Some engineering properties of composite corn-banana custard flour

Alimi, B.A.[1*], Sibomana, M.S.[1], Workneh, T.S.[1] and Oke, M.O.[2]

[1]Bioresources Engineering, School of Engineering, College of Agriculture, Engineering and Science, University of KwaZulu-Natal, Private Bag X0l, Pietermaritzburg, Scottsville, 3209, South Africa.

[2]Department of Food Science and Engineering, Faculty of Engineering and Technology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

*Corresponding author: Alimi, B. A.
Email: bun5574@yahoo.com
Telephone: +2347036711250; +27738948678
Fax: +27-33-260 5818

ABSTRACT

Engineering properties of composite corn-banana custard flour (CF) products developed by incorporating native, heat-moisture treated or annealed banana starch (BS) as a percentage (15, 25 or 35%) of the composite were determined. Morphological study showed bigger oval BS granules occupying void spaces in the matrix resulting in more compact composite CF structure and in turn, higher bulk density with increasing level of BS inclusion. Experimental variables had marked effect on the pasting properties of the CF samples. Incorporation of BS led to significant ($p<0.05$) reduction of the swelling power of the CF samples from 1.85 to 1.16 g/g. Gelling and boiling points varied significantly ($p<0.05$) between 73.00 to 81.67 ˚C and 78.33 to 88.33 ˚C, respectively. Moisture adsorption isotherm showed a type II sigmoidal shaped curve. Experimental variables and granules orientation in the matrices are suggested to be the major influence on the trends observed in the studied engineering properties.

Keyword: heat moisture treatment; annealed; banana starch; pasting properties; granules morphology

PRACTICAL APPLICATION

This study was proposed to enhance the health functionality of corn based custard through the incorporation of native and hydrothermally modified banana starch as a percentage of the resulting composite custard flour. The established health enhancing functionality of unripe green banana and further improvement of its functional properties through hydrothermal modifications could add value to the composite custard flour. It is hoped that the products developed would appeal to health conscious people and be useful for the management of type II diabetes and cardiovascular diseases which are normally aggravated by the consumption of energy dense foods.

INTRODUCTION

The world is faced with increasing incidence of diseases and deaths related to the consumption of energy dense foods (Choo and Aziz 2010). Energy dense foods have been implicated in devastating health problems like type-2 diabetes and obesity (WHO 2015). Obesity is a major factor for a number of chronic non-communicable diseases like cardiovascular diseases and cancer. World Health Organisation (WHO) linked 80% of deaths through non communicable diseases to the diseases associated with the consumption of energy dense foods (WHO 2008). It was further projected that deaths through these means could rise to 44 million in 2020 if urgent steps are not taken. This scenario places a big challenge on food scientists to come up with innovative formulations for healthier dietary choices. One of the approaches available to food researchers to reduce these chronic diseases is through the incorporation of food ingredients with functional capability that could alter the digestion of foods especially carbohydrate in the human body system through slow release of glucose into the blood stream (Agama-Acevedo *et al*. 2012). However, this innovation would be better appreciated by the consumers if it improves on the functionality of the existing foods trusted by the consumers over time (Alimi *et al*. 2016; Alimi and Workneh 2016). One of such foods with international appeal is starch-based custard.

Starch-based custard flour is made into a semi-solid fine textured gruel or thin paste by first dissolving in water and then boiled in a calculated amount of water. The pap like gruel from custard is a popular breakfast meal in many parts of the world (Tárrega and Costell 2006). Its fluidity makes it an ideal food for weaning infants and convalescence after sickness. Corn starch, the traditional base material of custard, is responsible for its gelling capability during heating and consistency. Often, ingredients like salt, flavours, colourants and protein source are added to give the resulting gruel after heating the desired sensory appeal and nutritional enrichment (Okoye *et al*. 2008). However, corn starch is an energy dense food material with high glycemic index (GI) of 81±6 (Atkinson *et al*. 2008). Therefore, there is urgent need to improve on the functionality of custard to make it an ideal food for health-conscious people. Partial substitution of corn starch in the formulation with food ingredients of known health enhancing functionality like green banana starch could be a veritable approach to achieve this objective.

The nutraceutical/functional potential of green banana starch has been reported by several authors (Englyst *et al*. 1992; Apario-Saguilán *et al*. 2007; Choo and Aziz 2010). The health functionality of banana is due to its resistant starch (RS) component. Unripe banana was reported by Faisant *et al*. (1995) to have the highest concentration of RS content of all natural products. Resistant starch is a class of starch that is not digested in the upper intestinal tract of man. It however undergoes fermentation in the colon through the action of microorganisms to produce short chain fatty acids (SCFA), which are known have to beneficial effects on human health (Agama-Acevedo *et al*. 2012). However, RS present in natural products such as banana are not heat stable and are easily destroyed when exposed to high temperature especially during processing. Type 3 RS (RS3) formed through hydrothermal modification of starch which induces gelatinization and subsequent destruction of starch granular structure is of importance in a food system that would be exposed to high temperature during processing because it remains indigestible after high temperature processing (Farhat *et al*. 2001). Hydrothermally modified starch is encouraged in food processing because of its safety over other modification methods

(Alimi *et al*. 2016). Therefore, incorporating RS3 into corn based custard could enhance its health functionality.

This study was proposed to enhance the health functionality of corn based custard through the incorporation of native and hydrothermally modified banana starch as a percentage of the resulting composite custard flour. The established health enhancing functionality of unripe green banana and further improvement of its functional properties through hydrothermal modifications could add value to the composite custard flour. It is hoped that the products developed would appeal to health conscious people and be useful for the management of type II diabetes and cardiovascular diseases which are normally aggravated by the consumption of energy dense foods (Alimi *et al*. 2014).

However, blending two different starch materials could alter the properties of the resulting composite starch product (Devi and Haripriya 2012). Relative contents of amylose, amylose/amylopectin ratio and non-starchy components such as protein and fat in individual base materials and level of substitution could affect such engineering properties as pasting, functional and moisture sorption of the resulting product (Onitilo *et al*. 2007; Adetuyi *et al*. 2009). These changes could affect the storage stability of the composite and final quality of the custard paste. Therefore, the objectives of this study were to determine the pasting, functional and moisture sorption properties of composite corn-banana custard flours.

MATERIALS AND METHODS

Banana Starch

Native Starch. Native starch was extracted from matured green banana (*Musa paradisiaca*) obtained at a fresh vegetable market in Ogbomoso, Nigeria. The method of Kim *et al*. (1995)

was used for the starch extraction. This involved blending the diced banana pulp in a warring blender, passing the slurry obtained through the muslin cloth with addition of distilled water to remove debris and filtering with 150 μm sieve size. The starch obtained after discarding the supernatant was washed with distilled water to remove impurities and dried in a forced air oven for 24 h at the temperature of 48˚C to the desired moisture content.

Hydrothermal Modification of Native Banana Starch. Heat moisture treatment (HMT) and annealing methods of hydrothermal modification were used to obtain modified starches. Heat moisture treated starch was obtained according to the method of Li *et al*. (2011). The moisture content of native banana starch was raised from 11.8% to 20% and thereafter heated in a forced air circulation oven at 110 ˚C for 16 h.

The procedure described by Jacobs and Delcour (1998) was used to produce annealed banana starch. Native banana starch suspension in distilled water (1:2 w/v) in a sealed container was heated in a thermostated water bath for 24 h at 50 ˚C. The residue obtained after passing the slurry through Whatman No. 1 filter paper was dried at 35 ˚C for 24 h in an oven.

Corn Starch

Commercial custard (100% corn starch obtained from Premier Foods, Waterfall city, South Africa) was used as reference material.

Sample Preparation and Design of Experiments

Native, heat moisture treated and annealed banana starch samples were substituted separately into the corn starch at 15, 25 and 35% of the total composite flour. The constituents were thoroughly mixed with blender to achieve homogeneity.

The experiments were based on two factors of banana starch samples (based on treatment) and levels of substitution. They were arranged in a randomized block design consisting of three starch samples (native, HMT and annealing) at threes levels of inclusion (15, 25 and 35%). Commercial custard product (100% corn starch) served as control.

Granular Arrangements in Custard Flour Samples

Arrangement of starch granules in the composite custard flour was captured with a scanning electron microscope (EVO LS15, ZEISS International, Germany). An ion sputtering device (EIKO IB-3 ion coater, Eiko Engineering Company, Hitachinaka, Japan) was first used to coat thin layer of flour with gold prior to scanning under the microscope.

Pasting Properties

The pasting properties were determined with a Rapid Visco Analyser (RVA model 4500, Perten instruments, Australia). The procedure involved dispersion of 3.42 g of custard flour sample in 25.08 g of distilled water contained in an RVA container and stirred. The slurry obtained was then subjected to controlled cycle of heating and cooling at constant strain. The analysis was conducted on 14% moisture basis and the idle (peak) temperature of 91 ˚C.

Water Absorption Capacity

The determination of water absorption capacity (WAC) was carried out according to the method of Beuchat *et al*. (1975) as described by Alimi *et al*. (2016). It involved mixing of 1 g of custard flour sample in 10 mL of distilled water to form suspension, left at laboratory temperature for 1 h followed by centrifuging at 200 x g for 30 min with Avanti® J-26XPI super speed centrifuge (Beckman Coulter, USA). The resultant residue after draining the supernatant was weighed with the tube. The WAC was calculated as change in weight based on the weight of original sample and expressed in percentage.

Oil Absorption Capacity

The procedure described by Alimi *et al*. (2016) which involved mixing 1 g custard flour sample with 10 mL of sun flower vegetable oil (0.87 g/ cm^3 density) in a previously weighed centrifuge tube using a spatula was used. The suspension obtained was centrifuged at a speed of 350 x g for 15 min using Avanti® J-26XPI super speed centrifuge (Beckman Coulter, USA). The supernatant was carefully separated from the residue and the weight of the tube and residue noted. The oil absorption capacity was calculated as the percentage increase in weight with reference to original weight of the sample.

Swelling Power and Solubility

A custard flour (500 mg) suspension in distilled water (20 mL) was heated with continuous shaking in a water bath at 60 ˚C for 30 min. The slurry obtained was cooled and centrifuged at 1900 x g for 15 min with Avanti® J-26XPI super speed centrifuge (Beckman Coulter, USA). The supernatant was transferred into an evaporating dish. The weights of custard (X), centrifuge tube containing custard flour slurry before heating (C_1) as well as centrifuge tube and residue after decanting to remove supernatant (C_2) were noted.

$$\text{Swelling power } SP = \frac{C_1 - C_2}{X} \qquad (1)$$

The weight of evaporating dish containing the supernatant was noted before drying at 110 ˚C for 20 min. Solubility was calculated as the remnant after drying the supernatant base on the weight of custard flour sample and expressed as g/100 g of custard flour (Alimi *et al*. 2016).

Densities and Powder Flowability

The method of Narayana and Narasinga-Rao (1984) was used to determine the densities of custard flour samples. Loose bulk density (LBD) was determined by filling 50 g of Custard sample into a measuring cylinder and noting the volume. Packed bulk density (PBD) was obtained by continuous tapping of the cylinder till there was no more change in volume. The ratios of loose and packed weight to the volume (g/mL) were the LBD and PBD, respectively. Carr index and Hausner ratio according to Carr (1965) were used to determine the flowability of the custard flour samples.

$$\text{Carr index } (\%) = 100(PBD - LBD) \Big/ LBD \qquad (2)$$

$$\text{Hausner ratio} = PBD / LBD \qquad (3)$$

The Carr index (%)values of 5-10, 12-16, 18-21 and 23-28 denoted excellent, good, fair and poor flow properties, respectively (Carr 1965).

Gelation and Boiling Temperatures

The points were determined according to the method of Narayana and Narasinga-Rao (1982) as reported by Falade and Okafor (2014). The custard sample (10 g) suspension in distilled water in a 250 mL beaker was made up to 100 mL by adding more distilled water. A thermometer clamped on a retort stand with its bulb submerged in the suspension was used to monitor the temperature. The suspension was heated on a stove with continuous stirring using magnetic stirrer until the suspension began to gel and then boil. The gelation and boiling temperatures were recorded.

Water Sorption Determination

The custard flour samples (3 g each) were dried in hot air oven at 105 °C until constant weight to remove loose water. The sorption experiments (of the dried samples) were then conducted on the samples at 12, 27 and 35 °C to mimic temperate, tropical and subtropical temperatures, respectively. Equilibrium moisture content (EMC) was determined at 25, 40, 55, 70 and 90 % equilibrium relative humidity (ERH) for each temperature according to equation (4).

$$\text{EMC} = \frac{\left(M_f - M_i\right)}{M_i} \qquad (4)$$

Where EMC, M_f and M_i are the equilibrium moisture content, final weight and initial weight, respectively of the sample.

Water activity, a_w, was calculated from ERH thus:

$$a_w = \frac{ERH}{100} \qquad (5)$$

The experiments were conducted in a controlled climate test chamber (CTS model C-40/100, Hechingen, GmbH) with temperature and humidity range of -40 ^{o}C to 180 ^{o}C and 10% to 98% and accuracy of ± 0.1 °C and ± 0.1%, respectively. Weights of the samples were checked daily until constant weight for 2 days (Ghodake 2007). The total time of approximately 30 s was ensured for the removal, weighing and returning of each sample to the test chamber. This was to minimize moisture absorption from the environment during weighing. The temperature/ERH combinations for each condition were as presented in TABLE 1.

Commented [MO1]: Dr Alimi, you need to give explanation here using Ghodake (2007).

Statistical Analyses

All experimental analyses except pasting properties were replicated three times. Replicated data were analysed using SPSS 15.0. The means obtained from one way analysis of variance were separated using Duncan Multiple Range Test (Duncan, 1955). The sorption graph was obtained using Microsoft Excel (2010) software.

RESULTS AND DISCUSSION

Granular Arrangements

Representative structures showing the arrangement of banana and corn starch granules in the composite custard flour are shown in Fig. 1 (a-c). Corn starch granules were smaller and polyhedral while banana starch granules were bigger, elongated and oval. Increasing banana starch content in the composite flour resulted in a more compact structure as shown in the Figure. The bigger granules of banana starch occupied the spaces in the corn starch matrix. This is similar to the observation of Falade and Ayetigbo (2015). As previously reported by Alimi *et al*. (2016), both heat moisture treatment (HMT) and annealing (ANN) modification methods did not alter the structure of banana starch granules. Hence, the spatial arrangements of modified and native banana starch granules were similar in the composite custard samples.

Pasting Properties

TABLE 2 shows the changes in pasting properties of custard samples with incorporation of native and modified banana starch at varying levels into corn starch. Incorporation of banana starch generally conferred higher pasting temperature as evidenced by the higher pasting temperature observed for composite custard as compared with that of corn custard. Eliasson

(1980) established positive relationship between the strength of interactive forces within the starch granules and pasting temperatures. The increase in pasting temperature with increased banana starch inclusion is an indication of stronger cohesion in the composite matrices and higher thermal energy requirement for granules breakdown and subsequent gel formation (Alimi *et al*. 2016).

Peak viscosity (PV) which measured the swelling capability of starch had irregular trends in the custard samples. While it was increasing with increased banana starch content in native banana-corn starch composite custard flour, it was decreasing in both annealed and HMT included composite custard. Presence of moisture within the starch granules of the samples is the major influence to the trend observed. Higher PV is an indication of greater ease of swelling of starch granules during heating due to weaker cohesive forces within the granules. Presence of moisture within the granule structure favours low PV. The presence of moisture within the granules enhances the loosening of the granule structure and encouraged the formation of crystallites in the amorphous region. The lowest PV observed for custard flour incorporated with HMT starches was a result of its highest moisture presence which strengthened the cohesive forces within the granules and increased its resistance to swelling (Gebre-Mariam and Schmidt 1996; Alimi *et al*. 2016). The time required for the disintegration of starch granules during processing, peak time (PT), was generally decreasing with increasing content of banana starch in the composite custard flour samples. Breakdown viscosity (BV) measures the fragility of starch to the effect of applied heat and shear forces. Breakdown viscosity was generally decreasing with progressive inclusion of native or modified banana starch in the composite custard flour. Composite custard flour with HMT starch content had lowest BV. Breakdown viscosity is related to paste stability. Lower BV indicates higher resistance to effect of heat and shear stress and therefore better paste stability. Increased resistance offered by HMT starch was previously reported by Alimi *et al*. (2016). Setback viscosity (SBV), the difference between final viscosity (FV) and PV, measures the retrogadation tendency of starch or flour and stability of paste during cooling (Zaidul *et al*. 2007). Inclusion of native or modified banana starch in the custard flour led to increase in SBV and by implication, the retrogadation tendency of the composite custard. The SBV was increasing with increasing level of native or modified banana starch substitution in the custard samples. Factors such as the variation in the sizes of the granules within the starch networks, amylose and amylopectin ratio and their association could be responsible for differences in the pasting properties of the custard samples. Effect of modifications on banana starch, level of inclusion of banana starch in the composite custard flour and spatial distribution of starch granules in the matrix are suggested to be the major influence on the identified factors.

Functional Properties

Oil absorption capacity (OAC) of custard samples shown in TABLE 3 increased with the inclusion of native or modified banana starch from 8.69% (CS) to 9.77% (N35). This indicates increased lipophilic tendency with the inclusion of banana starch. This is a desirable attribute when there is need to fortify with fat/oil source. The lipophilic end would provide surface for the adherence of fat/oil.

Water absorption capacity (WAC) indicates the level of compactness of the molecular structure of starch in flour as it relates to the amount of water a food product could retain following application of mild pressure (Falade and Okafor 2014). Water absorption capacity (TABLE 3) varied between 36.35% (H15) to 37.81% (A35). The knowledge of WAC of the custard samples is a useful guide for the quantity of water to be added to ensure uniform consistency. Generally low WAC of all the samples shows their desirability for making thinner gruels (pap) (Oduro-Yeboah *et al*. 2012).

Swelling power (SP) measures the hydration capacity of flour materials. Incorporation of banana starch led to significant ($p < 0.05$) reduction of SP of custard flour from 1.85 (CS) to 1.16 (N35). Since SP is a function of interactive forces within starch molecules (Adebowale *et al*. 2009; Alimi *et al*., 2016), it could be explained that inclusion of banana starch in the matrix affected the symmetry due to large variation in sizes and shapes of the granules thereby resulting in the weakening of interactive forces within the network. The result was the reduction in SP. Solubility also varied significantly from 0.40 (N15 and A25) to 1.80 (H35).

Gelling point, the temperature at which flour suspension forms thick paste upon the application of heat, increased significantly ($p < 0.05$) from 73.00 ˚C (CS) to 81.67 ˚C (A15) (TABLE 3). Similar to the observation of Jane *et al*. (1992), inclusion of banana starch into custard flour enhanced stability of the flour samples to heat as shown with the attendant increase in gelling temperature. The higher gelling temperatures of the composite custard flour samples were as a result of the need for more energy to overcome the resistance to swelling imposed by the added materials. Boiling point temperature of the custard flour samples varied significantly ($p < 0.05$) from 78.33 ˚C (N35) to 88.33 ˚C (H25).

Densities of a material give information on its handling, packaging, stacking and transportation requirements. Values of loose and bulk pack densities, Carr's index and Hausner ratio are shown in TABLE 3. Loose pack density of the custard samples ranged from 0.51 g/cm^3 (N15) to 0.54 g/cm^3 (H35). Bulk pack density of the custard flour samples increased significantly ($p < 0.05$) with the inclusion of native or modified banana starch. Bulk pack density significantly ($p < 0.05$)

increased with increasing level of native (0.733 to 0.778 g/cm^3) and HMT (0.729~~3~~ to 0.775~~8~~ g/cm^3) banana starches in the composite custard. Higher bulk pack density value indicates more compactness of the granules within the matrices and hence, more volume reduction during packing. Carr’s index and Hausner ratio preview the extent of densification that would occur during the packing of powdered materials. The higher the values of Carr’s index and Hausner ratio, the denser the material and the poorer is its flowability (Carr 1965). Carr’s index and Hausner ratio of custard samples increased with the inclusion of banana starch. In fact, addition of banana starch in the composite custard led to 150% increase in Carr’s index. The implication is better compactness and poorer flowability with the inclusion of banana starch in the custard flour. The increasing void spaces taken by denser banana starch granules and the orientation of the granules in the matrix could be responsible for these observations.

Formatted: Superscript

Formatted: Superscript

Water Sorption Characteristics

Water adsorption behavior of food systems is an important factor for the determination of appropriate storage condition and selection of packaging materials. Custard flour samples displayed normal hygroscopic characteristic previously reported for starch and flour samples (Cardoso and da Silva Pena 2014). The equilibrium moisture content was generally increasing with increasing water activity for an isothermal point (Fig. 2). The typical sigmoid shaped curve obtained is an indication that the adsorption in the samples was multilayer typical of cereal based samples with micro-capillary structure (Oyelade *et al*. 2008).

The moisture sorption behaviour of the flour has major influence on those properties that are dependent on water activity especially microbiological safety, physicochemical and functional properties of food systems (Torres *et al*. 2012). It could affect the reconstitution and gelling properties of the flour as well as the stability and overall acceptability of the custard paste.

CONCLUSION

Type and ratio of banana starch had significant ($p<0.05$) influence on the studied engineering properties of the composite custard flour. The major drivers of the variation in the properties were the sizes, shapes and orientation of the granules in the matrices. These factors affect compactness, cohesive forces and the limit of structural alignment of the granules in the network. Moreover, inclusion of native or hydrothermal modified banana starch enhanced the paste stability, lipophilic tendency and the packaging/stacking quality of the custard flour. These are evidenced with the decrease in breakdown viscosity (971-872 cP), increased oil absorption capacity (8.69-9.77) and increased bulk packing density (0.650-0.778), respectively with the inclusion of banana starch. The enhanced functional properties exhibited by the composite custard flour samples could promote their production on commercial scale for the benefits of health conscious people.

REFERENCES

ADEBOWALE, K. O., HENLE, T., SCHWARZENBOLZ, U., and DOERT, T. 2009. Modification and properties of African yam bean (Sphenostylis stenocarpa Hochst. Ex A. Rich.) Harms starch I: Heat moisture treatments and annealing. Food Hydrocolloid. *23*(7), 1947-1957.

ADEGUNWA, M. O., ALAMU, E. O. and FASANYA, O. O. 2012. Effects of processing on the physicochemical properties and carotenoid contents of plantain flour. J. Food Process. Preserv. *36*, 339-347.

ADETUYI, F.O., BADEJO, O.F., IKUJENLOLA, A.V. and OMOSULI, S.V. 2009. Storage influence on the functional properties of malted and unmalted maize (Zea mays L ssp mays) and soybean (Glycine max L Merrill) flour blends. Afr. J. Food Sci. *3*(2), 56-60.

AGAMA-ACEVEDO, E., ISLAS-HERNÁNDEZ, J. J., PACHECO-VARGAS, G., OSORIO-DÍAZ, P. and BELLO-PÉREZ, L. A. 2012. Starch digestibility and glycemic index of cookies partially substituted with unripe banana flour. LWT-Food Sci. Technol. *46*(1), 177-182.

ALIMI, B.A. and WORKNEH, T.S. 2016. Consumer awareness and willingness to pay for safety of street foods in developing countries: a review. Int. J. Consumer Stud. *40*, 242-248

ALIMI, B.A., SHITTU, T.A. and SANNI, L.O., 2014. Effect of hydrocolloids and egg content on sensory quality of coated fried yam chips. J. Culin. Sci. Technol. *12*(2): 168-180.

ALIMI, B. A., WORKNEH, T. S. and OKE, M. O. 2016. Effect of hydrothermal modifications on the functional, pasting and morphological properties of South African cooking banana and plantain. Cy TA Journal of Food. http://dx.doi.org/10.1080/19476337.2015.1137356/

APARICIO-SAGUILAN, A., SAYAGO-AYERDI, S.G., VARGAS-TORRES, A., TOVAR, J., ASCENCIO-OTERO, T.E. and BELLO-PÉREZ, L.A. 2007. Slowly digestible cookies prepared from resistant starch-rich lintnerized banana starch. J. Food Composition Analysis *20*(3),175-181.

ATKINSON, F.S., FOSTER-POWELL K. and BRAND-MILLER J.C. 2008. International Tables of Glycemic Index and Glycemic Load Values. Diabetes Care, *31*, 2281-2283.

BEUCHAT, L.R., CHERRY, J.P. and QUINN M.R. 1975. Physicochemical properties of peanut flour as affected by proteolysis. J. Agric. Food Chem. *23*, 616-620.

CARDOSO, J.M. and da SILVA PENA, R. 2014. Hygroscopic behavior of banana (Musa ssp. AAA) flour in different ripening stages. Food Bioproduct. Process. *92*(1), 73-79.

CARR, R.L. 1965. Evaluating flow properties of solids. Chem. Eng. *72*, 163-168.

CHOO, C.L. and AZIZ, N.A.A., 2010. Effects of banana flour and β-glucan on the nutritional and sensory evaluation of noodles. Food chem. *119*(1), 34-40.

COVA, A., SANDOVAL, A.J., BALSAMO, V. and MÜLLER, A.J. 2010. The effect of hydrophobic modifications on the adsorption isotherms of cassava starch. Carbohydr. Polym. *81*(3), 660-667.

DEVI, K. and HARIPRIYA, S. 2014. Pasting Behaviors of Starch and Protein in Soy Flour-Enriched Composite Flours on Quality of Biscuits. J. Food Process. Preserv. *38*(1), 116-124.

DUNCAN, B.O. 1955. Multiple range and multiple F test. Biometrics, *11*, 1-42.

ELIASSON, A.C. 1980. Effect of water content on the gelatinization of wheat starch. Starch-Stärke *32*, 270-272.

ENGLYST, H.N., KINGMAN, S.M. and CUMMINGS, J.H. 1992. Classification and measurement of nutritionally important starch fractions. Eur. J. Clinical Nutr. *46*, 33-50.

FAISANT, N., BULEON, A., COLONNA, P., MOLIS, C., LARTIGUE, S., GALMICHE, J.P. and CHAMP, M. 1995. Digestion of raw banana starch in the small intestine of healthy humans: structural features of resistant starch. British J. Nutr. *73*(01), 111-123.

FALADE K. O. and OKAFOR C.A. 2014. Physical, functional, and pasting properties of flours from corms of two Cocoyam (Colocasia esculenta and Xanthosoma sagittifolium) cultivars. J. Food Sci. Technol. *52,* 3440-3448.

FALADE, K.O. and AYETIGBO, O.E. 2015. Effects of annealing, acid hydrolysis and citric acid modifications on physical and functional properties of starches from four yam (Dioscorea spp.) cultivars. Food Hydrocolloid. *43,* 529-539.

FARHAT, I.A., PROTZMANN, J., BECKER, A., VALLÈS-PÀMIES, B., NEALE, R. and HILL, S.E. 2001. Effect of the extent of conversion and retrogradation on the digestibility of potato starch. Starch-Stärke, *53*(9), 431-436.

GEBRE-MARIAM, T. and SCHMIDT, P. C. 1996. Isolation and Physico-chemical Properties of Enset Starch. Starch-Stärke, *48*(6), 208-214.

GHODAKE, H.M. GOSWAMI, T.K. and CHAKRAVERTY, A. 2007. Moisture sorption isotherms, heat of sorption and vaporization of withered leaves, black and green tea. J. Food Eng. *78,* 827–835

JACOBS, H. and DELCOUR, J. A. 1998. Hydrothermal modifications of granular starch, with retention of the granular structure: A review. J. Agric. Food Chem. *46*(8), 2895-2905.

JANE, J., SHEN, L., CHEN, J., LIM, S., KASEMSUWAN, T. and NIP, W.K. 1992. Physical and Chemical Studies of Taro Starches and Flours. Cereal Chem. *69,* 528-535.

KIM, Y. S., WIESENBORN, D. P., ORR, P. H., and GRANT, L. A. 1995. Screening potato starch for novel properties using differential scanning calorimetry. J. Food Sci. *60*(5): 1060-1065.

LI, S., WARD, R., and GAO, Q. 2011. Effect of heat-moisture treatment on the formation and physicochemical properties of resistant starch from mung bean (Phaseolus radiatus) starch. Food Hydrocolloid. *25*, 1702-1709.

NARAYANA, K. and NARASINGA RAO, M.S. 1982. Functional properties of raw and heat processed winged bean (Psophocarpus tetragonolobus) flour. J. Food Sci. *47*(5), 1534-1538.

NARAYANA, K. and NARASINGA RAO, M.S. 1984. Effect of partial proteolysis on the functional properties of winged bean (Psophocarpus tetragonolobus) flour. J. Food Sci.. *49*(3), 944-947.

ODURO-YEBOAH, C., ONWULATA, C., TORTOE, C. and THOMAS-GAHRING, A. 2014. Functional properties of plantain, cowpea flours and oat fiber in extruded products. J. Food Process. Preserv. *38*(1), 347-355.

OKOYE, J.I., NKWOCHA, A.C. and AGBO, A.O. 2008. Nutrient composition and acceptability of soy-fortified custard. Continental. J. Food Sci. Technol. 2: 37-44.

ONITILO, M.O., SANNI, L.O., DANIEL, I., MAZIYA-DIXON, B. and DIXON, A. 2007. Physicochemical and functional properties of native starches from cassava varieties in Southwest Nigeria. J. Food Agric. Environ. *5*(3 and 4), 108.

OYELADE, O.J., TUNDE-AKINTUNDE, T.Y., IGBEKA, J.C., OKE, M.O. and RAJI, O.Y. 2008. Modelling moisture sorption isotherms for maize flour. Journal of stored products research *44*, 179-185.

TÁRREGA, A. and COSTELL, E. 2006. Effect of inulin addition on rheological and sensory properties of fat-free starch-based dairy desserts. Int. Dairy J. *16*(9), 1104-1112.

TORRES, M.D., MOREIRA, R., CHENLO, F. and VÁZQUEZ, M.J. 2012. Water adsorption isotherms of carboxymethyl cellulose, guar, locust bean, tragacanth and xanthan gums. Carbohydr. Polym. *89*(2), 592-598.

WHO. 2008. Burden: mortality, morbidity and risk factors. In: ncd reports. http://www.who.int/nmh/publications/ncd_report_chapter1.pdf. Accessed on November 26, 2015.

WHO. 2015. Obesity and overweight. World Health Organisation (WHO) factsheet no 311. http://www.who.int/mediacentre/factsheets/fs311/en/. Accessed on November 26, 2015.

ZAIDUL, I. S. M., YAMAUCHI, H., TAKIGAWA, S., MATSUURA-ENDO, C., SUZUKI, T. and NODA, T. 2007. Correlation between the compositional and pasting properties of various potato starches. Food Chem. *105,* 164-172.

TABLE 1.

Temperate	**Tropical**	**Subtropical**
12°C and 25 % RH	27°C and 25 % RH	35°C and 25 % RH
12°C and 40 % RH	27°C and 40 % RH	35°C and 40 % RH
12°C and 55 % RH	27°C and 55 % RH	35°C and 55 % RH
12°C and 70 % RH	27°C and 70 % RH	35°C and 70 % RH
12°C and 90 % RH	27°C and 90 % RH	35°C and 90 % RH

TABLE 2.

Sample	Pasting Temperature (ºC)	PV (cP)	Peak time (min)	Trough (cP)	FV (cP)	BV (cP)	SBV (cP)
N15	77.35	4224	5.40	3352	4424	872	1072
N25	78.65	4318	5.33	34.94	4853	824	1359
N35	81.00	4415	5.33	3597	5290	818	1693
A15	77.35	4264	5.53	3453	4379	811	926
A25	80.25	4245	5.47	3514	4632	731	1118
A35	81.70	4198	5.33	3451	4853	747	1402
H15	77.20	38.91	5.47	3148	4180	743	1032
H25	80.25	3980	5.40	3209	4487	771	1278
H35	82.45	3920	5.47	3349	4672	571	1323
CS	75.05	4239	5.40	3268	4058	971	790

TABLE 3.

Sample	OAC (%)	WAC (%)	SP	SI	GT (ºC)	BT (ºC)	LPD (g/cm^3)	BPD (g/cm^3)	CI	HR
N15	8.80 ± 1.03^{a}	37.38 ± 1.18^{a}	1.19 ± 0.78^{ab}	0.40 ± 0.20^{a}	73.67 ± 3.21^{ab}	79.33 ± 4.04^{ab}	0.51 ± 0.00^{a}	0.733 ± 0.006^{bc}	44.39	1.44
N25	9.26 ± 0.21^{a}	36.69 ± 0.44^{a}	$1.69\pm0.0.13^{abc}$	0.80 ± 0.53^{ab}	79.33 ± 3.51^{ab}	84.00 ± 3.61^{abc}	0.51 ± 0.01^{ab}	0.759 ± 0.012^{cd}	48.48	1.49
N35	$9.77\pm.08^{a}$	36.47 ± 1.40^{a}	$1.16\pm0.0.07^{a}$	1.47 ± 0.46^{bcd}	75.33 ± 3.06^{ab}	78.33 ± 2.89^{a}	0.52 ± 0.01^{abc}	0.778 ± 0.018^{d}	49.77	1.50
A15	9.44 ± 1.03^{a}	37.10 ± 0.81^{a}	1.77 ± 0.114^{bc}	0.53 ± 0.12^{a}	81.67 ± 1.53^{ab}	86.33 ± 3.51^{abc}	0.52 ± 0.01^{abc}	0.719 ± 0.021^{b}	38.31	1.38
A25	9.02 ± 0.16^{a}	37.09 ± 0.70^{a}	1.64 ± 0.15^{abc}	0.40 ± 0.20^{a}	79.67 ± 1.53^{ab}	86.00 ± 1.0^{abc}	0.52 ± 0.01^{abc}	0.712 ± 0.035^{b}	36.71	1.38
A35	9.04 ± 0.31^{a}	37.81 ± 0.14^{a}	1.63 ± 0.26^{abc}	0.87 ± 0.31^{ab}	75.00 ± 6.56^{ab}	82.33 ± 7.51^{ab}	0.52 ± 0.01^{ab}	0.716 ± 0.020^{b}	39.08	1.39
H15	8.69 ± 0.54^{a}	37.77 ± 0.96^{a}	1.52 ± 0.15^{abc}	1.40 ± 0.53^{bcd}	79.00 ± 6.56^{ab}	87.00 ± 7.94^{abc}	0.53 ± 0.01^{bc}	0.729 ± 0.016^{bc}	36.91	1.37
H25	9.47 ± 0.55^{a}	36.35 ± 01.50^{a}	1.71 ± 0.25^{abc}	1.60 ± 0.53^{cd}	79.00 ± 7.55^{ab}	88.33 ± 3.51^{bc}	0.51 ± 0.00^{a}	0.733 ± 0.006^{bc}	43.91	1.44
H35	9.01 ± 0.41^{a}	36.85 ± 0.82^{a}	1.51 ± 0.25^{abc}	1.80 ± 0.40^{cd}	79.33 ± 0.58^{ab}	92.33 ± 2.89^{c}	0.54 ± 0.02^{c}	0.775 ± 0.007^{d}	44.23	1.44
CS	8.69 ± 0.48^{a}	37.56 ± 0.53^{a}	1.85 ± 0.23^{c}	1.07 ± 0.23^{abc}	73.00 ± 2.00^{a}	85.33 ± 5.03^{abc}	0.53 ± 0.02^{abc}	0.650 ± 0.033^{a}	23.77	1.24

ILLUSTRATIONS

TABLE 1.

TEMPERATURE/EQUILIBRIUM RELATIVE HUMIDITY COMBINATIONS FOR THE DETERMINATION OF EQUILIBRIUM MOISTURE CONTENT

TABLE 2.

PASTING PROPERTIES OF CUSTARD SAMPLES*

*Data not replicated

PV: peak viscosity; FV: final viscosity; BV; breakdown viscosity; SBV: setback viscosity; N15: 15% native banana starch incorporated custard flour; N25: 25% native banana starch incorporated custard flour; N35: 35% native banana starch incorporated custard flour; A15: 15% annealed banana starch incorporated custard flour; A25: annealed banana starch incorporated custard flour; A35: 35% annealed banana starch incorporated custard flour; H15: 15% HMT banana starch incorporated custard flour; H25: 25% HMT banana starch incorporated custard flour; H35: 35% HMT banana starch incorporated custard flour; CS: corn starch (commercial custard)

TABLE 3.

FUNCTIONAL PROPERTIES OF CUSTARD FLOUR SAMPLES*

*Means in the same columns followed by different letter(s) superscript are significantly different at 5% confident level ($p<0.05$).

OAC: oil absorption capacity; WAC: water absorption capacity; SP: swelling power; SI: solubility index; GT: gelling temperature; BT: boiling temperature; LBD: loose packed density; BPD: bulk packed density; CI: Carr’s index; HR: Hausner ratio; N15: 15% native banana starch incorporated custard flour; N25: 25% native banana starch incorporated custard flour; N35: 35% native banana starch incorporated custard flour; A15: 15% annealed banana starch incorporated custard flour; A25: annealed banana starch incorporated custard flour; A35: 35% annealed banana starch incorporated custard flour; H15: 15% HMT banana starch incorporated custard flour; H25: 25% HMT banana starch incorporated custard flour; H35: 35% HMT banana starch incorporated custard flour; CS: corn starch (commercial custard)

FIG. 1.

REPRESENTATIVE ELECTRON MICROGRAPHS OF COMPOSITE CUSTARD FLOUR

a: composite flour with annealed banana starch inclusion at 15% level (A15); b: composite flour with annealed banana starch inclusion at 25% level (A25); c: composite flour with annealed banana starch inclusion at 35% level (A35); BS: banana starch; CS: corn starch

FIG. 2.

WATER ADSORPTION ISOTHERM CURVES OF A REPRESENTATIVE CUSTARD SAMPLE (A15)

EMC: equilibrium moisture content; a_w: water activity

Acknowledgements

Authors acknowledge the University of KwaZulu-Natal, South Africa for funding this research. Dr. Buliyaminu Adegbemiro Alimi gratefully acknowledges the postdoctoral fellowship award provided by the College of Agriculture, Engineering and Sciences, University of KwaZulu-Natal, South Africa.

Conflict of Interest

The authors declare no conflict of interest.

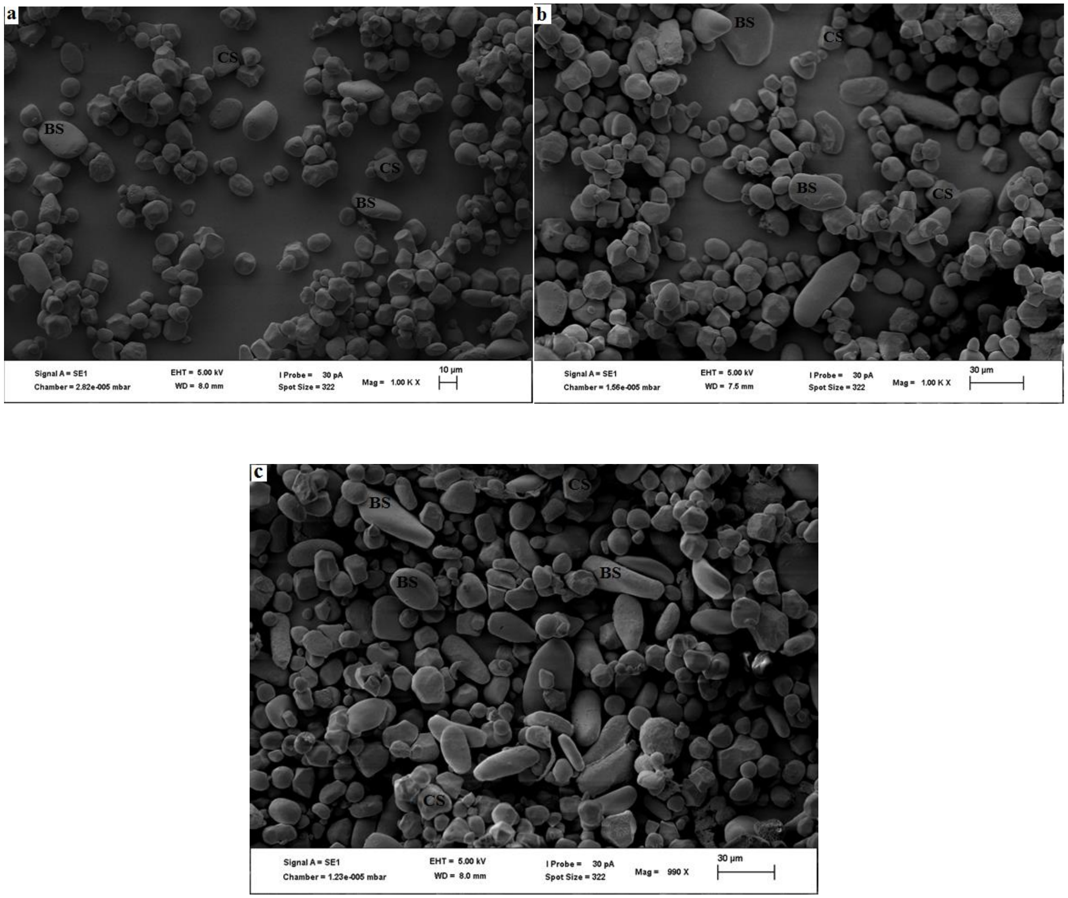
a
CS
BS
CS
BS
Signal A = SE1
Chamber = 2.82e-005 mbar
EHT = 5.00 kV
WD = 8.0 mm
I Probe = 30 pA
Spot Size = 322
Mag = 1.00 K X
10 µm
b
BS
CS
BS
CS
Signal A = SE1
Chamber = 1.56e-005 mbar
EHT = 5.00 kV
WD = 7.5 mm
I Probe = 30 pA
Spot Size = 322
Mag = 1.00 K X
30 µm
c
CS
BS
BS
BS
CS
Signal A = SE1
Chamber = 1.23e-005 mbar
EHT = 5.00 kV
WD = 8.0 mm
I Probe = 30 pA
Spot Size = 322
Mag = 990 X
30 µm

Fig. 1.

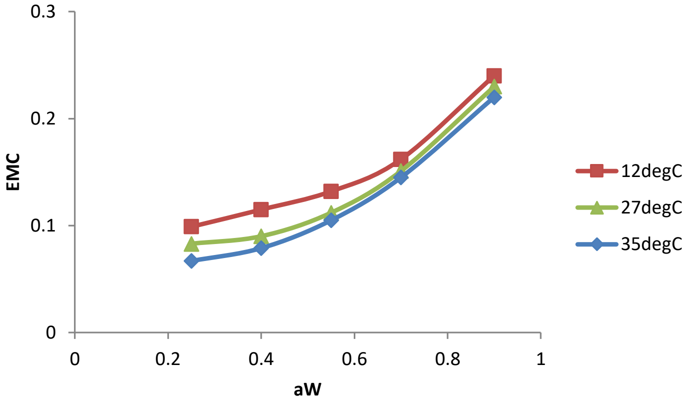

Fig. 2.