https://dx.doi.org/10.4314/afsjg.v16i1.3

Quality Characteristics of Gluten-Free Noodles Prepared from Rice and Underutilised Ghanaian Crops

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Received: 21 November 2022 Accepted: 22 August 2023

Abstract
This study sought to assess the paste and quality acceptability of rice noodles by blending rice flour (RF) with starches from two underutilised Ghanaian crops (yam and cocoyam). Local breeds of yam (*Dioscorea spp*.) and cocoyam (*Colocasia esculenta*) starches were blended with rice flour at different ratios. The paste properties and noodle qualities of rice flour (RF) blended with yam starch (YS) and cocoyam starch (CYS) were evaluated and compared. The blends of both starches under study had a significant positive effect on the swelling power, amylose content, and water holding capacity of RF, thereby positively impacting the noodles' textural and taste acceptability. The RF:YS blends had paste characteristics such as higher final viscosity (473.80–405.58 RVU), trough viscosity (258.67–234.55 RVU), and peak viscosity (307.86–240.44 RVU) values, making them better suited for noodle production than the RF:CYS blends. More so, RF:YS blends produced noodles with higher firmness, shear resistance, and eating quality than RF:CYS blends, which produced noodles with softer and less chewy in texture. Both starch blends significantly reduced the cooking time of RF noodles. The starch sources had a greater impact on the acceptability of the noodles than their blend ratios with RF. The textural properties of noodles could be used to predict their cooking and sensory characteristics. Using these underutilised crop starches in various food systems could help reduce the pressure on the existing commercial starches.

Keywords: cocoyam starch; gluten-free noodles; pasting property; underutilised Ghanaian crops; yam starch

Caractéristiques Qualitatives des Nouilles Sans Gluten Préparées à Partir de Riz Et de Cultures Ghanéennes Sous-Utilisées

Résumé

Cette étude visait à évaluer la pâte et l'acceptabilité de la qualité des nouilles de riz en mélangeant la farine de riz (FR) avec des amidons provenant de deux cultures ghanéennes sous-utilisées (igname et cocoyam). Des races locales d'amidons d'igname (*Dioscorea spp*.) et de cocoyam *(Colocasia esculenta*) ont été mélangées à la farine de riz à différents ratios. Les propriétés de la pâte et les qualités des nouilles de la farine de riz (RF) mélangée à l'amidon d'igname (YS) et à l'amidon de cocoyam (CYS) ont été évaluées et comparées. Les mélanges des deux amidons étudiés ont eu un effet positif significatif sur le pouvoir de gonflement, la teneur en amylose et la capacité de rétention d'eau de la FR, ce qui a eu un impact positif sur l'acceptabilité texturale et gustative des nouilles. Les mélanges RF: YS présentaient des caractéristiques de pâte telles qu'une viscosité finale (473,80-405,58 RVU), une viscosité en creux (258,67-234,55 RVU) et une viscosité maximale (307,86-240,44 RVU) plus élevées, ce qui les rendait mieux adaptés à la production de nouilles que les mélanges RF: CYS. En outre, les mélanges RF: YS ont produit des nouilles plus fermes, plus résistantes au cisaillement et de meilleure qualité gustative que les mélanges RF: CYS, qui ont produit des nouilles à la texture plus molle et moins moelleuse. Les deux mélanges d'amidon ont réduit de manière significative le temps de cuisson des nouilles RF. Les sources d'amidon ont eu un impact plus important sur l'acceptabilité des nouilles que leurs rapports de mélange avec le FR. Les propriétés texturales des nouilles pourraient être utilisées pour prédire leurs caractéristiques culinaires et sensorielles. L'utilisation de ces amidons de culture sous-utilisés dans divers systèmes alimentaires pourrait contribuer à réduire la pression exercée sur les amidons commerciaux existants.

Mots Clés: amidon de taro; nouilles sans gluten; propriétés de collage; cultures ghanéennes sous-utilisées; amidon d'igname,

Introduction

Rice flour is among the various flours used to produce wheat-free foods (Ylimaki *et al*., 1991). Due to the better understanding and diagnosis of celiac diseases (Collin *et al*., 2002), wheat allegiance (Poole *et al*., 2006), and gluten sensitivity (Goldstein & Underhill, 2001), there has been a high demand by consumers for wheat-free food. Rice noodle has high digestibility and an absence of gluten and is a substitute for wheat pasta in Europe (Charutigon *et al*., 2008; Qazi *et al*., 2014). Producing high-quality rice-based noodles would be desirable for the wheat-free food market. Yoenyonbuddhagal & Noomhorm (2002) and Qazi *et al*. (2014) reported that the absence of gluten in rice flour results in the starch content determining the structural network of its noodles. Therefore, extensive studies have been conducted on replacing rice flour with various starches from different botanical origins, such as sweet potato, mung bean, canna, cassava, corn, potato, and ginger (Kasemsuwan *et al*., 1998; Surojanametakul *et al.,* 2002; Kaur *et al*., 2005; Thao and Noomhorm, 2012; Qazi *et al*., 2014; Quaisie *et al*., 2017).

Yam (*Dioscorea* spp.) and cocoyam *(Colocasia esculenta)* are two important food crops in many parts of Africa, Asia, and the Caribbean (Baah *et al*., 2009). Cocoyam is a good starch source for domestic and industrial utilisation in tropical Africa due to its high carbohydrate content and availability. However, in terms of industrial application, cocoyam would be regarded as underutilised when compared with cassava and potatoes, even though there have been extensive studies on its starch (Lawal O. S., 2004; Mweta *et al*., 2010; Gbadamosi & Oladeji, 2013; Obadina *et al*., 2013; Ashogbon, 2014). Tetchi *et al*. (2007) and Nwokocha *et al*. (2009) reported higher amylose levels in cocoyam starch (26.7% and 33.3%, respectively), which makes it suitable for noodles production. That is, the amylose content of starch or flour is significantly correlated with its noodle quality. Yam (*Dioscorea spp*.), on the other hand, has about 70–82% digestible starch (Gallant *et al*., 1982; Amoo *et al*., 2014), with an amylose level of 31.33% (Aprianita *et al*., 2009), and exhibits more stability against heat and mechanical treatment due to its viscosity stability at high temperatures (Amoo *et al*., 2014). Peroni *et al*. (2006) reported that yam has a higher phosphorus content (0.022%) than other tropical root and tuber crops (cassava and sweet potato). It is, therefore, indispensable to increase the use of these underutilised crop starches in order to reduce the pressure on the existing commercial starches as well as extend the application of these crops in food systems. Hence, this study sought to determine the effects of starches from these underutilised Ghanaian crops (cocoyam and yam) on rice flour paste and its noodle quality.

Materials and methods

Materials

Rice flour was provided by Nanjing Ganzhiyuan Sugar Co., Ltd. and Cho Heng Rice Vermicelli Factory Co., Ltd., China. Council for Scientific and Industrial Research, CSIR-Food Research Institute (FRI), Ghana, provided the native yam (*CRI-Pona*) and cocoyam (*CRI-Gye me de, SCJ98/005*) starch powders.

Methods

Rice flour: starch blend formulations

Pure rice flour (RF) was substituted at 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100 (wb) ratios, each with yam starch (YS) and cocoyam starch (CYS). To ensure granules of homogeneous size, the uniformly blended samples were sieved with an 80-mm mesh sieve, packaged in airtight polythene bags, and stored at 4 °C until used.

Colour determination

The colours L* (lightness/darkness), a* (hue, red/green), and b* (hue, yellow/blue) of both raw and cooked noodles prepared from pure RF, YS, and CYS and their formulated blends were determined (in triplicates) using a chroma metre (CR-400, Japan). The whiteness value was calculated according to Eq. (1).

$$\text{Whiteness} = \sqrt{(100 - L)^2 + a^2 + b^2}$$

Amylose content determination

The amylose content of rice flour and the formulated blends with various starches were determined by following the iodine colorimetric method described by Ratnayake *et al*. (2001).

Determination of swelling power and solubility

The swelling power (SP) and solubility index (S) of pure RF and native starches with their formulated blends were measured using the method described by Oke *et al.* (2013). The swelling power (SP) and solubility index (S) were calculated as:

$$S = \frac{\textit{weight of soluble starch / floor}}{\textit{weight of sample on dry basis}} \times 100$$

$$SP = \frac{\textit{weight of sedimented paste}}{\textit{weight of sample on dry basis} \times (100 - s)} \times 100$$

Pasting properties
The pasting analysis of RF and native starch formulations (at various ratio levels) was carried out by following the methods outlined by Quaisie *et al*. (2017).

Noodles preparation
The noodles were prepared with RF, native cocoyam and yam starch, and their formulated blends (28 g sample). Firstly, 3.0 g of the sample was gelatinized with 20 mL of boiled distilled water and then added to 25 g of the sample to make a 45% slurry concentration. This was transferred into a 20-cm-diameter acrylic plate, then spread uniformly to form a sheet of about 1.0 mm thickness, and finally allowed to equilibrate for 5 minutes. To complete the gelatinization step, it was steamed for 4 minutes at 92.5 °C and immersed in cold water for about 1 minute. The noodle sheet was retrograded for 30 min at 25 °C, then scraped and cut into strips of 5 mm in width and dried at 40 °C in a convection dryer to 12% moisture content.

Cooking quality of noodles
The noodles cooking qualities, such as cooking loss (CL), rehydration (Re), broken rate (Br) and cooking time (Ct) were determined according to the methods described by Hormdok & Noomhorm (2007). Broken rate (Br) was measured by recording the number of broken noodles after cooking and calculated as:

$$\textit{Broken rate}\ (\%) = \frac{\textit{number of broken noodle strands}}{\textit{initial number of noodle strands used}} \times 100$$

Texture analysis of noodles
The texture of the cooked noodles, kept in a covered Petri dish, was analysed within 15 minutes (after cooking) using a texture analyser (TA/XT2i, Stable Micro Systems, Surrey, UK). Texture profile analysis (TPA) was carried out as described by Bhattacharya *et al*. (1999). A cylinder probe (P/36) was used to compress a strand of cooked noodles with a thickness of 1.0 mm until 75% deformation was attained at a speed of 1.0 mm/s. A 0.5-second pause was allowed between the first and second compressions. From the force-time curve of the texture profile, textural parameters, including hardness (HD), springiness (SP), cohesiveness (CO), gumminess (GU), and chewiness (CH) were obtained. Ten independent measurements were made for each sample.

Sensory evaluation
Both dried and cooked noodle samples were prepared for sensory evaluation by panelists. For the cooked noodles, samples were boiled within the optimum cooking time. The samples stored in tightly covered plastic food containers were tested within 30 minutes after cooking. Cooked noodles were assessed for taste, appearance, texture, flavour, and overall acceptability by 60 participants recruited from the Food Science Department of Hunan Agricultural University in Changsha, China, using a five-point hedonic scale, where 5 = like very much and 1 = dislike very much. Each panelist assessed six samples per day in four batches (24 samples in total) in a balanced sequential order

Statistical analysis
The experiments and analysis were conducted in triplicate. A one-way ANOVA test and the Duncan Multiple Range Test (DMRT) were used to analyze the data in order to compare means at the 0.05 level of significance. Pearson's correlation coefficient was calculated using SPSS version 23.

Results and Discussions

Colour characteristics of rice flour and native starches
Colour plays an essential role in the assessment of rice noodle quality for consumers (Thomas *et al*., 2014). There were

Table 1. The colour values of pure rice flour, native yam and cocoyam starch

Sample	L*	a*	b*	whiteness
RF: YS/CYS				
RF (100:0)	96.72± 0.10[a]	0.04± 0.01[c]	2.52± 0.01[c]	95.82± 0.11[a]
YS (0:100)	91.08± 0.12[b]	0.62± 0.03[b]	4.69± 0.01[a]	89.90± 0.10[b]
CYS (0:100)	89.20± 0.17[c]	1.12± 0.02[a]	4.49± 0.04[b]	88.12± 0.30[c]

Different letters within each column represents significant ($p < 0.05$) differences. Rice flour (RF), yam starch (YS), cocoyam starch (CYS)

significant ($p<0.05$) differences among RF, YS and CYS in terms of L*, a*, b*, and whiteness (Table 1). RF had a significantly lower degree of redness and yellowness than YS and CYS. In contrast, RF had a significantly higher degree of lightness and whiteness than YS and CYS (Table 1). The results of the colour measurement also showed that the degree of redness was highest in CYS (a* = 1.12), whereas the degree of yellowness was highest in YS (b* = 4.69). These findings suggest that the colour of the formulated blends of RF with YS and CYS could significantly influence the overall whiteness of the samples, which will, in turn, affect the colour of the noodles produced. Tan *et al*. (2009) reported that starches with lower chroma but a higher lightness are preferred for noodle processing.

Physiochemical characteristics of RF, native starches and their formulated blends.

The swelling power (SP), water binding capacity (WBC), solubility (S), and amylose content of RF, native starches, and their formulated blends (Table 2) varied significantly ($p < 0.05$) probably due to the variation in their crystalline nature, granule structure, size distribution, and stability of the starch (Zuluaga *et al*., 2007). The amorphous and crystalline domains of starch can be assessed by its solubility (S) and swelling power (SP) (Sandhu & Singh 2007). The low SP of RF (10.82 g/g) characterizes it as a highly restricted-swelling starch, which is a desirable characteristic for noodles preparation; that is, the cross-linkages within their granules reduce their swelling and stabilize them against shearing during cooking in water (Massaux *et al*., 2008; Oke *et al*., 2013). The SP of YS (16.10 g/g) also fell within restricted-swelling starches, while that of CYS (21.60 g/g) fell under moderately swelling starches. The YS and CYS significantly affected the SP of RF's blends according to their proportionate increments. However, the blends with YS remained a highly restricted-swelling starch, which is still appropriate for noodles. The presence of amylose crystallites in place of gluten in rice flour supports the creation of a solid network through linkage building at junction zones (Mestres *et al*., 1988). Also, an increase in amylose content tends to restrict the swelling of starch, which is a desirable characteristic for the production of value-added products such as noodles (Shimelis & Rakshit, 2005). Hence, all the starches under study could improve the qualities of rice noodles produced from their formulated blends since all the samples, including rice flour (RF), had a high amylose content ranging from 26.05 to 40.80%. Also, starch with a high amylose content has higher firmness, resulting in a high resistance of the starch to take up water

Table 2. Physiochemical properties of rice flour, native yam and cocoyam starch and their formulated blends

Sample	WBC (%)	SP (g/g)	S (%)	Total amylose content (%)
RF: YS/CYS				
RF (100:0)	94.40 ± 0.25^{e}	10.82 ± 0.16^{g}	9.40 ± 0.52^{f}	26.05 ± 0.18^{i}
YS (0:100)	112.70 ± 2.35^{bc}	16.10±0.26^{c}	14.13± 0.64^{b}	40.80 ± 0.12^{a}
CYS (0:100)	110.00 ± 2.96^{cd}	21.60 ± 0.87^{a}	14.27 ± 0.61^{b}	33.17 ± 0.80^{d}
RF:YS (80:20)	116.23±1.37^{ab}	12.03±0.15^{f}	9.93 ± 0.12^{ef}	29.35 ± 0.56^{g}
RF:YS (60:40)	116.37±1.80^{ab}	12.93±0.35^{e}	10.93 ± 0.50^{e}	31.97 ± 0.02^{e}
RF:YS (40:60)	117.03±3.32^{a}	13.23±0.23^{e}	12.73 ± 0.50^{cd}	34.92 ± 0.02^{c}
RF:YS (20:80)	117.60±0.52^{a}	14.13±0.57^{d}	13.73 ± 0.64^{bc}	37.86 ± 0.04^{b}
RF:CYS (80:20)	117.80 ± 1.77^{a}	12.83 ± 0.21^{e}	10.67 ± 0.46^{e}	27.50 ± 0.05^{h}
RF:CYS (60:40)	109.77 ± 5.39^{cd}	14.53 ± 0.42^{d}	12.47 ± 0.92^{d}	28.90 ± 0.12^{g}
RF:CYS (40:60)	107.43 ± 1.15^{d}	16.27 ± 0.32^{c}	12.87 ± 0.46^{cd}	30.20 ± 0.10^{f}
RF:CYS (20:80)	112.13 ± 1.62^{bc}	19.80 ± 0.36^{b}	15.53 ± 0.61^{a}	31.71 ± 0.07^{e}

RF, YS, CYS are rice flour, yam, and cocoyam starch respectively. Mean ± SD values superscripted by different letters are significantly different ($p < 0.05$). SP = swelling power, WBC = water binding capacity, S = solubility

to swell (Table 2).

Pasting properties

The pasting properties of RF, the various starches, and their formulated blends are summarized in Table 3. The rigidity of the starch granules affects the granule swelling potential on which the pasting property is dependent (Bhattacharya *et al*., 1999). Rice noodle quality may be predicted by the RVA and textural parameters of the gel since there is a significant correlation between them (Bhattacharya *et al*., 1999). The results revealed significant differences in pasting characteristics among the starch samples, probably due to the differences in their amylose content (Egharevba, 2019). According to Gujral *et al*. (2013), the lipid content and the homopolysaccharide constituent compounds (amylose and amylopectin) affect the pasting properties of starch. Both YS and CYS showed higher PV than RF probably due to enhanced granule swelling in connection with amylose leaching (Qazi *et al*., 2014). The PV of RF significantly increased with the addition of YS and CYS in their formulated blends, with formulated YS blends recording higher values than CYS blends (Table 3). Our finding agrees with the report by Qazi *et al*. (2014) that the interaction of starches with RF influences the PV of RF. The trough viscosity (TV) values ranged between 143.20 and 258.67 RVU, with YS recording the highest value (Table 3). According to Yadav *et al.* (2011), noodles produced from starch paste with higher TV have superior eating qualities; hence, noodles from the various starches under study with RF blends may result in the aforementioned.

The ability of a sample to withstand heat and shear stress is determined by its relative breakdown (RBD) (Adebowale *et al.,* 2005). The rank order for RBD for the pure starches and rice flour was CYS>RF>YS. The RBD significantly decreased with an increased proportion of YS in the RF formulated blends, whereas RBD increased with an increased proportion of CYS in the RF formulated blends. FV significantly increased with an increased proportion of YS in RF formulated blends, whereas an increased proportion of CYS in RF formulated blends resulted in a significant decrease (Table 3). Higher FV values of YS and its blends with RF may be due to the retrogradation ability of high-soluble amylose in YS during cooling (Gujral *et al*., 2013). The difference between the viscosity of the hot and cold pastes of the starch describes its setback. Except for RF:YS (80:20), RF had a significantly higher relative setback (RSB) than all the samples studied. Substitution of RF with increasing proportions of YS and CYS significantly reduced the RSB of RF. This finding agrees with the findings of Qazi *et al*. (2014) and Zaidul *et al*. (2007), who recorded reductions in the RSB of rice and wheat when blended with corn, canna, and sweet potato starch, respectively. Gujral *et al*. (2013) reported a significant correlation between the FV, RSB, and PV of starches isolated from different barley cultivars, which concurs with the results reported herein. From the results of this study, all the starches had a lower pasting temperature (P_T) and peak time (P_t) when compared to RF, which, in effect, reduced the pasting temperature (P_T) and peak time (P_t) of their formulated blends suggesting that YS and its blends with RF are economically desirable (Baah *et al.,* 2009; Oke *et al*., 2013). However, Peroni *et al*. (2006) also investigated the thermal, shear, and mechanical stability of starches and concluded that starches with higher P_T (as seen with RF) have strong bonding forces in the granule interior, which turn out to provide higher mechanical agitation resistance. The blending of YS and CYS at various proportions significantly influenced RF's pasting properties (PV, TV, RBD, FV, RSB, P_t, and PT). In this study, the pasting properties depended on the starch type and

Table 3. Pasting properties of Rice flour paste, native corn, potato, yam and cocoyam starch and their formulated blends

Sample	PV (RVU)	TV (RVU)	RBD (RVU)	FV (RVU)	RSB (RVU)	P_{time}(min)	PT (°C)
RF: YS/CYS							
RF (100:0)	173.30±1.57^{i}	143.20±2.27^{h}	17.37±1.03^{d}	308.28±1.54^{f}	53.55±0.80^{a}	6.64±0.8^{a}	89.57±0.46^{a}
YS (0:100)	307.86±5.92^{a}	258.67±4.79^{a}	15.98±0.26^{e}	473.80±5.56^{a}	45.41±0.86^{d}	5.27±0.07^{f}	81.70±0.05^{d}
CYS (0:100)	213.75±2.32^{d}	147.92±3.41^{gh}	30.80±0.85^{a}	236.39±4.05^{k}	37.43±0.56^{g}	4.87±0.00^{g}	82.60±0.00^{c}
RF:YS (80:20)	196.47±1.00^{f}	167.33±0.88^{e}	14.83±0.76^{f}	350.89±5.51^{e}	52.30±0.92^{a}	6.53±0.07^{a}	84.80±0.44^{b}
RF:YS (60:40)	207.17±2.39^{e}	185.17±1.96^{d}	10.62±0.39^{g}	366.08±7.56^{d}	49.41±0.52^{b}	6.18±0.04^{b}	83.40±0.05^{c}
RF:YS (40:60)	226.33±1.67^{c}	205.64±2.14^{c}	9.15±0.35^{h}	386.83±2.30^{c}	46.84±0.43^{c}	5.73±0.07^{d}	82.60±0.88^{c}
RF:YS (20:80)	240.44±6.96^{b}	234.55±6.56^{b}	2.45±0.11^{i}	405.58±7.63^{b}	42.18±0.53^{ef}	5.38±0.04^{e}	81.75±0.05^{d}
RF:CYS (80:20)	184.50±1.67^{h}	158.89±1.97^{f}	13.88±0.33^{f}	289.47±1.09^{g}	45.11±0.52^{d}	6.62±0.04^{a}	84.23±0.03^{b}
RF:CYS (60:40)	190.17±0.44^{g}	158.56±1.22^{f}	16.62±0.57^{de}	280.25±4.23^{h}	43.41±1.28^{e}	5.91±0.10^{c}	83.13±0.51^{c}
RF:CYS (40:60)	196.39±0.71^{f}	152.42±1.20^{g}	22.39±0.35^{c}	261.39±1.22^{i}	41.69±0.70^{f}	5.20±0.07^{f}	82.58±0.82^{c}
RF:CYS (20:80)	212.53±4.42^{d}	152.75±1.54^{g}	28.12±0.91^{b}	246.25±0.98^{j}	37.97± 0.56^{g}	4.87±0.00^{g}	83.18±0.46^{c}

RF, YS, CYS are rice flour, yam, and cocoyam starch respectively. Mean ± SD values superscripted by different letters are significantly different ($p < 0.05$). SP = swelling power, WBC = water binding capacity, S = solubility concentration. The reports by Zaidul *et al*. (2007), Punchaarnon *et al.* (2008), and Qazi *et al*. (2014) validate the outcome of this study.

Cooking loss (%) and rehydration (%)
Cooking loss and degree of rehydration (degree of swelling) are two major factors that inform consumer choice while purchasing noodles. Good quality rice noodles must remain firm, chewy, and non-sticky after cooking; they must cook fast with little cooking loss (Zuluaga *et al*., 2007). Noodles prepared from pure RF had a lower cooking loss (6.76%) than YS, CYS, and their blends (Fig. 1a). Though both YS and CYS caused a significant ($p < 0.05$) increase in the cooking loss of RF in their formulated blends at an increasing concentration, the cooking loss caused by CYS was rather moderate. The differences in the cooking loss of the various samples studied could be associated with the differences in the starch granule swelling ability, resulting in a corresponding difference in resistance to shear-induced disintegration. This result agrees with Surojanmetakul *et al*. (2002), who blended rice flour with potato, corn, and cassava starches. Thomas *et al*. (2014) also recorded much higher cooking losses in noodles made from flour (Korean varieties) of different rice genotypes (6.7–46.9%). Optimal rehydration is a desirable characteristic of cooking quality in noodles and, therefore, needs to be considered since insufficient rehydration usually results in a hard, coarse texture of the noodles, in contrast; excess water uptake often produces noodles that are too soft and sticky (Hormdok & Noomhorm, 2007). YS and CYS had higher rehydration rates (287.37% and 305.01%, respectively) than RF. However, these higher rehydration rates observed in the starches under study did not significantly increase the rehydration rate of RF and contrasts the findings by Surojanmetakul *et al*. (2002), who reported a significant increase in rehydration yield when rice flour was blended with potato and cassava starch. These findings suggest that the ability of a starch to rehydrate depends on the starch source since different starches have different granule structures and swelling powers.

Cooking time (min) and broken rate (%)
Figure 1b shows the graph for the broken rate of cooked rice noodles. By keeping a constant time for cooking, pure RF had the highest broken rate, followed by YS and CYS. There was no significant (p>0.05) effect on the broken rate of noodles prepared by blending RF with either YS or CYS. Prominent features of good quality noodles require a lower cooking time and a minimum loss of solids in the cooking water (Yadav *et al*., 2014). Both YS and CYS had a lower cooking time than RF and, therefore, decreased the cooking time of RF in their formulated blends at an increasing concentration (Fig. 1b). The difference in the cooking time of the various samples under study will affect the textural properties of their respective noodles as well as reduce the energy required for optimum cooking.

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Textural Properties of Rice Flour: Starch Noodles
The texture of cooked noodles is an indispensable characteristic of noodle products that determines their acceptance by consumers. From the TPA (Table 4), the hardness of noodles prepared from RF and the formulated blends with starch varied from 10876.04 g to 4330.71 g, with both YS (5008.68 g) and CYS (4330.71 g) having lower values as compared to RF (7252.40 g). The starches under study tend to decrease RF's hardness (HD) of RF in their blends, except for 80:20 (RF: YS and RF: CYS). The magnitude of the values recorded in this study for HD was higher than that reported by Bhattacharya *et al*. (1999). Noodle elasticity is measured by its springiness (SPr). The SPr produced by YS and CYS were lower than RF.

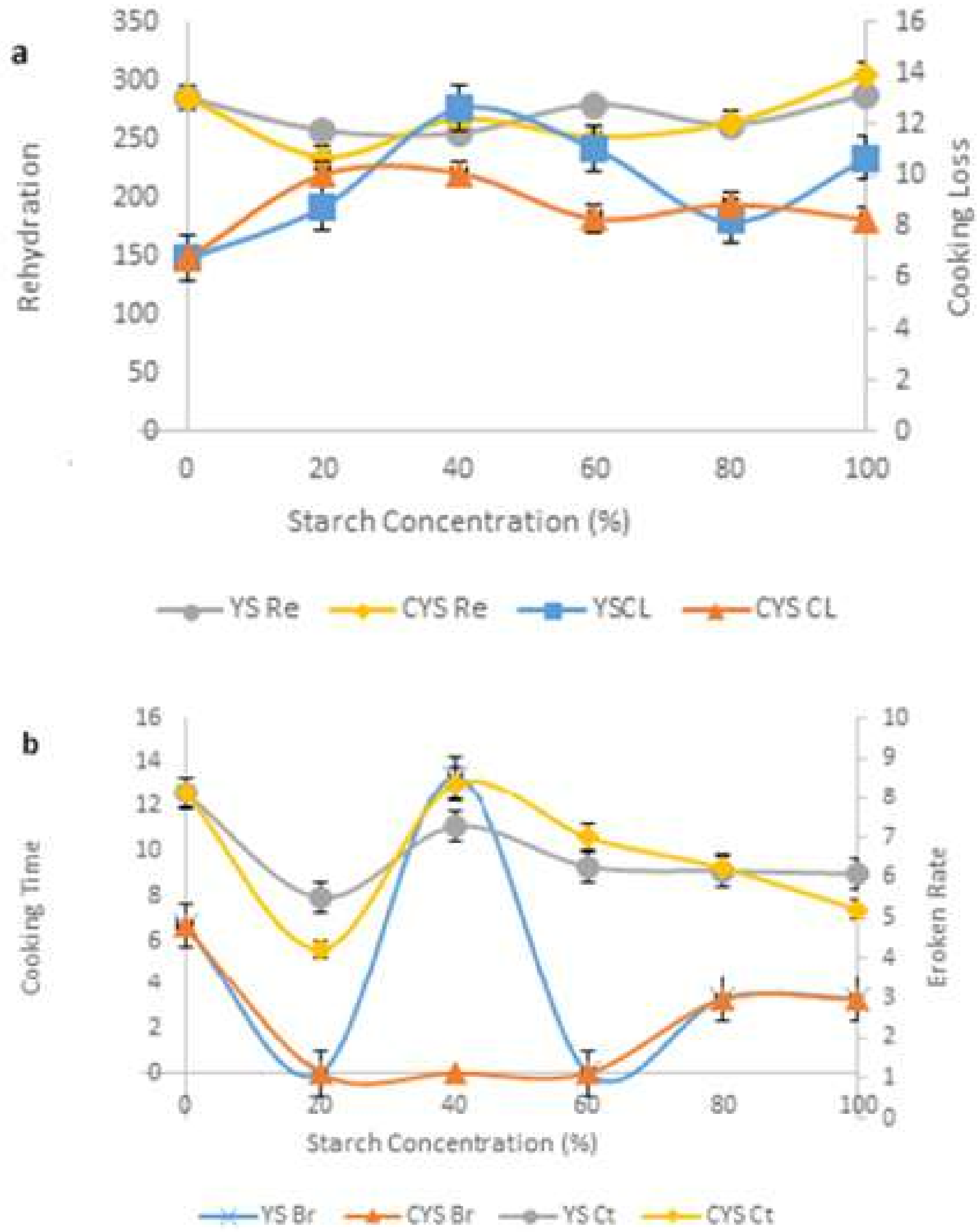

Figure 1. (a) Cooking Loss, CL (%) and Rehydration, Re (%), (b) Broken Rate, Br (%) and Cooking Time, Ct (min) representing the cooking quality of noodles from Rice flour (RF), native yam and cocoyam starch and their blend formulation.

Table 4. Textural properties of rice flour noodles native yam and cocoyam starch and their blend formulations

Sample	Hardness	Springiness	Cohesiveness	Gumminess	Chewness
RF: YS/CYS					
RF (100:0)	7252.40[bc]	1.02[abc]	0.82[de]	5892.60[bc]	6085.05[ab]
YS (0:100)	5008.68[cd]	0.92[bcd]	0.89[ab]	4464.00[c]	4119.11[bc]
CYS (0:100)	4330.71[d]	0.83[cd]	0.88[bc]	3855.26[c]	3213.98[c]
RF: YS (80:20)	10876.04[a]	1.04[ab]	0.81[e]	8705.29[a]	8335.68[a]
RF: YS (60:40)	6578.64[bcd]	1.14[a]	.86[bc]	5660.05[bc]	5751.92[bc]
RF: YS (40:60)	4575.41[cd]	0.94[bcd]	0.85[cd]	3879.41[c]	3675.59[bc]
RF: YS (20:80)	4736.57[cd]	0.91[bcd]	0.88[bc]	4264.76[c]	3886.17[bc]
RF: CYS (80:20)	8033.25[b]	0.84[bcd]	0.92[a]	7424.72[ab]	6353.72[ab]
RF: CYS (60:40)	5403.02[bcd]	0.79[d]	0.89[ab]	4202.12[c]	3858.27[bc]
RF: CYS (40:60)	5591.15[bcd]	0.80[d]	0.89[ab]	4993.28[c]	4072.14[bc]
RF: CYS (20:80)	4890.13[cd]	0.91[bcd]	0.87[bc]	4279.00[c]	3808.09[bc]

Significant difference at $p < 0.05$ exists between means with different letters in the same column

Hence, their formulated blends with RF also had lower SPr, except for RF: YS (80:20, 60:40).

Hou *et al*. (1997) reported that hardness, cohesiveness, and chewiness are the eating qualities of cooked noodles. YS and CYS increased the cohesive value of the various RF substituted blends. Except for the 80:20 (RF:YS and RF:CYS), YS and CYS did not significantly ($p > 0.05$) influence the gumminess of the RF formulated blends (Table 4). Similar results were recorded for the chewiness of RF and its formulated blends with YS and CYS. The TPA has shown that noodles prepared from RF:YS (80:20) had higher hardness, chewiness, elasticity, and gumminess, as well as less cohesiveness (stickiness) than the other samples. In contrast, most of the noodle samples produced from the RF: CYS blends were softer and less chewy in texture.

Sensory characteristics and consumer acceptance of raw and cooked noodles

Consumers are keen on selecting quality noodles; they highly prefer noodles with excellent characteristics such as a transparent appearance, a strong bite with a smooth, firm surface, and a non-sticky elastic texture (Zhang *et al*., 2010). Results from the sensory evaluation of raw and cooked noodles showed that the appearance of both raw and cooked noodles made from YS and its blends with RF had higher acceptability than those made from CYS and its blends (Table 5). This observation may be due to the darker colour of CYS, which tends to lower the whiteness of the noodles in the formulation with RF. Regarding preference for texture, CYS noodles had the lowest value of 2.27 due to their lower hardness and chewiness resulting from the high SP of the starch granule (Lauzon *et al*., 1995). This is further evinced by the rapid swelling ability (lower pasting

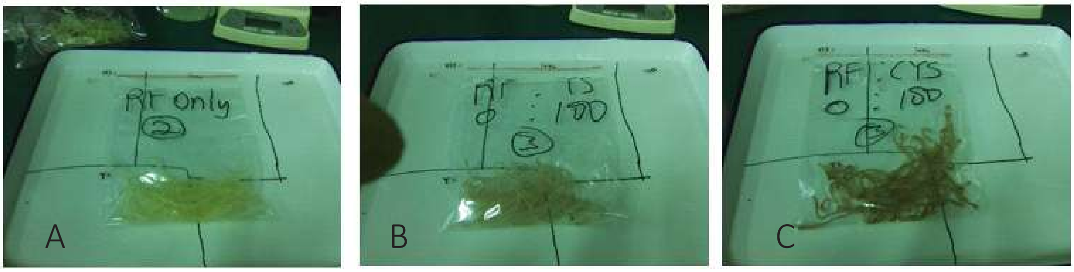

Fig. 2: Image of dried noodles prepared from A: Rice flour only; B: Yam starch only; C: Cocoyam starch only

Table 5. Sensory evaluation of (Raw-dry/cooked) Noodles

Sample	Cooked Noodles					Dry Noodles		
	Appearance (colour)	Texture	Flavour	Taste	Overall acceptability	Appearance (colour)	Texture	Overall acceptability
RF: YS/CYS								
RF (100:0)	4.03±0.4^{a}	3.67± 0.6^{a}	3.93± 0.3^{a}	3.80± 0.5^{a}	4.10± 0.3^{a}	4.20± 0.5^{a}	4.18± 0.5^{a}	4.17± 0.4^{a}
YS (0:100)	2.58± 0.5^{d}	2.63± 0.5	2.28± 0.5^{f}	2.52± 0.5^{d}	2.67± 0.5^{fg}	2.70± 0.5^{cd}	3.73± 0.6^{b}	2.93± 0.6^{cdef}
CYS (0:100)	2.00± 0.3^{e}	2.27± 0.4^{f}	2.35± 0.5^{e}	2.55± 0.6^{d}	2.48± 0.5^{g}	1.97± 0.2^{f}	2.85± 0.4^{f}	2.67± 0.5^{f}
RF: YS (80:20)	4.00± 0.4^{a}	3.68± 0.6^{a}	3.72± 0.6^{ab}	3.78± 0.8^{a}	3.75± 0.5^{b}	4.07± 0.4^{a}	3.32± 0.7^{cde}	3.35± 0.5^{b}
RF: YS (60:40)	3.97± 0.3^{a}	3.00± 0.2^{bcd}	3.42± 0.6^{bc}	3.48± 0.7^{ab}	3.30± 0.5^{c}	3.22± 0.6^{b}	3.57± 0.8^{bc}	3.27± 0.6^{bc}
RF: YS (40:60)	3.07± 0.3^{b}	2.92± 0.3^{cd}	3.30± 0.6^{c}	3.37 0.6^{b}	3.23± 0.4^{c}	3.15± 0.4^{b}	3.47± 0.8	3.23± 0.7^{bcd}
RF: YS (20:80)	2.70± 0.5^{cd}	3.07± 0.3b^{cd}	2.88± 0.3^{d}	2.97± 0.2^{c}	3.10± 0.3^{cd}	2.78± 0.5^{c}	3.05± 0.5^{ef}	2.98± 0.7^{bcdef}
RF: CYS (80:20)	3.10± 0.6^{b}	3.20± 0.4^{b}	3.75± 0.5^{a}	3.35± 0.5^{b}	3.17± 0.4^{cd}	2.82± 0.7^{c}	3.13± 0.7^{def}	3.07± 0.9^{bcde}
RF: CYS (60:40)	2.88± 0.7^{bc}	3.17± 0.6b^{cd}	3.42± 0.8^{bc}	2.98±0.2^{c}	3.05± 0.6^{cde}	2.58± 0.8^{cd}	2.92± 0.6^{f}	2.92± 0.9^{cdef}
RF: CYS (40:60)	2.77± 0.4^{cd}	3.07± 0.3^{bcd}	3.37± 0.6^{c}	2.70± 0.5^{cd}	2.93± 0.3^{de}	2.47± 0.5^{de}	3.47± 0.8^{bcd}	2.87± 0.3^{def}
RF: CYS (20:80)	2.62± 0.5^{cd}	2.87± 0.3^{de}	3.25± 0.5^{c}	2.63± 0.6^{cd}	2.82± 0.4^{ef}	2.25± 0.4^{ef}	3.42± 0.8^{bcde}	2.78± 0.4^{ef}

Means with different letters in the same column are significantly different from each other at $P < 0.05$

time) of the granules of CYS, demonstrating its lower resistance to swelling and, hence, its susceptibility to disintegration due to induced shear (Sefa-Dedeh *et al*., 2002). The flavour of noodles made from RF was very well accepted compared to the two starches under study; this concurs with the findings from Fari *et al*. (2011) and Surojanametakul *et al*. (2002). The taste of noodles prepared from RF was highly accepted compared to those made from YS and CYS and their formulated blends with RF. However, the taste of the noodle sample prepared from RF: YS (80:20) was not significantly (p>0.05) different from RF.

In general, YS stands out among the two starches by positively influencing the acceptability of RF in their formulated blends and, therefore, stands a better chance of being selected over CYS.

Pearson correlations between textural, cooking, and sensory properties of cooked noodles.

The hardness of the noodles produced did not significantly affect the cooking loss of the noodles, even though there was a positive correlation among them (Table 6), implying that the cooking loss of noodles is independent of the hardness of the noodles. On the other hand, the hardness of the noodles had a significant positive correlation with the overall acceptability of both raw and cooked noodles (r = 0.578 and 0.731 at $p < 0.01$). Furthermore, the hardness (r = -0.568) and cooking time (r = -0.697) of the noodles negatively correlated with rehydration. The cooking time is significantly dependent on the noodle's hardness. The rehydration and cooking time of the noodles were also determined by their gumminess and chewiness, as there was a negative and positive significant correlation between them respectively (Table 6). The overall acceptance of the raw noodles had a significant positive correlation with the overall acceptance of cooked noodles. Thus, the qualities of cooked noodles can be predicted by the qualities of raw (dry) noodles. In general, the noodles textural properties correlated well with the cooking and sensory properties of the noodles.

Conclusion and recommendation

Blending native YS and CYS with RF at

Table 6. Correlations among sensory properties, textural properties (paste and cooked noodles) and cooking properties of noodles

	ACCN	ACRN	CL	Re	Br	Ct	HDg	SPrg	COg	GUg	CHg	HD	SPr	GO	GU
ACRN	.904**														
CL	-.237	-.339													
Re	-.337	-.098	-.697**												
Br	-.038	.051	.170	.113											
Ct	.846**	.669**	.167	-.683**	-.084										
HDg	.102	.136	.257	-.299	-.164	.298									
SPrg	.261	.205	-.390	.057	-.064	.220	.111								
COg	.314	.255	-.467*	.067	-.225	.258	.178	.891**							
GUg	.362	.322	-.147	-.185	-.234	.425	.654**	.708**	.833**						
CHg	.364	.323	-.156	-.182	-.234	.423	.636**	.727**	.842**	.999**					
HD	.731**	.578**	.199	-.568**	-.032	.838**	.410	.305	.235	.496*	.497*				
SPr	.238	.270	-.060	.097	.554**	.016	-.584**	-.226	-.415	-.591**	-.582**	.039			
CO	-.794**	-.824**	.370	-.019	-.080	-.515*	.053	-.164	-.199	-.201	-.204	-.578**	-.431		
GU	.695**	.536*	.243	-.604**	-.025	.829**	.427	.291	.216	.488*	.488*	.993**	.018	-.499*	
CH	.737**	.579**	.227	-.578**	.072	.838**	.305	.247	.148	.372	.373	.981**	.192	-.575**	.980**

ACC = overall acceptability of cooked noodles; ACRN = overall acceptability of raw noodles; CL= cooking loss; Re= rehydration; Br = broken rate; HDg = hardness of gel; SPrg = springiness of gel; COg = cohesiveness of gel; GUg = gumminess of gel; CHg = chewiness of gel; HD = hardness of noodles; SPr = springiness of noodles; CO = cohesiveness of noodles; GU = gumminess of noodles; CH = chewiness of noodles; *, ** = significant at p<0.05 and p<0.01, respectively.

various concentrations resulted in RF's variation in the physiochemical, pasting, textural, cooking, and sensory properties. YS exhibited higher trough viscosity, final viscosity, and pasting viscosity, which makes it better for selection over CYS in the blend formulation with RF. Noodles made from CYS and its formulated blends were least accepted by consumers due to their lower hardness, chewiness, gumminess, and whiteness. Although the starch source and the proportion added to RF significantly influenced the noodles' properties, the noodles' overall acceptability was instead determined by the starch source and not the ratio of a particular added starch. The cooking and sensory characteristics of noodles were highly predicted by their textural properties.

It is recommended that to improve the textural, shear resistance, thermal resistance, and retrogradation properties of native yam and cocoyam starches, physical (hydro-thermal) and chemical (etherification, esterification, cross-linking) treatments could be adopted.

Conflict of interest

All authors declare that they have no conflicts of interest.

References

American Association of Cereal Chemists. Approved Methods Committee, 2000. Approved methods of the American association of cereal chemists. AACC.

Adebowale, Y. A., Adeyemi, I. A. & Oshodi, A. A. 2005. Functional and physicochemical properties of flours of six Mucuna species. *African Journal of Biotechnology* 4(12): 1461 - 1468

Amoo, A. R. N., Wireko-Manu, F.D. & Oduro I. 2014. Physicochemical and Pasting Properties of Starch Extracted from Four Yam Varieties. *Journal of Food and Nutrition Sciences* 2(6): 262-269.

Aprianita, A., Purwandari, U., Watson, B. & Vasiljevic, T. 2009. Physico-chemical properties of flours and starches from selected commercial tubers available in Australia. *International Food Research Journal* 16: 507-520.

Ashogbon AO. 2014. Chemical and functional properties of cocoyam starch and wheat starch blends. *International Journal of Biotechnology and Food Science* 2: 94-101.

Baah, F.D., Maziya-Dixon, B., Asiedu, R., Oduro, I. & Ellis, W.O. 2009. Nutritional and biochemical composition of D. alata (Dioscorea spp.) tubers. *J. Food Agric. Environ* 7(2): 373-378.

Bhattacharya, M., Zee, S. Y. & Corke, H. 1999. Physicochemical properties related to quality of rice noodles. *Cereal chemistry* 76(6): 861-867.

Charutigon, C., Jitpupakdree, J., Namsree, P. & Rungsardthong, V. 2008. Effects of processing conditions and the use of modified starch and monoglyceride on some properties of extruded rice vermicelli. *LWT-Food Science and Technology* 41(4): 642-651.

Collin, P., Kaukinen, K., Välimäki, M. & Salmi, J. 2002. Endocrinological disorders and celiac disease. *Endocrine reviews* 23(4): 464 - 483.

Fari, M. J. M., Rajapaksa, D. & Ranaweera, K. K. D. S. 2011. Quality characteristics of noodles made from selected varieties of Sri Lankan rice with different physicochemical characteristics. *Journal of the National Science Foundation of Sri Lanka* 39(1).

Gallant D. J, H. Bewa, Q. H. Buy, B. Bouchet, O. Szylit & L. Sealy. 1982. Ultrastructural and nutritional aspects of some tropical tuber starches. *Starch/Stärke* 34: 255-262.

Gbadamosi, S. O. & Oladeji, B. S. 2013. Comparative studies of the functional and physico-chemical properties of isolated cassava, cocoyam and breadfruit starches. International Food Research Journal 20(5): 2273-2277.

Goldstein, N. S. & Underhill, J. 2001. Morphologic features suggestive of gluten sensitivity in architecturally normal duodenal biopsy specimens. *American journal of clinical pathology* 116(1): 63-71.

Gujral, H. S., Sharma, P., Kaur, H. & Singh, J. 2013. Physiochemical, Pasting, and Thermal Properties of Starch Isolated from Different Barley Cultivars. International Journal of Food Properties 16(7): 1494 – 1506.

Hormdok, R. & Noomhorm, A. 2007. Hydrothermal treatments of rice starch for improvement of rice noodle quality. *LWT-Food Science and Technology* 40(10): 1723-1731.

Hou, G., Kruk, M., Petrusich, J. & Colletto, K. 1997. Relationships between flour properties and Chinese instant fried noodle quality for selected US wheat flours and Chinese commercial noodle flours. *Journal of Chinese Cereal and Oil Association* 12: 7-13.

Kaur, L., Singh, J. & Singh, N. 2005. Effect of glycerol monostearate on the physico-chemical, thermal, rheological and noodle making properties of corn and potato starches. *Food Hydrocolloids* 19(5): 839-849.

Kasemsuwan, T., Bailey, T. & Jane, J. 1998. Preparation of clear noodles with mixtures of tapioca and high-amylose starches1. *Carbohydrate Polymers* 36(4): 301-312.

Lauzon, R.D., Shiraishi, K., Yamazaki, M., Sawayama, S., Sugiyama, N. & Kawabata, A. 1995. Physicochemical properties of cocoyam starch. *Food hydrocolloids* 9(2): 77-81.

Lawal, O.S. 2004. Composition, physicochemical properties and retrogradation characteristics of native, oxidised, acetylated and acid-thinned new cocoyam (Xanthosoma sagittifolium) starch. *Food chemistry* 87(2): 205-218.

Massaux, C., Sindic, M., Lenartz, J., Sinnaeve, G., Bodson, B., Falisse, A. & Deroanne, C. 2008. Variations in physicochemical and functional properties of starches extracted from European soft wheat (Triticum aestivum L.): The importance to preserve the varietal identity. Carbohydrate Polymers 71(1): 32-41.

Mestres, C., Colonna, P. & Buléon, A. 1988. Characteristics of starch networks within rice flour noodles and mungbean starch vermicelli. *Journal of food science* 53(6): 1809-1812.

Mweta, D. E., Labuschagne, M. T., Bonnet, S., Swarts, J. & Saka, J. D. 2010. Isolation and physicochemical characterisation of starch from cocoyam (*Colocasia esculenta*) grown in Malawi. Journal of the Science of Food and Agriculture 90(11): 1886-1896

Nwokocha, L.M., Aviara, N.A., Senan, C. & Williams, P.A. 2009. A comparative study of some properties of cassava (Manihot esculenta, Crantz) and cocoyam (Colocasia esculenta, Linn) starches. *Carbohydrate polymers* 76(3): 362 - 367.

Obadina, A. O., Fegha, GD. & Olugbile, A. O. 2013. Effect of fermentation periods on chemical and physicochemical properties of cocoyam starch. *Starch-Stärke* 65(9-10): 747-752.

Oke, M.O., Awonorin, S.O. & Workneh, T.S. 2013. Effect of varieties on physicochemical and pasting characteristics of water yam flours and starches. *African journal of Biotechnology* 12(11): 1250-1256.

Omoregie Egharevba, H. O. 2020. Chemical properties of starch and its application in the food industry. *Chemical properties of starch*. *Intech Open*. Available at: http://dx.doi.org/10.5772/intehopen.87777

Peroni, F. H. G., Rocha, T. S. & Franco, C. M. L. 2006. Some structural and physicochemical characteristics of tuber and root starches. *Food Science and Technology International* 12(6): 505-513.

Poole, J. A., Barriga, K., Leung, D. Y., Hoffman, M., Eisenbarth, G. S., Rewers, M. & Norris, J. M. 2006. Timing of initial exposure to cereal grains and the risk of wheat allergy. *Pediatrics* 117(6): 2175 - 2182.

Punchaarnon, S., Pathipanawat, W., Puttanlek, C., Rungsardthong, V., & Uttapap, D. 2008. Effects of relative granule size and gelatinization temperature on paste and gel properties of starch blends. *Food Research International* 41(5): 552-561.

Qazi, I., Rakshit, S.K., Tran, T., Ullah, J. & Khan, Z. 2014. Effect of blending selected tropical starches on pasting properties of rice flour. *Sarhad Journal of Agriculture* 30(3): 357 - 368.

Quaisie, J., Liao, L., & Wu, W. 2017. Effect of blending ginger starch (*Zingiber officinale*) on the dynamic rheological, pasting and textural properties of rice flour. *African Journal of Food Science* 11(8): 263-272.

Ratnayake, W., Hoover, R., Shahidi, F., Perera, C. & Jane, J. 2001. Composition, molecular structure, and physicochemical properties of starches from four field pea (*Pisum sativum L.*) cultivars. *Food Chemistry* 74(2): 189–202.

Sandhu, K.S. & Singh, N. 2007. Some properties of corn starches II: Physicochemical, gelatinization, retrogradation, pasting and gel textural properties. *Food Chemistry* 101(4): 1499-1507.

Sefa-Dedeh, S. & Kofi-Agyir Sackey, E. 2002. Starch structure and some properties of cocoyam *(Xanthosoma sagittifolium* and *Colocasia esculenta)* starch and raphides. *Food Chemistry* 79(4): 435–444.

Shimelis, E. A., Meaza, M. & Rakshit, S. K. 2006. Physico-chemical properties, pasting behavior and functional characteristics of flours and starches from improved bean (Phaseolus vulgaris L.) varieties grown in East Africa. Agricultural Engineering International: The CIGR Ejournal. Manuscript FP 05 015 Vol VIII.

Surojanametakul, V., Tungtakul, P., Varanyanond, W. & Supasri, R. 2002. Effects of partial replacement of rice flour with various starches on the physicochemical and sensory properties of Sen Lek noodle. Kasetsart Journal (Natural Science) 36: 55-62.

Tan, H.Z., Li, Z.G. & Tan, B. 2009. Starch noodles: History, classification, materials, processing, structure, nutrition, quality evaluating and improving. *Food Research International* 42(5-6): 551-576.

Tetchi, F. A., Rolland-Sabaté, A., Amani, G. N. G. & Colonna, P. 2007. Molecular and physicochemical characterization of starches from yam, cocoyam, cassava, sweet potato and ginger produced in the Ivory Coast. *Journal of the Science of Food and Agriculture* 87(10): 1906-1916.

Thao, H. M. & Noomhorm, A. 2011. Modeling and effects of various drying methods on sweet potato starch properties. *Walailak Journal of Science and Technology (WJST)* 8(2): 139-158.

Yadav, B.S., Yadav, R.B. & Kumar, M., 2011. Suitability of pigeon pea and rice starches and their blends for noodle making. *LWT-Food Science and*

Technology 44(6): 1415-1421.

Yadav, B. S., Yadav, R. B., Kumari, M. & Khatkar, B. S. 2014. Studies on suitability of wheat flour blends with sweet potato, *colocasia* and water chestnut flours for noodle making. *LWT-Food Science and Technology* 57(1): 352-358.

Ylimaki, G., Hawrysh, Z. J., Hardin, R. T. & Thomson, A. B. R. 1991. Response surface methodology in the development of rice flour yeast breads: sensory evaluation. *Journal of Food Science* 56(3): 751-755.

Yoenyongbuddhagal, S. & Noomhorm, A. 2002. Effect of physicochemical properties of high-amylose Thai rice flours on vermicelli quality. *Cereal chemistry* 79(4): 481-485.

Zaidul, I. S. M., Norulaini, N. N., Omar, A. M., Yamauchi, H. & Noda, T. 2007. RVA analysis of mixtures of wheat flour and potato, sweet potato, yam, and cassava starches. *Carbohydrate Polymers* 69(4): 784 - 791.

Zhang, W., Sun, C., He, F., & Tian, J. 2010. Textural Characteristics and Sensory Evaluation of Cooked Dry Chinese Noodles Based on Wheat-Sweet Potato Composite Flour. *International Journal of Food Properties* 13(2): 294–307.

Zuluaga, R., Putaux, J. L., Restrepo, A., Mondragon, I. & Ganán, P. 2007. Cellulose microfibrils from banana farming residues: isolation and characterization. *Cellulose* 14(6): 585-592.