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Structural, rheological and in-vitro digestibility properties of composite corn-banana starch custard paste

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A B S T R A C T

This study investigated the influence of native or hydrothermally modified banana starch on structural, rheological and in-vitro digestibility properties of corn starch custard pastes. Banana starch was incorporated into the formulation in the ratio 1:4 (g/g) of the composite. Amylose content in the pastes varied significantly ($p < 0.05$) from 17.61 to 27.27 g/100 g. Scanning electron micrographs revealed similar homogenous, non-continuous, flake-like network structure for all paste samples. Addition of modified banana starch generally reduced the strength of the pastes. Generally, the paste samples showed shear thinning behavior of thermoplastic materials. Banana starch inclusion in the custard formulation significantly ($p < 0.05$) increased the slowly digestible starch fraction of the pastes, while the addition of annealed or heat moisture treated banana starch significantly ($p < 0.05$) increased the resistant starch component.

1. Introduction

Consumers are increasingly demanding for foods that will impart positively on their health in addition to the traditional roles of meeting the nutritional requirements (Alimi, Shittu, & Sanni, 2014; Alimi, Workneh, & Oke, 2016b). This demand stemmed from increasing incidence of debilitating diseases and alarming number of deaths linked with consumption of some foods, especially those with high calorie content. Consumption of high calorific foods have been implicated in the occurrence of cardiovascular and neurodegenerative diseases, type II diabetes, obesity and several types of cancers (WHO, 2015). This scenario has challenged the food scientists to come up with innovative food products that would combine the dietary need satisfaction with disease management attributes. The approaches proposed includes the systemic manipulations of high calorie foods especially carbohydrates to alter their digestion path in human digestive system. The manipulations are done to produce components that usually remain undigested in the upper intestinal tract or an intermediate starch that is digested slowly in the small intestine resulting in sustained slow release of glucose to the blood stream (Agama-Acevedo, Islas-Hernández, Pacheco-Vargas, Osorio-Díaz, & Bello-Pérez, 2012).

Studies have shown that functional improvement of the existing foods trusted by consumers over time is the most appropriate approach to deliver the health benefits (Alimi & Workneh, 2016; Alimi et al., 2016b). One of the most often consumed foods the world over that could be used to achieve this purpose is starch based custard paste or gruel. Custard is a fine textured semi-solid gruel or paste prepared by dissolving custard starch in water and then make into paste by adding calculated amount of boiling water. The resulting paste is often consumed as weaning and breakfast foods by infants and adults in many parts of the world (Tárrega & Costell, 2006). The fluidity of the thin paste also makes it an ideal convalescent food. The major constituent which makes up about 95% of the starch for custard paste is corn starch. It is responsible for the gelling capability and consistency of the gruel during heating. It is also responsible for the high calorific index of the paste because of its high glycemic index (GI) value of approximately 81 (Atkinson, Foster-Powell, & Brand-Miller, 2008). High GI foods are known for rapid release of glucose into the blood stream thereby raising the blood glucose level (Agama-Acevedo et al., 2012). Therefore, improving the functionality of custard paste through incorporation of established health enhancing ingredients could make it an ideal food for health conscious people.

Ripe green banana is in a class of food that contains a significant

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amount of resistant starch (RS). Resistant starch is a starch fraction known for beneficial health giving functionality in human system (Alimi, Sibomana, Workneh, & Oke, 2016a). It is fermented by microbes in the large intestine to form short chain fatty acids, which contributes to intestinal health. Therefore, the inclusion of banana starch in custard formulation could impart positively on human health through the alteration of the digestion path of the paste in human digestive system. However, RS contents from natural sources like banana may be reduced under conditions of high temperature encountered during processing in the food industry.

Starch modifications methods such as heat-moisture treatment (HMT) and annealing (ANN) have been successfully used to produce starch that are resistant to high temperature and pressure during food processing. These physical methods of starch modification are preferred over other modification methods in the food industry because of their safety advantage (Alimi et al., 2016b). They both involve controlled application of heat and moisture to starch under such condition that gelatinization would not occur (da Rosa Zavareze & Dias, 2011; Singh, Kaur, & McCarthy, 2007). The functional properties exhibited by hydrothermal modified starches were imparted by the strong interactives forces within the granules formed as a result of structural re-organization (Alimi, Workneh, & Sibomana, 2016c). Hydrothermal modification of banana starch to form type 3 resistant starch (RS3) could be of benefit in custard formulation for health conscious people since these category of starch could retain its indigestibility over time after high temperature processing (Farhat et al., 2001). Beside the possible effect of native and hydrothermally modified green ripe banana starches on the digestibility pathway of the custard paste in the human system, they may also affect other properties that may be useful for the process control. Performance of native and hydrothermally modified banana starches had been studied in such food products as pasta (Ovando-Martinez, Sáyago-Ayerdi, Agama-Acevedo, Goñi, & Bello-Pérez, 2009), cookies (Agama-Acevedo et al., 2012) and noodles (Choo & Aziz, 2010). However, to our knowledge, the inclusion of hydrothermally modified banana starch in custard paste formulation has not been reported. The facts stated above could give importance to the production of custard paste with native or modified banana starch as functional ingredient. Furthermore, ripe banana deteriorates very fast with several tonnages being lost during the seasonal gluts. Hence, the incorporation of banana starch as a functional ingredient in custard formulation may be one of several ways of reducing postharvest losses. Therefore, the objectives of this study were to investigate the in-vitro digestibility and some physicochemical properties of composite corn-banana custard paste.

2. Materials and methods

2.1. Experimental materials

Green ripe banana (*Musa paradisiaca*) was purchased from a fresh grocery store in Ogbomoso, Nigeria and transported immediately to the laboratory for starch extraction. Commercial custard (pure corn starch obtained from Premier Foods, Waterfall city, South Africa) was used as the base material. Enzymes (pancreatin from porcine pancreas, P7545; amyloglucosidase from aspergillus, A9913; glucose oxidase kit, GAGO-20) were supplied by Sigma-Aldrich Pty Ltd, Johannesburg, South Africa.

2.2. Starch extraction

Native banana starch was extracted as previously described (Alimi et al., 2016b). Extracted starch was dried in a forced air convective oven at a temperature of 48 °C for 24 h. The dried native starch was packed in an airtight Ziploc bags and kept at 4 °C until analyzed.

2.3. Hydrothermal modifications of native banana starch

Banana starch was modified using heat moisture treatment (HMT) and annealing (ANN) as described by Alimi et al. (2016b).

2.4. Composite corn-banana custard starch formulation

Native, heat moisture treated and annealed banana starches were incorporated separately into corn starch at 1:4 (g/g) of the total composite. The constituents were thoroughly mixed together with a blender. Commercial custard (pure corn starch) was used as reference.

2.5. Custard paste preparation

The protocol for medium consistency paste preparation was determined during preliminary trials. It involved dissolving 75 g custard starch in 75 mL distilled water with thorough mixing. Boiled water (425 mL) was then added to form paste. The paste samples were allowed to cool, freeze dried and grinded. The grinded freeze dried paste samples were packed in airtight Ziploc bags and stored at 4 °C for further analyses.

2.6. Apparent amylose contents

The quantity of amylose in freeze dried paste samples was determined by the iodine binding method described by Williams, Kuzina, and Hlynka (1970). Briefly, samples (20 mg) were weighed into a 50 mL beaker. Samples were dispersed in 10 mL solution of 0.5 N KOH for 5 min. The dispersed samples were transferred to 100 mL volumetric flasks and diluted to the mark with distilled water, with careful rinsing of the beaker. An aliquot portion of the test solution (10 mL) was pipetted into a 50 mL volumetric flask, and 5 mL solution of 0.1 N HCL was added. Iodine reagent (0.5 mL) was also added and the volume diluted to 50 mL. The absorbance of the blue colour formed was measured at 625 nm after 5 min. The amylose contents of the samples were estimated from a calibration curve for standard amylose.

2.7. In-vitro digestibility of custard paste

Digestibility of freeze-dried custard paste samples was done as reported by Naidoo, Amonsou, and Oyeyinka (2015). Briefly, porcine pancreatic α-amylase (3.89 g) was dispersed in water (25.7 mL), centrifuged for 10 min at 2500×g, and 18.7 mL of supernatant was collected. Amyloglucosidase (1 mL) diluted in deionized water (2 mL) was added to the supernatant. The solution was freshly prepared for the digestion analysis. Aliquots of guar gum (10 mL, 5 g/L) and sodium acetate buffer (5 mL, 0.5 M) were added to the starch samples (0.5 g, dry basis) in plastic centrifuge tubes. Seven glass balls (10 mm diameter) and 5 mL of enzyme solution were then added to each tube, following the incubation in a water bath (37 °C) with agitation (170 rpm). Aliquots (0.5 mL) were taken at intervals and mixed with 4 mL of 80% ethanol, and the glucose contents in the mixture were measured using glucose oxidase and peroxidase assay kits. Nutritional starch fractions based on digestibility were: RDS represents portion of starch that was hydrolyzed within 20 min of incubation; SDS represents the starch hydrolyzed between 20 and 120 min; while RS was estimated as the starch not digested after 120 min of incubation.

2.8. Strength of the paste

The modified method of Leung, Barron, and Davis (1983) was used for the analysis of the paste strength. Paste samples from the preparation above were kept at 4 °C for 2 h to cool the samples. The paste strength was determined by a texture analyzer (TA.XT2, Stable Micro System Ltd, UK). A cylindrical probe of 6.35 mm was programmed for pre-test speed of 1.5 mm/s, test speed of 1.0 mm/s, post-test speed of 1.0 mm/s and to move the distance of 4.0 mm into the sample. The peak force of penetration into the paste over the distance was taken as the paste strength.

2.9. Rheology

The rheological properties of the custard paste samples were measured as described by Oyeyinka, Singh, Adebola, Gerrano, and Amonsou (2015). The flow parameters were determined using a controlled stress Rheolab rheometer (model 80,732,808, Anton Paar, Austria) of rotational cylindrical geometry. Briefly, 10 g of custard powder was dispersed in 100 mL, gelatinized and rapidly transferred into the hollow ring within the holding cylinder. Starch pastes were allowed to equilibrate at 60 °C for 10 min. Shearing was done with cylindrical spindle which rotated within the hollow column of the cylinder containing the paste. The pastes were measured at shear rates ranging between 10 and 1000 s^{-1}. The data were fitted into Ostwald-de Waele Power-Law Model (Barnes, Hutton, & Walters, 1989) as follows:

$$\tau = k\gamma^{n} \quad (1)$$

Where τ is the shear stress (Pa), k is the consistency coefficient, (Pa s^n), γ is the shear rate (s^{-1}) and n is the flow behaviour index.

2.10. Microscopy

The morphological changes induced by gelatinization on custard samples were observed with a scanning electron microscope (SEM) (EVO LS15, ZEISS International, Germany) following the procedure described by Alimi et al. (2016c). Thin layer of custard starch and freeze-dried custard gel paste samples was attached to the SEM stub with a double sided adhesive tape. The samples were coated with gold using an ion sputtering device (EIKO IB-3 ion coater, Eiko Engineering Company, Hitachinaka, Japan) before examination under the microscope.

2.11. X-ray diffraction (XRD)

Diffraction patterns of custard starch and freeze-dried gel paste were captured with an X-ray diffractometer (Empyrean, PANanalytical, Almelo, Netherlands) coupled with a sample changer and image plate detector. Scanning region of diffraction was registered at Bragg angle (2Θ) 3° to 40°, generator settings of 40 kV and 40 mA, and scan step time of 8.225 s. Gaussian fit tool was used to generate the amorphous and peak areas. Plots were generated with Origin software. Multi peak fittings were done using Gaussian fit tool to get integrated areas of crystalline peaks (Ac) and amorphous peaks (Aa). Crystallinity index, Xc (%), was then calculated from the equation below.

$$\text{Crystallinity index, Xc (\%)} = \frac{100\,Ac}{(Ac + Aa)} \quad (2)$$

Ac is the area of crystalline region while Aa is the area of amorphous region.

2.12. Data analyses

Experiments were done at least in duplicates. Data were analysed using SPSS 15.0. The means obtained from one way analysis of variance were separated using Duncan Multiple Range Test.

3. Results and discussion

3.1. Apparent amylose contents

Apparent amylose contents of custard pastes varied from 17.61 to 27.27 g/100 g for custard containing native banana starch and annealed banana starch respectively (Table 1). Differences in amylose contents could be due to the extent of amylose leaching during the modification processes (Aguirre-Cruz, Méndez-Montealvo, Solorza-Feria, & Bello-Pérez, 2005). The highest amylose content observed for paste sample with annealed BS starch inclusion compared to other paste samples could be due to restriction to amylose leaching imposed by its more organized structure. This organized structure could be the consequence of strong intercellular networks which resulted from crystalline perfection, re-organization of starch molecules and amylopectin double helices (Alimi et al., 2016c; da Rosa Zavareze & Dias, 2011; Gomes, da Silva, & Ricardo, 2005). The amorphous portion of starch is mainly amylose and its relative content has significant influence on some parameters important for process control in the processing of starch based products (Alimi et al., 2016b).

3.2. X-ray diffraction

X-ray diffraction analysis was employed to observe the change in the degree of crystallinity of starch samples as a result of gelatinization. Diffraction patterns of custard starch samples are shown in Fig. 1a. Freeze-dried custard samples showed C-type diffraction pattern with the characteristic peak around 5–7 (2Θ), doublet between 17 and 19 and other peaks at 16, 24 and 28. C-type diffraction pattern, being a combination of A and B, could be as a result of the contribution of the ingredients. Corn starch contributed its characteristic A-type pattern (Gebre-Mariam, Abeba, & Schmidt, 1996) while banana starch contributed B- type pattern (Alimi et al., 2016b). Gelatinization, however, changed their diffraction patterns to similar processing induced V_H type crystal as evidenced with the presence of peaks at 19 and 22 (2Θ) (Van Soest & Vliegenthart, 1997). The patterns of the pastes are shown in Fig. 1b. The V_H structure is formed after processing as a result of rapid recrystallization of the single helical amylose structures during cooling (Pelissari, Andrade-Mahecha, do Amaral Sobral, & Menegalli, 2013).

The crystallinity index of custard starch and paste samples varied from 17.33 to 17.91% and 17.60–18.10%, respectively (Table 2). Generally, except for NBCS, freeze-dried paste samples had higher crystallinity index than their corresponding starch samples. This could be due to the combine effects of recrystallization of the single-helical amylose structures during cooling (Pelissari et al., 2013) and the prominence of amylopectin molecules as a result of the loss of loosely associated amylose in the matrices during paste preparation (Kaur, Sandhu, & Lim, 2010).

3.3. Morphological properties

Scanning electron micrographs of representative composite custard starch showed spatial arrangement of corn (smaller, polyhedral) and banana (elongated, spheroid) starch granules in the composite (Fig. 2). However, gelatinized samples showed homogenous non-continuous gel network structure (Fig. 3), which could

Table 1
Amylose contents, paste strength and power law parameters of custard pastes.

Sample	Apparent amylose contents (g/100 g)	Paste strength (g)	n	K (Pa s)	r^2
CS	$24.03^a \pm 0.02$	$12.87^a \pm 0.961$	$0.025^a \pm 0.001$	$71.000^b \pm 0.650$	0.725
ABCS	$27.27^a \pm 0.01$	$11.07^a \pm 1.342$	$0.024^{ab} \pm 0.001$	$78.135^{ab} \pm 1.940$	0.723
HBCS	$19.26^{bc} \pm 0.01$	$12.47^a \pm 1.62$	$0.021^c \pm 0.001$	$102.990^a \pm 0.659$	0.713
NBCS	$17.61^c \pm 0.01$	$12.87^a \pm 0.35$	$0.022^c \pm 0.001$	$88.935^{ab} \pm 1.630$	0.674

Mean ± SD. Mean with different superscript letters along a column are significantly different ($p < 0.05$).
CS: corn starch (commercial custard), ABCS: composite annealed banana-corn starch.
HBCS: composite HMT banana-corn starch, NBCS: composite native banana-corn starch.

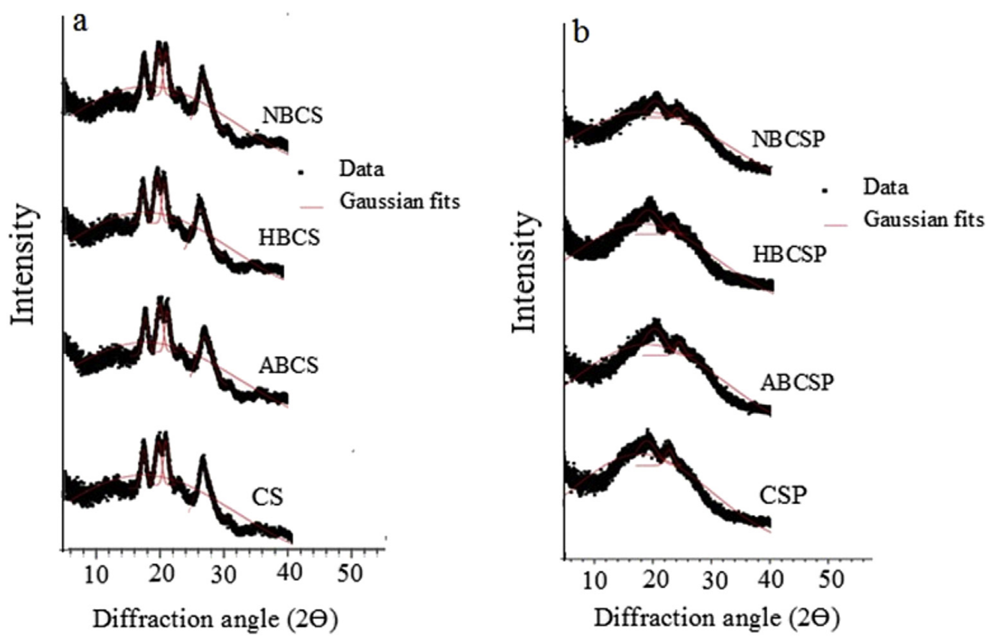

Fig. 1. X-ray diffractograms of (a) custard starch and (b) custard paste samples CS: corn starch (commercial custard), ABCS: composite annealed banana-corn starch HBCS: composite HMT banana-corn starch, NBCS: composite native banana-corn starch CSP: corn starch (commercial custard) paste, ABCSP: composite annealed banana-corn starch paste, HBCSP: composite HMT banana-corn starch paste, NBCSP: composite native banana-corn starch paste.

Table 2
Crystallinity index of custard starch and paste samples.

Sample	Starch		Paste	
	Crystalline index (%)	r^2	Crystalline index (%)	r^2
CS	17.41	0.91	18.1	0.94
ABCS	17.33	0.91	18.07	0.94
HBCS	17.91	0.91	18.04	0.94
NBCS	18.00	0.90	17.54	0.95

CS: corn starch (commercial custard), ABCS: composite annealed banana-corn starch.
HBCS: composite HMT banana-corn starch, NBCS: composite native banana-corn starch.

be due to the rupturing of starch granular structure. Starch granules appear to have lost their identity forming thick discontinuous flake-like gel networks. This observation has been previously reported for composite polymer gels (Joshi, Aldred, Panozzo, Kasapis, & Adhikari, 2014).

3.4. Rheology and strength of custard pastes

Gelatinized custard samples showed similar shear thinning behavior typical of pseudoplastic materials (Fig. 4). Similar behavior was reported for corn starch-based custard flavored with caramel jam (Ramírez-Sucre & Vélez-Ruiz, 2014). There was apparent divergence in viscosity values at lower stress region and near convergence at higher stress region. Similar to the report of Spada, Marczak, Tessaro, Flôres, and Cardozo (2015) on custard, the flow behavior depicted the dependence of viscosity on shear rate. The decrease in viscosity with increasing shear rate was an indication of the weakening of the cellular granule networks and subsequent structural breakdown with the application of shear stress (Oyeyinka et al., 2015). The differences in amylose contents (Table 1) of the starches and the type of mixture may also have influenced their viscosity.

The Ostwald-de Waele's Power Law model was used to present the flow behavior of the custard systems (Table 1). The adequacy of the model to explain the flow behavior of starch-based custard system has been previously demonstrated (Abu-Jdayil, Mohameed, & Eassa, 2004; De Wijk, Prinz, & Janssen, 2006; Spada et al., 2015). The flow response showed that the inclusion of BS significantly ($p < 0.05$) augmented the flow consistency (k) of the custard paste. Although the consistency index values of the paste samples extended over a wide range (71.00–102.99 Pa s), the flow behavior index (n) covered a narrow interval (0.021–0.025) with r^2 value range of 0.674–0.725. The flow behavior characteristic shown by the pastes, as it is with all gelatinized polymer products, is a function of the nature and contribution of the materials in the

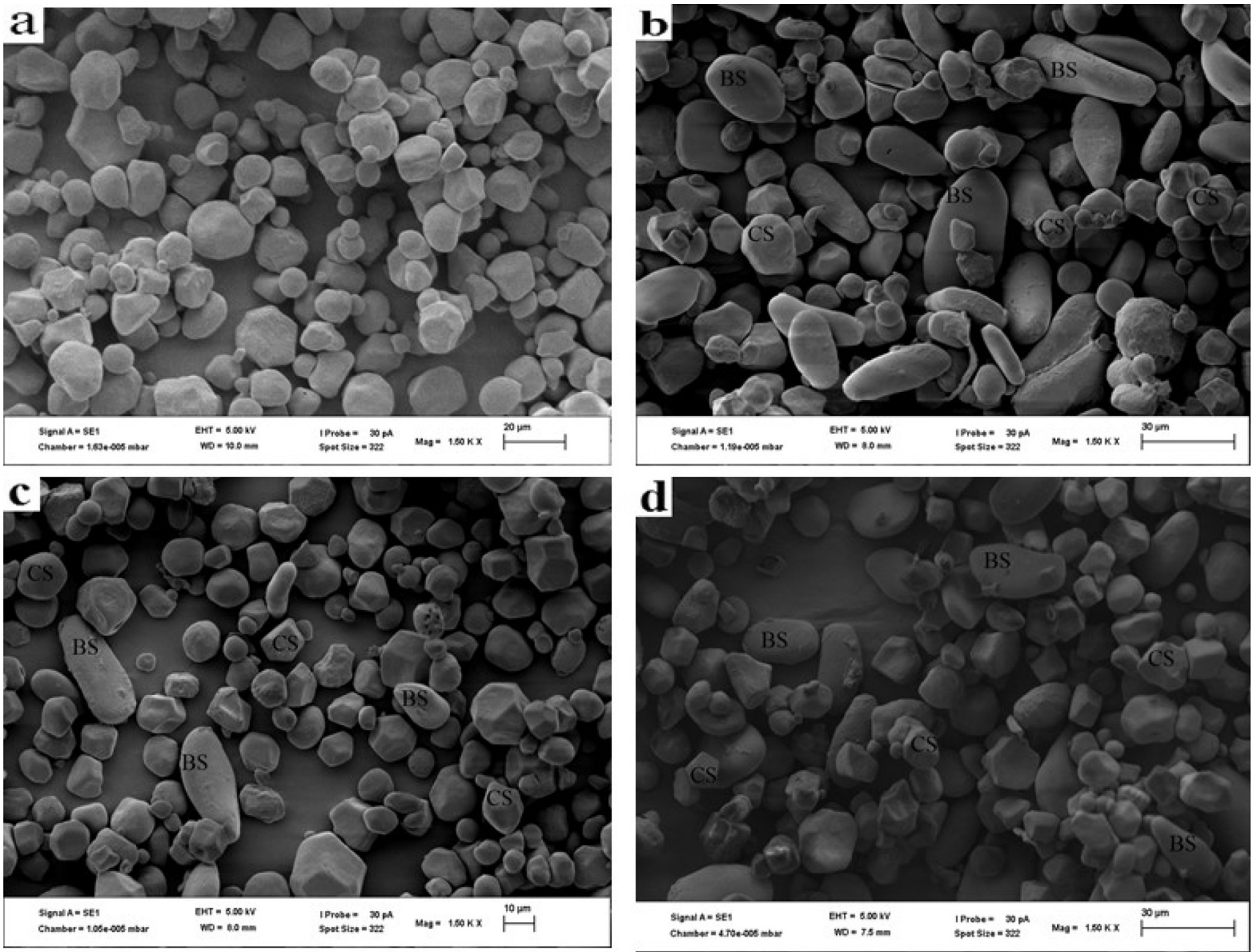

Fig. 2. Micrographs of the custard starch composite custard paste. a: corn starch (commercial custard) b: composite annealed banana-corn starch, c: composite HMT banana-corn starch d: composite native banana-corn starch.

matrix (Ramírez-Sucre & Vélez-Ruiz, 2014).

Paste strength values ranged from 11.07 g to 12.87 g (Table 1). There was no significant ($p < 0.05$) variation in the strength of the custard paste samples. A number of factors have been suggested to be responsible for the strength of starch paste. Intrinsic interaction of the starches which is governed by their relative hydrophilicity/hydrophobicity, ability to form complex, relative content of amylose/amylopectin, rearrangement of the amylose chains which led to increase in the porosity of the matrix and presence of non-starch polysaccharides which may hinder hydrogen bond formation could affect the paste strength (Charoenkul, Uttapap, Pathipanawat, & Takeda, 2011; Yadav, Guleria, & Yadav, 2013). The similar values obtained in this study could be due to the uniformity of the base materials and the synergy of interaction of the component ingredients.

3.5. Digestibility of custard gel paste

Results of digestibility tests on the freeze-dried custard paste samples are shown in Table 3. Rapidly digestible starch (RDS) of custard gel paste samples varied from 75.68 to 80.24 g/100 g. The values of RDS obtained in this study were comparable to those reported for cookies (87.41–95.41 g/100 g) (Agama-Acevedo et al., 2012) and noodles (78.92–93.05 g/100 g) (Choo & Aziz, 2010) with banana starch inclusion. The gelatinization process which led to the loss of crystalline structure and subsequent solubilization of the starch granules enhanced the hydrolysis of the paste by digestive enzymes (Zhang, Ao, & Hamaker, 2006). This may have accounted for the high RDS values obtained in this study. Custard paste with native banana starch (BS) inclusion had slightly higher RDS contents compared to those with modified BS. This could imply formation of indigestible starch fraction as a result of the modification of BS. Previous research has shown that ANN and HMT decreased starch granule swelling and susceptibility towards enzyme hydrolysis (Hoover, Hughes, Chung, & Liu, 2010). These were as a result of increase in crystalline perfection and increased interaction between amylose-amylose and amylose-amylopectin chains (Hoover et al., 2010).

Addition of BS to custard starch imparted beneficial attribute to the paste as shown with the increase in the slowly digestible starch fraction (Table 3). This could be as a result of improved compactness that BS added to the matrix. The presence of BS in the matrix could have helped to form viscous solution which may have slowed down the enzyme activities (Choo & Aziz, 2010). Previous report on the influence of food compactness on the diffusion of amylolytic products to the absorption mucosa confirmed our position (Björck,

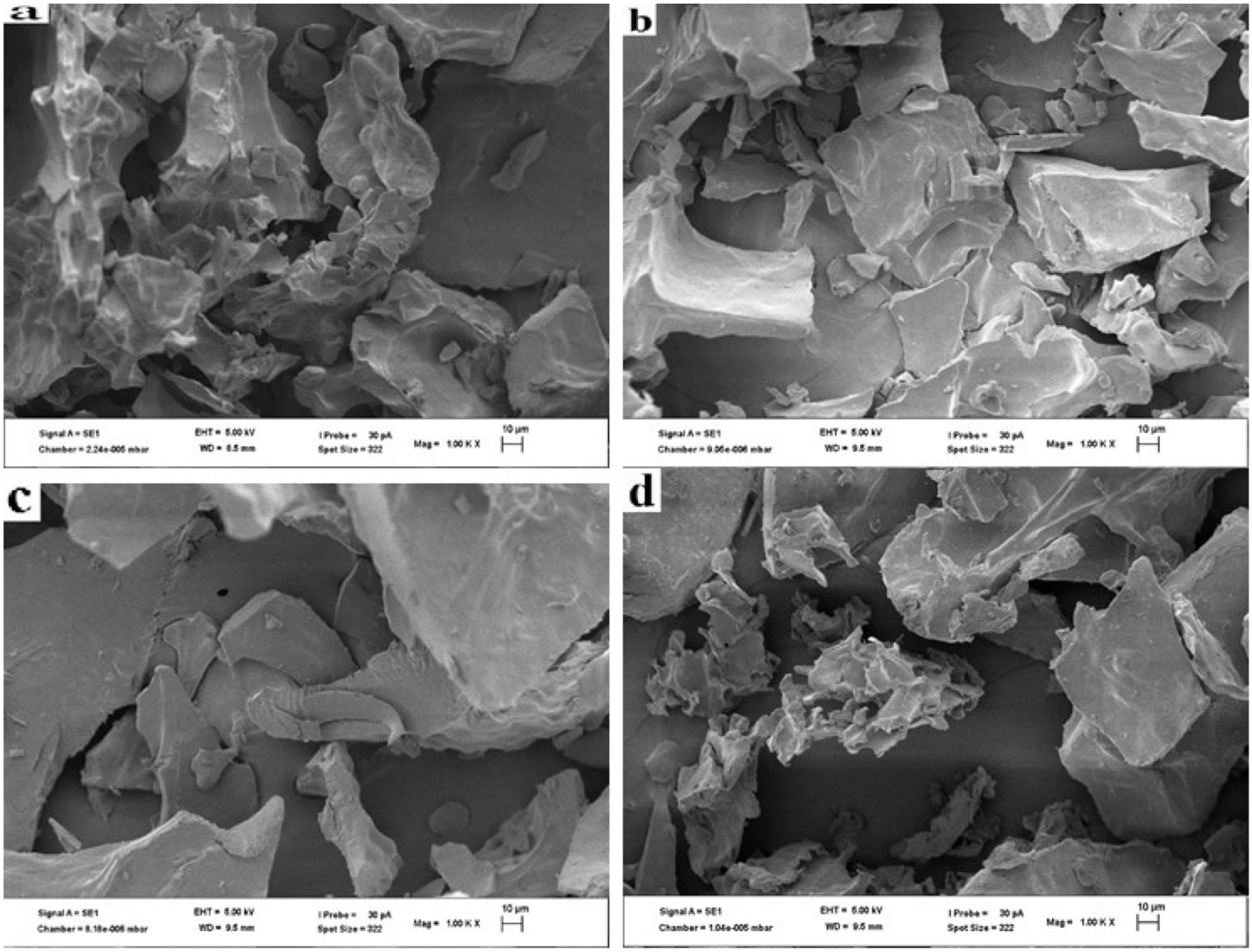

Fig. 3. Micrographs of the freeze dried custard starch pastes. a: corn starch (commercial custard) paste b: composite annealed banana-corn starch paste c: composite HMT banana-corn starch paste d: composite native banana-corn starch paste.

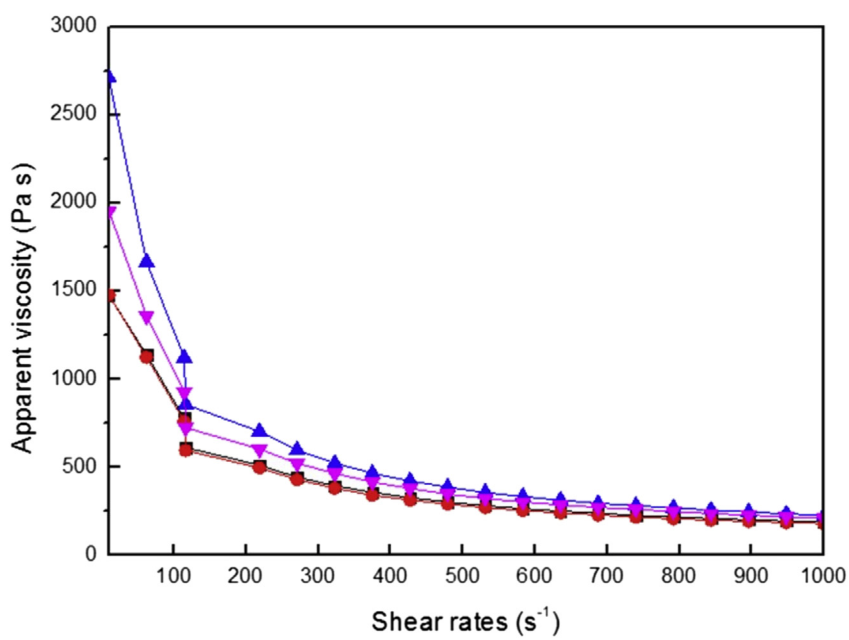

Fig. 4. Rheograms of the custard paste —■— CSP —●— ABCSP —▼— HBCSP —▲— NBCSP CSP: corn starch (commercial custard) paste ABCSP: composite annealed banana-corn starch paste HBCSP: composite HMT banana-corn starch paste NBCSP: composite native banana-corn starch paste.

Table 3
Nutritional starch fractions of custard pastes.

Samples	RDS (g/100 g)	SDS (g/100 g)	RS (g/100 g)
CS	$78.88^a \pm 1.23$	$9.23^c \pm 0.22$	$11.89^b \pm 0.04$
ABCS	$76.33^b \pm 0.10$	$10.20^b \pm 0.01$	$13.47^a \pm 1.20$
HBCS	$75.68^b \pm 0.11$	$10.94^b \pm 0.02$	$13.38^a \pm 0.34$
NBCS	$80.24^a \pm 0.02$	$14.28^a \pm 0.11$	$5.48^c \pm 0.24$

Mean ± SD. Mean with different superscript letters along a column are significantly different ($p < 0.05$).
CS: corn starch (commercial custard), ABCS: composite annealed banana-corn starch.
HBCS: composite HMT banana-corn starch, NBCS: composite native banana-corn starch.
RDS: rapidly digestible starch, SDS: slowly digestible starch, RS: resistant starch.

Granfeldt, Liljeberg, Tovar, & Asp, 1994). The reduced pace of digestion would prevent sudden increase in the blood glucose level by ensuring sustained slow release over time (Agama-Acevedo et al., 2012). The SDS values obtained with the addition of BS in this work were higher than those reported for cookies with 2.9 g/100 g BS (Aparicio-Saguilán et al., 2007) and cookies with 8.7 g/100 g BS (Agama-Acevedo et al., 2012). The beneficial aspect of this finding is the lowering of glycemic response that the higher SDS would induce in the digestive system (Choo & Aziz, 2010). Custard paste with modified starch also showed the highest contents of resistant starch (approximately 14 g/100 g) compared to custard paste with native banana starch and the control sample (Table 3). The higher resistant starch (RS) content of the custard paste containing annealed starch may be associated with its relatively higher amylose content (Table 1). This could be explained that the increased resistance induced by the modifications limited the access of amylase enzyme to amylose thereby reducing amylolytic hydrolysis (Naidoo et al., 2015; Oyeyinka, Singh, & Amonsou, 2016; Aparicio-Saguilan et al., 2007). It should be noted that corn starch had comparatively higher RS content than NBCS. Since the CS used in the study is a commercial product, it could be that it has been made to undergo some treatments that alter its digestion property. Hydrothermal modification is known to assist in the formation of RS3 which can withstand high processing temperature and remains undigested in human digestive system (Lehmann, Jacobasch, & Schmiedl, 2002).

4. Conclusions

Freeze-dried custard samples showed C-type diffraction pattern with varying amylose contents. Addition of native or hydrothermally treated banana starch enhanced the flow consistence of the custard pastes. Generally, the addition of banana starch increased the slowly digestible starch fraction of the pastes. The increase was marginal but significant with hydrothermal treated banana starch samples while it was substantially significant in native banana starch included custard paste. Custard paste samples containing hydrothermally modified banana starch had higher resistant starch fractions. The relatively high resistant starch contents of these samples suggest their potential used for the dietary management of caloric related diseases such as diabetes. These interesting results from in-vitro carbohydrate digestibility show the potential of the corn-banana starch paste to deliver health benefits along with its primary role of dietary need satisfaction.

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References

Abu-Jdayil, B., Mohameed, H. A., & Eassa, A. (2004). Rheology of wheat starch–milk–sugar systems: Effect of starch concentration, sugar type and concentration, and milk fat content. *Journal of Food Engineering, 64*(2), 207–212.
Agama-Acevedo, E., Islas-Hernández, J. J., Pacheco-Vargas, G., Osorio-Díaz, P., & Bello-Pérez, L. A. (2012). Starch digestibility and glycemic index of cookies partially substituted with unripe banana flour. *LWT-Food Science and Technology, 46*(1), 177–182.
Aguirre-Cruz, A., Méndez-Montealvo, G., Solorza-Feria, J., & Bello-Pérez, L. A. (2005). Effect of carboxymethylcellulose and xanthan gum on the thermal, functional and rheological properties of dried nixtamalised maize masa. *Carbohydrate Polymers, 62*(3), 222–231.
Alimi, B. A., Shittu, T. A., & Sanni, L. O. (2014). Effect of hydrocolloids and egg content on sensory quality of coated fried yam chips. *Journal of Culinary Science & Technology, 12*(2), 168–180.
Alimi, B., Sibomana, M., Workneh, T., & Oke, M. (2016a). Some engineering properties of composite corn-banana custard flour. *Journal of Food Process Engineering*. http://dx.doi.org/10.1111/jfpe.12444.
Alimi, B. A., & Workneh, T. S. (2016). Consumer awareness and willingness to pay for safety of street foods in developing countries: A review. *International Journal of Consumer Studies, 40*, 242–248.
Alimi, B. A., Workneh, T. S., & Oke, M. O. (2016b). Effect of hydrothermal modifications on the functional, pasting and morphological properties of South African cooking banana and plantain. *CyTA-Journal of Food, 14*(3), 489–495.
Alimi, B. A., Workneh, T. S., & Sibomana, M. S. (2016c). Effect of hydrothermal modifications on functional, pasting and structural properties of false banana (ensete ventricosum) starch. *Food Biophysics, 11*, 248–256.
Aparicio-Saguilán, A., Sayago-Ayerdi, S. G., Vargas-Torres, A., Tovar, J., Ascencio-Otero, T. E., & Bello-Pérez, L. A. (2007). Slowly digestible cookies prepared from resistant starch-rich lintnerized banana starch. *Journal of Food Composition and Analysis, 20*(3), 175–181.
Atkinson, F. S., Foster-Powell, K., & Brand-Miller, J. C. (2008). International tables of glycemic index and glycemic load values. *Diabetes Care, 31*(12), 2281–2283.
Barnes, H. A., Hutton, J. F., & Walters, K. (1989). *An introduction to rheology*. New York: Elsevier.
Björck, I., Granfeldt, Y., Liljeberg, H., Tovar, J., & Asp, N.-G. (1994). Food properties affecting the digestion and absorption of carbohydrates. *The American Journal of Clinical Nutrition, 59*(3), 699S–705S.
Charoenkul, N., Uttapap, D., Pathipanawat, W., & Takeda, Y. (2011). Physicochemical characteristics of starches and flours from cassava varieties having different cooked root textures. *LWT-Food Science and Technology, 44*(8), 1774–1781.
Choo, C. L., & Aziz, N. A. A. (2010). Effects of banana flour and β-glucan on the nutritional and sensory evaluation of noodles. *Food Chemistry, 119*(1), 34–40.
De Wijk, R., Prinz, J., & Janssen, A. (2006). Explaining perceived oral texture of starch-based custard desserts from standard and novel instrumental tests. *Food Hydrocolloids, 20*(1), 24–34.
Farhat, I. A., Protzmann, J., Becker, A., Vallès-Pàmies, B., Neale, R., & 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., Abeba, A., & Schmidt, P. (1996). Isolation and physico-chemical properties of enset starch. *Starch-Stärke, 48*(6), 208–214.
Gomes, A. M., da Silva, C. E. M., & Ricardo, N. M. (2005). Effects of annealing on the physicochemical properties of fermented cassava starch (polvilho azedo). *Carbohydrate Polymers, 60*(1), 1–6.
Hoover, R., Hughes, T., Chung, H., & Liu, Q. (2010). Composition, molecular structure, properties, and modification of pulse starches: A review. *Food Research International, 43*(2), 399–413.
Joshi, M., Aldred, P., Panozzo, J., Kasapis, S., & Adhikari, B. (2014). Rheological and microstructural characteristics of lentil starch–lentil protein composite pastes and gels. *Food Hydrocolloids, 35*, 226–237.
Kaur, M., Sandhu, K. S., & Lim, S.-T. (2010). Microstructure, physicochemical properties and in vitro digestibility of starches from different Indian lentil (Lens culinaris) cultivars. *Carbohydrate Polymers, 79*(2), 349–355.
Lehmann, U., Jacobasch, G., & Schmiedl, D. (2002). Characterization of resistant starch type III from banana (Musa acuminata). *Journal of Agricultural and Food Chemistry, 50*(18), 5236–5240.
Leung, H., Barron, F., & Davis, D. (1983). Textural and rheological properties of cooked potatoes. *Journal of Food Science, 48*(5), 1470–1474.
Naidoo, K., Amonsou, E., & Oyeyinka, S. (2015). In vitro digestibility and some physicochemical properties of starch from wild and cultivated amadumbe corms. *Carbohydrate Polymers, 125*, 9–15.
Ovando-Martinez, M., Sáyago-Ayerdi, S., Agama-Acevedo, E., Goñi, I., & Bello-Pérez, L. (2009). Unripe banana flour as ingredient to increase the undigestible carbohydrate of pasta. *Food Chemistry, 113*, 121–126.
Oyeyinka, S. A., Singh, S., Adebola, P. O., Gerrano, A. S., & Amonsou, E. O. (2015). Physicochemical properties of starches with variable amylose contents extracted from bambara groundnut genotypes. *Carbohydrate Polymers, 133*, 171–178.
Oyeyinka, S. A., Singh, S., & Amonsou, E. O. (2016). Physicochemical properties of starches extracted from bambara groundnut landraces. *Starch-Stärke*. http://

dx.doi.org/10.1002/star.201600089.
Pelissari, F. M., Andrade-Mahecha, M. M., do Amaral Sobral, P. J., & Menegalli, F. C. (2013). Comparative study on the properties of flour and starch films of plantain bananas (Musa paradisiaca). *Food Hydrocolloids, 30*(2), 681–690.
Ramírez-Sucre, M. O., & Vélez-Ruiz, J. F. (2014). Effect of formulation and storage on physicochemical and flow properties of custard flavored with caramel jam. *Journal of Food Engineering, 142*, 221–227.
da Rosa Zavareze, E., & Dias, A. R. G. (2011). Impact of heat-moisture treatment and annealing in starches: A review. *Carbohydrate Polymers, 83*(2), 317–328.
Singh, J., Kaur, L., & McCarthy, O. (2007). Factors influencing the physico-chemical, morphological, thermal and rheological properties of some chemically modified starches for food applications—a review. *Food Hydrocolloids, 21*(1), 1–22.
Spada, J. C., Marczak, L. D., Tessaro, I. C., Flôres, S. H., & Cardozo, N. S. (2015). Rheological modelling, microstructure and physical stability of custard-like soy-based desserts enriched with guava pulp. *CyTA-Journal of Food, 13*(3), 373–384.
Tárrega, A., & Costell, E. (2006). Effect of inulin addition on rheological and sensory properties of fat-free starch-based dairy desserts. *International Dairy Journal, 16*(9), 1104–1112.
Van Soest, J. J., & Vliegenthart, J. F. (1997). Crystallinity in starch plastics: Consequences for material properties. *Trends in Biotechnology, 15*(6), 208–213.
WHO. (2015). November 26, 2015. In *Obesity and overweight*. World Health Organisation http://www.who.int/mediacentre/factsheets/fs311/en/.
Williams, P., Kuzina, F., & Hlynka, I. (1970). Rapid colorimetric procedure for estimating the amylose content of starches and flours. *Cereal chemistry, 47*, 411–420.
Yadav, B. S., Guleria, P., & Yadav, R. B. (2013). Hydrothermal modification of Indian water chestnut starch: Influence of heat-moisture treatment and annealing on the physicochemical, gelatinization and pasting characteristics. *LWT-Food Science and Technology, 53*(1), 211–217.
Zhang, G., Ao, Z., & Hamaker, B. R. (2006). Slow digestion property of native cereal starches. *Biomacromolecules, 7*(11), 3252–3258.