range (15-25%) documented by Moorthy [45] for root and tuber starches. On the other hand, the AM value obtained for 100PPS was significantly (P<0.05) higher than that of 100CYS. The AM content of 100CYS fell within the range (15-25%) documented by Moorthy [45] for root and tuber starches. On the other hand, the AM value obtained for 100PPS was similar to values in the range (28.4-33.1%) previously reported by Sandhu and Lim [46]. The AM content of the SBs was higher than that of the control starches, except for the 30CYS/70PPS blend (Table 1). Unexpectedly, the 70CYS/30PPS blend with the highest AM content (non-additive tendency) and this indicates that the 100CYS was more significant than 100PPS in the manifestation of higher AM content in the blends.

A trend was developed in AM content indicating that control starches and the SBs respond differently to MW irradiation. As a consequence of subjection of the starch samples to MW treatment, there was increase in the AM content of the modified control starches and decrease in the AM content of the modified SBs (Table 1). The significant increment (P<0.05) in the AM of the control starches could be attributed to leaching out of AM from the starch granules due to exposure to MW radiation [47, 48]. Furthermore, the increase in AM content of the irradiated native starches could also be ascribed to the dissociation of some of the AM in the amylose-lipid complexes. The SBs behave differently to MW treatment when compared to the control starches. The decrease in the AM content of the modified SBs could be attributed to the increase in complexation of AM to lipids.

It has been documented that AM is more vulnerable to MW irradiation than amylopectin (AP). In one particular study, cereal starches (wheat, corn and waxy corn) were subjected to MW radiation, normal corn and wheat starches underwent pronounced alterations, whereas under the same condition, waxy corn starch was almost unaffected [24]. Therefore, the physicochemical properties of the 70CYS/30PPS blend with the highest AM content were expected to be more impacted by MW irradiation than the other starch samples. The latter statement can only be true if the AM content is not affected by other factors like the presence of free lipid that could form complexes with AM. Starches of high AM content like the 70CYS/30PPS blend could be potentially important in the production of noodles [10] and formation of resistant starch (RS). The health benefit of RS is boundless. Other significant applications of high AM starches were for making sweets [49], additive products and paper [50]. High-AM starches due to their strong gelation properties and helical linear polymer structure are significant film-forming materials [27].

**Bulk density, dispersibility, water absorption capacity and pH**

The bulk density (BD), dispersibility (DP), water absorption capacity (WAC) and pH of the starch samples were summarized in Table 2. The BD is a measure of the degree of coarseness or smoothness of starch sample particles. There was reduction in the BD of the control starches after being subjected to MW irradiation. This could be ascribed to smashing of the starch granules as a result of MW heating. The starch particles are most probable fragmented into small pieces and this reduces the coarseness. In disparity, the SBs behave differently to the MW treatment. With the exception of the 30CYS/70PPS blend, there was a significant increase (P<0.05) in the BD of the SBs due to MW irradiation. The starch granules could have been smashed and instant aggregation of the smashed particles with subsequent increase in coarseness and BD.
Table 4.2. Functional properties of native, modified starches and their blends

<table>
<thead>
<tr>
<th>Sample</th>
<th>Bulk density (g/ml)</th>
<th>Dispersibility (%)</th>
<th>Water Absorption Capacity (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>100CYS</td>
<td>0.80±0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83.00±0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>69.17±0.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.7±0.02&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>M100CYS</td>
<td>0.75±0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>85.00±0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>77.35±0.00&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.0±0.00&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>100PPS</td>
<td>0.82±0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>82.00±0.00&lt;sup&gt;c&lt;/sup&gt;</td>
<td>78.58±0.01&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.2±0.00&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>M100PPS</td>
<td>0.80±0.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83.00±0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>84.51±0.02&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.9±0.01&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>70CYS/30PPS</td>
<td>0.78±0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>86.00±0.02&lt;sup&gt;d&lt;/sup&gt;</td>
<td>75.72±0.01&lt;sup&gt;e&lt;/sup&gt;</td>
<td>7.2±0.03&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>M70CYS/30PPS</td>
<td>0.79±0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>84.00±0.02&lt;sup&gt;c&lt;/sup&gt;</td>
<td>75.72±0.05&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.0±0.02&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>50CYS/50PPS</td>
<td>0.80±0.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>85.00±0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>68.19±0.02&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7.1±0.04&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>M50CYS/50PPS</td>
<td>0.83±0.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>85.04±0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>80.18±0.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.9±0.00&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>30CYS/70PPS</td>
<td>0.82±0.01&lt;sup&gt;a&lt;/sup&gt;</td>
<td>86.00±0.04&lt;sup&gt;d&lt;/sup&gt;</td>
<td>91.38±0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.8±0.02&lt;sup&gt;f&lt;/sup&gt;</td>
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<tr>
<td>M30CYS/70PPS</td>
<td>0.82±0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83.00±0.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>87.29±0.04&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7.0±0.02&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Different superscripts along columns indicate statistically significant difference (P<0.01).

The high BD of modified SBs could be attributed to the compactness of the starch granules [51]. The changes could also be due to the alterations of the crystalline order and extent of starch-chain associations within the amorphous regions due to MW treatment [52]. The modified control starch (M100CYS) and blend (70CYS/30PPS) with the lower BD of 0.75 and 0.78g/mL, respectively, could be potentially useful in making dusting powder in the cosmetic industry.

Dispersibility (DP) is a measure of the capacity of starch flour to reconstitute in water. The higher the DP, the better the starch flour reconstitute in water [32]. There were significant differences (P<0.05) in DP between the control starches and their blends. The native starches and their blends respond differently to MW irradiation. The radiation resulted in an increase in the DP of the control starches, but a decrease in the values of the SBs. An increase in DP as a result of MW treatment could have been manifested by the radiation smashing the
granules into smaller particles. Consequently, the particles occupy lesser volume and resulted in increase in DP. The contraction in DP of the modified SBs in comparison to the SBs due to MW irradiation could be ascribed to smashing and instant agglomeration of the smashed particles. The bigger particles formed occupied more space and subsequent decrease in DP. The high DP (86%) starch blends (Table 2) could easily find application in adsorptive removal of ions from contaminated water system [53].

Water absorption capacity (WAC) determines the level of imbibition of water by the starch flour [33]. The MW radiation of control starches resulted in increase of the WAC. There was increase in WAC from 100CYS (69.17%) to M100CYS (77.35%) and from 100PPS (78.58%) to M100PPS (84.51%) as a result of MW irradiation. This could be ascribed to the impact of radiation on the amorphous amylose region of the starch granules. This part of the granules might be soften and widen resulting in water imbibition tendency and resultant increase in WAC. Similar increment was also observed in WAC when potato starch was subjected to vacuum MW [54]. As for the SBs, the mixing ratios, starch types and morphologies of the individual starches that constitute the blends must be taken into consideration. Microwave irradiation had no effect on the WAC of the 70CYS/30PPS blend. On the other hand, MW treatment impacted the WAC of the 50CYS/50PPS blend positively (increment) and the 30CYS/70PPS negatively (contraction). This behavior of WAC of the SBs could be attributed to the interplay of the following factors; the amylose content, mixing ratio, starch type, morphologies and bond strength between the two polymeric materials and the quantity and type of residual protein and lipid associated with the individual starches that constitute the blends.

MW irradiation had small but statistically significant (P<0.05) effect on the starch samples. The pH is a measure of the acidic or alkaline property of the liquid media, mostly aqueous in most reactions. The pH values of this work ranged from slightly acidic to slightly alkaline (6.7-7.2). The pH values of the investigated starch samples are within the acceptable range (4.5-7.5) specified for low acid food starches [55]. The differences in pH values have been attributed to various starch isolation methods and soil medium during plant growth for the control starches. As shown in Table 2, for the SBs the pH property is not a non-addictive of the individual starches that constitute the SBs. The pH value of 7.2 recorded for 100PPS was lower than 7.6 previously reported [22]. A pH range of 3.71-3.90 had also been documented for some rice starch media [56].

**Swelling power and water solubility index**

The swelling power (SP) and water solubility index (WSI) of the starch samples heated from 55 to 95°C at 10°C intervals were summarized in Figures 3 and 4. The SP of the starch samples do not raise at all at low temperatures (55-65°C). A steep raise in SP started at 75°C for all the starch samples (modified and the non-treated). There is always a higher SP associated with the root and tuber starches when compared to the legume starches. The restricted SP of the legume starches had always being ascribed to their usually high AM content. That is why they are not desired in frozen foods and need for modification, i.e., chemical, physical or dual modification to better their functionality for industrial applications. Therefore, it is expected as shown in Figure 3 that the SP of 100CYS is higher than that of 100PPS. The respond of the starch samples to MW-irradiation differs. There was increased in the SP of the following starch blends as a result of MW-heating; from 50CYS/50PPS to M50CYS/50PPS and 70CYS/30PPS to M70CYS/30PPS. In disparity, other starch samples have statistical significant decrease (P<0.05) in SP as a result of MW radiation. Similar reduction in SP due to MW influences had being documented in the literature. These plummeted values had been ascribed to the restructuring that occurred inside starch granules [57]. Another possible elucidation for reduced SP could be the rearrangement of crystalline regions within the starch granules, which might be more randomly scattered within the starch
granules [11], resulting in more crystalline perfection. Likewise reduction in SP of lotus seed starch due to MW irradiation had also being reported [57]. The previous increase in SP of two starch blends (50CYS/50PPS and 70CYS/30PPS) as a result radiation could be attributed to distortion in the starch granules leading to weakening of intra- and intermolecular bonds that enhanced water percolation into granules and resultant increase in SP. The bonding between the main polymeric components (AM-AM and AM-AP) of the granules could have being slackened and perhaps ruptured to promote amylase leaching (AML) and consequent increase in granular size.

The high swelling MW-modified starch blends (M50CYS/50PPS and M70CYS/30PPS) could be potentially useful as binder or extender in the industry [22]. Furthermore, these modified high swelling blends could also find applications in the pharmaceutical industry [58].

The response of the starch samples to MW-irradiation differ significantly (P<0.05). There was an increase in the WSI of all the starch samples (exception was the 100PP to M100PPS) when subjected to MW treatment. This could be ascribed to the decrease in crystalline perfection and attack on the amorphous regions, which brings about structural re-arrangement. The latter brings about weakening of the main polymeric bonds (AM-AM and AM-AP) and enhances swelling, rupturing of granules, AML that promotes swelling and subsequent increase in solubility. The highest WSI was due to the M70CYS/30PPS blend and the least was for M100PPS (Figure 4). The resistant of the modified control starch (M100PPS) to MW modification could be due to rigidity of its granules and strong bonds of its polymeric components. The structural re-arrangement that brings about increase in crystalline perfection is almost inevitable in this case (M100PPS).
Pasting properties

In the study of pasting properties, there is also a positive relationship among PV, BV and SP. When heated in an aqueous medium, the starch granules absorb water, get swollen and distended. The maximum extension or swollenness of the starch granules on the verge of rupture is called PV. Therefore, high PV is directly proportional to high BV and high SP. MW irradiation brings about significant differences (P<0.05) in the pasting parameters. The values of the parameters are summarized in Table 3. The trend in MW-irradiated control starches and the SBs differs. The PV of MW-modified control starches decreased and that of SBs increased with the exception of the 30CYS/70PPS blend. There is an uncanny relationship between the PV and BV of 100CYS and 100PPS. A thorough study of these two values indicates that the SP of 100CYS was higher than that of 100PPS. The decrease in PV and BV of these control starches as a result of MW irradiation could be ascribed to structural re-arrangement within the starch granules that leads to reduction in the ability of the granules to absorb water. There could be bond linkage strengthening of AM-AM and AM-AP. Furthermore, there could be formation of more hydrogen bond in the amorphous amylose region of the starch granules. Eventually, migration of water into the granules will be limited. Similar decrease in PV of MW-irradiated (0.5W/g, 60min) normal wheat and corn starches had being previously documented [24]. Other studies involving reduction in PV, as a result of MW treatment include that involving corn starch [59], waxy maize and amylo maize V starches [60]. All these reductions in paste viscosity as a result of MW modification was attributed to increase inter- and intra-molecular hydrogen bonding due to associations of starch chains [11].
Table 3. Pasting properties of Starch Samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>PV (RVU) ±</th>
<th>TV (RVU) ±</th>
<th>BV (RVU) ±</th>
<th>FV (RVU) ±</th>
<th>SV (RVU) ±</th>
<th>T (°C) ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>100CYS</td>
<td>476.42 ± 0.60</td>
<td>214.75 ± 0.75</td>
<td>261.71 ± 0.12</td>
<td>314.16 ± 0.16</td>
<td>99.41 ± 0.41</td>
<td>81.20 ± 0.60</td>
</tr>
<tr>
<td>M100CYS</td>
<td>366.37 ± 0.80</td>
<td>197.00 ± 0.37</td>
<td>261.71 ± 1.25</td>
<td>278.58 ± 0.40</td>
<td>81.58 ± 0.37</td>
<td>81.67 ± 0.03</td>
</tr>
<tr>
<td>100PPS</td>
<td>531.29 ± 0.08</td>
<td>313.96 ± 0.45</td>
<td>247.33 ± 0.37</td>
<td>462.37 ± 0.29</td>
<td>148.42 ± 0.16</td>
<td>78.72 ± 0.60</td>
</tr>
<tr>
<td>M100PPS</td>
<td>511.54 ± 0.50</td>
<td>272.95 ± 0.50</td>
<td>238.58 ± 1.00</td>
<td>404.00 ± 0.50</td>
<td>131.04 ± 0.50</td>
<td>79.22 ± 0.03</td>
</tr>
<tr>
<td>70CYS/30PPS</td>
<td>371.75 ± 0.02</td>
<td>204.75 ± 0.01</td>
<td>167.50 ± 0.04</td>
<td>305.33 ± 0.11</td>
<td>110.08 ± 0.44</td>
<td>81.55 ± 0.07</td>
</tr>
<tr>
<td>M70CYS/30PPS</td>
<td>383.00 ± 0.50</td>
<td>216.37 ± 0.50</td>
<td>166.62 ± 0.50</td>
<td>325.21 ± 0.50</td>
<td>108.83 ± 0.50</td>
<td>82.85 ± 0.50</td>
</tr>
<tr>
<td>50CYS/50PPS</td>
<td>384.22 ± 0.02</td>
<td>219.76 ± 0.02</td>
<td>164.45 ± 0.04</td>
<td>354.18 ± 0.00</td>
<td>113.98 ± 0.02</td>
<td>83.15 ± 0.07</td>
</tr>
<tr>
<td>M50CYS/50PPS</td>
<td>406.33 ± 0.54</td>
<td>240.75 ± 0.75</td>
<td>166.08 ± 0.29</td>
<td>381.25 ± 0.41</td>
<td>142.00 ± 0.16</td>
<td>83.35 ± 0.07</td>
</tr>
<tr>
<td>30CYS/70PPS</td>
<td>466.52 ± 0.04</td>
<td>257.14 ± 0.33</td>
<td>209.33 ± 0.50</td>
<td>399.42 ± 0.33</td>
<td>142.22 ± 0.60</td>
<td>81.55 ± 0.70</td>
</tr>
<tr>
<td>M30CYS/70PPS</td>
<td>439.37 ± 0.05</td>
<td>271.00 ± 0.46</td>
<td>168.37 ± 0.92</td>
<td>440.41 ± 0.54</td>
<td>169.41 ± 0.50</td>
<td>81.57 ± 0.03</td>
</tr>
</tbody>
</table>

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

In other studies, MW-irradiated (650W, 6min at 85°C) canna starch showed reduction in peak viscosity [37]. The trend in MW-irradiated control starches for PV, TV, FV and SV were similar, i.e., a decrease in these parameters for modified control starches when compared to the native starches. In contrast, trend in the opposite direction were also observed in MW-irradiated starch blends.

The usefulness of the TV lies in the computation of BV (PV-TV) and SV (FV-TV). The highest value of PV obtained for 100PPS (531.29RVU) and M100PPS (511.54RVU) could be potentially useful in the making of products needing high gel strength and elasticity [61]. With the obvious exception of the 50CYS/50PPS blend, MW irradiation brings about a decrease in the BV of the control starches and the SBs (Table 3). These reductions in the BV values as a result of MW-heat treatment could be attributed to structural rearrangement that resulted in resistant to granular swelling. This is easily justifiable by an increase in bond strength and more formation of hydrogen bond by starch chains. The lowest BV value was observed in the 50CYS/50PPS blend and the highest in 100CYS. This implies that the 50CYS/50PPS blend was the most resistant among the starch sample granules to fragmentation when thermally and mechanically agitated [22]. The granules of the 50CYS/50PPS blend were probably denser, more crystalline and compacted than those of the other starch sample granules [62]. This blend could be potentially significant in canned food and cases of sterilization in foods for children and the elderly. In contrast, the highest BV value for 100CYS (261.71 RVU) could be ascribed to its weak internal structure, the granules easily swell due to its low AM content (high AP content) (Table 3). The high PV value of 100CYS is also contributory factor to explain its high SP and tendency to easily swell and rupture when thermally agitated.

The high SV value of 100PPS was expected and characteristic of most legume starches. The high retrogradation rate associated with most legume starches was responsible for their non-popularity in the food industry and need for modification. The low SV values of 100CYS and M100CYS indicate their low rate of retrogradation and are easily accepted in the food industry, especially...
in the frozen food industry. The low values of 100CYS and its modified version could be attributed to their low AM content, though other factors could be involved. The high value of SV of the modified starch blend (M30CYS/70PPS) will not be easily accepted in the food industry, except the ones connected to the production of noodles and resistant starches.

The highest FV value of 100PPS is typical of most legume starches when compared to the root and tuber starches (100CYS) due to their usually higher AM content. High FV starches (M30CYS/70PPS and 100PPS) are desired in many food products, especially soups, sauces and dressings, they could also be utilized in wet stage paper production and the textile industry where high viscosity is needed [45]. In contrast, the low FV starches (70CYS/30PPS and M100CYS) could be necessary in the dry stage making of paper [45].

For all the starch samples, MW irradiation resulted in an increase in the pasting temperature (PT). With very few exceptions, this is the normal trend in the literature [24, 59, 60]. One of the few exceptions was when waxy corn starches were subjected to MW irradiation and no differences was observed in the PT between both starches (modified and the untreated) [24]. This was one of the evidence to show that AM is more susceptible to MW irradiation than AP. These increases in PT of MW-irradiated samples were attributed to intra-granular molecular rearrangement (granule compaction view as increase in complete density) that delayed the onset of starch gelatinization by the limited granule swelling and solubilization [36]. The lowest PT value of 100PPS and the blends (70CYS/30PPS and 30CYS/70PPS) indicate their tendency to easily form paste when compared to the other starch samples [10].

These least PT starch values could be preferred in some food industries because of reduced energy cost of production. In contrast, the highest PT value of the modified blend (M50CYS/50PPS) could be potentially utilized in canned foods processed at high temperature.

Conclusions

This study was a search for the microwaved starch blends that possessed the appropriate physicochemical properties for industrial applications. It has been shown that microwave irradiation have tremendous impact in altering the physicochemical properties of starch blends from various botanical sources. Microwave radiation impacted the properties of the control starches and the starch blends differently especially in the cases of amylose content and some of the pasting properties.

References


