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ORIGINAL ARTICLE

Assessment of nutritional quality, glycaemic index, antidiabetic and sensory properties of plantain (*Musa paradisiaca*)-based functional dough meals

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Abstract Nutrition transition to high energy-dense foods has been implicated as the major causes of diet related diseases. Plantain-based dough meals supplemented with soybean cake and cassava fibre were developed by combining them in different proportions using response surface methodology. The flour blends were analyzed for the nutritional composition while the glycaemic index, antidiabetic potentials and protein digestibility of the dough meals were determined in wistar rats. The nutritional and essential amino acid contents of the flour blends were comparable to that of cerolina (a commercially available food product commonly recommended for diabetic patients). The rats fed with the formulated dough meals had lower glycaemic index and glycaemic load, and the blood glucose was significantly reduced compared to cerolina and metformin (a synthetic antidiabetic drug). All the plantain-based dough meals were comparable to cerolina and metformin in terms of nutritional quality and blood glycaemic control activities, respectively. Hence, the formulated plantain-based dough meals have potential to be used for the prevention and management of diabetes mellitus.

Keywords Plantain-based meals · Glycaemic index · Functional food · Type-2 diabetes

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Introduction

Diabetes mellitus is a chronic metabolic disorder that is characterized by hyperglycemia, which results from insufficient or inefficient insulin secretion in the body, and it is associated with impaired carbohydrate, fat and protein metabolism. Type-2 diabetes, a non-insulin dependent diabetes mellitus, is the leading cause of death and disability, with over 285 million people living with diabetes worldwide (Shaw et al. 2010). The prevalence of Type 2 diabetes in developing countries is attributed to the nutrition transition and lifestyle changes from traditional diets, which are high in plant-based foods like grains, legumes and fruits/vegetables to more Western pattern diets that are high in sugars, fat, and animal-source foods (Popkin 2002; Kapoor and Anand 2002; Sun et al. 2010). This has also led to high prevalence of chronic and degenerative diseases.

The medicinal values of plant-based foods have assumed a more important dimension in recent years owing largely to the benefits that is associated with their nutrients and non-nutrients compositions (Eleazu et al. 2010). Cereals, grains and fruits/vegetables have substantial benefits in preventing and treating chronic diseases.

Plantain (*Musa paradisiaca*) is a giant perennial herb cultivated in many tropics and subtropical countries of the world. In Nigeria, it is the third most important staple after yam and cassava. It is a rich source of carbohydrates, iron, potassium and vitamin A, but low in fat and protein (Odenigbo et al. 2013). Plantain can be consumed in the ripe or unripe forms as well as boiled, fried, roasted, or when processed into flour and used to prepare local dough meal known as 'amala' (Idowu et al. 1996). It has remained the ultimate source of nutrients and non-nutrients that are beneficial to human in many parts of developing countries,

and they are used for socio-cultural, diabolic, nutritional and therapeutic purposes (Eleazu et al. 2010).

Soybean is an important source of vegetable protein in many parts of developed and developing countries and it is utilized in various food productions such as tofu (soybean curd), miso (fermented soybean paste) and soy-ogi. The increased acceptance of soybeans and their products is primarily associated with the high nutritional quality especially with respect to protein and amino acids, good functional properties in food applications, high nutritional value, availability and low cost (Gandhi 2009).

Cassava is an important staple food and cash crop in Sub-Saharan Africa (Agwu and Anyaeche 2007). It is the cheapest and most affordable source of calories for the majority of people living in developing countries.

Quite a number of studies have utilized plantain, soybean and maize in the production of foods (Osundahunsi 2006; Abiose et al. 2015) but there is dearth of information on the combinations of plantain flour, defatted soybean cake and cassava fiber. In this study, plantain flour, defatted soybean and cassava fiber were used to formulate functional dough meals which were analyzed for their potentials to be used in the prevention and treatment of diabetes.

Materials and methods

Sources of food materials and wistar rats

Freshly harvested matured unripe plantain (*Musa AAB*) was purchased from Ogbese Market, Akure, Cassava fibre was obtained from Matna Food Company, Owo, (company processing cassava tubers into starch) and Soybean cake was obtained from JOF Ideal Family Farms, Owo, (company processing soybean to vegetable oil) all in Ondo State, Nigeria. The wistar rats were obtained from Central Animal House, College of Medicine, University of Ibadan, Ibadan, Nigeria. The study protocol was approved by the Ethical Committee for Laboratory Animals of the School of Agriculture and Agricultural Technology, Federal University of Technology Akure, Nigeria.

Preparation of flour samples

After the preliminary cleaning and washing, the unripe plantain, Soy cake is defatted soybean meal and cassava fibre were oven-dried at 70 °C for 8, 2 and 8 h, respectively. The dried samples were separately milled using Philips laboratory blender (HR2811 model; Hong Kong) and sieved using sieve number 60 (British Standard) to obtain the various flours which were then packed in plastic container, sealed and stored at room temperature (~27 °C) for further analyses.

Formulations of plantain-based functional dough meal

The optimum combination of plantain flour, soybean cake and cassava fibre in the blended flour samples were determined using Response Surface Methodology (RSM). (Gen Stat Discovery, Edition 4). RSM statistical package was used to generate proportion of flour samples in the formulation with references to fiber (10 %), carbohydrate (55–65 %) and protein (20 %) requirements for diabetic patients (Franz et al. 1994) as follows: PSC-1 (19.0 % defatted soybean cake, 5.0 % cassava fiber and 76.0 % plantain flour), PSC-2 (15.0 % defatted soybean cake, 8.0 % cassava fiber and 77.0 % plantain flour) and PSC-3 (25.0 % defatted soybean cake, 8.0 % cassava fiber and 67.0 % plantain flour).

Chemical compositions plantain-based functional dough meal

Determination of proximate composition

The proximate composition was determined according to AOAC (2005). Moisture content was determined in a hot-air circulating oven (Gallenkamp). Total ash was determined by incineration (550 °C) of known weights of the samples in a muffle furnace (Hotbox oven, Gallenkamp, UK, size 3). Crude fat was determined by exhaustively extracting a known weight of sample in petroleum ether. Protein content (gN × 6.25) was determined by the micro-Kjeldahl method. Crude fiber was determined after digestion and carbohydrate content was determined by difference. The gross energy value of the food samples were estimated [in kJ/100 g] by using this formula—Gross energy (kJ/100 g dry matter) = (protein × 16.7) + (lipid × 37.7) + (carbohydrates × 16.7).

Determination of amino acid profile

The amino acid compositions of the blended flour samples were determined as described by Glew et al. (2005) with slight modification while the tryptophan content was determined in a separate analysis as described by Buzzigoli et al. (1990).

Determination of the antinutritional factors

Oxalate determination

Oxalate was determined according to Day and Underwood (1986) procedure. The sample was weighed (1.0 g), 75 ml of 15 N H_2SO_4 was added, stirred intermittently with a magnetic stirrer for 1 h and filtered using Whatman No 1

filter paper. About 25 ml of the filtrate was collected and titrated against 0.1 N $KMnO_4$ solutions till a faint pink colour appeared that persisted for 30 s.

Phytate determination

Phytate concentration was determined through phytic acid determination using the methods described by Lolas and Markakis (1975). The sample was weighed (2 g) into 250 ml conical flask, 100 ml of 2 % conc. HCl was added in the conical flask to soak the samples for 3 h, the sample mixture was filtered through a double layer filter paper, 50 ml of the sample filtrate was placed in a 250 ml beaker and 100 ml of distilled water was added and vortex for proper mixing. To the filtrate, 10 ml of 0.3 % ammonium thiocyanate solution was added as indicator and the filtrate solution was titrated with standard iron chloride solution which contained 1.95 mg iron/ml and the end point was signified by brownish-yellow colour that persisted for 5 min and the percentage phytic acid was calculated.

Cyanogenic glycoside determination

Cyanogenic glycoside was determined using alkaline picrate method. To the sample (5.0 g), 50 ml double distilled water was added in a conical flask and the mixture was allowed to stand overnight. The sample was filtered and 1 ml of the filtrate was taken into a corked test tube, 4 ml of alkaline picrate was added and incubated in a water bath for 5 min and colour changed from yellow to reddish brown after incubation for 5 min in a water bath to indicate presence of cyanide (Railes and Albrink 1981). The blank (containing 1 ml distilled water and 4 ml alkaline picrate solution) and sample readings were taken at absorbance of 490 nm.

Tannins determination

The samples (1.0 g) were dissolved in 10 ml double distilled water, vortex and left to stand for 30 min. at room temperature and centrifuged. The supernatant (2.5 ml) was measured into 50 ml volumetric flask. Similarly, 2.5 ml of standard tannic acid solution was measured into another 50 ml volumetric flask. To the sample and standard tannic solution, 1.0 ml of folin-dennis reagent was added and 2.5 ml of saturated Na_2CO_3 solution respectively and the mixtures were made to 50 ml in the flask with double distilled water and incubated for 90 min at room temperature. The absorbance of each sample was measured at 250 nm with the reagent blank at zero and the percentage tannin was calculated.

Trypsin inhibitor determination

Trypsin inhibition activity (TIA) was assayed in terms of the extent to which an extract of the defatted flour samples inhibited the action of bovine trypsin [EC 3.4.21.4] on the substrate benzoyl-DL-arginine-p-nitrianilide [BAPNA] hydrochloric. The blended flour samples (1 g each) were extracted continuously at ambient temperature for 3 h with 50 ml of 10 mmol/L NaOH using a mechanical shaker (Gallenkamp orbital shaker Surrey, UK). The pH of the resulting slurry was adjusted to 9.4–9.6 with 1 mol/L NaOH. After extraction, the suspension was shaken and diluted with double distilled water so that 1 ml of the extract produced trypsin inhibition of 40–60 % at 37 °C. The respective dilutions were noted. Consequently, TIA was calculated in terms of mg pure trypsin [Sigma type III, lot 20H0868] from the formula:

$$TIA = \frac{2.632DA \text{ mg pure trypsin inhibited g} - 1\text{sample}}{S}$$

where: D is the dilution factor, A is the change in absorbance at 410 nm due to trypsin inhibition per ml of diluted sample extract, and S is the weight of the sample.

Animal experimental design

Sixty healthy Wistar albino rats (4 weeks of age) were divided into six groups of 10 animals each and were allowed to acclimatize to the new environment for 7 days, while being fed commercial feed and water ad libitum. After 7 days, the six groups of rats were fed the plantain-based functional foods (PSC-1, -2 and -3), 100 % plantain flour, Cerolina (a commercial food) and basal diets, with a diet per group and water ad libitum for 28 days. The rats were weighed every 4 days interval. Urine was collected from each cage in a small urine container, which contained about 1 ml concentrated sulfuric acid. Fecal samples were also collected daily, weighed, dried, and milled prior to laboratory analysis. The protein qualities of the food products were determined using the following calculations:

Nitrogen retention (NR; dietary nitrogen retained in the body):

$$\boldsymbol{NR} = \text{Ni} - (\text{Nf} - \text{Nef}) - (\text{Nu} - \text{Neu})$$

Biological value (BV)

$$\boldsymbol{BV} = \frac{\text{Ni} - (\text{Nf} - \text{Nef}) - (\text{Nu} - \text{Neu})}{\text{Ni} - (\text{Nf} - \text{Nef})} \times 100$$

Food efficiency (FE):

$$\boldsymbol{FE} = \frac{\text{Weight gained}}{\text{Food intake}}$$

Net protein utilization (NPU)

$$\boldsymbol{NPU} = \frac{\text{Ni} - (\text{Nf} - \text{Nef}) - (\text{Nu} - \text{Neu})}{\text{Ni}} \times 100$$

Protein efficiency ratio (PER)

$$\boldsymbol{PER} = \frac{\text{Weight gained}}{\text{Protein intake}}$$

True protein digestibility (TD)

$$\boldsymbol{TPD} = \frac{\text{Ni} - (\text{Nf} - \text{Nef})}{\text{Ni}} \times 100$$

Protein rating (PR):

$$\boldsymbol{PR} = \boldsymbol{PER} \times \boldsymbol{daily\ protein\ intake}(\boldsymbol{g})$$

where: Ni = nitrogen intake in proteins on the test diet, Nf = faecal nitrogen whilst on the test diet, Nef = feacal nitrogen excreted on nitrogen-free diet (metabolic nitrogen), Nu = urinary nitrogen whilst on the test diet, Neu = urinary nitrogen excreted on nitrogen-free diet (endogenous nitrogen).

Hematological determinations

Blood collection

At the end of the experimental period, all rats were starved for about 3 h and weighed. Each rat was anaesthetized with chloroform inside a dessicator before being sacrificed. Blood was collected into Bijou bottles containing a speck of dried tetra-acetic ethylenediamine acid powder, and hematological indices were determined.

Hematological analysis procedures

Packed cell volume (PCV) was estimated by centrifuging about 75 Fl of each blood sample in heparinized capillary tubes in a hematocrit micro-centrifuge for 5 min. Total red blood cell count (RBC) was determined using normal saline as the diluting fluid. Hemoglobin concentration (HBC) was estimated using the cyanomethemoglobin method and mean corpuscular hemoglobin concentration (MCHC), mean corpuscular hemoglobin (MCH), and mean corpuscular volume (MCV) were calculated as follows: Mean corpuscular hemoglobin (MCH)

$$\boldsymbol{MCH} = \frac{\text{Hb}}{\text{Rbc}} \times 10$$

Mean corpuscular hemoglobin concentration (MCHC)

$$\boldsymbol{MCHC} = \frac{\text{Hb}}{\text{PCV}} \times 100$$

Mean corpuscular volume (MCV)

$$\boldsymbol{MCV} = \frac{\text{PCV}}{\text{Rbc}}$$

where Hb is the Hemoglobin

Determination of glycemic index and anti-diabetic potentials of formulated food samples in Wistar Albino rats

Experimental animals

Thirty-five Wistar albino rats (35) were weighed and divided into five groups containing seven rats each. The animals were allowed to acclimatize to their new environment for 7 days. After the adaptation period, the animals were reweighed and fasted for 12 h. The blood glucose of the animals were taken at zero time from the tail vein before feeding them with 2.0 g of the formulated food samples or glucose (control), which were consumed within 25 min. After the consumption, the serum glucose levels of the animals were measured using an automatic glucose analyzer ('Accu-chek Active' Diabetes monitoring kit; Roche Diagnostic, Indianapolis, USA).

Measurement of blood glucose response

Blood glucose curves were constructed from blood glucose values of animals at time 0, and 15, 30, 45, 60, 90 and 120 min intervals after consumption of the glucose (control) or formulated food samples of each group. The Incremental Area Under Curve (IAUC) was calculated for reference food (glucose) by the trapezoidal rule in every rats in each group separately as the sum of the surface of trapezoids between the blood glucose curve and horizontal baseline going parallel to x-axis from the beginning of blood glucose curve at time 0 to the point at time 120 min to reflect the total rise in blood glucose concentration after eating the reference food (glucose). The IAUC from the animals fed with the formulated food samples were similarly obtained. The glycemic Index (GI) for each diet was calculated by ratio of IAUC for each diet to the IAUC for glucose solution standard as reported by FAO/WHO (1991) using the following equation:

$$GI = \frac{Incremental\ area\ under\ 2\ h\ blood\ glucose\ curve\ for\ food\ samples\ (2.0\ g)}{Incremental\ area\ under\ 2\ h\ blood\ glucose\ curve\ for\ glucose\ (2.0\ g)} \times 100$$

Calculation of glycemic load (GL)

Glycemic load (GL) for each food sample was determined by the method of Salmeron et al. (1997). Each individual glycemic load was calculated by taking the percentage of the food's carbohydrate content in a typical serving food and multiplying it by its GI value. The following formula was used:

$$GL = \frac{Net\ Carbohydrate(g) \times GI}{100}$$

Net Carbohydrate = Total Carbohydrates in the food sample served.

Induction of diabetes mellitus

The baseline blood glucose levels of the animals were measured before being induced with alloxan drug. Fifty albino rats were induced by single intraperitoneal injection of freshly prepared solution of alloxan monohydrate (150 mg/kg. body weight) dissolved in physiological saline in overnight fasted Wistar Albino rats. The rats were allowed to drink 5 % glucose solution to avoid hypoglycaemic effects of the drug. The blood glucose levels in the animals were measured 72 h after alloxan administration through tail tipping using glucometer ('Accu-chek Active' Diabetes monitoring kit; Roche Diagnostic, Indianapolis, USA). The forty-two diabetic induced rats with serum glucose ≥250 mg/dl level were randomly divided into six groups containing seven rats each and four of the groups were fed with formulated food samples (PSC-1, PSC-2, PSC-3 and 100 % plantain). The remaining groups were treated with cerolina (a control sample) and metformin hydrochloride (an antidiabetic drug) respectively, and the rats in metformin group were fed with commercial animal feeds. The animals were fed with the diets for 28 days and blood glucose levels were measured in the morning at regular interval by drawing blood from each rat through tail tipping and the blood glucose level was measured using Glucometer kit ('Accu-chek Active' Diabetes monitoring kit; Roche Diagnostic, Indianapolis, USA)..

Sensory evaluation of dietary dough meal

Sensory evaluation was performed on the dietary dough meal samples using the descriptive 9-point Hedonic scale rating with 15 taste panelists that were familiar with the control sample (Cerolina). The rating was, 9 like extremely and 1, dislike extremely for each attribute evaluated. The assessments were conducted in a well lit room designed for sensory evaluation in the Department of Food Science and Technology. Dietary dough meal was prepared by stirring flour in boiling water 1:4 (v/v) of flour to water dispersion at 100 °C for 10 min. Panelists were from the University community and cut across age and sex.

Statistical analysis

The data were analysed using SPSS version 16.0. The mean and standard error of means (SEM) of the triplicate analyses were calculated. The analysis of variance (ANOVA) was performed to determine significant differences between the means, while the means were separated using the New Duncan Multiple Range Test (NDMRT) at $p < 0.05$.

Results

Proximate and mineral compositions

Proximate and mineral compositions of the plantain-based functional dough meal are presented in Table 1. Moisture content of the functional dough meals varied from 7.2 ± 0.01 in PSC-3 to 7.8 ± 0.01 g/100 g in PSC-1, and the values were comparable to that of Cerolina (7.45 ± 0.00 g/100 g). Crude protein content of the dough meals varied between 11.78 ± 0.07 g/100 g for PSC-2 and 16.49 ± 0.01 g/100 g for PCS-3, however, these values were significantly lower than the Cerolina. The results also showed that the protein contents of composite flours increased as the proportion of defatted soy cake flour added increased. The crude fiber content of functional dough meals varied from 1.29 ± 0.03 g/100 g for PCS-2 to 2.78 ± 0.06 g/100 g for PCS-3, and these values were significantly higher than 0.70 ± 0.02 g/100 g observed for Cerolina. The mineral compositions of functional dough meals are shown in Table 1. Potassium had the highest values varying from 18.80 ± 0.00 to 21.75 ± 0.00 mg/100 g, while zinc had the least values varying from 0.04 to 0.05 mg/100 g. The ranged value of calcium, magnesium and iron of the formulated diets were 1.40–2.40, 1.99–3.24 and 1.23–3.85 mg/100 g respectively, while that of Na/K molar ratio was 0.09–0.12. Comparatively, the values of Mg, Fe and Na/K molar ratio were significantly ($p < 0.05$) higher than that of Cerolina.

Nutritional quality, amino acid and antinutrient compositions of plantain-based functional dough meal

In vivo protein digestibility and the amino acid profile of the plantain-based functional dough meals is presented in Table 2. The results showed that PSC-3 had the highest nitrogen retention (NR; 4.42), biological value (BV; 74.14 %), net protein utilization (NPU; 74.14 %) and true

Table 1 Nutrient (g/100 g) and mineral (mg/100 g) compositions of plantain-based functional dough meals supplemented with soybean cake and cassava fibre flours

Parameters	PSC-1	PSC-2	PSC-3	PLT	CER
Moisture	7.80 ± 0.01^{a}	7.45 ± 0.03^{b}	7.2 ± 0.01^{c}	7.18 ± 0.05^{c}	7.45 ± 0.00^{b}
Total ash	$3.78^{b} \pm 0.03^{b}$	3.60 ± 0.01^{b}	5.36 ± 0.05^{a}	3.62 ± 0.11^{b}	1.85 ± 0.02^{c}
Crude protein	14.68 ± 0.03^{c}	11.78 ± 0.07^{d}	16.49 ± 0.01^{b}	8.25 ± 0.13^{e}	18.55 ± 0.02^{a}
Crude fat	4.26 ± 0.02^{d}	6.28 ± 0.03^{c}	8.85 ± 0.14^{a}	3.22 ± 0.21^{e}	7.41 ± 0.09^{b}
Crude fibre	2.29 ± 0.02^{b}	1.29 ± 0.03^{c}	2.78 ± 0.06^{a}	1.30 ± 0.07^{c}	0.70 ± 0.02^{d}
Carbohydrate	67.20 ± 0.04^{c}	69.48 ± 0.03^{b}	59.33 ± 0.04^{e}	76.41 ± 0.12^{a}	64.06 ± 0.12^{d}
Energy (KJ/100 g)	1528.18 ± 5.01^{c}	1593.81 ± 7.11^{b}	1599.84 ± 4.63^{b}	1535 ± 2.12^{c}	1658.94 ± 5.27^{a}
Sodium	1.89 ± 0.00^{b}	2.27 ± 0.00^{a}	2.29 ± 0.00^{a}	2.31 ± 0.07^{a}	0.77 ± 0.00^{c}
Potassium	21.20 ± 0.00^{b}	18.80 ± 0.00^{c}	21.75 ± 0.00^{b}	18.20 ± 0.05^{c}	63.15 ± 0.15^{a}
Calcium	2.30 ± 0.00^{a}	1.40 ± 0.00^{c}	2.40 ± 0.00^{a}	1.37 ± 0.04^{c}	2.20 ± 0.00^{b}
Magnesium	1.99 ± 0.00^{b}	3.24 ± 0.01^{a}	3.12 ± 0.00^{a}	3.11 ± 0.12^{a}	1.32 ± 0.00^{b}
Iron	3.85 ± 0.01^{a}	1.23 ± 0.03^{c}	1.84 ± 0.02^{b}	1.19 ± 0.03^{c}	0.15 ± 0.01^{d}
Zinc	0.04 ± 0.00^{c}	0.04 ± 0.00^{c}	0.05 ± 0.00^{b}	0.04 ± 0.00^{c}	0.07 ± 0.00^{a}
Manganese	0.04 ± 0.00^{b}	0.04 ± 0.00^{b}	0.06 ± 0.00^{a}	0.04 ± 0.00^{b}	0.06 ± 0.00^{a}
Copper	0.27 ± 0.00^{a}	0.04 ± 0.00^{b}	0.02 ± 0.00^{c}	0.04 ± 0.00^{b}	0.02 ± 0.00^{c}
Na/K	0.09^{b}	0.12^{a}	0.11^{a}	0.12^{a}	0.01^{c}

Values are Mean ± SEM. Where: PSC-1 = Soycake: 19.01 %; Cassava fibre: 5.0 %; Unripe plantain:75.99 %. PSC-2 = Soycake: 15.0 %; Cassava fibre: 8.0 %; Unripe plantain: 77.0 %. PSC-3 = Soycake: 25.0 %; Cassava fibre: 8.0 %; Unripe plantain: 67.0 %

Values with different alphabets across the row differ significantly at $p < 0.05$

CER Cerolina (control), *PLT* plantain (100 %)

protein digestibility (TD; 92.89 %) when compared with PSC-1 and PSC-2. The non-essential amino acids had glutamic acid as the highest with values ranging from 17.07 mg/100 g protein in PSC-3 to 17.46 mg/100 g protein in PSC-1, while cysteine content was the lowest values, which ranges from 1.14 mg/100 g protein in PSC-1 to 1.63 mg/100 g protein in PSC-2. Leucine had the highest values (7.15–7.72 mg/100 g protein) in essential amino acids, while tryptophan was the lowest for PSC-1 and methionine for the PSC-2 and PSC-3. The essential amino acid scores showed that the first and second limiting amino acids of the formulations were methionine and valine respectively.

The haematological properties of plantain-based functional dough meal are presented in Table 3. The packed cell volume (PCV) of the rats fed with the dough meal ranged from 27 to 35 %, red blood cells ranged from 3.0×10^{6} to 3.95×10^{6} mm^{3}, white blood cells (WBC) ranged from 5.0×10^{3} to 8.6×10^{3} mm^{3}, while haemoglobin concentration (Hb) ranged from 9.1 to 11.7 (Table 3). The range values of mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH) and mean corpuscular haemoglobin concentration (MCHC) of the rats fed with the experimental diets were 27.03–33.33 fL, 2.96–3.03 pcg and 33.43–33.70 g/dL respectively.

Anti-nutritional compositions of the dough meals are shown in Table 4. The concentration varied as follows: oxalate (0.45 ± 0.00–0.68 ± 0.00 mg/g), tannins (0.03 ± 0.00–0.07 ± 0.00 mg/g), phytate (8.93 ± 0.01–12.18 ± 0.81 mg/g), trypsin inhibitor (13.26 ± 0.22–21.15 ± 0.17 %) and hydrogen cyanide (0.24 ± 0.00–0.30 ± 0.00 mg/100 g). All the values are within the ranges obtained for the control sample.

Glycaemic index, glycaemic load and anti-diabetic potential of plantain-based dough meal

The glycaemic index (GI) and glycaemic load (GL) of the meal samples are presented in Fig. 1. The result showed that PSC-1 (36.9 %) sample had the lowest glycaemic index while PSC-2 (55.1 %) had the highest of the three. Similarly, PSC-1 had the lowest glycaemic load (GL; 24.5 %) and other samples had GL that correlate positively with the GI (Fig. 1a).

The anti-diabetic potential of plantain-based functional dough meals is presented in Fig. 1b. The result showed that there was significant difference between the percentages of blood glucose reduction in rats fed with plantain-based functional dough meals when compared with the rats fed with 100 % plantain flour alone. However, there was no significant difference ($p < 0.05$) between the rats fed with functional dough meals, particularly PSC-1 and PSC-3, and those rats fed with Cerolina and those administered with Metformin (a synthetic antidiabetic drug) groups.

Table 2 Protein quality and amino acid profile (mg/100 g protein) of plantain-based Functional dough meal supplemented with soybean cake and cassava fibre

Parameters	PSC-1	PSC-2	PSC-3	PLA	CER	*RDA
Feed intakes (g)	145.05^{e}	154.56^{d}	232.56^{b}	157.85^{c}	261.01^{a}	
Weight gained (g)	38.08^{c}	26.88^{d}	47.8^{b}	19.61^{e}	54.97^{a}	
Food efficiency	0.26^{a}	0.17^{c}	0.21^{b}	0.12^{d}	0.21^{b}	
Nitrogen retention	1.95^{d}	1.56^{c}	4.42^{b}	0.55^{e}	7.25^{a}	
Biological value (%)	57.14^{c}	53.67^{d}	74.14^{b}	49.46^{e}	93.63^{a}	
Net protein utilization (%)	57.14^{c}	53.67^{d}	74.14^{b}	49.46^{e}	93.63^{a}	
True protein digestibility (%)	89.94^{c}	76.07^{d}	92.89^{b}	91.49^{b}	99.63^{a}	
Protein Efficiency ratio	0.26^{a}	0.17^{c}	0.21^{b}	0.12^{d}	0.21^{b}	
Non-essential amino acids						
Aspartic acid	11.92^{b}	11.56^{b}	12.04^{a}		8.72^{c}	–
Tyrosine	2.62^{a}	1.96^{c}	2.66^{a}		2.46^{b}	–
Serine	5.65^{b}	5.69^{b}	5.82^{a}		5.23^{c}	–
Glutamic acid	17.46^{b}	16.34^{c}	17.01^{b}		24.57^{a}	–
Proline	7.20^{b}	7.57^{b}	7.61^{b}		10.65^{a}	–
Glycine	3.51^{a}	2.39^{b}	3.36^{a}		1.22^{c}	–
Alanine	4.95^{a}	3.66^{c}	4.82^{a}		4.10^{b}	–
Cysteine	1.14^{c}	1.63^{a}	1.20^{c}		1.55^{b}	–
Arginine	9.20^{a}	8.93^{ab}	8.68^{c}		6.93^{d}	2
Essential amino acids						
Valine	4.45^{a}	4.04^{ab}	3.80^{b}		4.23^{a}	3.5
Leucine	7.23^{a}	7.72^{a}	7.15^{a}		7.70^{a}	6.6
Isoleucine	3.25^{b}	3.03^{c}	4.93^{a}		3.21^{c}	2.8
Methionine	1.23^{a}	1.25^{a}	1.14^{b}		1.24^{a}	2.2
Phenylalanine	5.17^{c}	5.13^{c}	5.90^{a}		5.27^{b}	2.8
Lysine	6.38^{a}	6.28^{a}	6.61^{a}		4.66^{b}	5.8
Histidine	3.94^{a}	3.86^{a}	3.42^{b}		2.78^{c}	1.9
Tryptophan	1.09^{b}	1.28^{a}	1.47^{a}		0.91^{c}	1.1
Threonine	3.23^{b}	3.26^{b}	3.99^{a}		2.71^{c}	3.4
Predicted nutritional qualities						
TEAA + His + Arg/TAA %	49.30^{b}	48.85^{c}	51.72^{a}		43.22^{d}	–
TEAA/TAA %	36.11^{b}	36.19^{b}	39.14^{a}		33.33^{c}	–
TNEAA/TAA %	54.66^{a}	36.19^{c}	51.76^{b}		33.33^{d}	–
TSAA(Meth + Cys)	2.37^{c}	2.45^{b}	2.77^{a}		2.79^{a}	–
ArEAA (Phe + Tyr)	7.79^{b}	7.79^{b}	7.86^{a}		7.73^{b}	–
TEAA/TNEAA	0.66^{b}	0.66^{b}	0.76^{a}		0.56^{c}	–
First Limiting amino acid	Methionine	Methionine	Methionine		Methionine	–
Second Limiting amino acid	Valine	Valine	Valine		Valine	–

Values are Mean ± SEM. Where: PSC-1 = Soycake: 19.01 %; Cassava fibre: 5.0 %; Unripe plantain:75.99 %. PSC-2 = Soycake: 15.0 %; Cassava fibre: 8.0 %; Unripe plantain: 77.0 %. PSC-3 = Soycake: 25.0 %; Cassava fibre: 8.0 %; Unripe plantain: 67.0 %. * Recommended daily allowance (WHO/FAO 1991)

Values with different alphabets across the row differ significantly at $p < 0.05$

CER Cerolina (control), *PLT* plantain (100 %)

Sensory attributes of plantain-based functional dough meal

The sensory attributes of the functional dough meals are presented in Table 5. The PSC-1 sample was significantly rated higher in terms of appearance, mold-ability, mouth-feel, aroma, texture and overall acceptability when compared with other dough meals and control samples. There was no significant difference between the PSC-1 and PSC-2 samples, but there was significant difference between

Table 3 Haematological indices of Albino rats fed with plantain-based functional dough meal supplemented with soybean cake and cassava fibre

Parameters	PSC-1	PSC-2	PSC-3	PLT	CER
Erythrocyte sedimentation rate (mm/h)	0.5^{a}	0.5^{a}	0.2^{b}	0.2^{b}	0.5^{a}
Packed cell volume (%)	35.0^{a}	27.0^{b}	33.0^{a}	29.0^{b}	34.0^{a}
Red blood cells ($\times 10^{6}mm^{3}$)	3.95^{a}	3.0^{b}	3.7^{a}	3.2^{b}	3.8^{a}
White blood cells ($\times 10^{3}mm^{3}$)	5.8^{c}	8.6^{a}	5.0^{c}	6.2^{b}	6.1^{b}
Haemoglobin (g/dL)	11.7^{a}	9.1^{b}	11.1^{a}	8.7^{c}	11.3^{a}
Lymphocytes (%)	36^{b}	29^{c}	35^{b}	40^{a}	40^{a}
Neutrophils (%)	64^{b}	69^{a}	62^{cd}	58^{d}	60^{cd}
Monocytes (%)	2^{a}	2^{a}	2^{a}	2^{a}	2^{a}
Eosinophils (%)	2^{a}	2^{a}	1^{a}	2^{a}	2^{a}
Basophils (%)	1^{a}	1^{a}	2^{a}	1^{a}	1^{a}
Mean corpuscular volume (MCV; fL)	25.32^{d}	33.33^{a}	27.03^{c}	31.25^{b}	26.32^{d}
Mean corpuscular haemoglobin (MCH; pcg)	2.96^{b}	3.03^{a}	3.00^{a}	2.72^{c}	2.97^{b}
MCH concentration (MCHC; g/dL)	33.43^{c}	33.70^{a}	33.64^{b}	30.00^{e}	33.24^{d}

Values are Mean ± SEM. Where: PSC-1 = Soycake: 19.01 %; Cassava fibre: 5.0 %; Unripe plantain:75.99 %. PSC-2 = Soycake: 15.0 %; Cassava fibre: 8.0 %; Unripe plantain: 77.0 %. PSC-3 = Soycake: 25.0 %; Cassava fibre: 8.0 %; Unripe plantain: 67.0 %

Values with different alphabets across the row differ significantly at $p < 0.05$

CER Cerolina (control), *PLT* plantain (100 %)

Table 4 Antinutrient composition of plantain-based functional dough meal supplemented with soybean cake and cassava fibre

Parameters	Phytate (mg/g)	Oxalate (mg/g)	Tannin (mg/g)	Trypsin (%)	Cyanide (mg/100 g)
PSC-1	12.18 ± 0.81^{a}	0.45 ± 0.00^{c}	0.03 ± 0.00^{d}	13.26 ± 0.22^{d}	0.27 ± 0.00^{ab}
PSC-2	8.93 ± 0.01^{c}	0.68 ± 0.05^{a}	0.05 ± 0.00^{c}	21.15 ± 0.17^{a}	0.30 ± 0.00^{a}
PSC-3	10.15 ± 0.41^{b}	0.54 ± 0.00^{b}	0.07 ± 0.00^{b}	19.45 ± 0.00^{b}	0.24 ± 0.00^{b}
PLT	7.28 ± 0.04^{d}	0.65 ± 0.03^{a}	0.05 ± 0.00^{c}	12.22 ± 0.21^{e}	0.13 ± 0.02^{c}
CER	3.25 ± 0.81^{e}	0.68 ± 0.05^{a}	0.11 ± 0.00^{a}	15.77 ± 0.00^{c}	0.30 ± 0.00^{a}

Values are Mean ± SEM. Where: PSC-1 = Soycake: 19.01 %; Cassava fibre: 5.0 %; Unripe plantain:75.99 %. PSC-2 = Soycake: 15.0 %; Cassava fibre: 8.0 %; Unripe plantain: 77.0 %. PSC-3 = Soycake: 25.0 %; Cassava fibre: 8.0 %; Unripe plantain: 67.0 %

Values with different alphabets across the column differ significantly at $p < 0.05$

CER Cerolina (control), *PLT* plantain (100 %)

these samples and that of PSC-3 sample. This observation could be due to the level of soy bean cake substituted into the plantain flour, which was 25 % in PSC-3 compared with 19 % and 15 % in PSC-1 and PSC-2 respectively.

Discussion

The dough meals produced were very low in moisture content which is a determinant of its storage stability and the low moisture content of the dough meals is an indication that the plantain-based foods will keep long during storage. Protein supplementation (soy) for Type 2 diabetic patient has a therapeutic effect for both glycemic control and for cardiovascular risk (Jayagopal et al. 2002). The relatively higher protein content will make the current dough meal an excellent meal for diabetic patient. The incorporation of cassava fiber into the formulations resulted in increase in the crude fibre content of the dough meal. Studies have shown that consumption of fibers have positive benefits on health by increasing the volume of feacal bulk and thereby decreasing the time of intestinal transit, reducing cholesterol, glycemic levels and trapping mutagenic and carcinogenic agents (Beecher 1999). Improvements in diabetic control, reduction in blood glucose, insulin and sulfonylurea medications have been reported for fiber intakes in diabetic patients (Devinder et al. 2012).

The formulated diets were significantly higher in sodium, magnesium and iron than the control sample, but lower in potassium, calcium and zinc. The variation between the mineral compositions of formulated diets and Cerolina could be attributed to the differences in raw food materials, geographical sources of the food materials and the processing techniques. Findings have shown that low

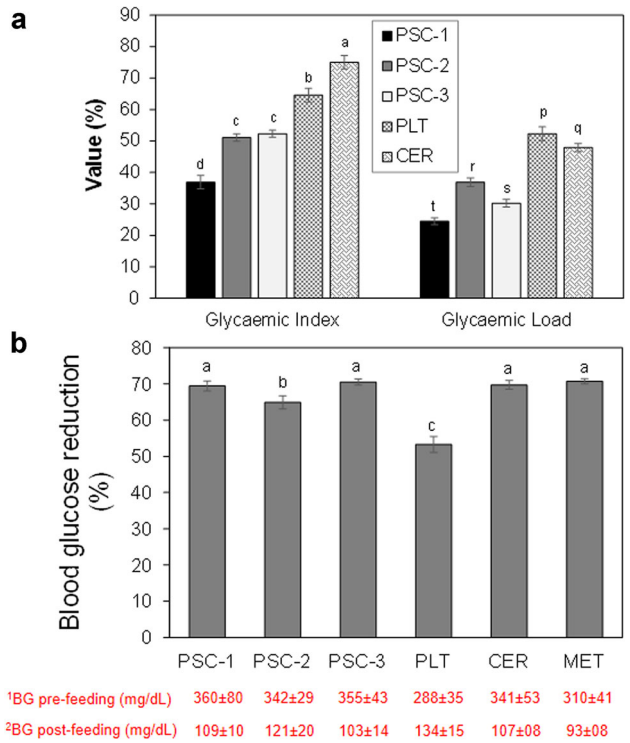

Fig. 1 Glycaemic index and Glycaemic load (**a**) of dough meal supplemented with soybean cake and cassava fibre, and Percentage of blood glucose reduction (**b**) in Wistar rats fed with the experimental diets, control and metformin. Values are Mean ± SEM. *Bars with different alphabet* show that they are significantly different ($p < 0.05$). GI classification: Low-GI = <55 %; Medium-GI = 56–69 %; High-GI = >70. GL classification: Low-GL = <10; Medium-GL = 11–19; High-GL = >20. Where: PSC-1 = Soycake: 19.01 %; Cassava fibre: 5.0 %; Unripe plantain: 75.99 %. PSC-2 = Soycake: 15.0 %; Cassava fibre: 8.0 %; Unripe plantain: 77.0 %. PSC-3 = Soycake: 25.0 %; Cassava fibre: 8.0 %; Unripe plantain: 67.0 %. *CER* Cerolina (Control), *PLT* plantain (100 %), *MET* metformin (a synthetic antidiabetic drug). [1]Blood glucose level in diabetic rats after being induced with aloxan. [2]Blood glucose level in rat after feeding them with formulated diets, metformin or cerolina

dietary intake of sodium and high dietary intake of potassium, calcium, and magnesium reduced the risk of cardiovascular disease, by lowering blood pressure and the risk of diabetes (Chatterjee et al. 2012). However, the Na/K ratio of the formulated diets are low enough which enhanced the dietary potential of the formulated diets.

Analysis of the amino acid composition showed that the dough meals were higher in aspartic acid, glutamic acid, glycine and arginine when compared with control sample. Nutritionally, the essential amino acids in the dough meals were higher in valine, leucine, isoleucine phenylalanine, lysine and histidine compared with FAO/WHO (1991) recommended daily allowances (RDA). The percentage ratios of TEAA to TAA in the samples ranges from 48.85 to 51.72 %, which were well above the 39 % considered to be adequate for ideal protein food for infants, 26 % for children and 11 % for adults (FAO/WHO 1991). Also, a food product with biological values of >70 is rated to be of good quality. With the values obtained in the current study, it implies that the plantain-based dough meals, particularly PSC-3 with 25 % soybean cake and 8 % cassava fibre, can adequately provide the daily essential amino acids for the consumers.

Hematological analysis of rat fed with the dough meals showed PCV, Hb, RBC, WBC, MCV, MCH and MCHC to be comparatively lower than values obtained for similar parameters in rats fed with similar product made of plantain-cowpea (Olapade et al. 2015). Finding showed that PCV, RBC and Hbc concentration decreased in anaemic condition while WBC influenced the immune response as high WBC was reported to the synonymous with microbial infection (Aletor and Egberongbe 1992).

Antinutritional factors are the major barriers to the use of legumes in the formulation of complementary diet as phytic acid chelates metal ions, especially zinc, iron, and calcium to form insoluble complexes in the gastrointestinal tract, and thereby reducing bioavailability of these vital minerals and protein for the normal growth and development (Soetan and Oyewole 2009). However, the anti-nutrients in the dough meals were found to be lower than the lethal doses of 2–5 g/kg for oxalate, 50–60 mg/kg for phytate, 30 mg/kg for tannin, 10 mg/kg for cyanogenic glycoside and 2.50 g/kg for trypsin inhibitor (Nwosu 2011).

Table 5 Sensory attributes of plantain-based functional dough meal supplemented with soybean cake and cassava fibre

Parameters	Appearance	Moldability	Mouth feel	Aroma	Texture	OA	Mean
PSC-1	7.13 ± 0.92^{a}	7.27 ± 1.16^{a}	7.60 ± 1.24^{a}	6.02 ± 1.89^{a}	7.07 ± 1.28^{a}	7.33 ± 0.98^{a}	7.07 ± 1.02^{a}
PSC-2	6.47 ± 1.19^{a}	6.93 ± 1.22^{a}	7.61 ± 1.40^{a}	6.01 ± 2.24^{a}	6.80 ± 0.86^{a}	7.20 ± 0.77^{a}	6.83 ± 1.03^{a}
PSC-3	6.33 ± 1.29^{a}	4.53 ± 1.92^{b}	5.87 ± 1.41^{b}	6.27 ± 2.09^{a}	5.82 ± 2.11^{a}	6.01 ± 1.51^{b}	5.80 ± 1.11^{c}
PLT	6.40 ± 1.12^{a}	6.71 ± 1.21^{a}	7.52 ± 1.24^{a}	6.35 ± 1.17^{a}	6.55 ± 0.77^{a}	7.11 ± 0.69^{a}	6.77 ± 1.01^{a}
CER	7.13 ± 2.03^{a}	5.27 ± 1.75^{b}	7.0 ± 1.36^{a}	6.67 ± 1.11^{a}	6.21 ± 1.93^{a}	6.73 ± 2.12^{ab}	6.50 ± 1.02^{b}

Values are Mean ± SEM. Where: PSC-1 = Soycake: 19.01 %; Cassava fibre: 5.0 %; Unripe plantain: 75.99 %. PSC-2 = Soycake: 15.0 %; Cassava fibre: 8.0 %; Unripe plantain: 77.0 %. PSC-3 = Soycake: 25.0 %; Cassava fibre: 8.0 %; Unripe plantain: 67.0 %

Values with different alphabets across the column differ significantly at $p < 0.05$

CER Cerolina (control), *PLT* plantain (100 %), *OA* overall acceptability

Glycaemic Index (GI) is a measure of the effects of carbohydrates on blood glucose levels and a tool for the dietary management of Type II diabetes (Brand-Miller et al. 2003; Sun et al. 2010). Low GI foods reduce postprandial blood glucose levels and this knowledge can be used in recommending and planning meals for diabetic patients (Hermansen et al. 2006; Agama-Acevedo et al. 2012). The soybean cake and cassava fibre in the plantain-based dough meal are pivotal to the low GI and GL observed. Low GI and GL foods produce a low plasma glucose concentration as a result of slower rates of gastric emptying and digestion of carbohydrate in the intestinal lumen and subsequently, a slower rate of absorption of glucose into the portal and systemic circulation hence, reduce the risk of coronary heart disease and type 2 diabetes (Liu et al. 2000; Salmeron et al. 1997), hence, information on diets GI may be useful in planning carbohydrate-based foods for individuals with diabetes (Hermansen et al. 2006). Study has shown that consumption of unripe plantain or bananas confers beneficial effects for human health, due to its high resistant starch (RS) content (Sajilata et al. 2006; Hernández-Nava et al. 2009; Ovando-Martinez et al. 2009). Eleazu et al. (2010) reported that unripe plantain pulp could be used to manage type 2 diabetes mellitus, and that it is usually eaten in boiled, fried, roasted or dough meal 'amala' forms.

Oral hypoglycaemic drugs such as the sulphonylureas and biguanides commonly used in the management of type 2 diabetes have side effects that include haematological, cutanecous, gastrointestinal reactions and disturbances in both liver and kidney. Also, the cost of the drugs coupled with an exponential increase in the prevalence of diabetes mellitus are impetus for formulation of functional foods as possible alternative therapies for the management of diabetes mellitus (Shodehinde et al. 2014).

Conclusion

Plantain-based dough meals developed with the incorporation of soycake and cassava fibre were found to be comparable to commonly consumed cerolina (a commercial food products) in terms of nutritional profile and glycaemic index. The hypoglycaemic properties of the dough meals showed that they compare favorably with metformin (a synthetic hypoglycaemic drug) in blood glycaemic control activities. Hence, the formulated plantain-based functional dough meals have potentials suitable for the prevention and management of diabetes mellitus.

Compliance with ethical standards

Conflicts of interest The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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