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Chemical composition, in vitro antioxidant properties, and phenolic profile of shallot (*Allium ascalonicum* L.)-enriched plantain biscuit

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Abstract

Background: Plant foods have gained tremendous consideration as a significant progenitor of bioactive substances with several therapeutic advantages over synthetic drugs. Shallot *(Allium ascalonicum* L.) together with plantain (*Musa paradisiaca* L.; particularly unripe ones) holds their applications as spice/food and folk medicine. Hence, this research pursues to explore the chemical composition, antioxidant activities (in vitro), and phenolic profile of shallot-enriched plantain biscuits. Processed shallot flour and unripe plantain flour were blended in different proportions (100% Plantain (SB0), 95% Plantain + 5% Shallot (SB5), 90% Plantain + 10% Shallot (SB10), 85% Plantain + 15% Shallot biscuit (SB15) and 80% Plantain + 20% Shallot biscuit (SB20), mixed with other ingredients to prepare biscuits. The proximate, mineral, anti-nutrient compositions, as well as antioxidant activities of shallot-enriched plantain biscuits and a commercial onion biscuit (COMBIS), were assessed using standard methods. Also, the physical properties and sensory attributes were evaluated using standard methods and polyphenols present in the developed biscuits were identified using HPLC–DAD.

Results: The study revealed that shallot-enriched plantain biscuits contained substantial nutritional contents as the protein content increased upon substitution of shallot flour. The mineral components and their anti-nutrient mineral ratio suggested their physiological impacts on nutrient bioavailability. In addition, the developed biscuit showed good physical and sensory characteristics and displayed remarkable antioxidant activities in vitro. Five polyphenols were detected in the biscuits (shallot-enriched plantain biscuit and COMBIS) with hydroxybenzoic acid being the predominant compound.

Conclusion: The developed shallot-enriched plantain biscuit may possess potential usefulness as a functional snack in the management of oxidative stress-related pathologies owing to the remarkable nutritional composition and significant antioxidant activities exhibited by the developed biscuit.

Keywords: Antioxidant, Minerals, Nutritional properties, Proximate analysis, Shallot, Plantain

Background

Biscuits are nutritious and tasty snacks made through the baking of flat unleavened dough (Olaoye et al. 2007). Biscuits are a favourite food product among varied groups of the populace because of their low cost, convenience (ready-to-eat), savoury, and shelf stability (Ajibola et al. 2015; Dhankhar et al. 2021). The fundamental components of biscuits are fat, sugar and flour. They can also

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be supplemented with proteins, vitamins, minerals, and fibres-rich ingredients to improve their nutritional value and sensory quality (Dhankhar et al. 2021). Omoba and Omogbemile (2013) emphasized the significance of biscuits as part of the commonly consumed baked cereal foods in Nigeria.

Plantain (*Musa paradisiaca* L.) is popularly grown in the southern region of Nigeria. It has been used in folk medicine to cure diseases (infectious and non-infectious) and wound healing (Amutha and Selvakumari 2016; Pereira and Maraschin 2015; Vu et al. 2018). Unripe plantain is an inexpensive energy source and it is therapeutically suitable for the populace managing diabetes due to its characteristic low glycaemic index (Akubor and Ishiwu 2013; Eleazu and Okafor 2015). Several therapeutic benefits of plantain have been reported (Ajijolakewu et al. 2021) including antimicrobial (Abdel Ghany et al. 2019; Asoso et al. 2016), anticancer (Abdel Ghany et al. 2019; Vijayakumar et al. 2017), antiulcer (Khamboonruang et al. 2015; Kumar et al. 2013), antioxidant, hypoglycaemic, and antidiabetic (Ademosun et al. 2021; Maruthai et al. 2019; Olugbuyi et al. 2021) activities. Plantain is rich in fibre, some vitamins (Vitamin A, C, E, B1, B2, B3, B6, and B9), as well as minerals such as potassium, iron (Tribess et al. 2009) but, have low levels of protein and fat (Odenigbo et al. 2013). Therefore, supplementation of plantain flour with inexpensive staples, such as legumes, cereals, and pulses, helps to improve the nutritional quality of plantain products (Famakin et al. 2016). In a previous animal study by Famakin et al. (2016), plantain (*Musa paradisiaca*)-based functional dough meals exhibited hypoglycaemic and antidiabetic potentials in alloxan-induced diabetic rats. Oluwajuyitan and Ijarotimi (2019) also reported on the anti-hyperglycaemic properties of dough meal from plantain flour enriched with tigernut (*Cyperus esculentus*) and defatted soybean (Glycine max).

Shallot originated from Asia and has been grown in different parts of the world (Moradi et al. 2013). Shallot is widely applied as a food spice (in cooking and salad preparation) and in folk medicine owing to its health-promoting potentials (Chope et al. 2011; Raeisi et al. 2016). Shallots comprise of several types of sugars, amino acids, minerals, vitamins (A, B, and C), sulphur components, enzymes, phytohormones (gibberellin and auxin), flavonoids, and saponins (Fasihzadeh et al. 2016; Sittisart et al. 2017; Sun et al. 2019). Ebrahimi et al. (2008) and Moradi et al. (2013) reported that shallots are very rich in essential fatty acids and mineral elements. Furthermore, Sittisart et al. (2017) showed that shallots extracts contained some polyphenols such as apigenin, allicin, ajoene, sapogenins, gallic acid, catechin, quercetin, kaempferol, thiosulphinates, and tannic acids (Moradi et al. 2013; Sittisart et al. 2017). Earlier researches have shown that shallot could be a distinct crop with health-promoting qualities such as; necessary in the evolution of nutraceuticals with top-notch remedial effects (Golubkina et al. 2019; Raeisi et al. 2016). Yin et al. (2006) suggested the use of shallot and scallion oils in food systems which may enhance lipid and microbial stability. Jalal et al. (2011) found that Iranian shallot extracts appear to improve learning and memory impairments in fructose-fed rats. According to Mohammadi-Motlagh et al. (2011), shallot showed promising properties in the management of inflammation and malignancy. Hosseini et al. (2017) reported that the Persian shallot extract exhibits protective potentials in the management of human hepatoma (liver cancer). Golubkina et al. (2019) reported that shallot is very rich in selenium and exhibits antioxidant properties. Recently, Omoba et al. (2022) documented that shallot-enriched amaranth-based extruded snacks possess antidiabetic potentials.

Date palm (*Phoenix dactylifera* L.) fruits are a dietary staple around the world (Tang et al. 2013). Date fruits are one of the most suitable substrates for developing valuable products namely dairy products, and bakery yeasts (Aleid 2011). The fruits are delicious and are sometimes used in the baking of biscuits as a sweetener because of their delicious sweet taste and fleshy mouthfeel. They are a highly rich source of sugar, nutrients, minerals, vitamins, and pharmaceutical secondary metabolites (Ahmed et al. 2014). In many ways, dates may be considered as an almost ideal food, providing a wide range of essential nutrients and potential health benefits (Ahmed et al. 2014; Jain 2013). The numerous health effects of date fruit include antioxidant, anti-mutagenic, and anti-inflammatory activity (Rahmani et al. 2014; Tang et al. 2013).

Previous authors have developed plantain-based food products such as plantain-brewers' spent grain biscuit (Omoba et al. 2013), plantain-wheat bread (Ajala et al. 2018). Oluwajuyitan and Ijarotimi (2019) also reported plantain flour enriched with tigernut (*Cyperus esculentus*) and defatted soybean (Glycine max) but there is a dearth of information on supplementing plantain flour with shallot. Hence, this research seeks to investigate the chemical composition (proximate, mineral, anti-nutrients), in vitro antioxidant properties, and the phenolic profile of shallot-enriched plantain biscuits. Furthermore, this study will assess the physical properties and sensory attributes of the shallot-enriched biscuit.

Methods

Materials

Shallot (*Allium ascalonicum* L.) was procured from *Shasha* Market, Akure, Ondo State, Nigeria. Mature unripe plantain (*Musa paradisiaca* L.) was collected from the Teaching and Research Farm of the Federal University of Technology Akure, Nigeria. The commercial onion biscuit (COMBIS) was purchased from Ceci Supermarket, Akure, Ondo State, Nigeria (see Additional file 1: Table for additional product information). Chemicals used for the study are of analytical brand and were procured from Sigma-Aldrich (United Kingdom).

Preparation of composite flour

Flour processing from unripe plantain

Plantain flour was produced from unripe plantain as reported by Oluwajuyitan and Ijarotimi (2019) with slight modification. A plantain colour chart was used to establish the degree of ripening (United Fruit Sales Corporation 1975). The plantains were peeled manually, chopped into smaller pieces, blanched (for 15 min at 100 ± 2 °C), and parched (at 60 ± 2 °C for 15 h) using a cabinet dryer (Plus11 Sanyo Gallenkamp PLC, UK). The dried sample was milled using a laboratory blender (Kenwood, BLX52 model, UK), and was sieved with the aid of a 60 mm mesh sieve (British Standard). The plantain flour obtained was packaged and sealed in an air-tight plastic container and was stored at 4 ± 2 °C for further use.

Processing of shallot flour

Shallot flour was produced as described by Setyadjit et al. (2017) with minor modifications. Shallots were sliced and rinsed thoroughly with clean water, drained for 20 min, after which they were soaked in 500 ppm sodium bisulphite solution for 10 min. They were rinsed with clean water and drained in a stainless-steel strainer for about 30 min. The drained shallots were spread on aluminium foil sheets and dried (60 ± 2 °C for 10 h) in a cabinet dryer (Plus11 Sanyo Gallenkamp PLC, UK). The dried shallots were blended (Model KM 901D; Kenwood Electronic, Hertfordshire, UK) until smooth. The shallot flour was packaged in a zip-seal food bag, sealed in a nonporous plastic vessel, and was preserved at 4 ± 2 °C until when required.

Processing of date flour

Date flour was processed as reported by Peter Ikechukwu et al. (2017). Dates were cut and were deseeded. The sliced dates were then rinsed thoroughly with clean water and drained in a stainless-steel strainer for about 30 min. The drained date slices were spread on aluminium foil sheets and dried (60 ± 2 °C for 24 h) in a cabinet dryer (Plus11 Sanyo Gallenkamp PLC, UK). The dried date slices were blended (Model KM 901D; Kenwood Electronic, Hertfordshire, UK) and screened with the aid of a sieve (60 mm mesh sieve, British Standard). The date flour was packaged in a zip-seal food bag, sealed in a nonporous plastic vessel, and was preserved at 4 ± 2 °C until when required.

Biscuit preparation

The method of Omoba and Omogbemile (2013) was employed with moderate modification. Shallot and plantain flours (200 g) in different proportions (Table 1) and date palm flour (60 g) were measured for the preparation of the dough. Eighty grams (80 g) of Margarine (facilitated the biscuit to spread out during baking) and 0.5 g of xanthan gum (served as dough thickener or stabilizer) were added to the flour, and 120 ml of water was used to mix all the ingredients to form a smooth dough. The dough was rolled out by hand on a tray (5 mm height) and was cut with the aid of a round-shaped biscuit cutter (4.9 cm diameter). The dough pieces neatly arranged on a baking tray laced with buttered aluminium foil were baked (160 ± 2 °C for 30 min) in a pre-heated Unox steam convection oven and cooled to room temperature for 30 min. Biscuits were packed in airtight, thick, zip-seal food bags, placed in low-density polyethylene bags, and preserved at 4 ± 2 °C.

Determination of proximate compositions and energy value of shallot-enriched plantain biscuits

The proximate and mineral compositions of developed biscuits were assessed by the AOAC (2012) method. The total carbohydrate content was estimated as shown below:

$$\% \text{ Carbohydrate} = 100 - (\% \text{ Moisture} + \% \text{ Ash} + \% \text{ Protein} + \% \text{ Crude fibre}).$$

Afterwards, the dry weight of the proximate composition was calculated from the wet weight (% composition) and presented in the results on a dry weight basis (g/100 g).

Energy value was determined as described by Bhattacharjee et al. (2013). The calculation is presented below:

Table 1 Blending ration of plantain-shallot biscuit

Samples	Formulations	Blending ration (expressed in %)		
		Unripe plantain	Shallot	Total
COMBIS	Commercial onion biscuit	–	–	–
SB0	Plantain + Shallot	100	0	100
SB5	Plantain + Shallot	95	5	100
SB10	Plantain + Shallot	90	10	100
SB15	Plantain + Shallot	85	15	100
SB20	Plantain + Shallot	80	20	100

COMBIS: Commercial onion biscuit, SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit

$$\text{Energy Value (Kcal/100 g)} = (\text{Crude protein} \times 4) + (\text{Total carbohydrate} \times 4) + (\text{Crude fat} \times 9).$$

Determination of mineral composition, anti-nutrient content, and anti-nutrient mineral molar ratios of shallot-enriched plantain biscuits

Determination of mineral composition

Evaluation of the mineral constituents (potassium, calcium, sodium, iron, and zinc) of the biscuits were done according to standard methods of the AOAC (2012).

Determination of anti-nutrient composition

The biscuits were assayed for oxalate (Day and Underwood 1986), phytate (Wheeler and Ferrel 1971), tannin (Makkar et al 1993), and saponin (Brunner 1984) contents.

Calculation of phytate/oxalate minerals molar ratios

The phytate and oxalate mineral molar ratios of the biscuits were calculated from data generated for phytate and oxalate contents, and mineral compositions estimations as described by Ma et al. (2005).

Analysis of the in vitro antioxidant properties of shallot-enriched plantain biscuits

Estimation of total phenol and flavonoid contents

The total phenolic content of biscuits was evaluated employing Folin–Ciocalteu reaction technique as previously described by Singleton et al. (1999), and the total flavonoid content was evaluated employing a colourimetric procedure as previously reported by Dewanto et al. (2002). The total phenol and flavonoid contents of biscuits were stated as gallic acid equivalents (GAE, mg gallic acid/g sample) and rutin equivalents (RE, mg quercetin/g sample), respectively.

Estimation of the ferric reducing antioxidant potential

Ferric Reducing Antioxidant Potential (FRAP) of biscuits were assessed given to the method reported by Pulido et al. (2000) and stated as mg ascorbic acid equivalent/g sample.

Estimation of radical scavenging activities

The free radical scavenging potential of biscuits was evaluated using 2'-Azinobis-3-ethylbenzothiazoline-6-sulphonic acid (ABTS) (Re et al. 1999), 2, 2-Diphenyl-1-picrylhydrazyl (DPPH) (Chanda and Dave, 2009), and hydroxyl (OH•) (Halliwell et al. 1987) radicals scavenging assays.

Determination of physical properties of shallot-enriched plantain biscuits

The weight and the diameter of biscuits were determined using a weighing balance and a calibrated ruler, respectively, according to a modified method of Omoba and Omogbemile (2013). The thickness and spread ratio of biscuits were evaluated as described by the approved methods committee of the American Association of Cereal Chemists (AACC 2000). The spread ratio was evaluated as the ratio of the biscuit diameter to thickness after baking. The breaking strength was determined using an Instron Texture Analyzer according to the method described by Nanditha et al. (2008). The colour of biscuits was also estimated as previously reported by Rocha and Morais (2003) using a portable tristimulus reflectance colourimeter. The colour was reported with a CIE– L* a* b* uniform colour space (–Lab), where L* signifies lightness, a* signifies chromaticity on a green (−) to red (+) axis, and b* chromaticity on a blue (−) to yellow (+) axis.

Sensory evaluation of shallot-enriched plantain biscuits

A descriptive 9-point Hedonic scale rating was employed as previously reported by Iwe (2002). Fifty (50) semi-trained panelists were used for sensory evaluation of shallot biscuits and the extreme like and dislike ratings were rated 9 and 1 for each evaluated attribute, respectively. The evaluations were carried on in a properly ventilated and lighted room designated for sensory assessment in the Department of Food Science and Technology, Federal University of Technology, Akure. The biscuits were analysed for their appearance, aroma, taste, texture, crispiness, grittiness, and overall acceptability.

Identification of phenolic compounds in plantain-shallot biscuits using high-performance liquid chromatography (HPLC–DAD)

Plantain-shallot biscuits were screened to identify the polyphenols present using a high-performance liquid chromatographic diode array detector (HPLC–DAD) as described by Saliu et al. (2021). Samples were liquefied in aqueous acetonitrile (10 mg/20 ml) and vigorously mixed for about 30 min. Afterwards, the aqueous end of the mixture was run off while the organic solvent end was collected into a 25 ml standard flask. The analysis was performed on a Shimadzu HPLC system (NexeraMX) fitted with uBONDAPAK C18 column (length 100 mm, diameter 52 (4.6 mm, and thickness 7 µm). The mobile phase consisted of a mixture of aqueous acetonitrile (acetonitrile/water, 70:30). The extracts were injected at a volume of 5 µl and the flow rate was set at 2.0 ml/min for water and 5 ml/min for acetonitrile at a pressure of

15 mph. Compounds were detected by a UV detector at 254 nm. The retention times of the detected compounds were evaluated using a standard solution at a concentration of 0.985 mg/g. The extract was infused into the HPLC machine to get a curve with peak area and retention time in a chromatogram. The peak area was subsequently used in comparison with that of standard relative to the concentration of the standard to get the concentration of the samples.

Statistical analysis

All determined data were in triplicates. Errors were recorded as standard deviation from the mean and results were stated as Mean ± SD. Figures were then subjected to analysis of variance (ANOVA) using SPSS (IBM version 21.0, USA) and GraphPad Prism 6.01 (GraphPad Software Inc., CA, USA), while the comparison of mean values was further done using the New Duncan Multiple Range Test (NDMRT), and values of $p < 0.05$ were considered to be significantly different.

Results

Proximate composition of shallot-enriched plantain biscuits

Table 2 presents the proximate composition of shallot-enriched plantain biscuits. Moisture contents varied from 10.01 g/100 g (SB5) to 11.02 g/100 g (SB20). Moisture contents of developed biscuits were considerably greater than COMBIS (6.22 g/100 g) and (SB0) biscuits (7.26 g/100 g). The crude protein values of the biscuits varied from 11.32 g/100 g (SB5) to 12.81 g/100 g (SB20) and were higher than the COMBIS (6.93 g/100 g) and SB0 (8.11 g/100 g). The crude fibre contents of plantain-shallot biscuits were also higher in comparison with COMBIS (6.28 g/100 g) and SB0 (7.40 g/100 g) as values ranged from 10.24 g/100 g (SB5) to 11.28 g/100 g (SB20). The developed biscuits showed higher energy values than COMBIS (169.87 kcal/100 g) and SB0 (205.44 kcal/100 g) as the energy values ranged from 259.99 kcal/100 g in SB5 to 272.14 kcal/100 g in SB20.

Table 2 Proximate composition of shallot-enriched plantain biscuits (Dry weight basis)

	Moisture (g/100 g)	Ash (g/100 g)	Crude fibre (g/100 g)	Crude protein (g/100 g)	Crude fat (g/100 g)	†Carbohydrate (g/100 g)	†Energy value (Kcal/100 g)
COMBIS	6.22 ± 0.02[e]	6.33 ± 0.02[e]	6.28 ± 0.02[f]	6.93 ± 0.02[f]	7.10 ± 0.02[e]	19.55 ± 0.10[e]	169.87 ± 0.68[e]
SB0	7.26 ± 0.01[d]	7.41 ± 0.01[d]	7.40 ± 0.01[e]	8.11 ± 0.02[e]	7.73 ± 0.01[d]	25.85 ± 0.29[d]	205.44 ± 1.17[d]
SB5	10.01 ± 0.01[c]	10.24 ± 0.02[c]	10.24 ± 0.02[d]	11.32 ± 0.04[d]	10.92 ± 0.01[c]	29.12 ± 0.17[a]	259.99 ± 0.39[c]
SB10	10.88 ± 0.03[b]	11.24 ± 0.03[b]	11.11 ± 0.03[c]	12.38 ± 0.04[c]	11.91 ± 0.03[b]	29.44 ± 0.05[a]	274.46 ± 0.63[a]
SB15	10.91 ± 0.01[b]	11.27 ± 0.02[b]	11.16 ± 0.01[b]	12.53 ± 0.02[b]	11.96 ± 0.02[a]	28.62 ± 0.02[b]	272.25 ± 0.15[b]
SB20	11.02 ± 0.01[a]	11.41 ± 0.01[a]	11.28 ± 0.01[a]	12.81 ± 0.02[a]	12.10 ± 0.01[a]	28.22 ± 0.03[c]	272.14 ± 0.01[b]
*RDA	< 10.00	< 3.00	< 5.00	> 14.00	10.00 – 25.00	64.00	344–425

Values are expressed as mean ± SD ($n = 3$). Values with different letters down the columns are significantly different at $p < 0.05$.

† Calculated values. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit. *RDA = Recommended Dietary Allowance (Suitor and Murphy 2013; WHO 2003)

Table 3 Mineral composition of shallot-enriched plantain biscuits (Dry weight basis)

	Ca (mg/100 g)	K (mg/100 g)	Na (mg/100 g)	Fe (mg/100 g)	Zn (mg/100 g)	†Na/K
COMBIS	2.15 ± 0.01[f]	2.84 ± 0.05[f]	2.95 ± 0.05[a]	6.34 ± 0.04[a]	0.10 ± 0.03[d]	1.04 ± 0.10[a]
SB0	3.31 ± 0.01[e]	24.34 ± 0.54[a]	2.63 ± 0.08[b]	1.41 ± 0.03[f]	0.07 ± 0.01[f]	0.11 ± 0.01[b]
SB5	6.53 ± 0.03[d]	22.54 ± 0.79[b]	2.58 ± 0.11[b]	2.95 ± 0.02[d]	0.11 ± 0.01[c]	0.11 ± 0.01[b]
SB10	9.95 ± 0.02[c]	19.86 ± 0.06[c]	2.17 ± 0.08[c]	3.36 ± 0.01[b]	0.10 ± 0.01[e]	0.11 ± 0.02[b]
SB15	11.64 ± 0.01[b]	17.65 ± 0.12[e]	1.85 ± 0.04[d]	1.50 ± 0.01[e]	0.13 ± 0.01[b]	0.10 ± 0.01[b]
SB20	11.79 ± 0.04[a]	15.49 ± 0.48[e]	1.64 ± 0.06[e]	3.17 ± 0.02[c]	0.16 ± 0.02[a]	0.11 ± 0.02[b]
*RDA	19.0 – 8081.00	19.00 – 502.00	30.00 – 134.00	10.00 – 15.00	0.23 -2.10	< 1.00

Values are expressed as mean ± SD ($n = 3$). Values with different letters down the columns are significantly different at $p < 0.05$.

† Calculated values. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit.

*RDA = Recommended Dietary Allowance (Suitor and Murphy 2013; WHO 2003)

Mineral composition of shallot-enriched plantain biscuits

Table 3 shows mineral compositions of shallot-enriched plantain biscuits. Potassium is predominant in the developed biscuits ranging from 15.49 mg/100 g (SB20) to 24.34 mg/100 g (SB0) which are significantly ($p < 0.05$) higher than 2.84 mg/100 g observed in COMBIS. Also, the biscuits contain an appreciable amount of calcium varying from 6.53 mg/100 g (SB5) to 11.79 mg/100 g (SB20). Zinc had the least concentration (0.07 mg/100 g–0.16 mg/100 g) in all the samples. The ratios of Na/K of all formulated biscuits (0.10–0.11) are below 1 however COMBIS had a value (1.04 ± 0.01) relatively above the critical point (1.00). Furthermore, there is no significant difference between shallot-enriched plantain biscuits and SB0.

Anti-nutrients composition and anti-nutrient mineral molar ratios of shallot-enriched plantain biscuits

Table 4 displays anti-nutritional content and anti-nutrient molar ratios of shallot-enriched plantain biscuits. A significant difference was not observed in the concentrations of tannins in the developed biscuits (0.01 mg/g) compared to COMBIS (0.02 mg/g). Saponin concentration varied from 0.04 mg/g (SB20) to 0.23 mg/g (COMBIS), similarly, oxalate concentration varied from 0.03 mg/100 g (SB20) to 0.07 mg/100 g (COMBIS). Phytate concentration ranged from 0.08 mg/100 g (SB20) to 0.19 mg/100 g (COMBIS). Overall, incorporation with shallot subsequently reduced the anti-nutrients in the samples when compared to the SB0.

The molar ratio of phytate and mineral of calcium, iron, and zinc in shallot-enriched plantain biscuits

The phytate/mineral molar ratios were calculated (Table 4) to investigate the relationship between the phytate and the bioavailability of the minerals in the shallot-enriched plantain biscuits and the control samples. Phytate:calcium molar ratio of the biscuits ranged from 0.01 (SB20) to 0.02 (SB5) and were significantly ($p < 0.05$) lower when compared with 0.06 and 0.09 in SB0 and COMBIS, respectively. For phytate:iron molar ratios, the values ranged from 0.06 (SB0) to 0.13 (SB20). Phytate:zinc molar ratio values varied from 0.49 (SB20) to 2.79 (SB0). The (phytate:calcium)/zinc molar ratio values of the developed biscuits varied from 4.09 (COMBIS) to 14.64 (SB10). The oxalate: calcium ratios values ranged from 0.03 (SB20) to 0.31(COMBIS).

Total phenol and total flavonoid contents of shallot-enriched plantain biscuits

Total phenol (TP) and total flavonoid (TF) contents of the developed biscuits (Table 5) followed dose-dependent patterns. At 0.05 mg/mL concentration of the biscuit extracts, the total phenol content ranged from

Table 5 Total phenol and total flavonoid of enriched plantain biscuits

	Total Phenol (mg GAE/g)	Total Flavonoid (mg RE/g)
	0.05 mg/mL	0.50 mg/mL
COMBIS	2.76 ± 0.13^{d}	0.02 ± 0.01^{d}
SB0	3.04 ± 0.09^{d}	0.04 ± 0.01^{c}
SB5	3.71 ± 0.45^{cd}	0.05 ± 0.01^{bc}
SB10	4.68 ± 0.29^{bc}	0.06 ± 0.01^{b}
SB15	6.07 ± 0.23^{ab}	0.06 ± 0.01^{b}
SB20	6.57 ± 0.41^{a}	0.09 ± 0.01^{a}

Values are expressed as mean ± SD ($n = 3$). Values with different letters down the columns are significantly different at $p < 0.05$. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit

Table 4 Anti-nutrients composition and anti-nutrient mineral molar ratios of shallot-enriched plantain biscuits

	COMBIS	SB0	SB5	SB10	SB15	SB20	CV
Tannins (mg/g)	0.02 ± 0.01^{a}	0.01 ± 0.01^{b}	0.01 ± 0.01^{c}	0.01 ± 0.00^{d}	0.01 ± 0.00^{e}	0.01 ± 0.00^{e}	0.03 mg/g
Saponins (mg/g)	0.23 ± 0.04^{a}	0.12 ± 0.01^{c}	0.13 ± 0.02^{b}	0.09 ± 0.02^{d}	0.06 ± 0.01^{e}	0.04 ± 0.01^{f}	-
Oxalates (mg/100 g)	0.07 ± 0.01^{a}	0.05 ± 0.01^{b}	0.05 ± 0.01^{b}	0.05 ± 0.02^{b}	0.04 ± 0.01^{b}	0.03 ± 0.01^{b}	250 mg/100 g
Phytates (mg/100 g)	0.19 ± 0.01^{a}	0.18 ± 0.01^{a}	0.12 ± 0.01^{c}	0.14 ± 0.00^{b}	0.09 ± 0.01^{d}	0.08 ± 0.01^{d}	5000 mg/100 g
†Phytate/[Ca]	0.09 ± 0.01^{a}	0.06 ± 0.01^{b}	0.02 ± 0.01^{c}	0.01 ± 0.00^{d}	0.01 ± 0.00^{e}	0.01 ± 0.00^{f}	0.24
†Phytate/[Fe]	0.03 ± 0.01^{e}	0.13 ± 0.02^{a}	0.03 ± 0.1^{d}	0.04 ± 0.01^{c}	0.06 ± 0.01^{b}	0.03 ± 0.01^{f}	> 1.0
†Phytates/[Zn]	1.90 ± 0.01^{b}	2.79 ± 0.04^{a}	1.02 ± 0.01^{d}	1.47 ± 0.10^{c}	0.72 ± 0.02^{e}	0.49 ± 0.01^{f}	15
†(Phytate × [Ca])/([Zn])	4.09 ± 0.10^{f}	9.22 ± 0.12^{b}	6.69 ± 0.07^{d}	14.64 ± 0.09^{a}	8.39 ± 0.06^{c}	5.75 ± 0.02^{e}	200
†Oxalate/[Ca]	0.31 ± 0.01^{a}	0.14 ± 0.02^{b}	0.07 ± 0.01^{c}	0.05 ± 0.01^{d}	0.03 ± 0.01^{e}	0.03 ± 0.01^{f}	2.5

Values are expressed as mean ± SD ($n = 3$). Values with different letters along the group are significantly different at $p < 0.05$.

† Calculated values. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit. CV: Critical value

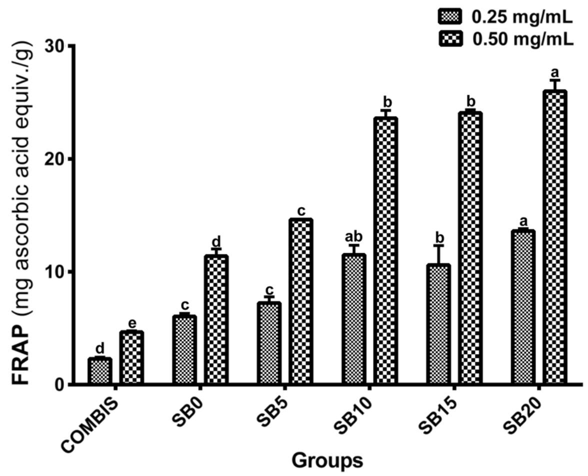

Fig. 1 Ferric reducing antioxidant potential of plantain-shallot biscuits. Values are expressed as mean ± SD ($n = 3$). Bars with different letters are significantly different at $p < 0.05$. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit

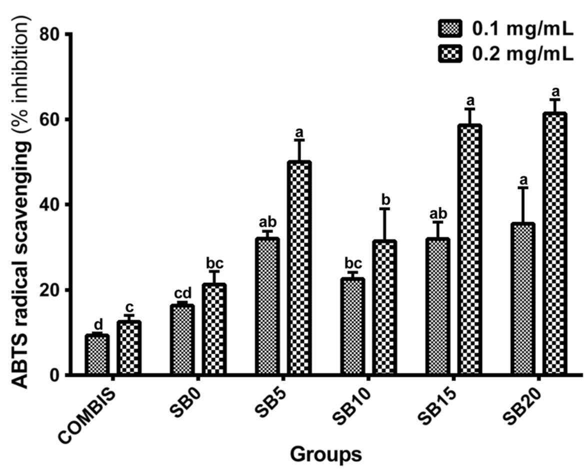

Fig. 2 ABTS inhibitory activities of plantain-shallot biscuits. Values are expressed as mean ± SD ($n = 3$). Bars with different letters are significantly different at $p < 0.05$. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit

2.76 mg GAE/g (COMBIS) to 6.57 mg GAE/g (SB20). At 0.50 mg/mL concentration of biscuit extract, the total flavonoid content varied from 0.02 mg RE/g (COMBIS) to 0.09 mg RE/g (SB20). The increase in substitution with shallot flour in developed biscuits considerably improved the total phenol and flavonoid contents of the

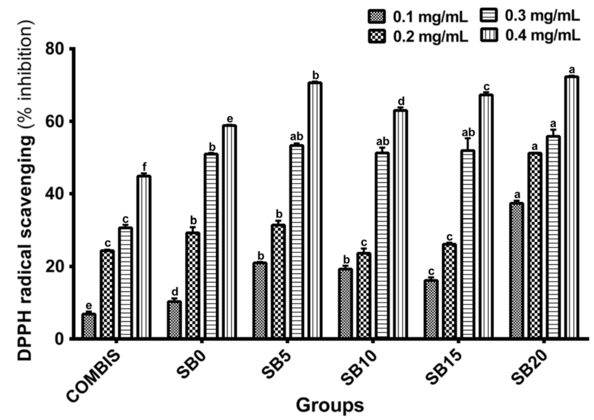

Fig. 3 DPPH inhibitory activities of plantain-shallot biscuits. Values are expressed as mean ± SD ($n = 3$). Bars with different letters are significantly different at $p < 0.05$. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit

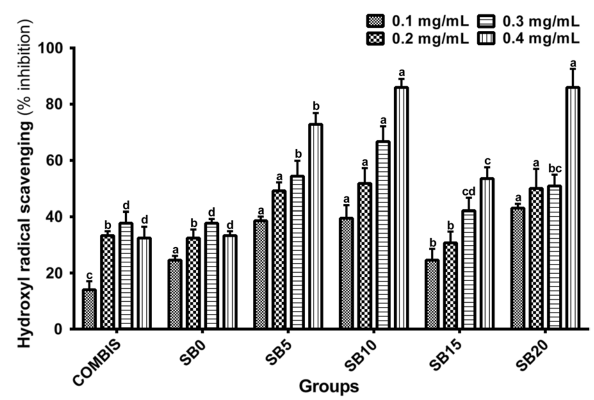

Fig. 4 Hydroxyl radical scavenging activities of plantain-shallot biscuits. Values are expressed as mean ± SD ($n = 3$). Bars with different letters are significantly different at $p < 0.05$. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit

biscuits. Consequently, SB20 displays the highest total phenol and total flavonoid contents.

In vitro antioxidant properties of shallot-enriched plantain biscuits

The antioxidant potentials of plantain-shallot biscuits were evaluated and a similar trend was observed in the free radicals (FRAP, ABTS, DPPH, OH) scavenging abilities of developed biscuits at different concentrations (Figs. 1, 2, 3, and 4, respectively). The highest scavenging ability was observed in SB20

Table 6 Physical properties of shallot-enriched plantain biscuits

	Weight(g)	Diameter (mm)	Thickness (mm)	Spread ratio	Hardness (mm)	Surface colour			†ΔE	†BI
						L*	a*	b*		
COMBIS	6.34 ± 0.13^{d}	63.00 ± 1.50^{a}	5.00 ± 0.51^{a}	12.60 ± 0.00^{a}	12.70 ± 0.53^{a}	67.77 ± 0.06^{a}	10.06 ± 0.02^{b}	28.04 ± 0.04^{a}	-	14.64 ± 0.02^{f}
SB0	15.36 ± 2.34^{abc}	48.55 ± 2.03^{b}	5.75 ± 1.02^{a}	8.66 ± 1.61^{b}	8.32 ± 0.28^{b}	49.19 ± 0.01^{b}	9.89 ± 0.01^{c}	15.35 ± 0.01^{e}	22.49 ± 0.06^{e}	17.18 ± 0.01^{e}
SB5	16.26 ± 1.42^{a}	49.01 ± 1.82^{b}	6.10 ± 0.39^{a}	8.05 ± 0.55^{b}	4.17 ± 0.06^{c}	42.44 ± 0.02^{e}	11.47 ± 0.00^{a}	18.26 ± 0.02^{b}	27.19 ± 0.07^{b}	23.05 ± 0.01^{a}
SB10	15.80 ± 0.94^{ab}	49.88 ± 1.22^{b}	6.15 ± 1.01^{a}	8.32 ± 1.58^{b}	4.60 ± 1.41^{c}	43.96 ± 0.05^{d}	9.32 ± 0.03^{d}	17.09 ± 0.05^{d}	26.22 ± 0.03^{c}	18.72 ± 0.04^{c}
SB15	12.84 ± 1.04^{c}	49.01 ± 1.27^{b}	5.28 ± 0.57^{a}	9.36 ± 0.84^{b}	5.87 ± 0.57^{c}	41.28 ± 0.01^{f}	8.78 ± 0.02^{e}	17.54 ± 0.01^{c}	28.52 ± 0.06^{a}	19.14 ± 0.03^{b}
SB20	13.22 ± 1.36^{bc}	47.63 ± 1.33^{b}	4.89 ± 0.83^{a}	9.97 ± 1.81^{b}	8.43 ± 0.67^{b}	44.25 ± 0.03^{c}	8.59 ± 0.04^{f}	18.27 ± 0.02^{b}	25.51 ± 0.01^{d}	17.76 ± 0.05^{d}

Values are expressed as mean ± SD ($n = 5$). Values with different letters down the columns are significantly different at $p < 0.05$.

† Calculated values. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit; L*: Lightness factor; a*: redness factor; b*: yellowness factor; ΔE: Overall difference in colour, BI: Browning index

whereas COMBIS showed the least. The results showed that the increasing incorporation of shallot flour does not necessarily increase the scavenging abilities. Even SB5 exhibited significant antioxidant properties in vitro; the values were in some cases similar to those of biscuits with a higher percentage substitution with shallot. Overall, SB20 showed a remarkable increase in antioxidant properties which may be due to the high incorporation of shallot flour.

Physical properties of shallot-enriched plantain biscuits

Table 6 displays the physical properties of shallot-enriched plantain biscuits. The weight of biscuits ranged from 6.34 g (COMBIS) to 16.26 g (SB5). The diameter of the developed biscuits ranged from 47.63 mm (SB20) to 63.00 mm (COMBIS). Although there was no notable difference ($p > 0.05$) in the diameters of the shallot-enriched plantain biscuits and SB0, however, COMBIS had a significantly ($p < 0.05$) higher diameter. The thickness of the developed biscuits ranged from 4.89 mm (SB20) to 6.10 mm (SB5). In addition, the thickness of samples SB0 and COMBIS showed no notable variations ($p > 0.05$).

The spread ratio of developed biscuits varied from 8.05 (SB5) to 12.60 (SB20). There was no significant variance ($p > 0.05$) among the formulated biscuits but COMBIS had a higher value which was significant ($p < 0.05$) from those of the developed biscuits. The hardness (mm) of the shallot-enriched plantain biscuits ranged from 4.17 mm (SB5) to 12.70 mm (COMBIS). The differences between the developed biscuits were significant ($p < 0.05$) when compared to COMBIS.

Colour attributes of shallot-enriched plantain biscuits

L* ranged from 41.28 (SB15) to 67.77 (COMBIS) as displayed in Table 6, and a* also varied from 8.59 (SB20) to 11.47 (SB5). The control samples (COMBIS and SB0) showed more lightness and redness tones (higher L* and a*) than the developed biscuits with lower values. The values of b* ranged from 15.35 (SB0) to 28.04 (COMBIS), COMBIS showed significantly ($p < 0.05$) higher b* than shallot-enriched plantain biscuits. A slight increase in yellowness was observed in shallot-enriched plantain biscuits over SB0. ΔE values ranged from 22.49 (SB0) to 28.52 (SB15), there is a distinct colour difference from the COMBIS. BI values ranged from 14.64 (COMBIS) to 23.05 (SB5).

Sensory evaluation of shallot-enriched plantain biscuits

The biscuits were assessed for aroma, texture, appearance, crispiness, taste, grittiness, and general acceptability (Table 7). The result showed there were no variations among the biscuits for the majority of the parameters assessed. Nonetheless, SB0 was generally accepted more than the shallot-enriched plantain biscuits. The addition of shallot reduced the overall acceptability but did not affect other attributes. Nevertheless, notable differences were not detected in the overall acceptability of SB0, SB5, SB10, and SB20.

Phenolic contents of shallot-enriched plantain biscuits using HPLC–DAD

As a result of the overall acceptability and antioxidant activities of SB0 and SB20, the polyphenols existing in the biscuit extracts were identified using HPLC–DAD and are highlighted in Table 8. The phenolic compounds profiled from the developed biscuits include hydroxybenzoic acid, cinnamic acid, ferulic acid, gallic acid, caffeic acid, and protocatechuic A with hydroxybenzoic acid being predominant in all the biscuits. SB20 showed the highest concentration of phenolic acids than SB0 and COMBIS.

Discussion

The variation in the moisture content (6.22 g/100 g–11.02 g/100 g) across the developed biscuits might be attributed to blending ratios and processing methods. Comparatively, the moisture content observed in the plantain-shallot biscuits is slightly higher than the acceptable limit (< 10.00) suggested by the Protein Advisory Group for biscuits (WHO 2003). The observed moisture difference might be due to moisture migration caused by the refrigeration temperature at which the flour was kept. Abbasi et al. (2009) reported that increased temperature decreased moisture content but elevated rehydration rates in onions. On the other hand, the moisture contents of different shallot species were reported to be within 80–87% (Sukasih and Musada 2018), which may have possibly influenced the slight rise in moisture content of the developed biscuits. This finding is similar to 4.52–10.62 g/100 g reported for biscuits supplemented with onion residue (Jiang et al. 2020). It is well established that the high value of moisture in flour samples suggests increased susceptibility to spoilage and subsequently, reduced shelf-life (WHO 2003). Therefore, a safe method of preservation has to be employed to safeguard the biscuits from spoilage.

Generally, this study revealed that the protein content (8.11 g/100 g – 12.81 g/100 g) of the plantain-shallot biscuits increased with an increment in the substitution with shallot flour. Yadav and Yadav (2012) reported 3.0 g/100 g protein in plantain flour, also, Oludunmila and Adetimehin (2016) reported 2.44 g/100 g–3.04 g/100 g protein content of biscuits made from the combination of unripe plantain, wheat, and watermelon (seeds) flours. High protein values in formulated biscuits as observed in this study could be a result of the incorporation of shallot flour.

Table 7 Sensory evaluation of shallot-enriched plantain biscuits

	Appearance	Aroma	Taste	Texture	Crispiness	Grittiness	Overall acceptability
SB0	6.72 ± 1.07[a]	6.30 ± 1.42[a]	6.34 ± 1.47[a]	6.40 ± 1.44[a]	6.20 ± 1.48[a]	6.06 ± 1.13[a]	6.72 ± 1.33[a]
SB5	6.48 ± 1.16[a]	6.04 ± 1.64[a]	6.14 ± 1.46[a]	6.14 ± 1.31[a]	5.96 ± 1.58[a]	5.90 ± 0.93[a]	6.42 ± 1.31[ab]
SB10	6.56 ± 1.50[a]	5.09 ± 1.57[a]	6.20 ± 1.58[a]	5.90 ± 1.50[a]	5.82 ± 1.72[a]	5.88 ± 0.89[a]	6.22 ± 1.47[ab]
SB15	6.42 ± 1.19[a]	6.10 ± 1.47[a]	5.90 ± 1.61[a]	5.90 ± 1.41[a]	5.92 ± 1.65[a]	5.82 ± 0.94[a]	5.94 ± 1.52[b]
SB20	6.26 ± 1.37[a]	6.18 ± 1.62[a]	6.20 ± 1.85[a]	6.12 ± 1.69[a]	5.96 ± 1.74[a]	5.98 ± 1.11[a]	6.30 ± 1.72[ab]

Values are expressed as mean ± SD ($n = 50$). Values with different letters down the columns are significantly different at $p < 0.05$. COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB5: 95% Plantain + 5% Shallot biscuit, SB10: 90% Plantain + 10% Shallot biscuit, SB15: 85% Plantain + 15% Shallot biscuit, SB20: 80% Plantain + 20% Shallot biscuit

Table 8 Phenolic contents of shallot-enriched plantain biscuits

Phenolic acids	*STA	COMBIS		SB0		SB20	
		Area	Conc. (mg/g)	Area	Conc. (mg/g)	Area	Conc. (mg/g)
Hydroxybenzoic acid	1.30	722.66	1.94	897.07	2.41	1010.36	2.71
Cinnamic acid	1.85	167.29	0.45	348.75	0.94	436.58	1.17
Ferulic acid	2.18	44.93	0.12	161.94	0.44	246.78	0.66
Gallic acid	6.12	124.44	0.33	165.80	0.45	243.53	0.65
Caffeic acid	2.63	–	–	83.93	0.23	153.67	0.41
Protocatechuic A	4.02	–	–	42.49	0.11	114.72	0.31

COMBIS: Commercial onion biscuit; SB0: 100% Plantain biscuit, SB20: 80% Plantain + 20% Shallot biscuit. *STA: Standard retention time

The plantain-shallot biscuits could help to influence the growth, development, and repair of tissues. Essential nutrients, like proteins, are needed for biochemical activities, building, and repair of new tissues in the organs of the body (Oyarekua 2010). The fibre contents (7.40 g/100 g – 11.28 g/100) of plantain-shallot biscuits are higher than the recommended dietary allowance by WHO (2003). Yadav and Yadav (2012) reported 3.6 g/100 g of crude fibre in plantain flour, similarly, Oludunmila and Adetimehin (2016) reported low fibre content (2.75 g/100 g–4.01 g/100 g) of biscuits made from a combination of unripe plantain, wheat, and watermelon (seeds) flours. In this study, developed biscuits are rich in fibre and this might due to the incorporation of shallot flour. The position paper released by the American Society for Nutrition established that there is a link between consumption of diets abundant in fibre and reduced risk of cardiovascular diseases, diabetes especially type II diabetes (Cho et al. 2013). In addition, fibres possess hypolipidemic and hypoglycaemic potentials resulting in increased metabolic responses which interrupt breakdown and assimilation of carbohydrates in the gastrointestinal tract thereby leading to satiety (Post et al. 2012; Mirmiran et al. 2014). Dietary fibre has been presented to enhance insulin sensitivity in type II diabetes (Shah et al. 2015).

Lower energy values (169.87 kcal/100 g–274 kcal/100 g) were observed in biscuits when compared with the WHO/FAO standard of minimum 344 kcal /day (WHO 2003). The observed low energy values of the developed biscuits could be attributed to the low-fat content in plantain (the major raw material). This implies that the shallot-enriched plantain biscuit may suitably meet up to 50% of the daily energy requirement while other main meals which are major sources of energy could help to provide the remaining fraction of the daily calorie requirement.

Potassium is the most abundant element (15.49–24.34 mg/100 g) in the plantain-shallot biscuits. The decrease in potassium with increased shallot incorporation could be attributed to a decrease in plantain composition; since reports have established plantain to contain appreciable high levels of potassium (Odenigbo et al. 2013; Osundahunsi 2009). A high amount of potassium has been reported to increase iron utilization in the body and both potassium and sodium function in regulating the body pH, muscle and nerve signals, body fluids, glucose assimilation, and protein reservation in cell development (Omoba and Omogbemile 2013). There are several reports on the function of digestible potassium in hypoglycaemic function and subsequent precaution against type 2 diabetes (Aaron and Sanders 2013; Chatterjee et al. 2010, 2011; Clegg et al. 2020; Gonçalves and Abreu

2020). The plantain-shallot biscuits contain an appreciable amount of calcium (3.31 mg/100 g–11.79 mg/100 g) which is higher than the amount observed in the market sample, COMBIS (2.15 mg/100 g). There was an increase in calcium content as shallot incorporation increased, this corroborates the 80.86% increase in calcium content of biscuits with a corresponding increase in onion residue (Jiang et al. 2020). Calcium takes part in bone formation, blood clotting, muscle contraction, heartbeat regulation, and cellular homeostasis (Pravina et al. 2013). In addition, calcium has been linked to having protective potentials against type 2 diabetes mellitus (Ahn et al. 2017). On the other hand, the biscuits showed a poor source of zinc element (0.07 mg/100 g–0.16 mg/100 g). Zinc supports the immune system and the minimum recommendation of 10 mg/day dietary zinc is required (Roohani et al. 2013) thus, consumers of the biscuit may need to source the vital mineral from other food sources such as legumes and nuts. The enhanced mineral profile has been linked with high ash contents of foods (Jan et al. 2015) and this study demonstrated that incorporation of shallot flour enhanced the mineral contents of biscuits. The observed ratio of Na/K for the biscuits from the study is less than the critical value (1.00) which could be attributed to the high amount of potassium over sodium which was observed in both 100% Plantain (SB0) and shallot-enriched plantain biscuits.

Phytates occur naturally in plant species and they exist in foods in varying quantities which may range from 0.1 to 6.0% (Gupta et al. 2015). They are negatively charged compounds so they bind with positively charged metal ions such as magnesium, iron, calcium, and zinc to form complexes and that leads to depletion in the assimilability of these ions with reduced rates of digestion (Olagunju et al. 2018; Samtiya et al. 2020). Oxalate has been recognized to bind to calcium leading to the development of crystals and hence kidney stones (Brzezicha-Cirocka et al. 2016; Kirejczyk et al. 2014; Lorenz et al. 2013). Anti-nutritional compositions (tannins, saponins, oxalates, and phytates) of the developed biscuits were generally low (0.01–0.02 mg/g, 0.04–0.23 mg/g, 0.03–0.07 mg/100 g, 0.08–0.19 mg/100 g, respectively) when compared with their recommended tolerable levels (CDA 2000). Therefore, the biscuits can be considered non-toxic for ingestion with no adverse effects as regards the bioavailability of minerals for the body. The low levels of these anti-nutrients may have been influenced by the processing procedures employed during the preparation of samples. Processing techniques such as dehusking, blanching, milling, soaking, fermentation, baking, cooking usually facilitate the decrease in the anti-nutritional constituents in foods (Coulibaly et al. 2011; Gupta et al. 2015; Temesgen 2013). Ayodele et al. (2019) reported a decrease in phytate and oxalate contents of unripe plantain after boiling.

Phytate/oxalate mineral molar ratios of the biscuits; phytate/Ca (0.01–0.06), phytate/Fe (0.03–0.13), phytate/Zn (0.49–2.79) and oxalate/Ca (0.03–0.14) were lesser than their corresponding critical values (0.24, > 1.0, 15, and 2.5, respectively) as stated by Ma et al. (2005). This is an implication that the minerals in the biscuits would be available for absorption in the body system.

The total phenol and total flavonoid contents and antioxidant activities of formulated biscuits followed a dose-dependent pattern. An increase in substitution with shallot flour showed significantly higher total phenol content (3.04–6.57 mg GAE/g at 0.05 mg/mL concentration) in comparison with COMBIS (2.76 mg GAE/g). Also, the same goes for the total flavonoid content of developed biscuits (0.04–0.09 mg RE/g at 0.50 mg/mL concentration) which are higher than that of COMBIS (0.02 mg RE/g). The increase in total phenol and total flavonoid contents of developed biscuits could be ascribed to the high amount of polyphenols present in shallot. Shallot has been reported to contain various phytochemicals such as quercetin, gallic, kaempferol (Sukasih and Musada 2018; Wenli et al. 2019), hence, the reason for the high total phenol contents when compared with the samples with no shallot. Polyphenolic compounds have been widely documented to exhibit outstanding antioxidant potentials (Aladesanmi et al. 2020; Liu et al. 2019). This explains the reason for the higher level of free radicals (FRAP, ABTS, DPPH, and OH) scavenging abilities of shallot-enriched plantain biscuits than COMBIS and SB0. An increase in shallot flour supplementation in biscuits exhibited higher scavenging and reducing abilities of these free radicals. These results agree with the discoveries of Jiang et al. (2020) where increased total phenol, total flavonoid contents, and DPPH radical scavenging ability of biscuits was reported due to augmentation of biscuits with onion residue.

The information on the impact of nutritional polyphenols on human health is constantly growing which consolidates their protective role against many human diseases (D'Angelo 2020; Krzysztoforska et al. 2019). They are an essential group of secondary metabolites generated as an adaptive reaction to biological stress situations (Ashraf et al. 2018). Polyphenols are capable of scavenging a wide range of reactive oxygen species via various mechanisms such as suppression of reactive oxygen species formation by inhibiting the enzymes involved in their production and upregulation/protection of antioxidants. Therefore, the antioxidant abilities of the developed biscuits could be credited to the polyphenols present in the shallot which has been reported to contain various polyphenols (Fasihzadeh et al. 2016; Sittisart et al. 2017; Soininen et al. 2012; Sun et al. 2019).

The increase (12.84–16.26 g) in weight of formulated biscuits when compared to 6.34 g in COMBIS might be credited to improved protein content arising from the addition of shallot (Adeola and Ohizua 2018) and resistant starch present in the plantain. Resistant starch has been studied to have the ability to bind water and increase swelling ability (Ashraf et al. 2012). The observed values in this study were greater than the values (7.33–9.37 g) previously stated for plantain-brewers' spent grain biscuit (Omoba et al. 2013), Acha-based biscuit (9.20–10.0 g) enriched with Bambara nut and unripe plantain (Agu et al. 2014) but similar in range with the result (15.08–19.29 g) reported for biscuit produced with unripe plantain, wheat, and pumpkin seed composite flour (Bello et al. 2020).

Spread ratio is a parameter used to assess the standard of flour used in formulating biscuits and the ability of the biscuit to rise (Bala et al. 2015). The spread ratio of the shallot-enriched plantain biscuits could have been influenced by the rivalry among ingredients for the available water and nutrients; the spread ratio of developed biscuits (8.66–9.97) are significantly different from COMBIS (12.60); biscuits with superior spread ratios are more preferred (Omoba and Omogbemile 2013). The values of both diameter and spread ratio obtained in this research were higher than the values reported by Adeola and Ohizua (2018) and Bello et al. (2020) but similar (spread ratio) to values reported by Agu et al. (2014), and Omoba and Omogbemile (2013) for different blends of raw materials. The addition of shallot further reduced the hardness of the biscuits compared with the market sample, COMBIS. This might be attributed to the addition of shallot interfering with the crosslink matrixes of resistance starch in the shallot-enriched plantain biscuits. A similar trend was also observed when onion residue was added to processed flour from wheat in the manufacture of biscuits (Jiang et al. 2020); they proposed that the onion residue might have affected the matrixes of gluten which decreased the hardness observed in the biscuits product.

The reduction of lightness (41.28–44.25) and redness (8.59–11.47) tones observed across the formulated biscuits could be attributed to enhanced synthesis of Maillard reaction between reducing sugars and amino acids caused by the addition of shallots and the development of melanoidins which led to non-enzymatic browning, baking temperature and time could also affect the colour (Jiang et al. 2020; Pereira et al. 2013). The reduced redness intensity could also be due to the destruction of anthocyanin by some circumstances such as pH, heat, light, and temperature; anthocyanin is responsible for the redness in shallot (Sukasih and Musada 2018). Meanwhile, some species of shallot have been reported to contain yellowish red colour (Sukasih and Musada 2018).

The overall difference in colour (ΔE) is a parameter used to show the degree of colour variation between control and stored samples (Pathare et al. 2013; Patras et al. 2011). Adekunte et al. (2010) stated that variances in colour can be analytically categorized as small differences ($1.5 < \Delta E$) distinct ($1.5 < \Delta E < 3$), and very distinct ($\Delta E > 3$). The incorporation of shallot may be a contributing factor to the darker colour among the developed biscuits (22.49–28.52) as observed in this study. Browning index (BI) is employed to depict general differences in browning colour. Assessment of browning index is important in food industries for effective grouping and rating practices for market conditions to be met. This arises from the oxidation (both enzymatic and non-enzymatic) of phenolic compounds present in the commodities (Pathare et al. 2013). The difference (14.64–23.05) may have occurred as a result of non-enzymatic browning which is linked with degradation reactions of carbohydrates such as the caramelization and Maillard reactions (Pathare et al. 2013).

Colour is an essential feature since it influences the cravings of consumers. It is a key quality criterion used as a procedure check during food processing such as roasting and baking (Pereira et al. 2013). Colour helps to direct the market performance of a product. The use of food-grade colours may not be out of place to make them more appealing to consumers.

The sensory attributes of foods usually influence the consumers' desire and approval of products that ultimately determine the success or failure of any food product. The results (5.94–6.72) were identical to that of Jiang et al. (2020) who described that the supplementation of biscuits with onion residue decreases their overall acceptability without having an adverse effect on other parameters.

The findings obtained from the phenolic profiling of shallot-enriched plantain biscuits using HPLC–DAD were comparable to that of Simin et al. (2013) who did a comprehensive identification and quantification of small yellow onion. Hydroxybenzoic acid was the principal phenolic acid with SB20 having the highest concentration (2.71 mg/g in SB20, 2.41 mg/g in SB0, and 1.94 mg/g in COMBIS) than other polyphenols. Several studies have reported that dietary polyphenols such as hydroxybenzoic acid, gallic acid, ferulic acid, caffeic acid, and protocatechuic acid possess excellent hypoglycaemic, antioxidants, and antidiabetic potentials (Dzydzan et al. 2019; Patel et al. 2012; Sun et al. 2020). Ferulic, cinnamic, and caffeic acids have been reported to exhibit possible mechanisms of antidiabetic activity via effective intestinal sucrase and hepatic gluconeogenesis inhibitions which may facilitate lessening of postprandial hyperinsulinemia and hyperglycaemia in type 2 diabetes (Adisakwattana et al. 2004, 2009; Liu et al. 2000; Ohnishi et al. 2004). The phenolic compounds were most abundant in SB20 and that could be attributed to the substitution of plantain flour with a relatively high amount of shallot flour. Shallot has been reported to have a variety of phytochemicals present in them such as hydroxybenzoic acid and gallic acid (Sukasih and Musada 2018; Wenli et al. 2019). The high concentration of hydroxybenzoic acid may suggest the antidiabetic potential of the biscuit sample, especially SB20.

Conclusions

The study established that the shallot-enriched plantain biscuits contained a substantial amount of nutritional and mineral components. The developed biscuits showed good physical and sensory characteristics which give an insight into the unique properties possessed by the shallot in that its incorporation did not negatively affect the sensory characteristics of the biscuits. Furthermore, the shallot-enriched plantain biscuits exhibited significant antioxidant activities. Notably, the phenolic compounds characterized from the biscuit samples include hydroxybenzoic acid, ferulic acid, cinnamic acid, gallic acid, caffeic acid, and protocatechuic A, these compounds could be key contributors to the antioxidant activities exhibited by the developed product. Hence, the developed biscuit may possess potential usefulness as a functional snack in the management of oxidative stress-related pathologies.

Abbreviations

DPPH: 2,2-Diphenyl-1-picrylhydrazyl; TCA: Trichloroacetic acid; TBA: Thiobarbituric acid; ABTS: 2,2′-Azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) di-ammonium salt; TROLOX: 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid; AAE: Ascorbic acid equivalent; GAE: Gallic acid equivalents; RE: Rutin equivalents; CV: Critical value; HPLC–DAD: High-performance liquid chromatography with diode array detection; STA: Standard retention time; ΔE: Overall difference in colour; BI: Browning index.

Supplementary Information

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Additional file 1: **Supplementary Table**. Additional Information on COMBIS (as provided on the package).

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Authors' contributions

AEA and OSO conceived and designed the experiment, AEA sourced and processed the materials, AEA and SSJ carried out the experiments. SSJ processed the experimental data, AEA and SSJ wrote the first draft of the manuscript, OSO and AIO substantively reviewed the manuscript, and OSO and AIO supervised the research work. All authors discussed the results and commented on the manuscript. All authors gave consent to submit the manuscript for publication in the Bulletin of the National Research Centre. All authors read and approved the final manuscript.

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Declarations

Ethical approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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