Extrusion cooking of cassava-soy flour with 200 g/kg wheat bran promotes slower oral processing during consumption of the instant porridge and higher derived satiety

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Highlights

- Wheat bran addition increased viscosity of porridge.
- Porridge with 200 g/kg wheat bran had longer oral exposure.
- Adding wheat bran to the composite porridge increased feelings of satiety.
- Increased viscosity of porridge was associated with promoting satiety.

Abstract

In this study, the descriptive sensory attributes, oral processing characteristics of and subjective satiety responses for extrusion cooked cassava-soy porridge with wheat bran at 0, 100 and 200 g/kg addition levels were determined. Fifteen subjects (23 - 47 years, mean BMI 22.6 kg/m^2) consumed 250 g of each porridge type over 8 breakfast meals while being video recorded. Oral exposure time and number of bites, and eating and bite rates were determined. Subjects rated hunger, fullness and desire to eat before meal, post meal and periodically over 3 h post consumption. A separate panel profiled the descriptive sensory attributes of the porridges. The addition of wheat bran increased visually perceived viscosity and presence of visible particles. The porridge with 200 g/kg wheat bran was eaten with more bites and at a slower rate thus, having longer oro-sensory exposure. Also, the porridge with 200 g/kg wheat bran led to greater reduction in subjective reported hunger compared to the other porridges. Wheat bran as a source of dietary fibre has the potential to be incorporated as a component of extruded starch-rich foods to produce instant products which can promote satiety.

Keywords: dietary fibre; food texture; oral exposure duration; oral processing; viscosity;

1. Introduction

In recent years, the health benefits associated with dietary fibre has increased consumer demand for fibre-rich products. Studies have shown the benefits of diets rich in dietary fibre in reducing the risks of developing type-2 diabetes (Wang, Fang, Gao, Zhang, & Xie, 2016; Aune, Norat, Romundstad, & Vatten, 2013), cardiovascular diseases (Aune et al., 2016), and weight management (Kim et al., 2016; Boaz, Leibovitz, & Wainstein, 2013).

Dietary fibre has been reported to suppress hunger and increase satiety through its ability to add bulk to the diet and increase viscosity of foods (Slavin & Green, 2007). Increase in viscosity has been shown to influence average bite size, eating rate (consumption of volume per minute) and overall *ad-libitum* energy consumed to satiation (Ziljstra, Mars, de Wijk, Westerterp-Plantenga, & de Graaf, 2008). Dietary fibres are conventionally classified as water soluble or insoluble (Chawla & Patil, 2010). In a previous study on the extrusion cooking of a cassava-defatted toasted soy composite with wheat bran addition, Oladiran & Emmambux, (2017) demonstrated that extrusion cooking promotes the fragmentation of wheat bran insoluble dietary fibre. The fragmentation leads to an increase in soluble dietary fibre content and consequent increase in viscosity of extrudates.

Several factors have been shown to directly impinge on food intake regulation and satiety. These factors include food form (McCrickerd, Chambers, Brunstrom, & Yeomans, 2012), food texture (Chambers, 2016), food composition (Fiszman & Varela, 2013; Clark & Slavin, 2013) and individual differences in endocrine levels (De Silva & Bloom, 2012). Differences in appetitive and satiety responses have been demonstrated for liquid, semi-solid and solid foods.

Liquid foods are reported to induce weaker suppressive appetitive response compared to semi-solid and solid foods (Mattes & Rothacker, 2001; Tsuchiya, Almiron-Roig, Lluch, Guyonnet, &

Drewnowski 2006). The duration of oro-sensory exposure was highlighted as the major contributing factor to the response elicited.

In a review by Krop, et al., (2018), subjective appetite was reported to be influenced by manipulating components of oral processing such as eating rate, texture and chewing. The authors found that subjective appetite reduced in studies where participants were given foods that increased oral processing time and/or slowed the rate of eating. The review concluded that textural complexity that leads to a slower eating rate could be used to enhance oral processing thereby promoting satiety.

The texture of food will determine the extent to which it requires oral processing. Several authors have demonstrated that food texture can be manipulated to influence oral processing properties such as number of chews, number of swallows, eating rate, oro-sensory exposure. Ferriday et al., (2016) showed that variations in oral processing properties of the different foods studied influenced satiety after consumption of a fixed portion of each food. Foods with a chewy, hard or viscous texture usually require more mastication and are eaten more slowly. Bolhuis et al., (2014) also reported longer oro-sensory exposure time for harder or more viscous foods due to the need to masticate these foods.

There is also increasing evidence on the impact of some macronutrients on satiety. Foods high in dietary fibre were reported to have a more suppressive effect on hunger compared to other macronutrients (Bellissimo & Akhavan, 2015). This is attributed to the ability of dietary fibre to increase chewing and limit eating rate by promoting the secretion of saliva and gastric juice thereby leading to the expansion of the stomach with a consequent increase in satiety (Slavin & Green, 2007). The ability of some fibres to increase viscosity also contributes to the strong suppressive appetitive response they elicit post ingestion (Chambers, McCrickerd, & Yeomans, 2015).

There are limited studies on the effect of wheat bran on satiety. Lyly et al. (2009) investigated the effect of guar gum, wheat and oat bran on satiety using a beverage as carrier product. The authors reported that the beverage with wheat bran was more satiating compared to the porridge without fibre but less satiating compared to those with oat bran or guar gum. This may have been due to the higher soluble dietary fibre content in oat bran and guar gum. Extrusion cooking has been reported to be useful in modifying the functionality of wheat bran (Oladiran & Emmambux, 2017) by redistributing the insoluble dietary fibre to soluble dietary fibre ratio thus followed by increased viscosity. Here the effects of wheat bran addition to a cassava-soy composite, that were extrusion cooked to an instant porridge, on sensory properties, oral processing and subjective satiety responses when consuming the porridge, were determined.

2. Materials and methods

2.1 Materials

High quality cassava flour with particle size of ≤ 250 µm produced according to the Food and Agricultural Organization (FAO) method (Dziedzoave, Graffham, & Boateng, 2003) was purchased from Thai Farm International (Ogun State, Nigeria). The process for manufacturing the flour was as follows: fresh cassava roots were peeled, washed, sliced, pressed, grated, dried, milled, sifted to a particle size of ≤ 250 µm, and bagged. The flour contained 84.45 g/100g starch, 9.8 g/100g moisture, a pH of 5.7 and 0.5 g/100g crude fibre. Toasted defatted soy flour with particle size of ≤ 212 µm was purchased from Petrow Foods (Johannesburg, South Africa) and wheat bran was obtained from Food Corp (Pretoria, South Africa) and milled to a particle size of ≤ 500 µm.

2.2 Methods

2.2.1 Extrusion cooking

Cassava and defatted toasted soy flours were uniformly mixed using a Talsa mixer (90 ST, Xirivella, Spain) in a ratio of 65:35 (w/w). Wheat bran was added to the cassava-defatted toasted soy mixture at 0, 100 and 200 g/kg level and mixed thoroughly. Water at a dosing rate of 3 l/h and feed rate at 25 kg/h was fed into a co-rotating twin screw extruder (TX 32, CFAM, Potchefstroom, South Africa) with a barrel comprised of five heating zones set at 60/80/100/140/140 °C respectively. A die opening of 3 mm was used and the screw speed was maintained at 200 rpm. Extrudates were immediately dried in an oven at 90°C for 5 min and milled after cooling using a hammer mill. The ground extruded products were kept in air tight plastic buckets and refrigerated at 4 °C in preparation for analysis.

2.2.2 Sample preparation

Four soft porridges (200 g/L solids) were prepared by adding boiling water to the extrudates and a commercial instant sorghum porridge product used as standard. Xylitol (1.5 g/100g) was added to sweeten the porridges. The porridges were stirred to get products of uniform consistency devoid of lumps. Prior to sensory evaluation, the porridges were kept at 50 °C on a warming tray (Sunbeam SWT-250, Johannesburg, South Africa) for a maximum duration of 5 min. The dietary composition of the extruded instant porridges and commercial instant sorghum product is shown in Table 1. The portion size served for the oral processing and satiety test would provide about 10% of an adult's daily energy requirement.

Table 1: Nutritional composition of 250 g portions of extruded cassava-soy porridge with 0, 100 and 200 g/kg wheat bran and an instant commercial product

	Carbohydrate (g)	Protein (g)	Fat (g)	Dietary fibre (g)	Sweetener (g)	Energy content (kJ)
Extruded cassava-soy composite	34.3	9.75	0.15	5.75	3.75	805.8
composite with 100 g/kg wheat bran	33.5	9.40	0.20	7.20	3.75	788.3
composite with 200 g/kg wheat bran	32.1	8.55	0.23	9.05	3.75	751.9
Commercial product	37.4	3.55	1.25	3.00	3.75	795.4

2.2.3 Descriptive sensory analysis

The generic descriptive analysis method according to Einstein (1991) was used. A separate, experienced, trained sensory panel (n=11) participated in 8 h of training which took place over 4 days. The four prepared porridges were served in glass ramekins (40 g portions) covered with aluminum foil and with stainless steel teaspoons. Through consensus, descriptive terms (Table 2) and scale anchors for the evaluation of the porridges were developed and defined by panellists. Reference standards were used to ensure that all panellists agreed on the various sensory descriptors identified (Table 2). Thirty descriptors were used to differentiate amongst the porridges. Each panellist evaluated each porridge four times giving 44 data points. The order of sample presentation was randomized over the panel using the Williams Latin square design. Filtered tap water was used to rinse the mouth before and between samples. Tests were conducted in a sensory evaluation laboratory equipped with individual booths. The panellists entered their responses directly on to Compusense Five software (Compusense Five release 4.6, Compusense, Guelph, Ontario, Canada).

2.2.4 Dynamic viscosity

The dynamic viscosity of the porridges was measured with a Physica MCR 101 rheometer with Rheoplus software®, (Anton Paar, Ostfilderm, Germany). The vane in cup geometry with measuring system ST22-4V-40-SN20447 was used in this study. Porridge containing 200 g/L solid content was prepared and held at 50 ºC for 5 min to equilibrate. The porridge was then transferred into the rheometer cup and maintained at 50 ºC. The porridge was stirred with a vane and the viscosity was recorded over a shear rate range of 0.01 to 1000 s^{-1}.

Table 2: Sensory descriptors and evaluation guidelines used by sensory panel to evaluate cassava- soy porridges with 0, 100 and 200 g/kg wheat bran addition

Descriptor	Definition	References	Rating scale
Aroma			
Overall aroma	Intensity of the overall aroma of the porridge		Not intense = 0 Very intense = 10
Earthy aroma	Intensity of aroma associated with the earth or damp soil,	Damp soil = 10	Not earthy = 0 Very earthy = 10
Toasted nut aroma	Intensity of aroma associated with toasted peanuts	Toasted peanuts = 10	Not nutty = 0 Very nutty = 10
Starchy aroma	Intensity of aroma associated with under-cooked maize porridge	35 g/100g ACE maize flour in boiling water =10	Not starchy = 0 Very starchy = 10
Bran aroma	Intensity of aroma associated with whole grain products	20 g/100g ground Kelloggs All bran flakes in boiling water = 10	Not bran-like = 0 Very bran-like = 10
Soy aroma	Intensity of aroma associated with soya beans or soy products	35 g/100g defatted toasted soy flour in boiling water = 10	Not soy-like = 0 Very soy-like = 10
Cassava aroma	Intensity of the aroma characteristic of cassava porridge	10 g/100g high quality cassava flour in boiling water = 10	Not cassava = 0 Very intense cassava = 10
Appearance			
Brown colour	Degree to which porridge appears brown	Chocolate milk = 10	Not brown = 0 Very brown = 10
Glossy	Amount of shine or gloss perceived on the surface of the product	Egg white = 10	Not glossy = 0 Very glossy = 10
Viscosity	Perceived thickness of product when it is stirred	Filtered water = 0 Hullet's golden syrup = 10	Not viscous = 0 Very viscous = 10

Table 2 *Cont.*

Sticky	How the spoon adheres to the product when it is used to pull the porridge from the sides of the bowl	10 g/100g high quality cassava flour in boiling water = 10	Not sticky = 0 Very sticky = 10
Particles	Visible specks present in product. Particles can be different colours	Cooked sorghum porridge (Monati super mabele) = 7	No particles = 0 Many particles = 10
Flavour			
Sweet	Intensity of the sweet taste of which sucrose is typical	2 g/100g sucrose solution = 5	Not sweet = 0 Very sweet = 10
Sour	Intensity of the sour taste associated with citric acid	Mageu No 1 beverage = 7	Not sour = 0 Very sour = 10
Umami	Intensity of theumami taste of monosodium glutamate	10 g/100g aromat seasoning in boiled water = 10	Not umami = 0 Very umami = 10
Starchy flavour	Intensity of the flavour associated with under-cooked maize porridge	35 g/100g ACE maize meal in boiling water = 10	Not starchy = 0 Very starchy = 10
Earthy flavour	Intensity of the flavour associated with the earth or soil, natural	Damp soil = 10	Not earthy = 0 Very earthy = 10
Toasted nut flavour	Intensity of the typical flavour of peanuts	Toasted peanuts = 10	Not nutty = 0 Very nutty = 10
Beany flavour	Intensity of the flavour associated with under-cooked legumes	20 g/100g cowpea flour in boiled water = 10	Not beany = 0 Very beany = 10
Mouthfeel and Texture			
Coarse	The degree of grittiness or graininess in porridge as a result of small particles	Iwisa stiff maize porridge (35 g/100g flour in water) =5	Not coarse = 0 Very coarse = 10
Thickness	A measure of consistency of the porridge in the mouth	Water = 0 Thick cooked maize porridge = 10	Not thick = 0 Very thick = 10

Table 2 *Cont.*

Adhesiveness	Degree to which product adheres to the palate surface during mastication	Water = 0 Cooked Jungle Oats = 5 Peanut butter = 10	Not adhesive = 0 Very adhesive = 10
Astringent	Intensity of the dry puckering sensation on the tongue and other mouth surfaces	Strong black tea = 10	Not astringent = 0 Very astringent = 10
Aftertaste			
Sour aftertaste	Intensity of the sour taste associated with citric acid	Mageu No 1 beverage = 7	Not sour = 0 Very sour = 10
Astringent aftertaste	Intensity of the dry puckering sensation on the tongue and other mouth surfaces	Strong black tea = 10	Not astringent = 0 Very astringent = 10
Beany aftertaste	Intensity of the flavor associated with under-cooked legumes	20 g/100g cowpea flour in boiled water = 10	Not beany = 0 Very beany = 10
Sweet aftertaste	Intensity of the sweet taste of which sucrose is typical	2 g/100g sucrose solution = 5	Not sweet = 0 Very sweet = 10

2.2.5 Subjects and experimental procedure – oral processing and satiety related perceptions test

Volunteers (n=15) were recruited from the Department of Food Science, University of Pretoria. Participant eligibility was based on age of 18-50 years, body mass index (BMI) of between 18 and 30 kg/m and a low dietary restraint ≤ 8 based on the three-factor eating questionnaire-R18 (TFEQ-R18) (Karlsson, Persson, Sjöström, & Sullivan, 2000), no food allergies or intolerances and not following a special or restricted diet at the time of the study. The qualified panel had a mean age of 34 ± 9 y and BMI of 22.6 ± 2.6 kg/m^2. Based on the TFEQ-R18, the mean cognitive restraint, emotional and uncontrolled eating scores of the subjects were 2.5 ± 1.4, 1.4 ± 0.6, and 1.9 ± 0.8 respectively. For $p = 0.05$, a treatment difference of 10 mm on the satiety scale, and completing the study with data from 15 participants was estimated to provide a power level of approximately 0.9 (Flint, Raben, Blundell, & Astrup, 2000). Participants were informed about the purpose of the study and written consent was obtained from each participant. The Ethics Committee of the Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa (reference EC 160713-054), granted ethical approval for the study.

Participants were instructed to fast for at least 8 h before evaluation of porridges. They arrived at the sensory laboratory at 07:30 am daily and each session began with ratings of hunger level (how hungry do you feel right now?), fullness (how full do you feel right now?) and desire to eat (how strong is your desire to eat right now?) recorded on 100 -mm visual analog scales (VAS) on paper. The scales were anchored from "not much at all" on the left to "extremely much" on the right. Each participant evaluated the food privately in a sensory booth fitted with a web camera that was placed below the computer monitor. The video recording on the monitor was minimized to prevent distractions and eliminate factors that might influence eating behaviour.

At each breakfast session, each participant was served a 250g portion of one of the breakfast porridges and a stainless-steel teaspoon and was instructed to eat the full portion at their normal eating rate while being video recorded. Hunger, fullness and desire to eat as before were rated immediately after eating and at intervals of 30, 60, 90, 120, 150 and 180 min from end of consumption of the porridge.

The order of consuming the four porridges on different days was randomized over the panel. There was a total of eight sessions to obtain 2 replicates per panellist for each porridge type. The method by Forde, van Kuijk, Thaler, de Graaf, & Martin (2013a) was used for video-data collection. A total of 120 video recordings were coded for oral processing characteristics using the linguistic annotator software (ELAN 4.9.1, Max Planck Institute for Psycholinguistics, The Language Archive, Nijmegen, The Netherlands). The number of bites was coded as a key point event while total oral exposure time was coded as a continuous event. Eating rate (g/min) was calculated by dividing the mass of food consumed by the total oral exposure time. Bite size (g/bite) was calculated by dividing the mass of porridge served by the number of bites it took to consume the food. Bite rate (s^{-1}) was calculated by dividing the number of bites taken to consume the porridge by the total oral exposure time. Calorie velocity was estimated as eating rate multiplied by energy density. All videos were coded by a single coder. Each participant received ZAR 70.20/ h for the time (total 8 h) spent to eat the breakfast porridge in the sensory laboratory.

2.3 Statistical analyses

All data were analysed using IBM SPSS Statistics 20 for Windows (Armonk, NY, USA). Significance was set at $P<0.05$ and means were separated using Fisher's least significant difference (LSD) test. Mean descriptive panel ratings per replicate were subjected to analysis of variance (ANOVA) with porridge type as the independent variable. One-way ANOVA was used to analyse differences in oral processing characteristics of porridges. The satiety related measures (hunger, desire to eat and fullness) were assessed by a mixed model repeated measures ANOVA with treatment (porridge type) and time as repeated factors. Graphical curves were drawn as a function of time for each satiety measure. The total area under curve was calculated from the post meal consumption time points of each satiety measure using the trapezoid rule. Associations between satiety related measures and oral processing characteristics were evaluated by calculating Pearson correlation co-efficient.

3. Results

3.1 Descriptive sensory evaluation

Thirty descriptors describing aroma, appearance, mouthfeel and aftertaste were generated to characterize the sensory properties of cassava-soy porridges with and without wheat bran (Table 1). The effect of wheat bran addition (0, 100 and 200 g/kg) in the porridges on descriptive sensory ratings is shown in Table 3.

Bran aroma was perceived more in the composite porridge with 200 g/kg wheat bran and the commercial product compared to the porridges with no or 100 g/kg wheat bran. Starchy aroma was strongly but equally perceived in all four porridges. The addition of wheat bran reduced cassava aroma in the porridge. The intensity of earthy, soy and toasted nut aroma was not significantly (p>0.05) different in porridges with and without wheat bran. In terms of appearance, the addition of wheat bran increased the visually perceived viscosity and presence of particles but reduced the glossiness of the porridges. There was no significant (p>0.05) difference in the brown colour and stickiness of the porridges including the commercial product.

Table 3: Descriptive sensory ratings of extrusion cooked cassava-soy porridges with 0, 100 g/kg and 200 g/kg wheat bran and an instant commercial product

	Sensory attribute	Cassava-soy composite	Composite with 100 g/kg added wheat bran	Composite with 200 g/kg added wheat bran	Commercial product	*P*-value
Aroma	Overall aroma	6.5 ± 0.0 ab	6.6 ± 0.1 ab	6.1 ± 0.5a	7.8 ± 0.5 b	0.033
	Earthy aroma	4.2 ± 0.0 b	4.6 ± 0.1 b	4.3 ± 0.1 b	2.1 ± 0.1 a	0.000
	Toasted nut aroma	2.6 ± 0.4 a	3.3 ± 0.4 a	3.0 ± 0.7 a	5.6 ± 0.3 b	0.010
	Starchy aroma	3.8 ± 0.0 a	4.6 ± 0.7 a	4.6 ± 0.2 a	3.0 ± 0.3 a	0.051
	Bran aroma	2.7 ± 0.0 a	3.8 ± 0.2 a	5.0 ± 0.4 b	5.5 ± 0.4 b	0.002
	Soy aroma	5.2 ± 0.3 b	5.0 ± 0.1 b	4.6 ± 0.4 b	0.9 ± 0.2 a	0.000
	Cassava aroma	4.2 ± 0.8 b	2.7 ± 0.6 ab	2.3 ± 0.6 ab	0.4 ± 0.1 a	0.013
Appearance	Brown colour	6.5 ± 1.1 a	6.3 ± 0.1 a	6.2 ± 0.1 a	6.2 ± 0.1 a	0.926
	Glossy	8.2 ± 0.0 d	6.3 ± 0.3 c	4.7 ± 0.2 b	3.2 ± 0.0 a	0.000
	Viscosity	3.4 ± 1.6 a	6.4 ± 0.7 b	8.5 ± 0.1 d	8.0 ± 1.1 c	0.007
	Sticky	5.5 ± 0.2 a	5.5 ± 0.5 a	6.5 ± 0.6 a	5.6 ± 1.1 a	0.416
	Particles	0.7 ± 0.0 a	3.0 ± 0.5 b	5.9 ± 0.3 c	8.5 ± 0.2 d	0.000
Flavour	Sweet	1.3 ± 0.2 a	1.3 ± 0.1 a	1.2 ± 0.2 a	6.6 ± 0.6 b	0.000
	Sour	1.6 ± 0.1 a	1.9 ± 0.2 a	1.8 ± 0.2 a	5.7 ± 1.2 b	0.007
	Umami	2.7 ± 0.8 a	3.1 ± 0.9 a	2.7 ± 0.4 a	2.0 ± 0.4 a	0.292
	Starchy flavour	4.6 ± 0.6 ab	5.2 ± 0.1 ab	5.5 ± 0.1 b	3.2 ± 0.9 a	0.049
	Earthy flavour	2.6 ± 0.5 a	2.7 ± 0.1 a	2.7 ± 0.6 a	4.8 ± 0.0 b	0.011
	Toasted nut flavour	2.5 ± 0.6 a	2.7 ± 0.1 a	2.7 ± 0.6 a	4.8 ± 0.0 b	0.016
	Beany flavour	5.4 ± 1.1 b	5.7 ± 0.7 b	5.0 ± 0.1 b	1.2 ± 0.6 a	0.009
Mouthfeel And Texture	Coarse	0.6 ± 0.1 a	2.8 ± 0.2 b	5.0 ± 0.8 c	6.1 ± 0.3 c	0.001
	Thickness	2.7 ± 0.7 a	5.0 ± 0.2 b	8.7 ± 0.1 d	6.9 ± 0.1 c	0.000
	Adhesiveness	5.1 ± 0.1 b	5.4 ± 0.0 b	5.7 ± 0.1 b	3.4 ± 0.8 a	0.019
	Astringent	3.3 ± 0.4 a	3.9 ± 0.3 a	4.0 ± 0.3 a	3.5 ± 0.8 a	0.430
Aftertaste	Sour aftertaste	1.7 ± 0.4 ab	1.6 ± 0.0 a	1.8 ± 0.2 a	4.2 ± 1.1 b	0.031
	Astringent aftertaste	2.9 ± 0.8 a	3.5 ± 0.2 a	3.4 ± 0.2 a	3.4 ± 1.0 a	0.780
	Beany aftertaste	4.3 ± 1.3 b	4.6 ± 0.6 b	3.7 ± 0.6 ab	0.6 ± 0.1 a	0.022
	Sweet aftertaste	1.0 ± 0.1 a	1.0 ± 0.0 a	1.0 ± 0.0 a	5.0 ± 0.8 b	0.002

Values are mean ratings for a trained panel (n=12) ± standard deviation. The definition of attributes is shown in Table 1. Values within the same row followed by the same letter are not significantly different ($p<0.05$)

As expected the intensity of flavour attributes of the commercial product differed significantly (*p*>0.05) from the experimental porridges. The experimental porridges with and without wheat bran did not differ in flavour attributes. It has been reported that the addition of a thickener can only modify flavour of foods if added at a concentration higher than its critical concentration (c*). Below the c* value, the presence of macromolecules does not affect flavour perception (Tournier, Sulmont-Rosse, & Guichard, 2007). Wheat bran addition increased the coarseness and thickness of porridges. However, the intensity of other mouthfeel and texture attributes were not significantly (*p*>0.05) different among the composite porridges and commercial product.

Bran aroma was perceived more in the composite porridge with 200 g/kg wheat bran and the commercial product compared to the porridges with no or 100 g/kg wheat bran. Starchy aroma was strongly but equally perceived in all four porridges. The addition of wheat bran reduced cassava aroma in the porridge. The intensity of earthy, soy and toasted nut aroma was not significantly (*p*>0.05) different in porridges with and without wheat bran. In terms of appearance, the addition of wheat bran increased the visually perceived viscosity and presence of particles but reduced the glossiness of the porridges. There was no significant (*p*>0.05) difference in the brown colour and stickiness of the porridges including the commercial product.

Only the intensity of beany aftertaste was rated significantly higher in cassava-soy with and without wheat bran compared to the commercial sorghum product used as standard. All the other aftertaste attributes were rated low in the composite porridges while the commercial sorghum product was rated significantly (*p*>0.05) higher.

The descriptive sensory profiles of extruded cassava-soy composite porridge with and without wheat bran and the commercial product used as reference are shown in Figure 1. The porridge

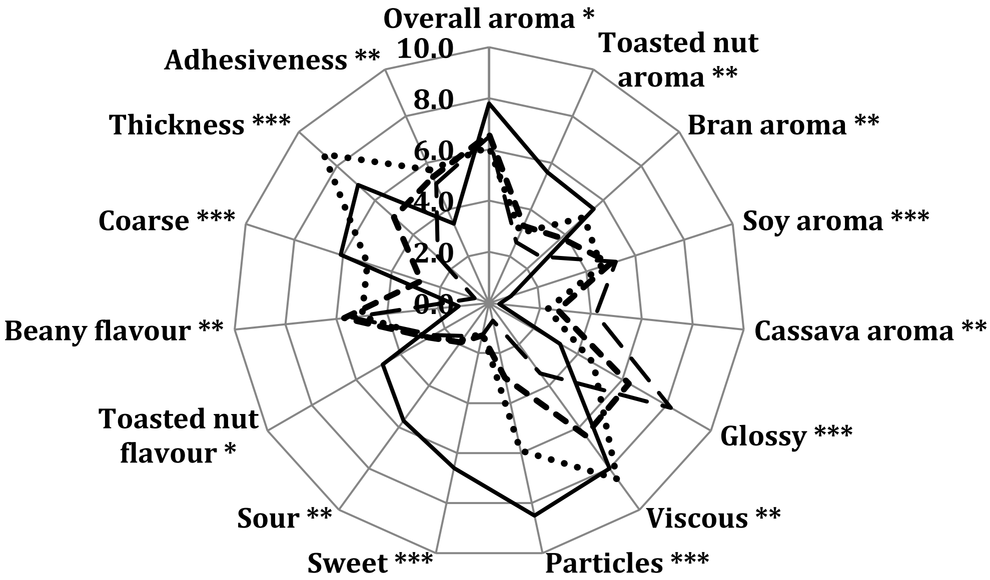
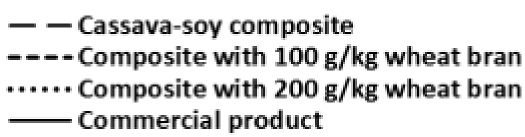


Figure 1: Spider plot of descriptive attributes of extruded cassava-soy composite porridge with 0, 100 and 200 g/kg wheat bran and an instant commercial product. * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.



with 200 g/kg wheat bran was characterized as more viscous, thicker, and with more visible particles compared to the porridges with 100 g/kg wheat bran and no wheat bran.

3.2 Dynamic viscosity

The viscosity measurements of the porridges are shown in Figure 2. Upon reconstitution of extrudates, high viscosity was observed with increasing wheat bran addition from 100 to 200 g/kg, while cassava-soy extrudate with no wheat bran was the least viscous at all shear rates. The commercial sorghum product used as standard was more viscous than the porridge with no wheat bran but less viscous compared to the porridges with wheat bran.

3.3 Variability in oral processing characteristics across porridges

Table 4 summarizes the main oral processing characteristics for each porridge. There was no significant difference ($p>0.05$) in the average number of bites, bite sizes and bite rates used to consume a 250g portion of all the breakfast porridges. It took significantly more time ($p<0.05$) to orally process and complete the consumption of the porridge with 200 g/kg wheat bran compared to the other porridges. This suggests that the porridge with 200 g/kg wheat bran had a slower eating rate.

The calorie velocity which provides an estimate of the rate of calorie intake within a meal was between 59.3 and 83.2 kcal/g/min. The porridge with 200 g/kg wheat bran had the lowest calorie velocity. This indicates that the rate of calorie intake while eating the porridge with 200 g/kg wheat bran was low compared to the other porridges.

Table 4: Oral processing characteristics of extruded cassava-soy porridges 0, 100 and 200 g/kg wheat bran and an instant commercial product

Treatment	Bites	Oral Processing time (s)	Total meal duration (s)	Average bite size (g/bite)	Eating rate (g/s)	Bite rate (s^{-1})	Calorie velocity (Kcal/g/min)
Cassava-Soy composite	17a ± 2	111a ± 33	145a ± 40	16.0a ± 4.4	1.9b ± 0.5	0.12a ± 0.03	83.2b ± 23.4
Composite with 100 g/kg wheat bran	17a ± 5	133a ± 41	156a ± 45	15.0a ± 3.1	1.7b ± 0.5	0.12a ± 0.02	76.9b ± 22.2
Composite with 200 g/kg wheat bran	20a ± 4	163b ± 43	189b ± 45	13.6a ± 3.5	1.4a ± 0.3	0.11a ± 0.02	59.3a ± 15.1
Commercial product	17a ± 4	120a ± 35	147a ± 39	15.4a ± 3.2	1.8b ± 0.5	0.12a ± 0.03	81.6b ± 24.2
F value	2.1	10.3	6.9	2.3	5.8	5.7	7.7
df	3	3	3	3	3	3	3
P value	0.107	0.000	0.000	0.082	0.001	0.001	0.000

Values are means ± standard deviations of 2 independent experiments.
Values within the same column followed by different letters are significantly different ($p \leq 0.05$)

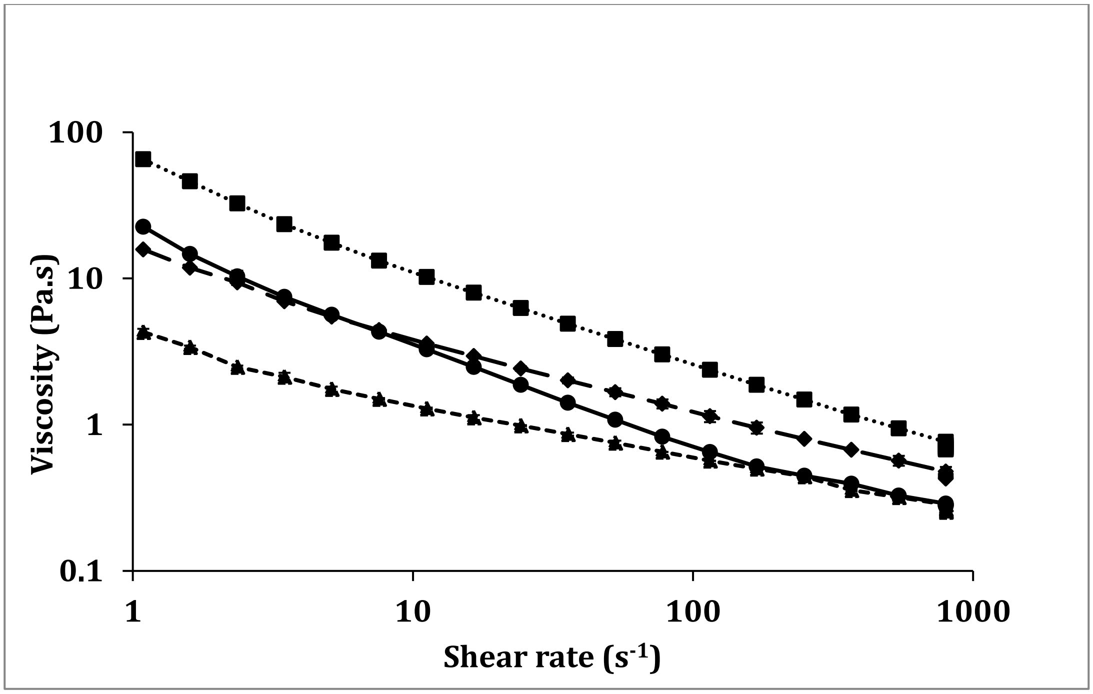


Figure 2: Apparent viscosity of extruded cassava-soy composite porridges with 0, 100 and 200 g/kg wheat bran and an instant commercial product at 50 ºC as a function of shear rate. Error bars represent standard deviation.

Cassava-soy composite
Composite with 100 g/kg wheat bran
Composite with 200 g/kg wheat bran
Commercial product

3.4 Satiety related ratings

The mean visual analog scale (VAS) scores for hunger, fullness and desire to eat post porridge ingestion completed every 30 min throughout the test period are shown in Figure 3. All test porridges led to significant changes from baseline ($p<0.01$) for all satiety measures rated. Hunger decreased as a result of consuming the porridge and then gradually increased for all test porridges from after consumption up to 3 h. Overall, the area under curve (AUC) of hunger was influenced by porridge type as the composite with 200 g/kg wheat bran led to greater reductions in hunger ($p = 0.029$) post consumption compared to the other porridges.

Statistically, there was no difference ($p>0.05$) in the total AUC of fullness and desire to eat post consumption of all porridges (Table 6). Repeated measures ANOVA revealed a significant treatment effect for hunger ratings ($p<0.008$) wherein hunger ratings were lower after ingestion of the porridge with 200 g/kg wheat bran compared to the other porridges. Fullness ratings were higher after consuming the porridges with 100 and 200 g/kg wheat bran compared to the other porridges ($p<0.022$), the desire to eat was lower after consuming the porridges with 100 and 200 g/kg wheat bran ($p<0.013$) compared to the other porridges. A post consumption effect of time was also observed for all the satiety measures. There was a change in the ratings for all satiety measures over the three hours after eating the meal; hunger ratings ($p<0.0001$) and fullness ratings decreased ($p<0.0001$), while the desire to eat increased ($p<0.0001$) with time. There was no significant porridge type × time interactions for all the satiety related measures.

3.5 Relationship between oral processing characteristics and satiety related measures

Table 5 summarizes the correlations between some oral processing characteristics and satiety related measures. The subjective hunger ratings reported correlated negatively and strongly with

Table 5: Correlations (Pearson's partial correlations) between oral processing variables and satiety measures (hunger, fullness and desire to eat)

	Hunger	Fullness	Desire to eat
Hunger	-		
Fullness	-0.81*	-	
Desire to eat	0.63*	-0.75*	-
Oral processing time (s)	-0.80*	-0.91**	-0.84**
Eating rate (g/min)	0.74*	-0.87**	0.92**

***** Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

Table 6: Total area under curve (AUC) for hunger, fullness and desire to eat post consumption (360 min) of extruded cassava-soy porridge with 0, 100 and 200 g/kg wheat bran and an instant commercial product

	Hunger	Fullness	Desire to eat
Extruded cassava- soy composite	9153b ± 273	8705a ± 200	8066a ± 439
composite with 100 g/kg wheat bran	7002ab ± 190	9905a ± 989	7643a ± 526
composite with 200 g/kg wheat bran	6093a ± 288	10932a ± 332	6505a ± 608
Commercial product	8683ab ± 482	9746a ± 974	8054a ± 144

Values are means ± standard deviations of 2 independent experiments.
Values within the same column followed by different letters are significantly different ($p \leq 0.05$)

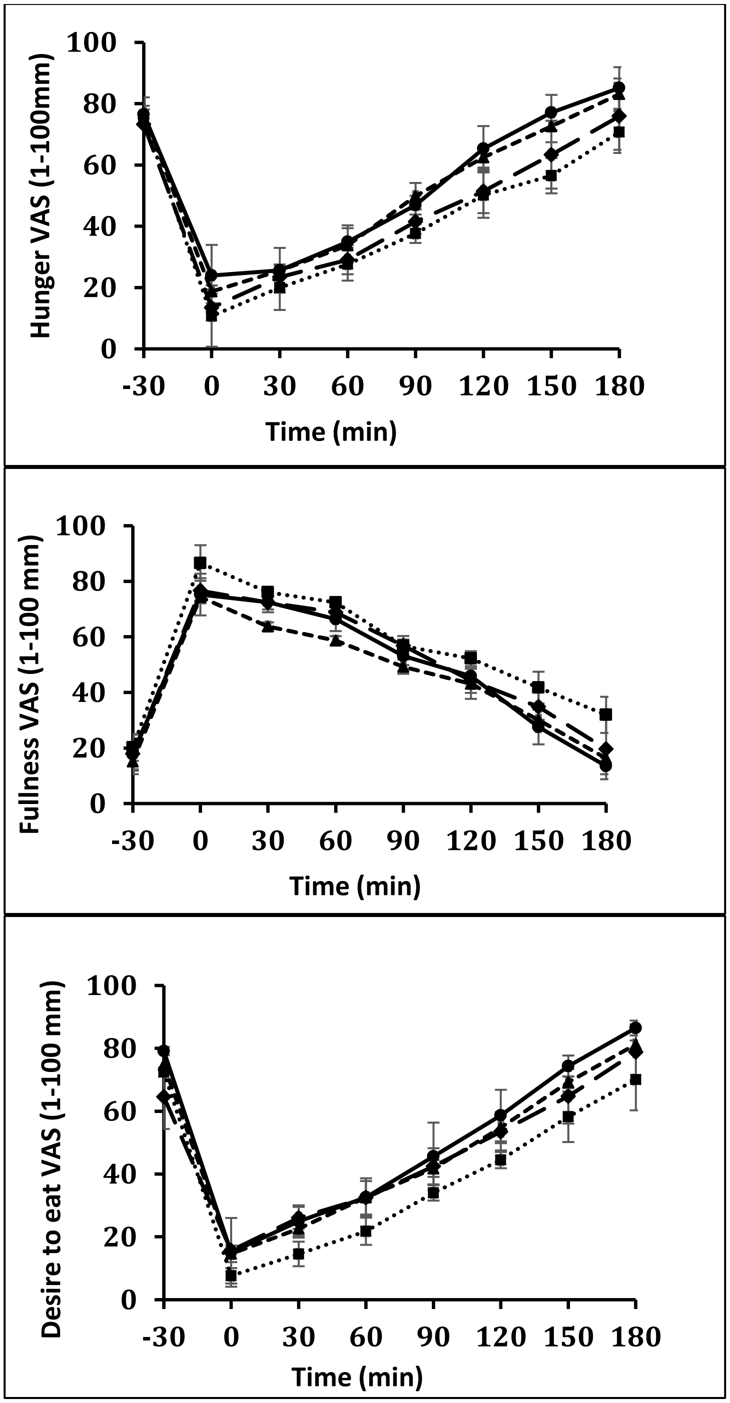
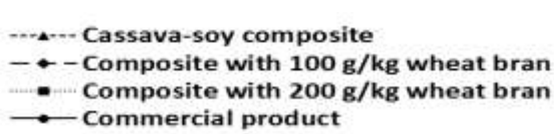


Figure 3: Mean VAS scores of hunger, fullness and desire to eat following the consumption of extruded cassava-soy porridges with 0, 100 and 200 g/kg wheat bran and an instant commercial product. Error bars represent standard deviations.



fullness (r = -0.81, p = 0.013) and weakly with desire to eat (r = 0.63, p = 0.05). Oral processing time was negatively correlated with hunger (r= -0.80, p = 0.05), fullness (r= -0.91, p = 0.01) and desire to eat (r= -0.84, p = 0.01). Porridges that had longer oral exposure were associated with lower hunger ratings post consumption (r= -0.80, p = 0.05). Porridges eaten at a slower rate (g/min) were associated with greater post meal fullness (r= -0.87, p = 0.01) and lower desire to eat post ingestion ((r= 0.92, p = 0.01).

4. Discussion

The bran aroma associated with composites with 100 and 200 g/kg wheat bran was as a result of the wheat bran that was added. The toasted nut aroma perceived in the composites (both with and without wheat bran) may be attributed to Maillard reaction products formed during extrusion cooking. Similarly, the brown colour observed in the cassava-soy containing porridges could be due to Maillard type reactions during extrusion cooking. Maillard reaction occurs between the free amino groups of proteins and the carbonyl group of reducing sugars at temperature between 140 – 165 °C (Singh, Gamlath & Wakeling, 2007) leading to browning and flavour development (Millward, 1999).

The porridge with 200 g/kg wheat bran was more viscous compared to the other porridges and the composite with no wheat bran was the least viscous. Extrusion cooking has been reported to promote depolymerization of insoluble dietary fibre and this leads to an increase in soluble dietary fibre portions (Brennan, Merts, Monro, Woolnough, & Brennan, 2008). Soluble dietary fibre in water forms a viscous fluid (Schneeman, 2008). The more soluble dietary fibre in the extrudates with wheat bran may be responsible for the higher viscosity observed in the porridges (Oladiran & Emmambux, 2017).

This study assessed the short-term satiating effects and oral processing characteristics of extruded cassava-soy porridge with and without wheat bran. The oral exposure when consuming the porridge with 200 g/kg added wheat bran was significantly longer and consuming that meal took much longer. Oral exposure time of a 250 g porridge portion with 200 g/kg wheat bran was 46% longer than porridge with no wheat bran.

Although, the porridge with 200 g/kg wheat bran had the highest dynamic viscosity and it was described as more viscous and thicker compared to the other porridges by the descriptive sensory panel, it should be noted that rheological measurement was not done under oral processing conditions and this presents a significant limitation in comparison with sensory perceived viscosity. A thicker product is eaten more slowly leading to prolonged oral exposure time and this would in turn increase the overall exposure to sensory stimulation in the oral and retro-nasal cavity, this is subsequently followed by increased satiety or suppressed appetite (Ruijschop et al., 2011; Bolhuis, Lakemond, de Wijk, Luning, & de Graaf, 2011). This was corroborated by the rate of eating the porridge with 200 g/kg added wheat bran which was also significantly lower than the other porridges.

The result of this study is in agreement with that of Zhu, Hsu & Hollis (2013) who reported that increasing the viscosity of a semi-solid food by the addition of guar gum resulted in a slower eating rate and longer oral exposure time compared to a test product without guar gum. Also, Mattes & Rothacker, (2001) reported that the longer oral exposure time observed for the thick shake used in their study compared to the thin shake was due to the more viscous texture of the thick shake.

The data obtained in this study is consistent in showing that wheat bran addition in cassava-soy porridge can increase satiety. The porridge with 200 g/kg wheat bran suppressed hunger more and post consumption and over a 3 h period thereafter compared to the other porridges. In a similar study, Isaksson et al., (2012), reported that consuming whole grain rye breakfast porridge increased feelings of fullness and decreased hunger compared to white wheat bread 4 h after consumption. The effect rye has on satiety was suggested to be mediated through stomach distention and delayed gastric emptying. Mathern, Raatz, Thomas, & Slavin (2009) also found that addition of fenugreek fibre to a breakfast porridge led to reduction in hunger and more fullness compared to a placebo breakfast and this was attributed to the viscosity of fenugreek which slowed down the rate of gastric emptying.

It has been indicated that a viscous beverage gives a different mouthfeel which may induce a sensation of fullness and satiety (Lyly et al., 2009; Mattes & Rothacker, 2001). It can be suggested that the thick and coarse mouthfeel of the porridge with 200 g/kg added wheat bran as described by the sensory panel may have contributed to its longer oral exposure time thus promoting feelings of satiety. The effects wheat bran had on satiety as observed in this study may be explained by several mechanisms, this includes that the high water holding capacity of dietary fibre may have increased stomach distention thus triggering signs of satiety (De Graaf, Blom, Smeets, Stafleu, & Hendriks, 2004). Another probable explanation could be that arabinoxylan, which is the water-soluble component of wheat bran increased the viscosity of intestinal content and this promoted delayed gastric emptying (Lafiandra, Riccardi, & Shewry, 2014). This consequently slowed down the rate of nutrient absorption in the small intestine thus giving rise to protracted feelings of fullness. Also, viscous fibres may form a barrier around undigested nutrients. This barrier inhibits or delays the activities of digestive enzymes by limiting their accessibility to the substrate for digestion and by also slowing down diffusion of nutrients. As a result, digestion and absorption would occur at a much slower rate (Brennan, Blake, Ellis, & Schofield, 1996) and this is consequently followed by a decline in feelings of hunger.

The satiating properties of the porridge with 200 g/kg wheat bran may also be attributed to cognitive influences during consumption of the porridge driven by sensory properties whereby the thicker porridge is expected to be more filling based on past eating experience. According to Chambers (2016), before food arrives in the gut, pre-ingestive signals from the consumer's expectations about that food (involving attention and memory processes), the pleasure they experience while eating it and the sensory appraisal of the food will influence how much of the food is eaten at that eating episode (satiation) and also after consumption. Early pre-ingestive signals from cognitive and sensory processes are described as the main drivers of satiation according to the satiety cascade, and the combination of cognitive, sensory, post-ingestive and post-absorptive signals determine the experience of satiety (Chambers et al., 2015).

In this study, strong correlations were observed between oral exposure and the satiety measures. De Graaf & Kok, (2010) suggested that oral exposure is essential to achieve optimal satiety. A longer oral exposure of food was found to decrease food intake (Wijlens, Erkner, Mars, & de Graaf, 2015; Bolhuis et al., 2011). The coating of food in the oral mucosa may contribute to the sensory sensations that lead to a longer oral exposure time (Prinz, Huntjens & Wijk, 2006). After a semi-solid food such as porridge is swallowed, a viscous salivary coating is retained on the back of the tongue (Prinz, Huntjens & Wijk, 2006). In this study, viscous porridge may have formed a coating that contained some bran particles in the oral mucosa thereby prolonging oral exposure time of porridge. Residue from the semi-solid food may also be retained on the surface of the tongue and teeth (Kashket, Van Houte, Lopez, & Stocks, 1991; Heath & Prinz, 1991). The retained coating contains residues or particles of food and this may lead to a prolonged perception of food aroma after the food bolus has been swallowed (Buettner, Beer, Hannig, & Settles, 2001). It is possible that a food that leaves coating and residues behind in the oral mucosa after food bolus has been swallowed may lengthen the time of oral sensory exposure. Although particle size of porridges was not determined instrumentally and residues retained in the oral mucosa after eating was also not investigated in this study, it can be speculated that more residues of the porridge that contained 200 g/kg wheat bran was probably retained in the oral mucosa after food bolus was swallowed and this may have contributed to the longer oral sensory exposure time observed for this porridge compared to the other porridges.

The result of this study is in support of similar studies (Chambers et al., 2015) which reported that dietary fibre has more satiating effects compared to other food macronutrients. The porridge with 200 g/kg wheat bran contained more dietary fibre hence the suppressive effect elicited on hunger. The *ad libitum* intake at lunch post 3 h of porridge consumption and time to the next meal were unfortunately not measured in this study. Future work on the effect of porridge that contains wheat bran on subsequent food intake should be carried out as this would help to elucidate on the effect of dietary fibre on *ad libitum* energy intake at the following lunch meal. Also, the commercial sorghum product may have been sweeter than the extruded cassava-soy test porridges as it was rated sweeter than the experimental porridges and this may somewhat have biased the satiety comparison. In future studies, the sweetness of experimental and commercial porridge should be matched and consumer acceptability of extruded porridges with wheat bran should be conducted to assess how consumers perceive the instant porridge and how its hedonic properties may be influencing the ingestion of the porridge. Future studies should consider determination of dynamic viscosity in the presence of artificial saliva at 37 ºC as this would help to better relate sensory perceptions such as mouth feel and texture as perceived by the consumers with dynamic viscosity measured instrumentally. This was shown by Laguna, Farrell, Bryant, Morina, & Sarkar (2017), who reported that addition of artificial saliva at 37 ºC during instrumental rheological measurement of commercial dairy colloids significantly affected the viscoelastic properties of dairy colloids.

5. Conclusions

The variations in oral processing of a fixed mass portion of extrusion cooked cassava-defatted toasted soy porridge with and without wheat bran is probably related to the difference in viscosity of the porridges. The solubilization of insoluble dietary fibre in wheat bran during extrusion cooking increases viscosity of porridge, the high viscosity prolongs oral exposure time and this in turn promotes feelings of satiety. This study therefore demonstrates that wheat bran as a source of dietary fibre has the potential to be incorporated into starch-rich foods with the use of extrusion cooking to produce instant products with potential health promoting properties.

Disclosure statement

The authors declare no conflict of interest

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