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Functional properties of soy-enriched tapioca

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The study was conducted to investigate the effect of soy-substitution on functional properties of tapioca a partially gelatinised irregular starch grit made from cassava. Starch was extracted from cassava tubers and soy-tapioca was produced by incorporation of full-fat soy flour into moist starch at four levels of substitution; 15: 85, 25: 75, 50: 50 before granulation and gelatinization. Functional properties of soy-tapioca samples: water absorption, bulk density, swelling capacity, oil absorption capacity, dispersibility, gelation capacity, syneresis, transmittance and pasting characteristics were determined and compared with that of tapioca. Results show that functional properties of soy-tapioca differ from each other as the ratio of soy substitution increases. Gelation, oil absorption, dispersibility, swelling, viscosity and transmittance, decreased as soy-substitution increased while water absorption capacity increased. Functional properties of soy-tapioca (15:85) suggest that it can compare favourably with that of tapioca. Enrichment of tapioca with soy flour to enhance its nutritional value is feasible however; increase in the level of soy substitution beyond 15% will alter the functional properties and affect the gelatinous nature of the tapioca meal. This may affect its acceptability and utilization by the consumers. Soy–tapioca (15: 85) can provide a nutrient dense alternative to tapioca and enhance nutritional security.

Key words: Functional properties, tapioca, cassava, starch grit, soy flour, soy-enriched tapioca, viscosity, soy-substitution.

INTRODUCTION

Tapioca is a partially gelatinised irregular starch grit made from cassava (*Manihot esculenta* Crantz). It is essentially a flavorless starchy ingredient or food usually taken as a milky pudding in many parts of Africa and as a snack such as fish crackers in South East Asia (Siaw et al., 1985) or used to thicken soups and sweeten the flavor of baked goods. Tapioca is produced from cassava a staple diet in many parts of Africa, South America and Asia. It is considered as the cheapest source of carbohydrate among cereals, tubers and root crops (Falade and Akingbala, 2008). Tapioca meal came into existence in the Southern part of Nigeria during the 20th century mostly among the inhabitants of Lagos and its environs (Nweke et al., 2002). It is made by peeling, grating, extraction of starch, from the roots followed by drying and heating to partly hydrolyze the starch to sugar and gel particles. All these processes reduce the amount of cyanide found in the tapioca meal and make the granulated product suitable for human consumption.

Soy-enriched tapioca refers to tapioca fortified with soy flour, which is gotten from the adequate processing of soybean *(Glycine max).* Cassava *(M. esculenta* Crantz*)* as the main raw material used in tapioca production is a rich source of energy, but nutritionally deficient because

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Abbreviations: LPD, Loose pack density; **WAC,** water absorption capacity; **OAC,** oil absorption capacity; **LGE,** lower gelation end point; **PV,** peak viscosity.

of its low protein, vitamin and mineral content (Montagnac et al., 2009). Soybeans (*G. max*) contains a reasonable amount of protein, minerals, vitamins and even phytochemicals such as isoflavones which is absent in the cassava root. Soybean is used as a source of protein supplement in many carbohydrate-protein food combinations because of its good balance of amino acid patterns (Conforti and Davis, 2006).

Many authors (Samuel et al., 2006, 2012; Kolapo and Sanni, 2009; Alalade, 2008; Oyewole et al., 2003; Metri et al., 2003; Tuma et al., 2003) have reported that enrichment or fortification of cassava/ based food with macro and micronutrients such as bioproteins and iron respectively could be a good vehicle for nutritional improvement and prevention of malnutrition.

Functional properties are those qualities in food that provides additional health benefits to consumers and have great impact on its utilization beyond satisfying the basic nutritional requirements (Mahajan and Dua, 2002). They influence the physical behavior of food or its ingredient during preparation, processing, and storage thereby altering the texture, appropriateness and sensory qualities of food. Samuel et al. (2012) reported the nutritional quality of soy-enriched tapioca and the potentials of improving malnutrition by utilization of this product.

However, effect of soy-substitution on the functional properties which may subsequently affect the texture, appropriateness, sensory qualities and utilization of the tapioca meal has not been reported. The objective of this study was therefore to investigate the functional properties of soy-enriched tapioca.

MATERIALS AND METHODS

Fresh cassava roots and soybean seeds were purchased from an open market in Iwo, Iwo local government area, Osun State, Nigeria.

Sample preparation

Starch was extracted from fresh cassava roots as described by Samuel et al. (2012). Full fat soy flour was prepared as described by the National Agricultural Extension Liaison Services (NAERLS), (1989). Tapioca was processed by roasting the moist cassava starch. The moist starch was granulated with the use of a sieve spread in a stainless steel pan, and roasted to form a coarse granulated product in the form of lumps of partly gelatinized starch. Soy tapioca was produced by the incorporation of full-fat soy flour into the moist starch at four levels of substitution: 0, 15: 85, 25: 75, 50: 50 (making samples A: 100% cassava starch; B: 85% cassava starch and 15% soy flour; C: 25% cassava starch and 75% soy flour; D: 50%cassava starch and 50% soy flour) just before roasting in the pan.

Functional properties

Least gelation capacity which is an indicator of gelation capacity was determined by the method of Sathe and Salunkhe (1981) using sample concentrations of 2 to 18% (w/v). Bulk density was determined by the method of Okaka and Potter (1979). 10 g of each of the soy-tapioca samples were placed in a 25 ml graduated cylinder and packed by gentle tapping of the cylinder on a bench top 10 times. The final volume of the samples were measured and expressed as g/ml.

Swelling power and solubility index of the samples were determined by gravimetric method of Leach et al. (1959). Amylose was carried out by the iodo-colorimetric method reported by Juliano (1971) and Williams et al. (1970). Water absorption capacity was determined by the method of Mercier and Feillet (1975). Fat absorption was determined by the method of Sosulski et al. (1976).

Paste clarity of the samples was determined by the method of Craig et al. (1989). 1% (w/v) of each sample was boiled at 100°C for 30 min under constant stirring; percentage transmittance was measured by a spectrophotometer (Jenway, Staffordshire, U.K.) at 620 nm after cooling to 30°C. The samples were stored in a refrigerator at 4°C and the transmittance was read each day for five days.

Paste syneresis was studied as described by Amani et al. (2004.; 2% (w/v) starch suspension was heated at 85°C for 30 minutes in a temperature controlled water bath under constant agitation. The gels obtained were subjected to cold storage at 4°C for 24 h in order to increase nucleation and then frozen at -20°C (for 24 h). The frozen gels were then thawed at 25°C for 6 h and then frozen at -20°C.

Five freeze-thaw cycles were performed. The exuded water, at the end of each cycle was gravimetrically determined by vortexing the thawed gels for 15 s followed by centrifugation at 1000 *g* for 20 min. pH was determined by weighing 1 g each of the samples into 10 mL of distilled water in a beaker, this was mixed properly, and the pH was read by means of a pH meter (model 3540, Jenway, Staffordshire, U.K).

Pasting characteristics were evaluated by Rapid Visco Analyzer (RVA) series 4 (Newport Scientific PTY. LTD) with the aid of thermocline for windows (version 1.1software, 1996). A 13-min profile, as described by Otegbayo et al. (2006), was used. It has the following time–temperature regime: idle temperature of 50°C for 1 min, heated from 50 to 95°C in 3 min 45 s and then held at 95°C for 2 min 30 s.

The sample was subsequently cooled to 50°C over a 3 min 45 s period, followed by a period of 2 min where the temperature was controlled at 50°C. Parameters extracted from the pasting profile were: peak viscosity, holding strength, breakdown, final viscosity, setback, peak time and pasting temperature. All analyses were done in triplicates.

Statistical analyses

The data generated from the results were subjected to statistical analysis using the Statistical Analysis Systems (SAS) package, version 8 of SAS Institute, Inc. Analysis of variance and means separations were calculated by the general linear models procedure (GLM). Differences ($p \leq 0.05$) between variables were evaluated by Turkey test.

RESULTS AND DISCUSSION

The results of the functional properties are presented in Table 1. The pH of the samples ranged between 8.97 and 9.26 showing that the tapioca samples are alkaline in nature. The amylose/amylopectin content of the soy-tapioca samples (Table 1) decreased as the level of soy substitution increased with the highest being 20.09% in

Table 1. Functional properties of tapioca and soy-tapioca samples.

Functional property	Sample			
	A	B	C	D
pH	9.26±0.05 [a]	9.05 ± 0.10 [a]	9.01±0.07 [a]	8.97±0.08 [a]
Amylose (%)	20.09± 0.23[a]	8.36± 0.31[b]	7.96± 0.07[c]	7.16± 0.15[d]
Loosed bulk density (g/ml)	0.50± 0.09[a]	0.52± 0.11[c]	0.53± 0.09[c]	0.53± 0.06[c]
Water absorption capacity (g/100 g)	125± 0.11[a]	147.5± 0.09[b]	160.0± 0.25[c]	170.5±0-017[d]
Oil absorption capacity (g/100 g)	2.15± 0.25[a]	1.96± 0.37[b]	1.75± 0.26[c]	1.66± 0.24[d]
Dispersibility (%)	87± 0.43[a]	73.0±0.65[d]	67.5± 0.56[b]	63.0± 0-33[bc]
Swelling capacity(g/g)	7.40±0.66[a]	6.60± 0.49[b]	5.40± 0.45[c]	4.60± 0.46[d]
Least gelation end point (%)	8.0± 0.0 [a]	8.0±0.0 [a]	16.0± 0.0 [b]	0.0

Means (n=3) with the same subscripts in the same row are not significantly different (P < 0.05). Sample A, 100% tapioca; sample B, 85 tapioca and 15% Full-fat soy flour; sample C, 75% tapioca and 25% full-fat soy flour; sample D, 50% tapioca and 50% full-fat soy flour.

tapioca (sample A) and the lowest being 7.16% in sample D (soy-tapioca 50: 50). Amylose is a constituent of starch that influences the textural quality of starch based foods and it has been reported to affect viscosity, gelatinization, textural quality, solubility, tackiness, gel stability, cold swelling and retrogradation (Satin, 1998). The higher the amylose content, the higher the tendency of starch to retrograde and also to form a gel (Shimelis et al., 2006).

The implication of the amylose content to the texture of tapioca is that the higher the amylose content the more gelatinous will be the reconstituted tapioca pudding. Due to soy-substitution, the gelatinous nature of the soy-tapioca samples is expected to be affected; with the soy-tapioca (15: 85) turning to be more gelatinous than the other soy-tapioca formulations since there was a reduction in starch.

Bulk density is very important for dietary bulk and packaging requirements (Karuna et al., 1996). It depends on interrelated factors including intensity of attractive inter particle forces, particle size and number of contact points (Peleg and Bagley, 1983). The bulk densities of soy-tapioca samples were higher than that of tapioca. The higher the loose pack density (LPD), the higher the bulk density. LPD indicates the free space between the foods when packed. A large free space is undesirable in packaging of foods because it constitute a large oxygen reservoir while a low LPD and lower bulk density result in greater oxygen transmission in the packed food.

The water absorption capacity (WAC) of the soy-tapioca samples increased as the level of soy-substitution increased. WAC is the ability of a product to associate with water under a condition where water is limiting. Afoakwa (1996) stated that proteins are mainly responsible for the bulk of water uptake and to a lesser extent, starch and cellulose at room temperature. WAC is important in foods where water will be imbibed without dissolution of protein, thus increasing their viscosity and body thickening (Seena and Sridhar, 2005). The increase in WAC of soy-tapioca samples as soy-substitution increased may be attributed to the hydrophilic nature of protein that is present in soy flour which is increasing with a concomittal decrease in the starch content.

As the soy-substitution is increasing, there is increase in the hydrophilic sites of the soy-tapioca, hence more water is absorbed (Otegbayo, 2000; Omueti et al., 2009; Maruatona et al., 2010, Ali et al., 2012.) The implication of this to the texture of soy-tapioca is that soy-tapioca with highest level of soy substitution (50: 50%) will absorb more water and form thicker pastes compared to that of tapioca (sample A) or other soy-tapioca formulations. The high WAC of the soy-tapioca samples may make them a useful ingredient in processing of soups, gravies, doughs, custard, sausages where it is important to imbibe water without dissolution of protein, thus attaining body thickening and viscosity.

Oil absorption capacity (OAC) is the ability of a food or food ingredient to absorb oil or fat. The ability of proteins to bind fat is important, since fats act as flavor retainers and increase the mouth feel of foods, improves palatability, extends shelf life of bakery or meat products, meat extenders, doughnuts, pan cakes, baked goods, and soup mixes. It is an indicator for flavour retention (Kinsella, 1976). It was observed in this study that the OAC decreased as soy-substitution increased with sample D (50: 50) having the lowest and sample A (100% tapioca) the highest. OAC has been attributed to physical entrapment of oil and the binding of fat to the polar chains of proteins (Zayas, 1997).

OAC usually increase as fat content increase due to increased lipid-lipid interactions, but the result gotten in this study deviated from this accepted theory because the OAC decreased as the soy-content increased. The decrease in OAC of the soy-tapioca samples may be due to the effect of more heat treatment of the soy-tapioca samples compared to the tapioca sample. The heat treatment of the soybean moiety in this study resulted from moist-heat treatment of soybeans to inactivate anti-nutritional components, oven drying of the flour and granulating stage of the soy-tapioca during processing. Nakai (1983), reported that the greater the amount of heat treatment that is given to a protein, the more hydrophobic the protein becomes, as a result of a greater number of hydrophobic groups being exposed through unfolding of the protein molecules. Similar observations were also reported for autoclaved and oven-dried cowpea flour (Giami, 1993), low-fat soya flour (Heywood et al., 2002), micronized cowpea flour (Mwangwela et al., 2007), roasted peanut flour (Yu et al., 2007) and heat treated Marama bean flour (Marautona et al., 2010). The implication of the decrease in OAC as degree of soy-substitution increased to the functionality of these soy-tapioca samples is that the tapioca and soy-tapioca (15: 85) with the highest OAC among them will be able to retain flavour and improve mouth feel compared to the other soy-substituted samples.

Dispersibility is the ability of flour to be wet without the formation of lumps, with simultaneous disintegration of agglomerates. The importance of dispersibility is that it indicates the reconstitution ability of the sample. Samples were significantly different in terms of their dispersibility and it ranged from 63.0 to 87.0% (Table 1). Sample A had the highest dispersibilty (87.0%) while sample D had the lowest (63.0%). High dispersibility of sample A (tapioca) is probably due to the absence of fat compared to samples B, C and D which had substantial amounts of fat due to substitution with soy flour.

There were significant differences ($P < 0.05$) in the swelling capacity of the samples. It ranged from 4.60 to 7.40 (g/g). Sample A (100% tapioca) had the highest (7.40) swelling capacity while sample D (50:50 soy-tapioca) had the least (4.60g/g). Swelling capacity is a function of process conditions, nature of material and type of treatment. Biopolymers such as starch contribute to the development of these characteristics. Higher swelling capacity of sample D compared to the other samples is expected since it has higher starch content compared to the other samples. The lower swelling power of the soy-tapioca samples may be due to formation of protein-amylose complex (Pomeranz, 1985) which can also contribute to reduction in the swelling capacity or due to presence of lipids in the soybeans which forms an insoluble amylose-lipid complex with amylose during swelling and gelatinization of the soy-substituted tapioca samples. This result is also in agreement with the report of Copeland et al. (2009), that formation of amylose-lipid complexes usually alters the functionality of food products by reducing their swelling power and altering their rheological properties.

The result of gelation capacity showed that the ability of the soy-tapioca samples to form gels decreased as the level of soy substitution increases (Table 1). Samples A and B had lower gelation end point (LGE) (8%), sample C (16%) while sample D did not form a gel but remained as a fluid. The high gelation end point of the soy tapioca samples could be as a result of competition for water between the protein moiety from soya flour and the starch component from the tapioca. This is similar to what was reported on pre-treated pigeon pea flour by Tiwari et al. (2008). In addition, formation of gel in these products could also be as a result of the formation of a protein-polysaccharide complex (Schmidt, 1981; Schmitz et al., 2006). However, since gelation does not depend on the quantity or quality of the protein alone but also on other components of the food sample, the presence of fat in the soy-bean which can introduce hydrophobic components to the tapioca samples may also contribute to their poor gelating ability. The implication of high gelation end point of the soy-tapioca samples is that they may not form thick gels or a gelatinous pudding on reconstitution as expected of a tapioca meal, but a viscous paste while the tapioca (samples A (100%) and B (15:85 soy-tapioca) with low LGE will form gelatinous puddings. Gelation is a significant functional property in infant feeding where low viscosity and low bulk density is favoured (Desikachar, 1980). Omueti et al. (2009) reported that the higher the gelation end point, (low gelation capacity), the more viscous will be the diet and the lower will be the dietary bulk. Thus, these soy-tapioca samples can be used as ingredients in complementary feeding since they have poor gelating capacity hence it is expected to form a diet of low viscosity with lower dietary bulk. This result implies that substitution of tapioca with soy bean at levels higher than 15% (as in sample B) will significantly alter the texture of the tapioca meal since tapioca is normally a gelatinous puddy and formation of a gel is important for its acceptance and utilization by the consumers.

Syneresis is a consequent of retrogradation of starch gels when subjected to freezing and thawing. Freezing of starch gels causes phase separation upon ice crystal formation, when thawed, water is expressed from the gel, this is known as syneresis. Result of syneresis of the samples is presented in Figure 1. Five freeze-thaw cycles were studied. It was observed that the syneresis profile of the samples at 4 and -20°C were very similar. The syneresis of all the samples increased after 24 h of storage (both at -4 and -20°C) and thereafter reduced and became fairly stable in most of the samples. This showed that the samples exhibit low syneresis and are fairly freeze-thaw stable, because products that show syneresis are considered not to be freeze-thaw stable. This is similar to results reported by Wu and Seib (1990) and Raina et al. (2006) on tapioca ice cream; that tapioca is freeze thaw-stable hence they are used as stabilizers in ice-cream formulations where it inhibits syneresis very well. The implication of this is that inclusion of soybean in the tapioca did not affect its freeze-thaw ability. This means that if the samples are either used as food or as a food component, they can be frozen or refrigerated without showing phase separation over a period of time. Copeland et al. (2009) stated that products where there is formation of starch-lipid complex (such as the soy-tapioca ; starch from tapioca, lipid from soybean) are usually freeze-thaw stable, hence they can be used to reduce stickiness in starchy foods, reduce staling in bread,

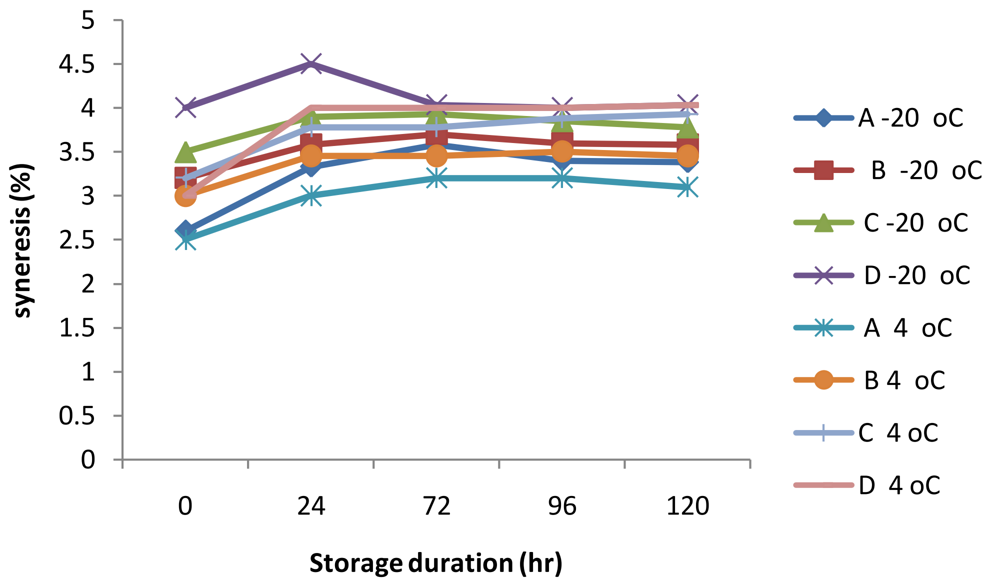

Figure 1. Effect of storage duration at 4 and -20°C on syneresis of tapioca and soy-tapioca samples.

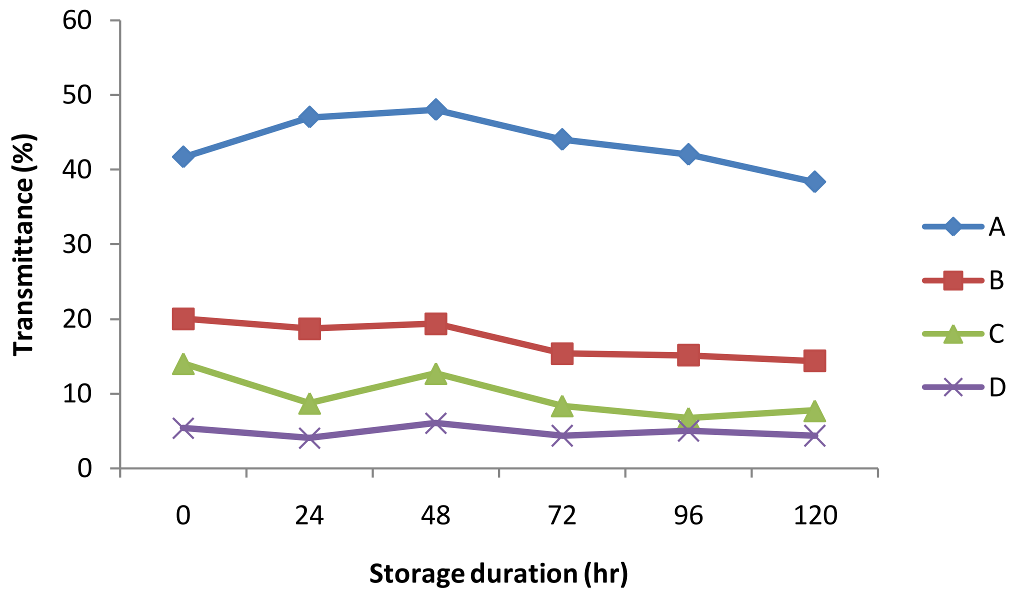

Figure 2. Effect of storage duration on paste clarity of tapioca and Soy-tapioca sample.

biscuits dough conditioners and crumb softeners and also to improve freeze-thaw stability. Paste clarity or transmittances of pastes of the tapioca and soy-tapioca samples showed that the clarity all decreased progressively during refrigerated storage (Figure 2); however the tapioca sample (A) had higher transmittance compared with the soy-tapioca samples. Light transmittance indicates the clarity of cooked starch paste. Reduced transmittance or opaqueness can occur due to granule swelling, granule remnants, leached amylose and amylopectin, amylose and amylopectin chain-length, intra-or intermolecular bonding and presence of lipids (Craig et al., 1989; Jacobson et al., 1997). Decrease in light transmittance of starch paste during storage indicates that retrogradation has taken place. Therefore soy-tapioca samples cannot be used as ingredients in gravies and soups where high clarity is required but can find application in food products where opaqueness is

Table 2. Pasting characteristics of tapioca and soy-substituted tapioca.

Sample	Peak viscosity (RVU)	Holding strength (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback (RVU)	Peak time (min)	Pasting temperature (°C)
A	305.34 ± 0.95[a]	160.67±0.61[a]	144.67±0.06[a]	237.21±0.93[a]	76.55±0.39[a]	4.20±0.01[a]	73.10±0.11[a]
B	287.59± 0.85[a]	158.71±0.87[a]	128.88±2.84[b]	231.88±1.14[a]	73.17±1.48[a]	4.50±0.03[a]	77.53±0.05[b]
C	143.75± 0.90[b]	100.59±0.65[b]	43.17±0.70[c]	154.21±4.40[b]	53.63±1.41[b]	4.80±0.01[a]	74.50±0.18[a]
D	78.46± 0.45[c]	65.83±0.59[c]	91.25±1.28[d]	91.25±0.59[c]	23.92±2.69[c]	5.37±0.01[b]	73.63±0.06[a]

Values are means±standard deviation; means (n=3) with the same subscripts in the same column are not significantly different (P < 0.05); RVU, rapid visco units; Sample A, 100% tapioca; sample B, 85 tapioca and 15% Full-fat soy flour; sample C, 75% tapioca and 25% full-fat soy flour; sample D, 50% tapioca and 50% full-fat soy flour.

important for example in noodle production and salad dressing. The result of the pasting characteristics of the tapioca and soy-tapioca samples is presented in Table 2. Pasting generally refers to changes in viscosity just before, during, and after the event of gelatinization (Zeng et al., 1997). Consequently, pasting also refers to changes in viscosity during gelation (Zeng et al., 1997). Generally, soy-tapioca samples (samples B-D) had lower values for peak viscosity, breakdown, holding strength and final viscosity but higher values for peak time and pasting temperature than tapioca sample (sample A).

High peak viscosity (PV) indicates that starches are highly resistance to swelling and rupturing. The lower peak viscosity of the soy-tapioca samples is not unexpected as this is due to the soy-substitution. Since PV is also an indication of the viscosity and binding capacity of the cooked starch, the soy-tapioca samples will not form a very thick paste. The lower viscosity of the soy-tapioca samples is expected, this is probably due to the interaction between protein and starch in the samples, the attraction of their opposite charges can form strong ionic bonds which can prevent loss of exudates from the granule therefore resulting in decrease in viscosity (Pomeranz, 1985). The implication of the higher pasting temperature of the soy-tapioca samples compared with the tapioca (sample A) is that they will have a longer cooking time compared to the tapioca sample (sample A), since pasting temperature is the onset of rise in viscosity and gelatinization temperature of the sample. This may be as result of inclusion of soy flour which has higher fat and protein content and can limit swelling due to formation of amylose-lipid complex (Leach et al. 1959; Akingbala et al., 1995; Copeland et al., 2009) or protein-amylose complex (Pomeranz, 1985). The lower breakdown and holding strength of soy-tapioca samples compared to tapioca indicate lower paste stability during the hold period, thus a lower resistance to mechanical fragmentation during heating and shear stress. High setback of the tapioca compared with the soy-tapioca samples indicate a higher tendency to retrograde and form cohesive pastes while the lower final viscosities of the soy-tapioca samples may imply that they will form viscous paste rather than a gel. The presence of the soy flour in the tapioca paste must have led to a reduction in the viscosity of the paste during cooling. Usually when starch pastes cool, there is increase in viscosity and formation of a gel as a result of intermolecular interaction between amylose and amylopectin, where the amylose is small or negligible (in waxy starches) there is reduced gel rigidity and only soft paste is formed. Thus this is the reason for the higher final viscosities of sample A and B compared to the other samples (B and C).

Conclusion

Incorporation of full fat soy flour into tapioca at different levels of substitution (0, 15, 25, and 50%) affected its functional properties differently. Increase in soy flour substitution resulted in increase in water absorption capacity and bulk density and a decrease in oil absorption capacity, swelling power, gelation capacity, paste clarity and pasting characteristics with a fairly stable freeze-thaw stability. Increase in the level of soy substitution beyond 15% (sample A) altered the gelatinous nature of the tapioca meal and may affect its acceptability and utilization by the consumers. The practical application of this study lies in the fact that since the functionality of a food has great impact on its utilization, the functional properties of sample B (soy–tapioca 15: 85) compared favourably with that of tapioca (sample A), hence it can provide a nutrient dense alternative to tapioca and enhance household food and nutritional security.

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