Physico-thermal and pasting properties of soy-melon-enriched "gari" semolina from cassava

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Abstract: The physical, thermal and pasting properties of "gari", a fermented and toasted cassava granule, enriched with 10% full fat soy-melon protein supplements, at different processing stages, were studied.   The stages at which the gari meal was enriched were: after fermentation but before toasting (PRT, soak-mix method) and after toasting (AFT, dry-mix method). Based on the result of the analysis of the physical properties, the swelling index of the samples decreased from 3.79 for the control sample to a range of 3.15-3.34 for the enriched samples.   Wettability values increased from 49 s for the control sample to about 135-148 s for the enriched gari.   A decrease in porosity from 42% for the control sample to 29.33%-32.33% for the enriched samples relative to their moisture contents was observed in the enriched samples.   Enriched "gari" sample of minimum average particle size (AFT) have the highest angle of repose of 37° while the control sample of maximum average particle size have the lowest angle of repose of 29°.   There was an increase in the degree of penetration by cone penetrometer from 19 mm for the control sample to a range of 22.43-23.90 mm for the enriched samples indicating higher gel strength for the control sample.   On the basis of the thermal properties, there was increase in swelling power and the solubility of all the samples with increase in temperature.   The control "gari" had significantly higher swelling power in a range of 5.17-6.68 g/g compared to that of the enriched samples (4.61-5.27 g/g) between the temperature of 45 and 90℃.   The control sample exhibited higher specific heat capacity of 1.222 kJ/(kg · K) than the enriched samples that ranged between 1.085-1.118 kJ/(kg · K).   On the basis of the pasting properties, the control sample had the highest viscosity of 300.92 RVU while the enriched samples had lower viscositiy.   The enriched samples formed paste at lower temperature 79.20-80.05℃ and took shorter time 3.93-4.07 min to gelatinize.   The enriched "gari" sample exhibited high setback and breakdown viscosity values of indicating that its paste will have lower stability against retrogradation than the un-enriched gari samples.

Keywords: Physico-thermal, pasting, toasting, enrichment, soy-melon "gari"

1   Introduction

"Gari" is a fermented, dewatered and toasted semolina from cassava, widely consumed all over West Africa and in Brazil (Kordylas, 1990).   It is the most popular cassava product consumed and the most important item in the diet of millions of Nigerians (IITA, 1990).   It forms a significant part of the diet in many of these countries where it is called "Farinha de mandioca" (Lancaster et al., 1982).   Traditionally, it is produced by

pressing the juice out of peeled, grated cassava roots, allowing a natural lactic acid fermentation to take place for 2-5 days.   The fermented mash is then toasted in an open aluminum pan over open fire until the starch gelatinizes to 65% of its native form and the moisture content falls to less than 12% dry basis (Chuzel, Gauthier and Griffon, 1986).   However, cassava and its products are low in protein, deficient in essential amino acids and therefore, have poor qualitative and quantitative protein content (Obatolu and Osho, 1992).   Thus, continuous dependence on "gari" without enrichment with meat, fish and/or other protein-rich sources would result in protein deficiency.   There is therefore, a need to search for

cheaper but good quality protein sources that are readily available (Oluwamukomi, 2008).   In Nigeria, there have been several attempts at overcoming the nutritional deficiency of cassava based diets by fortifying with soybean, which has high protein content of good quality (Sanni and Sobamiwa, 1994; Kolapo and Sanni, 2005). Results of previous studies on fortification of cassava products using soybean has shown that fortification improves nutritional quality of resulting meals (Edwards, Onyekwere, and Akinrele, 1977; Oke, 1972; Oshodi, 1985; Osho, 2003; Oluwamukomi, Adeyemi and Oluwalana, 2005).   However, fortification may also affect the functional and pasting characteristics of flour oriented foods (Jimoh and Olatidoye, 2009).

However, it is not enough to supplement the product alone, but there is need for proper study of its behaviour under certain thermal and physical treatments so as understand the physicochemical change in the products that are due to this enrichment.   Several studies have been carried out on the thermodynamic change in cassava products such as for "gari" (Chuzel and Zakhia, 1991; Ajibola, 1986), Lafun (Onayemi and Oluwamukomi, 1987), instant cassava flour and fufu (Sanni et al., 1999), cassava and melon seed (Aviara and Ajibola, 2002), while some observations have been made on the structural changes in roots and tubers food materials with varying influences on the mechanical and, therefore on the thermal, chemical, physical and even sensory properties of their products.

Similarly, Zakhia (1985) observed that the technological treatments involved in "gari" production (grating, squeezing, toasting) induce damage to about 3%-6% of the total amount of starch.   During toasting, cassava starch is heated in the presence of water, but the initial moisture content of about 1 g/g (d.b) of the cassava mash does not allow a complete gelatinization of the starch (Chuzel et al., 1986), but there is loss of crystallinity and extensive swelling of the starch granule. A complex meta-stable network is then formed which consists of amorphous regions (containing plasticizing water) and hydrated microcrystalline regions which did not dissolve during the partial gelatinization, and serve as junction zones (Levine and Slade, 1988).   Therefore

increase in both temperature (to 35℃) and water content (for a_w between 0.5 and 0.7) leach out more soluble starch (amorphous fractions and branched segments).   This increases the number of available adsorption sites and explains why "gari" becomes more hygroscopic at higher temperature and low water activity.

The thermal and pasting properties e.g. gelatinization temperature, starch solubility and swelling power are affected by several factors including cassava variety, temperature, moisture content, solvent concentration, amylose content, type of modifications (Perez, Breene and Bahnassey, 1998; Yoshimura et al.,1996; Liu, Eskin and Cui, 2006).   Starch gelatinization involves melting the polymer in an aqueous medium. When a water-starch suspension is heated, the starch undergoes a phase transition between 60 and 70℃.   Granule swelling increases with temperature and becomes irreversible when gelatinization occurs.   The swelling corresponds to a mass transfer of bulk water in the suspension to water associated with starch components (amylose and amylopectin).   The granule structure is generally dispersed when heat treatment reaches a certain level, and the solubilization of amylose chains leads to an increase in viscosity (Alloncle and Doublier, 1991; Sudhakar, Singhal and Kulkarni, 1996).   This change in viscosity is manifested by irreversible changes in properties such as the disruption of the semi-crystalline structure, seen as a loss of birefringence, and starch solubilization.   The phenomenon that follows gelatinization during the dissolution of starch and eventually leads to the total disruption of the granules is known as pasting (Liu et al., 2006).   During the cooling phase, the starch undergoes retro gradation in which the starch chains begin to re-associate in an ordered structure, and this is accompanied by another rise in viscosity, usually referred to as setback which is evidence in hot water reconstitution of "gari" (eba).   It is generally accepted that both the continuous phase (amylose) and the swollen granules contribute to the thermo-physical properties of starch gel (Biliaderis and Juliano, 1993; Biliaderis, 1992). Granule size and uniformity, amylose content, the macromolecular organization of granules, minor starch constituents, and the presence of other solutes, pH, starch

concentration and shear temperature– time regimes employed during gel preparation are all important to the visco-elasticity of starch dispersions (Biliaderis, 1998). At this point, one could observe that most studies on thermo-physical properties of cassava were concentrated on pure or chemically modified starch. Therefore, this study will look into the effect of enrichment on thermal, physical and chemical properties of soy-enriched "gari" (partially gelatinized cassava particles).

However, proper understanding of these properties will go a long way in the designing, modeling, simulation and optimization of "gari" processing operations and also assist in quantifying the impact of the enrichment at different level of toasting (pre-toasting, after-toasting etc), on the flavours, palatability and appearance of the end product (Oshodi, 1985). These properties constitute part of design parameters and necessary data required for numerical simulation and they include: solubility, swelling capacity and power, pasting behaviours and specific heat capacity, bulk density, wettability, porosity, angle of repose, and others taken at pre-toasting, and after toasting stages of garification. The objectives of this study are to produce soy-melon enriched "gari" from cassava and   evaluate the thermal, physical and chemical properties of soy-melon "gari" enriched at two different stages of garification process i.e. pre-toasting (soak mix) and after toasting (dry mix) stages and compare them with the control (Un-enriched) sample.

2   Materials and methods

2.1   Sources of raw materials

Cassava roots (*Manihot esculenta* Crantz) harvested and used on the same day was obtained from the research farm of the Federal University of Technology Akure, Ondo State Nigeria. Soybean (*Glycine max*) and melon seed (*Citrulis vulgaris*) used as protein supplements were purchased from Oba Market in Akure, Ondo State, Nigeria. They were sorted, packed and kept under refrigeration until used.

2.2   Methods

2.2.1   Preparation of soybean and melon seed flour blend (soy-melon flour)

The soybean seeds were cleaned and sorted before steam heated for 30-45 min at 100℃ and de-hulled after cooling by rubbing between palms to remove the seed coat by floatation.   The de-hulled seeds were air dried at oven temperature of 70-80℃ until they were completely dried and then dry milled   into powder using magnetic Blender (SHB- 515 model made by Sorex Company Limited) to obtain the soy-flour.   The melon seeds were sorted, cleaned and toasted in a steel pan at temperature of 80-90℃． The toasted melon was cooled, and milled into powder to obtain the melon flour.   These two flours (soy and melon flours) were blended together in proportion based on their protein contents (using Pearson Square method) to have the soy-melon supplement. This supplement was then used to enrich the "gari" samples (at 10% level) at pre-toasting (PRT) (soak mix) and after toasting (AFT) (dry mix) stages of "gari" production.

2.2.2   Preparation of soy-melon enriched "gari"

Soy-melon gari was produced according to the methods of (Banjo and Ikenebomeh, 1996; Adeyemi and Balogh, 1985) (Figure 1).   The Cassava tubers were peeled manually with a sharp knife, washed and grated in a locally fabricated mechanical grater (Agunbiade, 2001). The grated wet mash were then packed into Hessian sack and allowed to ferment for 72 h after which they were pressed and dewatered with a mechanical press (Addis Engineering Nig. Ltd, Nigeria).
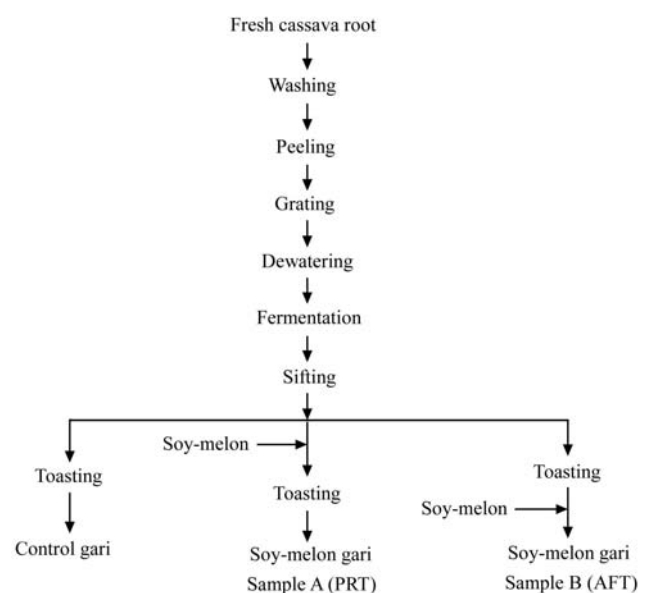

Figure 1   Processing techniques for control and soy-melon "gari" samples

2.3   Analysis

The dewatered wet cassava cake was pulverized with hands and sifted on a locally made raffia sieve of mesh (0.3 cm × 0.3 cm)   mounted on a rectangular wooden frame· 40 cm^2 to remove the fibers.   Part of the sifted cassava meal obtained was enriched with full fat soy-melon using 10% supplementation level and taking into consideration the water content of the mash of 65% (Akingbala, Oguntimehin   and Bolade, 1993) before toasting (PRT, soak mix method).   The toasted soy-melon gari was removed spread over a large spread of clean surface of woven Hessian sack and allowed to cool.   The cooled gari samples were then packaged in High Density Polyethylene (HDPE) film and kept under refrigerated storage until ready for further analysis.   The white and fluffy cassava meal was then introduced into a wide iron pan (garifier) for toasting.   The other part was enriched after toasting (AFT, dry mix method).

2.3   Analysis

2.3.1   Physical properties

"Gari" starch solubility and swelling power were determined according to the methods of Sasaki and Matsuki (1998).   Starch swelling index was determined by the modified method Ukpabi and Ndimele (1990). The reconstitution index was determined according to the method described by Banigo and Akpapunam (1987). Wettability of "gari" was determined on 1 g of the sample in triplicates according to the method reported by Armstrong et al. (1979).   The method of Ukpabi and Ndimele (1990) was used to determined bulk density of the "gari" samples.   The mean particle diameter dp of the "gari" particles sample was estimated (Geldart, 1986). Water holding capacity of the samples was determined as described by Metcalf and Gillies (1965).   Average granule diameter of "gari" samples was measured microscopically as described by Numfor and Noubi (1995).   The porosity (n) is determined by (Atkinson, 1993).   The angle of repose was determined by the method of Chen et al. (2004).   Gel strength of 'eba' (hot water reconstituted "gari" sample) was determined using Precision Cone Penetrometer (Bench top model, Pioden Controls Ltd., Canterbury, UK) to determine the depth of its cone into the hot water reconstituted gari.   The higher

the depth of penetration, the softer the gel and the lower the gel strength, while the lower the depth of penetration, the higher the gel strength (Bolade, Adeyemi and Ogunsua, 2009).

2.3.2   Thermal properties

The apparent amylose content was determined by the method of Farhat et al. (1999) with modifications.   The specific heat capacity of the "gari" samples was evaluated by using the equation developed by Choi and Okos (1986), a modification of Siebel (1892) which takes into account the proximate composition of foods.

$$cp = 4.180Xw + 1.711Xp + 1.928Xf + 1.547Xc + 0.908X$$

where, X = mass fraction of component, subscripts w, p, f, c and a are for water, protein, fat, carbohydrate and ash, respectively and cp = specific heat, kJ/(kg · K).

2.3.3   Pasting properties

The pasting properties of the samples (soy-enriched "gari") were assessed in a Rapid Visco Analyzer (RVA-4) using the RVA General Pasting Method (Newport Scientific Pty Ltd, Warriewood, Australia) (Newport Scientific, 1998).   The sample was turned into slurry by mixing 3 g with 25 mL of water inside the RVA can and inserted into the tower, which was then lowered into the system.   The slurry was heated from 50 to 95℃ and cools back to 50℃ within 12 min, rotating the can at a speed of 160 r/min with continuous stirring of the content with a plastic paddle.   Parameters estimated were peak viscosity, setback viscosity, final viscosity, pasting temperature and time to reach peak viscosity.

2.3.4   Statistical analysis

Means and standard errors of the mean (SEM) of replicate scores were determined and subjected to analysis of variance (ANOVA) using the Statistical Package for Social Statistics (SPSS version 12).   Means were separated using the Duncan's New Multiple Range Test (Steel, Torrie and Dickey, 1997).

3   Results and discussion

3.1   Physical properties

The swelling index of starchy food material determines the ease of handling during, processing, preparation and storage.   The result in Table 1 shows the effect of starch modification through protein enrichment

of "gari" on the swelling properties of the product (Perez, Breene and Bahnassey, 1998). A significant decrease in swelling index of the control sample was observed from 3.79 to 3.15-3.34 for the enriched samples. This agrees with the findings of Oluwamukomi et al. (2005), Banjoh and Ikenebomeh (1996) and Oluwamukomi, Famurewa and Babalola (2007). This they attributed to the reduced starch component in the enriched samples which could have reduced the absorption of water. In a related study by Prinyawiwatkul et al. (1994), the reduced swelling capacity was attributed to high fat content which might have reduced the ability of the mixture of wheat and peanut flours to bind water. Cheftel, Cuq and Loriet (1985) also attributed this phenomenon to the presence of lipids in the soy-melon supplement which must have reduced the swelling capacity of the gari granules. However, the sample enriched after toasting (AFT) produced soy-"gari" of higher swelling and water holding capacities than pre-toasting enriched (PRT) sample. This was explained by Oluwamukomi et al. (2007) that it might have been due to the fact that the starch and protein components in the sample enriched after toasting contributed separately to the absorption of water and swelling thus increasing the swelling power of the sample enriched with soy-melon flour after toasting. Swelling capacity has been shown to give a greater volume and more feeling of satiety per unit weight of gari to a consumer and a swelling index of at least 3.0 was recommended to be preferred by consumers (Almazan, 1992).

Table 1   Physical properties of soy-melon enriched and control Gari samples

Measured variables	Control	PRT	AFT
Swelling index/v $\cdot$ v^{-1}	3.79[a]	3.15[c]	3.34[b]
Reconstitution index/v $\cdot$ v^{-1}	3.66[a]	3.08[c]	3.12[b]
Wettability/s	49[c]	135[b]	148[a]
Loosed Bulk Density/g $\cdot$ mL^{-1}	0.49[b]	0.51[a]	0.47[b]
Packed Bulk Density/g $\cdot$ mL^{-1}	0.51[c]	0.61[a]	0.58[b]
Water Holding Capacity/g $\cdot$ g^{-1}	3.91[a]	3.03[b]	3.45[b]
Porosity/%	42.0[a]	29.33[c]	32.33[b]
Gel strength (Depth of Penetration)/ mm	19.0[c]	22.4[b]	23.9[a]
Angle of repose/(°)	29[c]	33[b]	37.0[a]

Note: Values are means of triplicate determinations.

    [a,b,c] Values with similar superscripts within row are not significantly different ($P \leq 0.05$).

    PRT= Pre-toasting stage of enrichment (soak mix method);

    AFT= After-toasting stage of enrichment (dry mix method);

    Control= No supplement.

The wettability which was measured by the time taken in seconds by the soy melon gari granules to sink in water when dropped at a distance of 13 cm from the surface of the water (Adebowale, Sanni and Onitilo, 2008), increased from 49 s for the control sample to about 135-148 s for the enriched gari, with the after toasting "gari" (AFT) having the highest wettability. This is an indication that the enriched sample will take a longer period to sink into water. The smaller values in seconds the faster the ability of gari to sink and the faster the better the gari sample. This might have been due to the effect of the soy-melon supplement which must have changed the physical and chemical compositions of the gari and made it less susceptible to imbibe water. Hence the wettability was impaired and reduced drastically (Oluwamukomi et al., 2007). When compared with previous findings it was found that the wettability values ranging from 135-148 s for soy-melon 'gari' were higher than those of 27-35 s reported for D. alata yam flour (Udensi, Oselebe and Iweala, 1988) and 42.5 s reported for D. rotundata yam (Udensi and Okaka, 2000). This was an indication that the yam flours were denser and will sink faster than those of soy-melon 'gari' granules (Oluwamukomi, 2008).

Porosity is another important physical property characterizing the texture and the quality of dry and intermediate moisture foods (Karathanos and Saravacos, 1993). It is an important parameter in predicting diffusion properties of cellular foods (Abramoff and Magelhaes, 2004). A decrease in porosity was observed in the enriched samples, about 42% (0.4) for the control sample to 29.33%-32.33% for the enriched samples relative to their moisture contents. This is in agreement with Kassama, Ngadi and Raghavan (2003) who modeled porosity as a linear function of moisture content. The higher the moisture content, the higher the porosity.

Table 1 also shows the variation in angle of repose of the samples as a function of smoothness, roundness, sizes and stickiness of the particles. When the particles are smooth and round, the angle of repose is low, but for very fine and sticky materials the value is high (Chen, Lii and Lu 2004). Enriched "gari" sample of smaller average particle size (AFT) have highest angle of repose of 37°

while the control sample of high average particle size have the lowest angle of repose of 29°. Angle of repose is a useful parameter for optimum design of hoppers. The inclination angle of hopper wall should be larger than the grain angle of repose to ensure the continuous flow of grain by gravitational force (Sadeghi, Ashtiani and Hemmat, 2010).

As stated by Zobel (1984) the rate of gelatinization of starch is determined by the rate of starch granule swelling. Since protein enriched samples have relatively lower number of starch granule compared to the control sample, higher gel strength was observed in the control sample. This was indicated by the increase in the degree of penetration (19 mm) by cone penetrometer from 19 mm for the control sample to a range of 22.43-23.90 mm for the enriched samples. There was no significant difference in Packed and the Loosed bulk density between the Control and the enriched samples. However, there was a consistent higher Packed bulk densities than the Loosed bulk densities meaning that more quantity of supplemented gari can be packed than the control for the same specific volume (Fagbemi, 1999). This might have been due to starch content of the mixture (Iwe and Onadipe, 2001) which tends to make the mixture less bulky and lighter. Essentially it was generally observed that enrichment either improves or reduced the physical qualities of "gari" depending whether it was added before or after toasting.

3.2 Thermal properties

Table 2 shows the behavior of the samples under thermal treatments. There was increase in swelling power and the solubility of all the samples with increase in temperature. The control "gari" had significantly higher swelling power in a range of 5.17-6.68 g/g compared to that of the enriched samples (4.61-5.27 g/g) between the temperature of 45 and 90℃. Ruales, Valensia and Nair (1993) observed that there is a rapid swelling of starch granule at gelatinization temperature (72-81℃) which is probably responsible for high swelling power and solubility observed between 60 and 90℃ compared to that observed at 45 and 60℃.

It can be observed that enriched samples have relatively low swelling power and solubility values.

This is in agreement with the earlier observation of Leach, McCowan and Schoch (1959), who stated that the presence of substances such as lipids or phosphate groups lower the swelling capacity and solubility of starch. Purshottam et al., (1990) also reported on the inhibiting effect of lipids on swelling capacity of starchy foods.

Table 2   Thermal properties of soy-melon-enriched and control Gari samples

Measured variables	Control	PRT	AFT
Swelling power/g · g⁻¹			
45℃	5.17a±0.03	4.61c±0.1	4.83b±0.1
60℃	5.72a±0.1	4.86c±0.03	4.93b±0.03
90℃	6.68a±0.1	5.01c±0.1	5.27b±0.1
Solubility/g · g⁻¹			
45℃	4.35a±0.1	3.34c±0.1	3.86b±0.1
60℃	4.82a±0.04	3.55c±0.1	4.12b±01
90℃	5.07a±0.1	3.85±0.1	4.29b±0.02
Average granule diameter/μm			
45℃	29.32^a±2.8	23.56^b±1.3	11.89^c±1.1
60℃	56.94^a±2.9	30.99^b±1.4	23.14^c±2.6
90℃	69.98^a±1.3	34.19^c±1.7	34.35^b±3.4
Apparent amylose content/%	23.33^c±0.6	26.33^b±0.6	32.00^a±1.0
Specific heat capacity (Cp) /kJ · (kg · K)⁻¹	1.222^a±0.6	1.085^c±0.3	1.118^b±0.3

Note: Values are means of triplicate determinations.

[a,b,c]Values with similar superscripts within row are not significantly different ($P \leq 0.05$).

The solubility of starch is believed to be affected by factors such as inter-associative forces, swelling power, presence of surfactants and other associative compounds (Moorthy, 1985; Sibanda and Sychawska, 2000; Soni *et al.,* 1985). The solubility values of the "gari" samples appeared to be related to the starch granule size and amylose content.

During processing and storage of foods, heat may be transferred by conduction, convection or radiation. Conduction is the predominant mode of heat transfer, as such, information on the thermal properties of materials related to conduction is important. One of these properties is the specific heat of a material, Cp, which is the amount of heat needed (kJ) to increase the temperature of a unit mass (kg) by one degree (K). It can be observed from the Table 2 that control sample has the highest moisture content (11.50%) and it exhibited the highest Heat capacity of 1.222 kJ/(kg ·K). Siebel argued

that the specific heat of the food can never be greater than the sum of the specific heat of the solid matter and water since water in food materials exists side by side with the solid matter without any heat producing chemical reactions (Siebel, 1892, Choi and Okos 1986).

3.3 Pasting properties

The Rapid Viscometric plot obtained from the Rapid Viscometric Analyzer for control and enriched gari is as shown in Figure 2, while the pasting properties are shown in Table 3.   The pasting temperature of the gari samples ranged between 79.20 and 80.85℃ and were higher than values reported for dried fufu (76-78℃) (Sanni and Jaji, 2003), (63.07-63.60℃) by Adebowale et al. (2008) for toasted tapioca.   The pasting temperature is a measure of the minimum temperature required to cook a given food sample (Sandhu, Singh and Malhi, 2005), it can have implications for the stability of other components in a formula and also indicate energy costs (Newport Scientific, 1998).   The pasting temperature of the gari was generally lower than the boiling temperature; hence the gari could form a paste in hot water below boiling point (Adebowale et al., 2008).
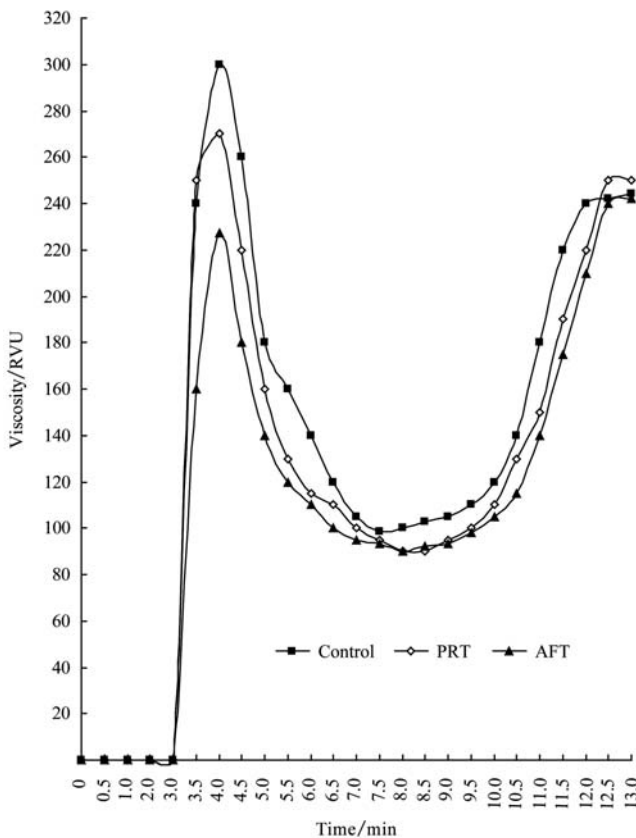

Figure 2   RVA plot for the enriched (PRT, AFT) and control gari samples

The peak time is a measure of the cooking time (Adebowale, Sanni and Awonorin, 2005).   This ranged between 3.93-4.07 min for the enriched gari samples and 4.07 min for the control gari sample.   The time to attain peak viscosity is considerably lower than that those reported for dried fufu (22-38 min) by Sanni and Jaji (2003), and pupuru (37-43 min) by Shittu et al. (2001), but in the same range for toasted tapioca (3.62-4.27 min) by Adebowale et al. (2008).

Table 3   Pasting properties of soy-melon enriched and control Gari samples

Measured variables	Control	PRT	AFT
Peak viscosity/RVU	300.92[a]	274.42[b]	227.50[c]
Trough 1/RVU	98.33[a]	96.00[b]	91.33[c]
Breakdown viscosity/RVU	202.58[a]	178.42[b]	136.17[c]
Set back viscosity/RVU	145.92[c]	155.00[a]	151.25[b]
Final viscosity/RVU	244.25[b]	251.00[a]	242.58[c]
Peak time/min	4.07[a]	3.93[b]	4.07[a]
Pasting temperature/℃	80.85[a]	80.05[ab]	79.20[b]

Note: Values are means of triplicate determinations and
[a,b,c] Values with different superscripts within row are significantly different ($P \leq 0.05$).
    PRT= Pre-toasting stage of enrichment (soak mix method);
    AFT= After-toasting stage of enrichment (dry mix method);
    CONTROL= No supplement;
    RVU = Rapid Viscometric Unit.

This might be due to the fact that gari is partially gelatinized during toasting.   Peak viscosity, which is the maximum viscosity, developed during or soon after the heating portion of the pasting test (Newport Scientific, 1998), is lower for   the enriched samples (227.50-274.42 RVU) and highest for the control sample (300.92 RVU). These ranges are lower compared to the range of values obtained for dried fufu (320-900 BU) as reported by Sanni and Jaji (2003), for toasted starch grits (352.86-476.52 BU) by Adebowale et al. (2008), for pupuru (362-430 BU) by Shittu *et al*. (2001) and for soy ogi (270-460 BU) by Oluwamukomi et al. (2005).   This is also because gari is partially gelatinized.   In Table 3, it could be observed that the control "gari" sample had the highest peak viscosity 300.92 RVU while the soy-melon enriched samples had lower peak viscosities with the after-toasting enriched sample having the least viscosity 227.50 RVU.   This agreed with the study of King, Aguerre and de Pablo (1985) who reported a significant decrease in the pasting viscosity of mung bean

starch enriched with soy- protein isolate. Peak viscosity is often correlated with the final product quality. It also provides an indication of the viscous load likely to be encountered during mixing (Maziya-Dixon, Dixon and Adebowale, 2004; Maziya-Dixon *et al.*, 2005). Two factors interact to determine the peak viscosity of a cooked starch paste: the extent of granule swelling (swelling capacity) and solubility. Higher swelling index is indicative of higher peak viscosity while higher solubility as a result of starch degradation or dextrinization results in reduced paste viscosity (Shittu et al., 2001; Zobel, 1984). These were corroborated by results of swelling power and solubility reported above. There was an increase of peak viscosity with increase in pasting temperature. The enriched samples formed pastes at lower temperature 79.20-80.05℃ and took shorter time 3.93-4.07 min to gelatinize meaning that the control sample ("gari" without supplement) was slower and required more heating to form paste. However, due to insignificant difference in the pasting temperature and relatively short pasting time of all the samples, their ease of cooking would depend on their granule swelling (Zobel, 1984). Two factors interact to determine the peak viscosity of cooked starch paste (Zobel, 1984): the extent of granule swelling (swelling power) and solubility. Sample of higher swelling index and capacity is expected to give higher viscosity peak as observed in the control "gari" sample.

During the hold period of a typical pasting test, the sample is subjected to a period of constant temperature (usually 95℃) and mechanical shear stress. This further disrupts the starch granule and amylose molecules generally leach out into solution and align in the direction of the shear (Maziya-Dixon et al., 2005). The period is sometimes called shear thinning, holding strength, hot paste viscosity or trough due to the accompanied breakdown in viscosity. It is the minimum viscosity value in the constant temperature phase of the RVA profile and measures the ability of paste to withstand breakdown during cooling (Newport Scientific, 1998). This ranged between 91.33 RVU for enriched sample and 98.33 RVU for the control sample. This period is often associated with a breakdown in viscosity (Ragaee and

Abdel-Aal, 2006). The rate of starch breakdown depends on the nature of the material, the temperature, the degree of mixing and shear applied to the mixture (Newport Scientific, 1998). The ability of a mixture to withstand heating and shear stress that is usually encountered during processing is an important factor for many processes especially those requiring stable paste and low retrogradation/syneresis. It is an indication of breakdown or stability of the starch gel during cooking (Zaidhul et al., 2006). The lower the value the more stable is the starch gel. The breakdown is regarded as a measure of the degree of disintegration of granules or paste stability (Dengate, 1984; Newport Scientific, 1998).

At breakdown, the swollen granules disrupt further and amylose molecules will generally leach out into the solution (Whistler and BeMiller, 1997). Higher values of breakdown are associated with higher peak viscosities which in turn are related to the degree of swelling of starch granules during heating (Ragaee and Abdel-Aal, 2006). More starch granules with a high swelling capacity result in a higher peak viscosity. The breakdown viscosity recorded by enriched samples was lower than that of the control/ Un-enriched gari. It reduced from 202.58 RVU in the Control to a range of 136.17-178.42 RVU in the enriched gari, with gari enriched before toasting having the higher value. During the final cycle of cooling from 95℃ to 50℃, the viscosity increased to a final viscosity owing to the alignment of the chains of amylose resulting in formation of a gel structure (Ragaee and Abdel-Aal, 2006; Sandhu et al., 2007). The final viscosity is an indication of the ability of the starch based food to form a viscous paste or gel after cooking and cooling. This ranged between 242.00 and 251.00 RVU for the enriched sample and 244.25 RVU for the control sample with the sample enriched prior to toasting having a higher value.

The viscosity after cooling to 50℃ represents the setback or viscosity of cooked paste. It is a stage where retrogradation or re-ordering of starch molecules occurs. It is a tendency to become firmer with increasing resistance to enzymic attack. It also has effect on digestibility. Higher setback value is synonymous to reduced dough digestibility (Shittu et al., 2001) while

lower setback during the cooling of the paste indicates lower tendency for retrogradation (Sandhu et al., 2007, Sanni et al., 2004). The final viscosity was highest for the gari enriched prior to toasting (251.00 RVU), while it ranged between 242.58 and 251.00 RVU for the enriched gari. These values were similar to values obtained for toasted tapioca grits (210.89-244.16 BU) by Adebowale et al. (2008). Enrichment caused an increased in the final viscosities. Enrichment with full fat flour resulted in higher setback values and higher tendency for the paste to become firmer and stiffer after cooling. The extent of increase in viscosity on cooling to 50℃ reflects the retrogradation tendency. The setback values increased with enrichment from 145.92 RVU for the Control sample to a range of 151.2 to 155.00 RVU for the enriched gari with higher value in sample enriched prior to toasting. The setback revealed the gelling ability or retrogradation tendency of the amylose. This was highest in sample enriched prior to toasting. This suggests that the highest amylose retrogradation occurred here. The low setback values of the control sample indicate low rate of retrogradation and syneresis (Ragaee and Abdel-Aal; 2006, Sandhu et al., 2007).

Generally for these samples, the peak viscosity, trough viscosity and the breakdown were found to be reduced with enrichment, while the final viscosity, setback viscosity increased or paste stability reduced. There were no appreciable differences in the peak time and pasting temperatures of both enriched and control samples. This shows that enrichment resulted in reduced peak viscosity, trough viscosity and the breakdown viscosity, while it also resulted in increased final and setback viscosities ($P \leq 0.05$). Also, values for Peak, trough and breakdown were higher in sample enriched before toasting. The high content of starch in the control gari compared to the enriched gari may have contributed to the higher peak viscosity, trough viscosity, breakdown viscosity.

The setback viscosity indicates the tendency of the dough to undergo retrogradation a phenomenon that causes the dough to become firmer and increasingly resistance to enzyme attack (Ihekoronye and Ngoddy, 1985). There is a serious implication on the digestibility of the dough when consumed. The low setback value and breakdown viscosity of the control "gari" sample indicates that it paste would have a high stability against retrogradation (Mazurs, Schoch and Kite, 1957) than the enriched samples. However, pre-toasting "gari" paste will have higher stability against retrogradation due to it lower setback value compared with the after-toasting. The enriched samples formed pastes at lower temperature 79.20-80.05℃ and took shorter time 3.93-4.07 min to gelatinize meaning that the control sample ("gari" without supplement) was slower and required more heating to form paste.

4 Conclusions

This study has revealed that the swelling index of the samples decreased and wettability values increased with enrichment with soy-melon supplement. "Gari" enriched after toasting had smaller average particle size (AFT) and higher angle of repose of 37°. The enriched samples formed pastes at lower temperature 79.20-80.05℃ and took shorter time 3.93-4.07 min to gelatinize meaning that the control sample ("gari" without supplement) was slower and required more heating to form paste. There was an increase in the degree of penetration by cone penetrometer for enriched samples indicating higher gel strength for the control sample without enrichment. Enrichment resulted in decrease in peak viscosities and lower pasting temperature; while the control "gari" sample exhibited lower setback and breakdown viscosity values indicating that the control sample will have a higher stability against retrogradation than the enriched samples. When compared with the control or un-enriched sample, the gari enriched prior to toasting was better in most of the pasting properties, bulk density, gel strength, and wettability index than the sample enriched after toasting; while the sample enriched after toasting had better swelling and reconstitution indices, swelling power, solubility and angle of repose than the sample enriched before toasting. Future study should aim at determining the effect of these physico-thermal and pasting properties on the sensory quality and general acceptability of the product.

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