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Nutritional, physicochemical and quality profiles of organically sweetened gluten-free breakfast meal from quinoa (*Chenopodium quinoa* Willd) and tigernuts (*Cyperus esculentus* L.)

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Abstract

By formulating a breakfast meal from quinoa and tigernuts that is organically sweetened, this study aimed to synergistically utilize the natural bioactive compounds embedded in both foods. When compared to commercial sample, all formulations had higher protein and fat contents. The meals contained little starch, and most significantly, over 35% of this starch was non-digestible. The main minerals found in the meals were potassium (481.81—592.47 mg/100 g), phosphorus (231.75—257.20 mg/100 g), magnesium (152.34—176.29 mg/100 g), and calcium (257.45—266.61 mg/100 g, with the Na/K molar ratio < 1.0 advantageous for those with high blood pressure. Regarding overall phenol and flavonoid contents, the meals outperformed the commercial product with remarkable antioxidant capacities when tested against different assays (FRAP, ABTS, and DPPH). The meals' inhibitory capacities on both carbohydrate-hydrolyzing enzymes were noticeably higher than that of the commercial product. Regardless of the amount of quinoa or tigernuts in each blend, the inhibitory performance was satisfactory (α-amylase 26.98—60.18%; α -glucosidase 19.47—40.02%). Similarly, the chemical properties of the meals as influenced by its higher protein, fats, dietary fibre, and low sugar, modulated its functional properties in a unique way. In terms of sensory assessment, the panelists ranked the meals similar and sometimes above the commercial ones with respect to all the organoleptic parameters considered.

Keywords Quinoa, Tigernuts, Breakfast meal, Organic sweetener, Nutritional profiles

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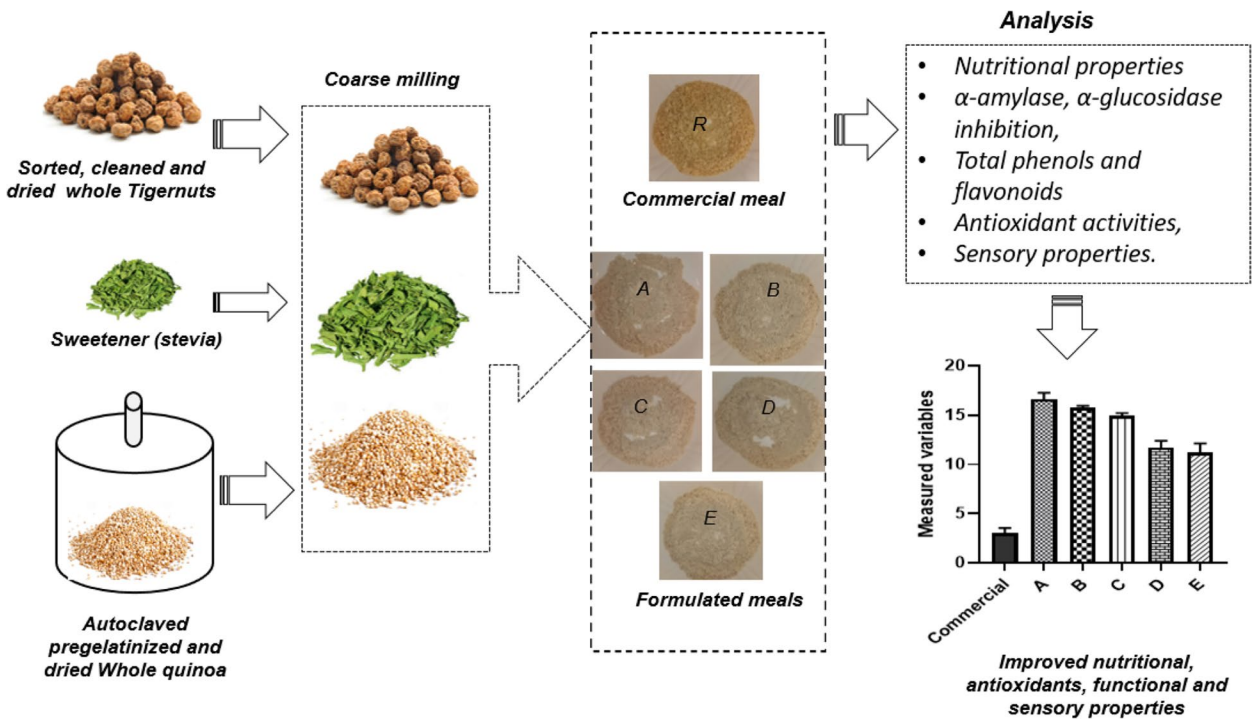
Graphical Abstract

A graphical representation of production, nutritional and functional characterization of stevia-sweetened breakfast meals from quinoa-tigernuts blends



Introduction

The term "food neophobia" refers to customers' propensity to avoid trying new foods, which may be due to rigidly enforced lifestyle, religious, or dietary constraints such as lactose-intolerance, gluten-allergy, low insulin etc. (Guzek 2019). However, considering the connection between diets and diseases in contemporary nutrition, the development of novel and functional foods tailored for various dietary restrictions becomes essential (Mirmiran 2014). Many of these foods have been determined to be superior to or at least somewhat healthier alternatives to the well-known conventional ones (Rojas-Rivas et al. 2018). A comprehensive nutritional and functional explorations of these novel foods, further lend credence to this acclaimed health significance. Experimental tests and even pre-clinical trials have revealed the capabilities of functional foods to rival synthetic drugs in ameliorating some debilitating non-communicable metabolic diseases like diabetes, hypertension, cardiovascular diseases, and some cancers (Hou et al. 2020; Lin et al. 2019). More often than none, especially in developing countries, these functional foods are developed from two or more underutilized, relatively cheap, and readily available plant materials. The food could be a breakfast cereal alternative, ready-to-eat snacks, main cause dough meal, etc. composed of complimentary blends of two or more items with the purpose of obtaining a synergistic nutritional outcome (Oluwajuyitan & Ijarotimi 2019; Yamsaengsung et al. 2012). One of these unconventional agricultural items that have found application in many functional breakfast meals, bakery and confectionery products, beverages, and deserts is quinoa (*Chenopodium quinoa* Willd). It is a gluten-free, pseudocereal that falls within the small list of foods popularly adjudged as "Superfoods" due to their remarkable nutritional compositions and possibility of serving as dietary solutions to some non-communicable diseases (Melini & Melini 2021). Due to its extraordinary recognition and food applications by new users, quinoa was named the food of the year on a global scale in 2013 (Kakabouki et al. 2018). Quinoa consumption is advantageous for lowering lipid peroxidation, thus preventing, and treating risk factors for cardiovascular disease, gastrointestinal disorders, and celiac disease (Noratto et al. 2019). Quinoa can be used as a flour to make

gluten-free bread and bakery goods, as well as a cooked cereal like porridge, in salads and desserts.

On the other hand, a tropic-based "Superfood" of exceptional nutritional significance is tigernuts (*Cyperus esculentus* L.) which has received unparalleled academic and culinary interest in recent years (Malashree et al. 2021). These tiny, tuberous rhizomes of a sedge grass have been around for thousands of years all throughout the planet. The tiger-striped exterior gives it its name, and its flavor is a cross between coconut and almond. They can be eaten raw, juiced, roasted, or boiled. Tigernuts are also offered as tigernuts flour, tigernuts milk, tigernuts oil and are packaged after being dried to make them shelf stable (Maduka & Ire 2018). These small tubers are low in calorie and high in fiber. Tigernuts are incredibly rich in resistant starch, which has gained a lot of attention for its potential to aid in weight loss (Yu et al. 2022). By preventing increase in blood sugar and causing satiety for longer than other foods with the same amount of calorie, resistant starch bypasses the stomach and small intestine without being digested (Amini et al. 2021). Additionally, it helps the digestive tract by acting as a prebiotic and promoting the development of healthy gut microbiota. Tigernuts has been applied as adjunct or major component of several functional food and beverage formulations and its nutritional contributions have been widely explored in literature (Babiker et al. 2021; Badejo et al. 2020a, 2020b, 2020c; Elizabeth & Tijesuni 2020; Kehinde et al. 2016). Therefore, creating a novel functional breakfast meal using whole quinoa grains and tigernuts would have enormous nutritional benefits. The diet would be excellent for a wide range of person with diverse health conditions. In addition to being gluten-free, the product would have a combined complete amino acid and fatty acid profiles, vitamins, dietary and insoluble fibers, as well as resistant starch.

Breakfast is often referred to as the most crucial meal of the day and has recently been linked to weight management, reducing cardio-metabolic risk factors, and improving cognitive function (Gibney et al. 2018), when appropriate items are selected. However, most healthy whole cereal breakfast meals are usually sweetened with table sugar and the dietary consequences of refined sugar has been clearly elucidated in literature (Duan et al. 2022; Neelakantan et al. 2021). Despite all the negative effects, many people cannot avoid using sugar as a food element. One of the main disadvantages of regular sugar produced from sugarcane is that the refining process removed all its natural useful additives (such as bioactive compounds like phenolic acids, flavonoids, etc.) which end up in by-products like molasses and brown sugar (Castro-Muñoz et al. 2022). For the same reason, people are becoming more and more interested in natural sweetening alternatives. Stevia (*Stevia rebaudiana*) is one of many natural non-caloric and bioactive-rich sweeteners. It contains stevioside which is 250 – 400 times sweeter than sugar (Farhan et al. 2020). In addition, it was discovered that adding stevioside to ready-to-serve peach beverages improved phenolic compositions, antioxidant profiles, and storage stability (Kovačević et al. 2018). Hence, using stevia as a natural sweetener in the formulation of a functional product would not only enhance the consumers' gustatory experiences but also broaden the demographics for which the products are used. Therefore, the overarching objective of this study is to develop a functional gluten-free breakfast meal sweetened with stevia, from the blends of whole quinoa grains (*Chenopodium quinoa* Willd) and tigernuts (*Cyperus esculentus* L.) and profile it's *in-vitro* nutritional, polyphenols, antioxidant, functional and organoleptic properties.

Materials and methods

Materials and preparation of stevia sweetened quinoa-tigernuts breakfast meal

White variety of organic pre-packed quinoa (*Chenopodium quinoa* var. *quinoa*) grains were purchased commercially through Jumia from Kirkland (Andean Farmers, Washington, USA). Fresh yellow variety of tigernuts tubers (*Cyperus esculentus* var. *rubrofuscus*) were purchased from a Northern-based supplier in Nigeria. Quinoa grains were thoroughly washed in excess water and drained—a process known to remove excess saponin from the grains (Edwards 2006). To imitate autoclaving conditions, the grains were pre-cooked at 121 °C for 10 min in a home pressure cooker according to a modified method of Sharma et al. (2022). The grains were allowed to cool, after being dried in a hot air oven at 50 °C for 2 h the grains were ground in a cyclotech mill (Gibbons Electric, Essex, UK), packed and vacuum-sealed in a Ziplock polyethylene bags and stored at room temperature. Fresh, sorted and cleaned yellow tigernuts tubers were oven dried at 60 °C for 20 h and pulverized (into relatively the same particle size as the quinoa) packed as stated above. Unadulterated stevia flour was supplied by a known producer and 200 g of each blend were prepared using equal amount of stevia as sweetener (0.5%) thus: 65% quinoa and 35% tigernuts, (Q65_T35), 60% quinoa and 40% tigernuts, (Q60_T40), 55% quinoa and 45% tigernuts, (Q55_T45), 50% quinoa and 50% tigernuts (Q50_T50), 45% quinoa and 55% tigernuts (Q45_T55). These blend ratios were chosen to mimic the typical break cereals (65–80% cereal, and 20–35% legume flours), which are often eaten with milk (Edima-Nyah et al. 2019). As a result, the amount of tigernuts used was increased, (a nut that simulates milk), in an effort to

replicate a sustainable alternative breakfast that does not require milk.

Chemical reagents

Chemical reagents, solvents and standards used were sourced from Sigma-Aldrich, Fluka and Merck and they were all analytical grades.

Proximate analysis

Proximate compositions of the blends were determined according to the standard AOAC method (Association of Officiating Analytical Chemists 2005). Carbohydrate was estimated by difference (100 – ∑other components). Atwater's conversion factors for protein (Protein × 4), fat (Fat × 9) and carbohydrate (Carbohydrate × 4) was used to estimate gross energy value of the flour in dry weight basis and reported as Kcal/100 g.

Resistant, digestible, and total starch determination

Using a glucose oxidase–peroxidase (GOPOD) kit (K-GLOX, Megazyme Bray, Ireland) and a Megazyme kit, resistant starch (RS) and digestible starch (DS) were measured in accordance with a modified method (Patindol et al. 2010). To remove proteins, samples were first treated for 1 h at 40 °C with 10 mL of HCl-KCl buffer (pH 1.5) and 200 µL of pepsin solution (100 mg/mL HCl-KCl buffer). At 37 °C for 16 h, the samples were incubated with 4.0 mL of pancreatic α-amylase solution containing diluted Amyloglucosidase, 300 U/mL, while being constantly stirred (200 strokes/min). The combined activity of the two enzymes caused the DS to be solubilized and hydrolyzed into glucose. Afterward, samples were cleaned by centrifuging at 2060 g for 10 min while being continuously stirred in 99% (v/v) and 50% (v/v) ethanol. Supernatant and pellet separation was followed by additional digestion (with 2 M KOH with vigorous stirring for 20 min in an ice-water bath over a magnetic stirrer). Separate incubations of the digested pellet and supernatant at 50 °C for 30 min (with 100 L of AMG; 3300 U/mL) and 20 min (with 10 L of AMG; 300 U/mL) each were performed. Utilizing the GOPOD kit, the absorbance at 510 nm was measured in comparison to the reagent blank to determine the amount of glucose released. To calculate the amounts of digestible starch (DS) and resistant starch (RS), respectively, a factor of 0.9 was applied to the glucose content of the digested pellet and supernatant, respectively. The sum of DS and RS was computed as total starch (TS).

Sugar content determination

Direct acid hydrolysis as described by AOAC (1990) was used to quantify starch content. A mixture of 5 g of the sample and 50 mL distilled cold water was mixed for 1 h, filtered and washed with cold water. The insoluble residue was heated with 200 mL water and 20 mL HCl for 2.5 h in a flask fitted with a reflux condenser. The condensate was cooled, few drops of phenolphthalein was added and neutralized with NaOH. The mixture was diluted to 250 mL, filtered and glucose was determined using the Lane-Eynon titration method.

Dietary fibre determination

The standard enzymatic–gravimetric method AOAC Official Method 991.43 (Lee et al. 1992) in which starch and protein were removed by enzyme-catalyzed hydrolysis, was used to determine the insoluble and soluble dietary fibre contents of triplicate samples of defatted whole flours from each source. After filtering the enzymatically altered mixture, the insoluble dietary fibre (IDF) residue was dried and weighed. Following ethanol precipitation, the filtrate was collected, dried, and weighed to obtain the soluble dietary fibre (SDF). According to AOAC (2005), the protein and ash content of each fibre residue's weight was adjusted.

Mineral profile determination

Potassium (K) and sodium (Na) were determined using a flame photometer (Corning EEL), while calcium (Ca), magnesium (Mg), iron (Fe), and zinc (Zn) contents were analyzed using the Atomic Absorption Spectrophotometer (AAS) (model 205, Buck Scientific, USA) (AOAC 1990). Total phosphorus by phospho-Vanadomolybdate method was determined using a spectrophotometer (model 7305, Jenway, UK).

Total phenol content determination

The Folin-Ciocalteu method, as described by Singleton et al. (1999) was used to determine the gruel's total phenol concentration. Folin (10%), sodium carbonate (20%), and 0.5 mL gruel extract were added to the mixture, which was then incubated at 30 oC for 60 min. A spectroscopic measurement of the clear bluish color was made (UV–Visible spectrophotometer, Shimadzu, 1800, USA). Miligram equivalents of gallic acid (mgGAE/kg) were used to express the sample's total phenol content.

Total flavonoid content determination

A modified version of Quettier-Deleu et al. (2000) was used to determine the total flavonoid content of the meal. In a nutshell, 2 mL of the meal's methanolic extract was combined with an equivalent volume of 2% methanolic aluminum trichloride ($AlCl_3$. $6H_2O$). The absorbance of the resulting clear solution was measured spectroscopically at 430 nm after 10 min using a UV–Visible spectrophotometer (Shimadzu, 1800, USA). For each 100 g

of the meal, the flavonoid content was estimated as milligram equivalent of quercetin.

FRAP antioxidant activity

The Pulido et al. (2000) approach was used to assess the meal's potential for lowering ferric levels in the blood. For the test, freshly made FRAP reagents were used. These contained 25 mL of 0.3 mol/L acetate buffer, pH 3.6, 2.5 mL of 20 mmol/L $FeCl_3.6H_2O$, and 2.5 mL of 10 mmol/L TPTZ (2,4,6-Tri(2-pyridyl)-s-triazine) solution in 40 mmol/L HCl. In a nutshell, 900 mL of FRAP reagent were combined with 100 mL of the sample extract, and the reaction was allowed to run for 30 min at 37 °C. Absorbance of the mixture was then assessed at 595 nm using a UV–visible spectrophotometer (UV–Visible 1800; Shimadzu, Japan). For calibration, a solution with known concentrations of Fe^{2+} was utilized.

ABTS antioxidant activity

The ability of the gruel to scavenge ABTS (2,2′-azino-bis (3-ethylbenthiazoline-6-sulphonic acid)) was determined as earlier described (Re et al. 1999). Briefly, a reaction involving 2.45 mM K2S2O8 and 7 mM ABTS aqueous solution was carried out in the dark for 16 h to create an ABTS stock solution. The final absorbance at 734 nm was adjusted with ethanol to 0.70 ± 0.02. At room temperature, a 200 µL aliquot of the diluted gruel extract was combined with a ten-fold ABTS solution. After 15 min, a UV–Visible spectrophotometer was used to detect the absorbance at 734 nm (UV–Visible 1800; Shimadzu, Japan). Trolox was used to create a calibration curve, and the result was represented as mmol of trolox equivalent per 100 g of the sample.

DPPH antioxidant activity

The ability of the gruel to scavenge radicals was tested using the procedure outlined (Gyamfi et al. 1999). In a nutshell, the sample extract was combined with an aliquot of 1 mL of 0.4 mM DPPH (1,1-diphenyl-2-picryhydrazyl) methanolic solution, and the mixture was then incubated for 30 min in the dark. In a UV–visible spectrophotometer, the absorbance of the clear mixture was measured at 516 nm (UV–Visible 1800; Shimadzu, Japan). The sample's DPPH free-radical scavenging activity was then calculated thus:

$$\%\text{DPPH scavenged} = \frac{Abs_{control} - Abs_{test}}{Abs_{control}} x100$$

α-amylase inhibitory activities

The aqueous extracts of the meal (500 µL) and equal volume of 0.02 M sodium phosphate buffer (pH 6.9 with 0.006 mol L NaCl) containing hog pancreatic α-amylase (EC 3.2.1.1; 0.5 mg/mL) were incubated at 25 °C for 10 min. Afterward, 500 µL of buffered 1% starch solution was added and the incubation was repeated (25 °C, 10 min). On addition of 1.0 mL dinitrosalicylic acid (DNSA), the reaction was discontinued and incubated at 100 oC for 5 min, cooled and diluted with distilled water (10 mL). The absorbance of the mixture was taken at 540 nm (UV–visible spectrophotometer, Shimadzu 1800, Japan). The sample's α-amylase inhibitory capacity was calculated according to Apostolidis et al. (2007) thus:

$$\%\alpha - \text{amylase inhibition} = \frac{Abs_{control} - Abs_{test}}{Abs_{control}} x100$$

α-glucosidase inhibitory activities

A 100 µL solution of α-glucosidase (EC.3.2.1.20) was added to 50 µL aqueous extract of the meal. After incubation for 10 min at 25 °C, 50 µL of a 5 mM *p*-nitrophenyl-α-D-glucopyranoside solution in 0.1 M phosphate buffer (pH 6.9) was added. The reaction mixture was further incubated for 5 min at 25 °C, and the absorbance was measured at 405 nm (UV–visible spectrophotometer, Shimadzu 1800, Japan). The sample's α-glucosidase inhibitory property was calculated (Oluwajuyitan et al. 2021) as shown below:

$$\%\alpha - \text{glucosidase inhibition} = \frac{Abs_{control} - Abs_{test}}{Abs_{control}} x100$$

Water and oil absorption capacities

Water and oil absorption capacities (WAC and OAC) of the formulated meals were determined (Omowaye-Taiwo et al. 2015). For WAC, about 1 g of the flour sample was suspended in 10 mL in a 15 mL centrifuge tube, mixed for 1 min at room temperature. The mixture was centrifuged after 30 min, at 1200 × g for 30 min. The volume of free water was read directly from the graduated tube and WAC was calculated thus:

$$WAC\% = \frac{Amount\ of\ water\ added\ -\ free\ water\ (ml)}{Weight\ of\ sample\ (g)}\ x\ density\ of\ water\ x\ 100$$

The experiment was repeated using corn oil instead of water, for OAC.

$$OAC\% = \frac{Amount\ of\ oil\ added\ -\ free\ oil\ (ml)}{Weight\ of\ sample\ (g)}\ x\ density\ of\ water\ x\ 100$$

Foaming capacity and stability

Foaming capacity (FC) and foaming stability (FS) were carried out according to methods of Sze-Tao and Sathe

(2000). The flour blend (2 g) was dispersed in 50 mL of distilled water in a 100 mL graduated cylinder the suspension was vigorously mixed to foam, and the volume was taken after 30 s. The percentage increase in volume after 30 s is expressed as foaming capacity.

$$Foaming\ capacity = \frac{Volumeafterwhipping - Volumebeforewhipping}{Volumebeforewhipping} x100$$

The cylinder was allowed to stand for 1 h and percentage change in foam volume is recorded as foaming stability.

$$Foaming\ stability = \frac{Volume\ of\ foam\ after\ set\ time}{Initial\ volume\ of\ foam} x100$$

Emulsion capacity

Emulsion capacity (EMC) of the flours were determined as reported (Fagbemi 1999). Briefly, 2 g of flour was dispersed in 40 mL of distilled water and mixed properly. Over a period of 5 min of continuous stirring, 10 mL of vegetable oil was added. The emulsion was transferred to a graduated centrifuge tube, boiled for 15 min at 85 °C and centrifuged until the oil volume separated remained constant. EMC was expressed as the percentage of oil emulsified per gram of the flour used thus:

$$Emulsion\ capacity = \frac{Volume\ of\ oil\ used\ (mL)\ -\ volume\ of\ oil\ separated\ (mL)}{Volume\ of\ oil\ used\ (mL)} x\ 100$$

Bulk density measurement

The bulk density of the meals were measured as described (Ferrari et al. 2013). Briefly, 5 g of the flour was placed in a 10 mL graduated cylinder and the cylinder was tapped several times until a constant volume was achieved and bulk density was calculated thus:

$$Bulk\ density\ (g/ml) = \frac{Weight\ of\ sample\ (g)}{Volume\ of\ sample\ after\ tapping\ (ml)}$$

Sensory and consumer acceptability assessment

A panel of 30 students and professionals from the Department of Food Science and Technology at the Federal University of Technology Akure, ranging in age from 18 to 49, taste-tested the breakfast meals produced from each flour mixture. The sampling and analysis of the samples were done as described by Markusse et al. (2018). Evaluations were conducted in a sensory analysis room with white light at ambient temperature. Between each sample, panelists were told to rinse their mouths with water. On a hedonic scale ranging from 1 (extreme dislike) to 9 (like extremely), the assessors were asked to rate how much they appreciated the taste, color, texture, and general acceptability of the reconstituted quinoa-tigernuts breakfast meal in comparison to a common commercial sample (Golden Morn).

Statistical analyses

Each analysis was performed in triplicate, except otherwise stated. Analysis of Variance (ANOVA) was used with Minitab 19.0 Minitab, Inc., State College, USA) to investigate the statistical variations between the formulated and commercial breakfast meals with respect to their nutritional profiles, functional properties, and organoleptic quality assessment. All figures were prepared using GraphPad (GraphPad Prism 8.01, San Diego, USA).

Results and discussion

Nutritional profile of stevia sweetened quinoa-tigernuts breakfast meal

Proximate compositions and mineral profiles of the meals formulated from the blends of autoclaved quinoa and tigernuts were statistically compared in dry weight basis (dwb) with that of a commercial breakfast cereal and the results are shown in Table 1. From the results, there was a significant variation in protein content between different formulations based on the proportion of quinoa to tigernuts, thus indicating the contribution of quinoa to the high protein content of the meal. Previous reports indicates that quinoa has no limiting amino acids in its protein, compared to common cereals (Culetu et al. 2021). Relative to commercial samples, all the formulations exhibited higher contents of protein with a range of 13.42 – 15.54 g/100 g. In other words, a 100 g serving of this meal is expected to take care of 50% and 27% daily dietary protein recommendations for children and adults, respectively (Hudson et al. 2021). While, tigernuts did not significantly influence the protein content of the blends, the values reported were within the range in literature (Thakur et al. 2021). However, the blends were considerably high in fats with the least (16.90 g/100 g) almost three times higher than the commercial samples (6.60 g/100 g). The contribution of tigernuts to the fat contents of the blends was apparent as the amount

Table 1 Nutritional profile of stevia sweetened quinoa-tigernuts breakfast meal

Parameters	Q65_T35	Q60_T40	Q55_T45	Q50_T50	Q45_T55	COM_GDM	
Proximate compositions (g/100 g)							
Protein	15.54 ± 0.53^{a}	14.90 ± 0.19^{ab}	14.48 ± 0.37^{b}	14.01 ± 0.09^{bc}	13.42 ± 0.30^{c}	12.35 ± 0.80^{d}	
Fats and oils	16.90 ± 0.17^{e}	18.63 ± 0.28^{d}	19.81 ± 0.20^{c}	21.44 ± 0.61^{b}	23.02 ± 0.37^{a}	6.60 ± 0.36^{f}	
Carbohydrate	47.18 ± 0.85^{b}	46.46 ± 0.45^{bc}	45.91 ± 0.40^{bc}	45.01 ± 0.64^{cd}	44.32 ± 0.32^{d}	67.19 ± 0.08^{a}	
Crude fibre	17.61 ± 0.18^{a}	17.32 ± 0.03^{b}	17.21 ± 0.02^{bc}	17.04 ± 0.03^{cd}	16.85 ± 0.09^{d}	7.20 ± 0.36^{e}	
Insoluble dietary fibre	8.61 ± 0.53^{d}	9.85 ± 0.39^{c}	10.83 ± 0.18^{b}	11.08 ± 0.20^{b}	12.35 ± 0.34^{a}	1.20 ± 0.00^{e}	
Soluble dietary fibre	3.72 ± 0.31^{b}	3.25 ± 0.07^{bc}	2.41 ± 0.38^{c}	3.01 ± 0.63^{bc}	4.03 ± 0.37^{b}	6.04 ± 0.11^{a}	
Starch	49.48 ± 0.78^{a}	48.41 ± 0.55^{a}	46.83 ± 0.24^{b}	45.44 ± 0.43^{c}	44.07 ± 0.37^{d}	39.11 ± 3.17^{e}	
Digestible starch	32.85 ± 1.44^{a}	32.64 ± 0.36^{a}	31.91 ± 0.13^{a}	33.72 ± 0.91^{a}	32.86 ± 0.89^{a}	36.07 ± 1.66^{e}	
Sugar	12.12 ± 0.05^{e}	12.82 ± 0.18^{d}	13.12 ± 0.07^{d}	13.88 ± 0.16^{c}	14.47 ± 0.18^{b}	22.68 ± 0.24^{a}	
Ash content	2.39 ± 0.03^{e}	2.49 ± 0.05^{de}	2.58 ± 0.12^{cd}	2.68 ± 0.02^{bc}	2.77 ± 0.03^{b}	5.68 ± 0.22^{a}	
Mineral compositions (mg/100 g)							
Calcium (Ca)	266.61 ± 1.64^{b}	263.38 ± 0.59^{c}	260.06 ± 1.38^{d}	259.63 ± 0.59^{d}	257.45 ± 0.89^{d}	455.0 ± 1.00^{a}	
Iron (Fe)	3.82 ± 0.12^{b}	3.83 ± 0.04^{b}	3.78 ± 0.03^{b}	3.55 ± 0.08^{c}	3.53 ± 0.11^{c}	9.08 ± 0.06^{a}	
Magnesium (Mg)	176.29 ± 5.95^{a}	164.78 ± 5.95^{ab}	160.35 ± 3.02^{bc}	155.10 ± 4.82^{bc}	152.34 ± 5.37^{c}	96.75 ± 5.00^{d}	
Sodium (Na)	11.25 ± 0.81^{e}	11.34 ± 0.48^{de}	12.85 ± 0.16^{cd}	13.66 ± 0.71^{bc}	14.52 ± 0.57^{b}	29.86 ± 3.65^{a}	
Potassium (K)	592.47 ± 9.00^{b}	562.5 ± 11.33^{bc}	551.68 ± 9.95^{c}	511.93 ± 14.17^{d}	481.81 ± 11.85^{d}		688.25 ± 6.94^{a}
Phosphorus (P)	257.20 ± 15.35^{a}	251.39 ± 8.34^{ab}	245.59 ± 5.46^{abc}	231.75 ± 7.91^{bc}	223.74 ± 4.71^{c}	132.11 ± 10.32^{d}	

(Q65_T35: 65% quinoa and 35% tigernuts, Q60_T40: 60% quinoa and 40% tigernuts, Q55_T45: 55% quinoa and 45% tigernuts, Q50_T50: 50% quinoa and 50% tigernuts, Q45_T55: 45% quinoa and 55% tigernuts) and commercial breakfast cereal (COM_GDM)

[a] [–e]Means that do not share a letter (superscript) across the row, are significantly different

increased with the proportion of tigernuts. Previous studies revealed the bioactive quality of fats composed in tigernuts which are mainly essential mono- (oleic; 71.36 – 73.58%) and -polyunsaturated (linoleic; 10.24 – 11.75%) and their nutritional importance (Özcan et al. 2021). Cookies formulated from a 50/50 wheat/tigernuts blends exhibited > 80% unsaturated fatty acids (oleic and linoleic acids) (Babiker et al. 2021). Hence, this product is suitable for most people regardless of their dietary lipid restrictions. Comparatively, the carbohydrate content of the commercial sample (due to the two major ingredients: maize and soybean) was higher than the blends. Most insoluble fractions of tigernuts are composed of fibre > 35% (Culetu et al. 2021). Therefore, as the content of tigernuts in the blends increases, the dietary fibre and its insoluble fraction increase (Table 1 and Fig. 1a). Studies have demonstrated a wide range of health benefits of a regular consumption of insoluble dietary fibre; (Ijarotimi et al. 2021; Shah et al. 2020). It is noteworthy to state that, most of these health significance of dietary fibre have been attributed to the consumption of quinoa as a functional diet (Noratto et al. 2019). The meals were low in starch contents, and most importantly, almost 35% of this starch were resistant starch (non-digestible), further supporting the acclaimed health benefits of quinoa and tigernuts (Fig. 1b). Starch has been classified into three fractions—rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS). The degree of starch hydrolysis has been correlated with the glycemic index (GI) of dietary products (Kaur et al. 2018). Thus, the formulated meals are expected to generate the least postprandial glucose when consumed, making them suitable for people with type-2 diabetes. Both digestible starch fraction and sugar contents of the commercial product were significantly higher than the formulated meals making them less healthy.

Tigernuts is naturally sweet and account for the gradual increase in sugar content as its proportion in the blend increases. Ash content of the commercial product (5.68 g/100 g) was statistically higher than those of the samples (2.39 – 2.77 g/100 g), a discrepancy that could be attributed to the botanical variations in the composite ingredients. The formulated meals were rich in essential minerals; composed primarily potassium (481.81 – 592.47 mg/100 g), phosphorus (231.75 – 257.20 mg/100 g), magnesium (152.34 – 176.29 mg/100 g), and calcium (257.45 – 266.61 mg/100 g). These minerals are crucial for a variety of metabolic processes in the human body, and deficiencies in one or more of them can cause metabolic problems (Ayele et al. 2017). Although, the potassium (688.25 mg/100 g), sodium (29.86 mg/100 g), iron (9.08 mg/100 g), and calcium (455.0 mg/100 g) levels in the commercial sample were noticeably greater, the Ca/P

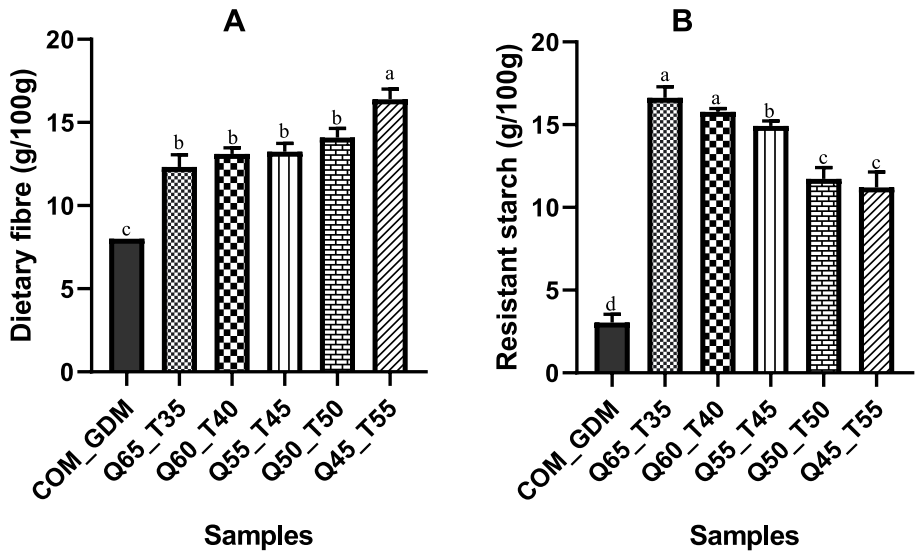


Fig. 1 Dietary fibre (**A**) and resistant starch (**B**) contents of stevia-sweetened breakfast meal formulated from the blends of quinoa-tigernuts. Bars with the same superscript are not significantly different ($P > 0.05$). Q65_T35: 65% quinoa and 35% tigernuts, Q60_T40: 60% quinoa and 40% tigernuts, Q55_T45: 55% quinoa and 45% tigernuts, Q50_T50: 50% quinoa and 50% tigernuts, Q45_T55: 45% quinoa and 55% tigernuts and COM_GDM: commercial breakfast cereal meal

ratio of the meals adequately satisfies recommended ratio 1–2:1 for bone health (Loughrill et al. 2017), especially in the samples containing larger proportion of quinoa. Similarly, the Na/K molar ratio observed in the samples (0.02—0.03) is beneficial because a value of 1.0 has been advised for people with high blood pressure (Palmer & Clegg 2020).

Phenolic compounds and antioxidant activities of stevia-sweetened quinoa-tigernuts breakfast meal

Whole grains such as whole oats, whole wheat, bulgur wheat, buckwheat, quinoa, rye, millet, sorghums etc., naturally house an array of essential phytochemicals many with well-proven health benefits (Omoba & Dada 2015). However, the majority of ready-to eat breakfast foods are from refined cereals that have been over-milled. Hence, they are not particularly known for high bioactive compounds. As shown in Fig. 2, quinoa-tigernuts formulated meals were significantly higher than the commercial product in terms of total phenol and flavonoid contents. It is noteworthy to state that, the complimentary influence of stevia on the exhibited high contents polyphenols in the samples may not be minor. Similarly, a controlled thermal processing such as autoclaving has been proven to have a positive influence on phenolic compounds in quinoa (Sharma et al. 2022). The values of these parameters gradually increased with the amount of quinoa, supporting the widely acknowledged better nutritional benefits of whole grains over those that have undergone industrial processing (Călinoiu & Vodnar 2018). However, when routinely ingested, the levels of these nutrients (Total phenols: 6.45 – 8.59 mgGAE/g; Flavonoids: 64.92 – 115.6 mgQE/g) acquired from these meals are significantly high enough to positively impact some bioactive activities.

Similar to total phenol and flavonoid contents of the formulated meal, the antioxidant activities followed the same trend (Fig. 3). The synergy between quinoa, tigernuts and stevia culminated in a product with remarkable antioxidant capacities on ferric reducing antioxidant potential (FRAP), 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) and, 2,2-diphenyl-1-picrylhydrazyl (DPPH) assays compared to the commercial product. As expected, the high contents of total phenol and flavonoid; both with verifiable antioxidative strengths (Adnan et al. 2020), has a bearing on these observations. Specifically, the significance of ferric reducing potential of these products indicates ability of the sample to reduce Fe^{3+} to Fe^{2+}, with FRAP values ranging from 2.65 to 5.81μmolFe^{2+}E/g). FRAP had a strong correlation with total phenol and flavonoid contents at 0.97 and 0.93, respectively (results not shown); thus, reasserting phenolic compounds as the main components responsible for the antioxidant activities in these meals. A similar observation was reported on the phenolic and antioxidant characterization of 18 gluten-free flours, including quinoa (Rocchetti et al. 2018). In the same vein, the meals had comparable antioxidant capabilities on DPPH and ABTS, both of which had strong coefficients of correlation with total phenol and flavonoid contents (DPPH versus TPC: 0.8837; TFC: 0.91 and ABTS vs TPC: 0.97;

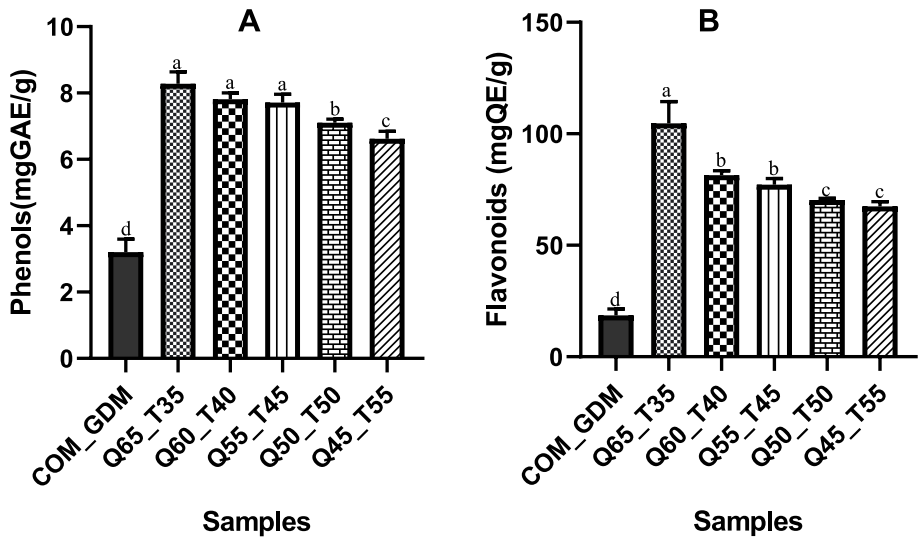


Fig. 2 Total phenol (**A**) and flavonoids (**B**) contents of stevia-sweetened breakfast meal formulated from the blends of quinoa-tigernuts. Bars with the same superscript are not significantly different ($P > 0.05$). Q65_T35: 65% quinoa and 35% tigernuts, Q60_T40: 60% quinoa and 40% tigernuts, Q55_T45: 55% quinoa and 45% tigernuts, Q50_T50: 50% quinoa and 50% tigernuts, Q45_T55: 45% quinoa and 55% tigernuts and COM_GDM: commercial breakfast cereal meal

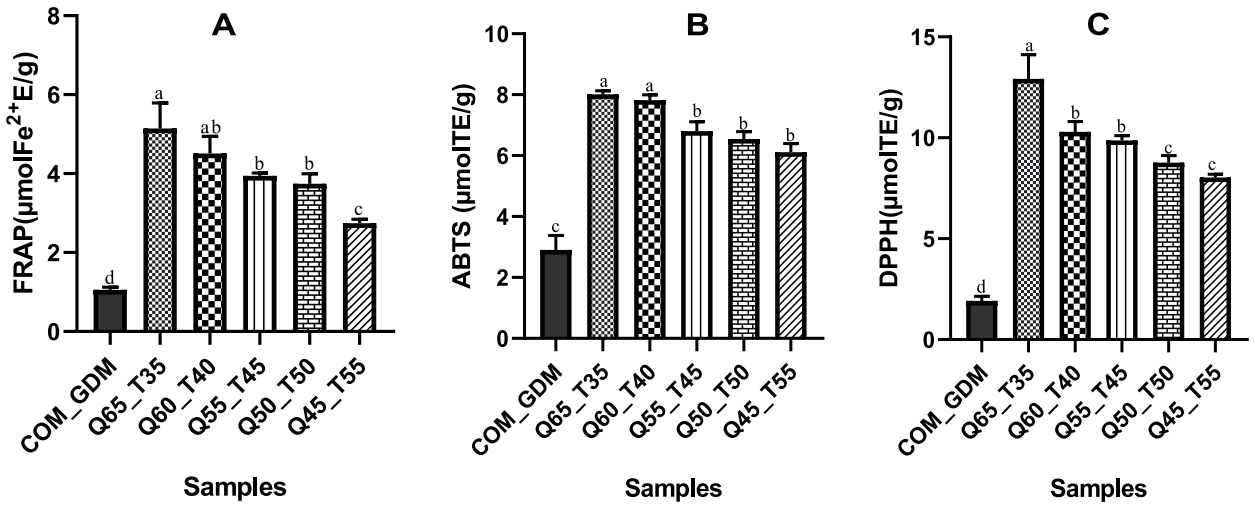


Fig. 3 FRAP (**A**), ABTS (**B**) and DPPH (**C**) antioxidant activities of stevia-sweetened breakfast meal formulated from the blends of quinoa-tigernuts. Bars with the same superscript are not significantly different ($P > 0.05$). Q65_T35: 65% quinoa and 35% tigernuts, Q60_T40: 60% quinoa and 40% tigernuts, Q55_T45: 55% quinoa and 45% tigernuts, Q50_T50: 50% quinoa and 50% tigernuts, Q45_T55: 45% quinoa and 55% tigernuts and COM_GDM: commercial breakfast cereal meal

TFC: 0.95). The protective effects of dietary antioxidants in preventing a number of degenerative and non-communicable diseases are supported by epidemiological research (van der Schaft & Voortman 2020). Other novel functional foods and beverages involving inclusion of whole or proportionate amount of tigernuts and quinoa were found to possess exceptional antioxidant properties (Badejo e al. 2020a; Badejo et al. 2020b; Păucean et al. 2015).

Carbohydrate-hydrolyzing enzymes (α-amylase and α-glucosidase) inhibitory properties of stevia sweetened quinoa-tigernuts breakfast meal

Inhibiting the enzymes responsible for breaking down starch (α-amylase) and absorbing glucose (α-glucosidase) has been proposed as a beneficial strategy for treating and preventing Type-2 diabetes (Coronado-Olano et al. 2021). Hence, as shown

in Fig. 4, the formulated meals inhibit both carbohydrate-hydrolyzing enzymes remarkably higher than the commercial product. Irrespective of the percentage of either quinoa or tigernuts, all the blends had satisfactory inhibitory performances (α-amylase 26.98 – 60.18%; α-glucosidase 19.47 – 40.02%) that can rival that of synthetic drugs such as acarbose (α-amylase 15.68 ± 2.41%; α-glucosidase 44.54 ± 3.89%) (Vadivel et al. 2011) with additional benefits of being 100% organic and cheaper. The action of the meals on postprandial glucose-release can be easily deduced from this enzyme-inhibition. Depending on preparation and other secondary adjuncts, these products could be a fascinating infant meal as well. A clinical trial by Noratto et al. (2019) discovered that consumption of quinoa for 15 days (pre-cooked, drum dried, and prepared as porridge or fruit shake, two doses of 100 g/day) by undernourished children, improved plasma insulin-like growth factor. However, the capacity of the meal to inhibit carbohydrate-hydrolyzing enzymes may be due to the interactions of dietary fiber, resistant starch, polyphenols, and other vital bioactive compounds embedded in quinoa, tigernuts and stevia.

Functional and sensory properties of stevia sweetened quinoa-tigernuts breakfast meal

The results of the functional and sensory properties are presented in Table 2. All the six functional properties i.e., emulsion capacity (EMC), foaming capacity (FOC) and stability (FOS) oil (OAC) and water absorption capacity (WAC) indexes and bulk density (BKD) were statistically different among the samples ($p < 0.05$). The proportion of tigernuts in the blends significantly influenced its EMC, which may be due to the high lipid composition of tigernuts. Similarly, high EMC has been associated with more exposed hydrophobic amino acid at the lipid-water interface (Chen et al. 2019). However, low value of EMC (25.96 ± 0.98 ml/g) was observed in commercial samples. FOC and FOS experienced opposing trends among the samples. FOC increases with the percentage of tigernuts. While authors have reported the dependency of FOC on the concentration of protein (Ayo-Omogie et al. 2021), the nature of the protein and other component within the food matrix could contribute to the foaming capacity. On the other hands, FOS increases with the percentage of quinoa. Partial denaturation of protein during hydrothermal pre-processing of quinoa could have reduced foaming properties of the meal (Okafor & Usman 2014). Oil absorption, also known as oil absorption capacity (OAC), is the binding of fat by the non-polar side chain of proteins. The physical trapping of oils is primarily responsible for oil absorption capacity, and it serves as a gauge of how quickly proteins bind to fat in food formulations. However, this property increased (from 158.67 to 176.67%) with the carbohydrate and protein contents of the meals—which could be an indication of a more hydrophobic side chains within the food matrix (Twinomuhwezi et al. 2020). The physical state of starch,

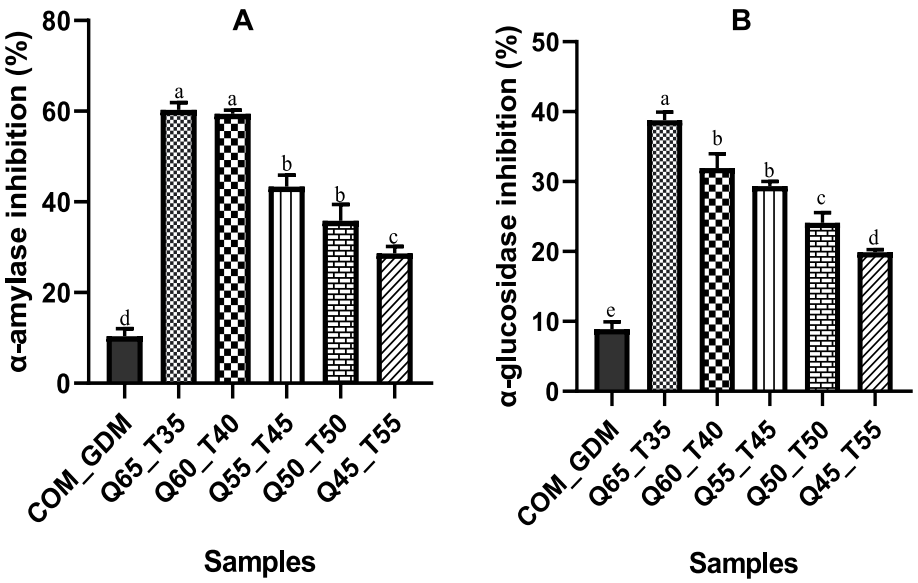


Fig. 4 α-amylase, (**A**) and α-glucosidase (**B**) inhibitory capacities of stevia-sweetened breakfast meal formulated from the blends of quinoa-tigernuts (Q65_T35: 65% quinoa and 35% tigernuts. Bars with the same superscript are not significantly different ($P > 0.05$). Q65_T35: 65% quinoa and 35% tigernuts, Q60_T40: 60% quinoa and 40% tigernuts, Q55_T45: 55% quinoa and 45% tigernuts, Q50_T50: 50% quinoa and 50% tigernuts, Q45_T55: 45% quinoa and 55% tigernuts and COM_GDM: commercial breakfast cereal meal

Table 2 Functional and organoleptic properties of stevia sweetened quinoa-tigernuts breakfast meal

Parameters	Q65_T35	Q60_T40	Q55_T45	Q50_T50	Q45_T55	COM_GDM
Functional Properties						
Emulsion capacity (mL/g)	27.43 ± 2.29^{c}	32.64 ± 2.29^{c}	40.48 ± 2.05^{b}	42.19 ± 1.76^{ab}	46.67 ± 1.32^{a}	25.96 ± 0.98^{c}
Foaming capacity (%)	7.75 ± 0.12^{d}	8.35 ± 0.25^{cd}	9.23 ± 0.27^{bc}	9.95 ± 0.17^{b}	11.64 ± 0.61^{a}	4.98 ± 0.05^{e}
Foaming stability (%)	3.49 ± 0.51^{a}	2.95 ± 0.31^{a}	2.63 ± 0.45^{ab}	1.76 ± 0.20^{bc}	1.27 ± 0.10^{c}	1.24 ± 0.02^{c}
Oil absorption capacity (%)	176.67 ± 3.06^{b}	172.67 ± 3.06^{b}	164.00 ± 4.00^{c}	163.67 ± 1.53^{c}	158.67 ± 2.52^{c}	188.65 ± 1.65^{a}
Water absorption capacity (%)	259.67 ± 4.51^{a}	234.67 ± 6.56^{b}	194.33 ± 5.33^{c}	195.67 ± 5.03^{c}	179.33 ± 6.11^{d}	184.65 ± 3.33^{d}
Bulk density (g/mL)	0.75 ± 0.01^{c}	0.80 ± 0.01^{b}	0.81 ± 0.02^{b}	0.81 ± 0.02^{b}	0.86 ± 0.02^{a}	0.53 ± 0.04^{d}
Sensorial assessments						
Color/Appearance	7.34 ± 0.82^{a}	7.28 ± 0.55^{a}	6.96 ± 1.02^{a}	7.39 ± 0.42^{a}	6.79 ± 0.94^{a}	7.45 ± 0.08^{a}
Taste	6.82 ± 0.88^{a}	7.44 ± 0.92^{a}	6.58 ± 1.44^{a}	7.23 ± 0.68^{a}	6.48 ± 1.04^{a}	7.38 ± 0.07^{a}
Texture/mouthfeel	6.94 ± 0.22^{ab}	7.55 ± 0.04^{a}	7.26 ± 0.32^{a}	7.68 ± 0.78^{a}	6.92 ± 0.06^{b}	7.11 ± 0.33^{a}
Flavor	7.88 ± 0.35^{a}	7.47 ± 0.18^{b}	6.75 ± 0.55^{c}	7.94 ± 0.02^{a}	7.06 ± 0.68^{bc}	7.63 ± 0.08^{b}
Acceptability	6.81 ± 0.67^{a}	7.39 ± 0.99^{a}	7.05 ± 0.66^{a}	6.84 ± 1.09^{a}	7.11 ± 0.61^{a}	7.52 ± 0.55^{a}

(Q65_T35: 65% quinoa and 35% tigernuts, Q60_T40: 60% quinoa and 40% tigernuts, Q55_T45: 55% quinoa and 45% tigernuts, Q50_T50: 50% quinoa and 50% tigernuts, Q45_T55: 45% quinoa and 55% tigernuts) and commercial breakfast cereal (COM_GDM)

[a] $^{-e}$Means that do not share a letter (superscript) across the row, are significantly different

dietary fiber, and protein in the meal may be related to rehydration properties such as WAC which represents a product's capacity to associate with water in situations where water is limited. Hence, low WAC (179.33 – 259.67%) of these meals as compared to those from pure cereals and legumes flours (Akinola et al. 2017; Simwaka et al. 2017) is a justifiable property as it is beneficial for making thinner gruels that could increase nutrients according to previous report (Ijarotimi et al. 2019). BKD is one of the key indicators of particle size, moisture content and structural changes in dry materials, and it's calculated as the weight of a particle per unit volume. BKD slightly increased with the inclusion of more tigernuts which may be due to density and particle size differentials. The variations in BKD of the blends were comparable to those observed from the blends of maize, defatted coconut and African yam (Okafor & Usman 2014) and mixture of popped gorgon nut flour and wheat flour (Kumar & Saini 2016). Sensory analysis scores of stevia-sweetened quinoa-tigernuts based breakfast gruel in comparison with the commercial product. According to the sensory analysis findings, there were no significant differences between the samples with respect to most of the sensory parameters. Color/appearance of the formulated meals were ranked equal to the commercial product and none of the sample scored below 6.70. An indication of how well the visual assessment of the product was preferred by the observers. Similarly, despite the commercial sample being sweetened with table sugar, the taste was not statistically ranked above experimental samples that were sweetened with stevia. The link between consumption of refined sugar and certain metabolic-related types of type-2 diabetes, hypertension, and cardiovascular diseases is well established (Hagger et al. 2017). Hence, the formulated products satisfy both the taste and physiological needs of potential consumers. Panelists ranked experimental samples containing tigernuts 40 – 50% tigernuts slightly higher in terms of mouthfeel/texture, which may be due to the creaming feel of tigernuts. Similar to flavor, a balance between quinoa and tigernuts produced a breakfast meal with delightful flavor, and this is consistent with the observation of (Badejo et al. (2020b) where higher percentage inclusion of tigernuts resulted in baobab-tigernuts beverage of better taste and flavor. Similarly, the panelists showed the same degree of overall acceptability of the formulated meals as the commercial sample.

Conclusion

This study developed stevia-sweetened functional breakfast meals formulated from the blends of pre-gelatinized quinoa and tigernuts and evaluated the nutritional, functional and organoleptic profiles in comparison with a commercial product. The formulated meals exhibited superior macro- and micronutrients profiles relative to the commercial product. Specifically, protein contents of the meals were significantly higher than the control and increase with the proportion of quinoa and similar trends were observed in other essential nutrient such as insoluble dietary fiber and resistant starch. Even though the quantities of potassium, iron, and calcium in the commercial sample were substantially higher, the Ca/P and Na/K molar ratio of the meals adequately satisfies the recommended ranges for bone health and osmotic

balance, respectively particularly in the samples containing a higher proportion of quinoa. In the same vein, the polyphenol contents (TPC and TFC) and their antioxidant capacities significantly favored the formulated meals. These essential nutritional properties may have further contributed to the ability of the samples to inhibit carbohydrate-hydrolyzing enzymes (α-amylase and α-glucosidase) thus making them suitable as functional foods for diabetic people in addition to being gluten-free. Also, the meals were not in any way less preferred in terms of functional and sensory properties when compared to the commercial product. Its substantial bioactive compounds such as dietary fibre, polyphenols, resistant starch etc., make them suitable for those with compromised health.

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Authors' contributions
OSJ: conceptualized the study, designed experiments, supervised data collection and the study; TOA: analyzed data, prepared the draft manuscript; OSJ: read and edited the manuscript. All authors read and approved the manuscript.

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Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The sensory evaluation of the products was conducted following the guidelines expressed in Institute of Food Science and Technology (IFST) ethical and professional practices for sensory analysis of foods (IFST 2020). The procedure was approved by the Ethical Committee School of Agriculture and Agricultural Technology, Federal University of Technology, Akure, Nigeria (FUTA/SAAT/2022/032). The member of the sensory panel who took part in the sensory evaluation verbally agreed to participate.

Consent for publication
Not applicable.

Competing interests
Not applicable.

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