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Physicochemical, in vitro starch digestibility and sensory characteristics of biofortified yellow maize-cowpea composite flours and biscuits

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Abstract

The consumption of whole grain cereals, pulses and their products, such as biscuits, is associated with protection against nutrition-related non-communicable diseases. Hence, the aim of this study was to evaluate the physicochemical qualities and in vitro starch digestibility of flours and biscuits formulated with biofortified yellow maize (M-f) and cowpea (C-f) composites, as well as the biscuits' sensory attributes. Biscuits, coded M-b, MC-b1, MC-b2, MC-b3, and C-b, were baked from composite flours of M-f and C-f (M-f:C-f, w/w) at the proportions of 100:0, 75:25, 50:50, 25:75, and 0:100, respectively. Refined wheat flour (W-f) and its biscuit (W-b) served as controls. Individually, the final viscosities of M-f (157.36 RVU) and W-f (159.12 RVU) were comparable ($p > 0.05$); but both were significantly higher ($p < 0.05$) than that of C-f (93.15 RVU). Among the composite flours, MC-f2 and MC-f3 had the highest final (175.43 RVU) and peak (65.52 RVU) viscosities, respectively. The total carbohydrate, crude fat, and energy value increased significantly ($p < 0.05$) with increasing proportion of M-f in the composite flours and biscuits, while the crude protein and ash contents increased with an increasing proportion of C-f. The ranges of total carbohydrate, crude fat, and food energy in the biscuits were 51.03 (C-b) - 68.27% (W-b), 12.15 (W-b) - 19.02% (M-b), and 414.33 (C-b) - 455.91 kCal/100 g (M-b), respectively. The concentrations of starch, amylose, amylose/amylopectin ratio, starch hydrolysis index (HI), as well as estimated glycaemic index (eGI) of the composite flours and biscuits decreased significantly with an increasing proportion of C-f. Thus, the ranges of starch and eGI in the biscuits were 41.02 (C-b) - 68.01% (W-b) and 34.99 (C-b) - 57.19% (W-b), respectively. Crude protein ($r = -0.715, -0.696$), starch ($r = 0.966, 0.954$), amylose ($r = 0.947, 0.931$), and amylopectin ($r = -0.947, -0.931$) significantly correlated with eGI and HI, respectively. The sensory acceptability of the composite biscuits improved as the proportion of C-f increased. Hence, it is concluded that increasing the level of cowpea in biofortified yellow maize-cowpea composite flours and biscuits enhanced their physicochemical and sensory attributes, and reduced their estimated GI.

Keywords Biofortified yellow maize, Composite biscuits, Cowpea, Glycaemic index, Physicochemical qualities, Sensory attributes

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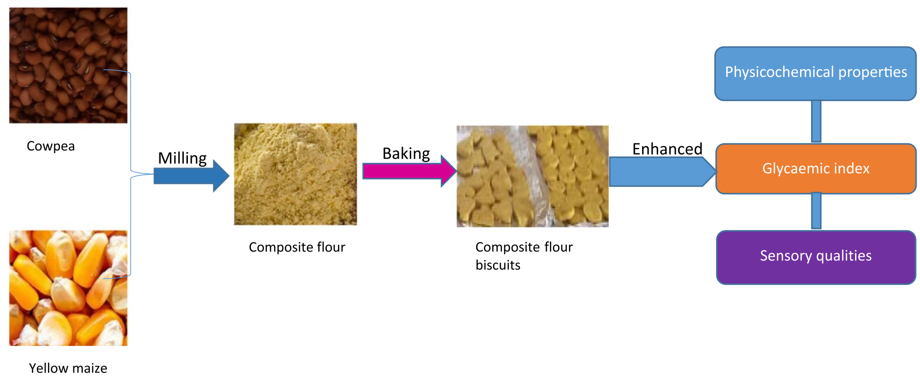
Graphical Abstract



Introduction

There exists a direct nexus between nutrition and some chronic non-communicable diseases, like obesity and type 2 diabetes (T2D). These nutrition-related non-communicable diseases (NR-NCDs), driven by unhealthy food environments, constitute a global health challenge that pose a barrier to socioeconomic growth worldwide (Ribeiro et al. 2019; Laar et al. 2020). Obesity and T2D have taken an epidemic proportion, affecting adults and children in both developing and developed countries (Irondi et al. 2021). Among the modifiable aetiological factors of obesity and T2D, over-nutrition, nutrition transition, as well as decreased physical activity, resulting from lifestyle changes, have been identified to be responsible for their rising prevalence (Shi 2016), with nutrition transition as the major driver (Ford et al. 2017). Nutrition transition explains the departure from traditional diets, comprising whole foods, including whole grains and pulses, with a minimal level of animal-source foods, salt, white flours, sugars and oils (Monteiro 2009), to high-energy but poor-nutrient diets, comprising processed foods, high fat and refined carbohydrates (Ford et al. 2017). One of the dangers associated with nutrition transition is that the enhanced sensory qualities of the over-processed foods can attenuate the homeostatic eating signals of a person; thereby promoting over-eating. For example, increased level of salt can override the satiety cues mediated by fat, and consequently, encourage over-eating (Bolhuis et al. 2016).

To sustainably mitigate the challenge of NR-NCDs generally, and actualize the World Health Organisation's (WHO) goal of checkmating the global increase in obesity and T2D prevalence by 2025 (WHO 2014) in particular, the food industry has a major role to play (Laar et al. 2020). There is also the need to shift from the consumption of "junk" (unhealthy foods) to healthy alternatives, especially plant-based foods (Develaraja et al. 2016). Recently, this approach has resulted in formulating low-fat/low-calorie and high-fiber foods, including biscuits, to address the public health concerns related to the intake of high-energy foods. In this respect, biscuits made from wholemeal grains have been reported as rich sources of bioactive compounds, and may offer a viable option to curb NR-NCDs (Cukelj et al. 2017; Irondi et al. 2021).

Biscuits, as a ready-to-eat baked food products, are well-liked for their availability and affordability in different sizes and shapes and a high nutritive value. Traditionally, they are designed to contain high sugar and fat using a refined wheat flour, making the calorie-conscious consumers to avoid eating them (Aggarwal et al. 2016). Besides being a high-energy snack, biscuits are known to be deficient in the health-promoting bioactive compounds typical of grains, such as polyphenols and dietary fiber, due to their formulation with refined ingredients (Fardet 2010). To develop functional biscuits for the calorie-conscious, obese and type 2 diabetic individuals, a partial or total replacement refined wheat flour with a wholemeal composite or multigrain flour is a viable option (Aggarwal et al. 2016; Olagunju et al. 2018). For instance, in a recent study, Ngaha et al. (2023) formulated biscuits from the blends of unripe banana, okra, and stevia leaves/jujube fruit. The authors concluded that the formulated biscuits had a low glycaemic index and were suitable as diabetic's biscuits. In another study, Di Cairano et al. (2022) formulated biscuits from the blends of buckwheat, lentil and sorghum flours, with sucrose as sweetener. Their findings indicated that the biscuits had a lower postprandial glycaemic index, relative to commercial biscuits formulations. In a related study, Lu et al. (2022) reported that adding chickpea flour enhanced the in vitro starch digestibility and physicochemical attributes of biscuits. Also, Erukainure et al. (2013) affirmed that the intake of fibre-enriched biscuits led to a decrease in the blood glucose, but increased the serum insulin and high-density-lipoprotein cholesterol levels of diabetic rats. Similarly, the intake of fibre biscuits resulted in a significant decrease in both postprandial and fasting blood glucose concentrations, and improved the lipid profile of streptozotocin-induced diabetic rats (Aggarwal et al. 2017). However, the physicochemical, in vitro starch digestibility and sensory characteristics of biscuits formulated with biofortified yellow maize-cowpea blends have not been reported. Hence, in a continued research effort to formulate value-added wheatless biscuits, this present study explored the blends of biofortified yellow maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L. Walp).

Biofortified yellow maize is a rich dietary source of bioactive constituents, such as carotenoids, phenolic compounds, vitamin C, and anthocyanins. Several health benefits, including antioxidant, anti-diabetic and anti-obesity properties (Irondi et al. 2019; Elemosho et al., 2021), have been ascribed to these bioactive compounds in biofortified yellow maize. Also, cowpea, a heat-tolerant and drought-resistant grain legume, is a rich and an important dietary source of calories, protein, and essential minerals and vitamins for human beings, mostly in the world's semi-arid regions (Sreerama et al. 2012; Awika and Duodu 2017). In addition, cowpea also serves as a rich food source of bioactive compounds, including polyphenolic compounds and peptides (Segura-Campos et al. 2011), with some known health benefits (Irondi et al. 2019). Furthermore, legumes are well-known for their characteristic low glycemic index (GI) that also contributes to their health benefits in obesity and T2D (Oboh and Agu 2010; Singhal et al. 2014). Further, gluten-allergy and the high cost of refined wheat flour, especially in nations that rely on wheat importation for their bakery industries, also necessitate finding suitable alternatives to refined wheat flour in baked food products. For example, in 2021, the cost of wheat rose by 31% due to COVID-19-related high-shipping costs, port disruptions, and increased demand (Dongyu 2022). Therefore, composite flours of wholemeal biofortified yellow maize and cowpea may be a promising option for the development of functional biscuits, with enhanced qualities. In addition, as a cereal and a legume, respectively, biofortified yellow maize and cowpea, complement each other in their nutritional qualities (Sparvoli et al. 2016), and this may improve the nutritional value of their composite biscuits. As reported by some previous studies, the incorporation of protein-rich flours from different sources, such as buckwheat, soya and amaranth grain, could improve the nutritional and functional qualities and lower the glycaemic index of the final product (Filipčev et al. 2011; Yang et al. 2019). Hence, this study set out to evaluate the physicochemical qualities and in vitro starch digestibility of flours and biscuits formulated with biofortified yellow maize and cowpea composites, as well as the biscuits' sensory qualities.

Materials and methods

Raw materials and chemicals

Cowpea (variety, IT10K-837-1) and provitamin A biofortified yellow maize samples (1 kg each) were obtained from the Crop Production Department, Kwara State University, Malete, and the Institute of Agricultural Research and Training, Ibadan, Nigeria, respectively. Each sample was sorted, milled into wholemeal flour, hermetically packed in an opaque sample container, and refrigerated (4 °C) until analyses. The reagents utilized in the analyses were all prepared from analytical grade chemicals and solvents. The chemicals, such as porcine-pancreatic α-amylase, phosphate buffered saline, D-glucose, perchloric acid, sulfuric acid, and phenol, used for the reagents preparation were products of Sigma-Aldrich Co. Ltd. (UK).

Wholemeal composite flours preparation

Wholemeal composites of biofortified yellow maize and cowpea flours, coded M-f, MC-f1, MC-f2, MC-f3, and C-f, were prepared by mixing the native biofortified yellow maize and cowpea flours at the ratios of 100:0; 75:25; 50:50; 25:75; 0:100 (% w/w), respectively. Refined flour of wheat (W-f) served as a control.

Table 1 Flour composition of maize-cowpea composite biscuits

Biscuit	Flour
M-b	100% biofortified yellow maize flour
MC-b1	75% biofortified yellow maize flour mixed with 25% cowpea flour
MC-b2	50% biofortified yellow maize flour mixed with 50% cowpea flour
MC-b3	25% biofortified yellow maize flour mixed with 75% cowpea flour
C-b	100% cowpea flour
W-b	100% refined wheat flour

Biscuits acronyms are as defined in the "Biscuit-baking process" section

Biscuit-baking process

The biscuit dough formulation and baking process were as reported by Saha et al. (2011), with a little modification. Composite biscuits (sugar-free) were formulated from the wholemeal flours described above (M-f, MC-f1, MC-f2, MC-f3, C-f) and designated M-b, MC-b1, MC-b2, MC-b3 and C-b, respectively, in line with our recent report (Irondi et al. 2021). The control biscuit (W-b) was baked with refined wheat flour (W). The flour compositions of the biscuits are presented in Table 1. The dough of each biscuit was prepared as per this formula: 100 g of flour, 30 g of shortening, 0.6 g of sodium chloride, 0.3 g of sodium bicarbonate, 0.6 g of ammonium bicarbonate, 20 g of water. A homogeneous mixture of the flour and shortening was prepared using a kitchen mixer for 5 min. Afterward, dough water in which sodium bicarbonate, sodium chloride, ammonium bicarbonate, as well as powdered milk (quantities are as stated in the formula) have been dissolved, was homogeneously mixed with the already prepared mixture of flour and shortening, to produce a uniform dough. Next, a rolling pin was used to knead the dough to achieve a uniform thickness. The biscuits' dough were subsequently cut into regular shapes (diameter: 43 mm) with the aid of a cutter, placed on a baking tray covered with the foil of aluminum, and baked for 10 min at 210 °C in a baking oven. Thereafter, the resulting biscuits (Fig. 1) were offloaded from the oven, cooled for 30 min, and stored hermetically in plastic containers at room temperature for further analyses.

Fig. 1 Biscuits: C-b, cowpea biscuit; MC-b3, yellow maize and cowpea composite flour biscuit (25:75 w/w); MC-b2, yellow maize and cowpea composite flour biscuit (50:50 w/w); MC-b1, yellow maize and cowpea composite flour biscuit (75:25 w/w); M-b, yellow maize biscuit; W-b, refined wheat flour biscuit. The pictures of the biscuits were presented in our recent report (Irondi et al. 2021)

Pasting properties analysis of flour samples

A Perten Scientific Rapid Visco Analyzer (RVA) machine (RVA-4, Springfield, IL), attached to a personal computer hosting Thermocline software, was employed to analyze the flours' pasting properties (Elemosho et al. 2020). The pasting properties measured were the peak, trough, breakdown, final and setback viscosities (presented as Rapid Visco Analyzer Units, RVU), the peak time (min), and the pasting temperature (°C). A suspension of the flour sample in a canister, prepared by dispersing 3 g of it in 25 mL of distilled water, was loaded on the RVA machine at a constant rate (160 RPM) of stirring. The programme used for the analysis was as follows: a holding period of 5 min at 25 °C; alternating heating between 25 and 95 °C at the rate of 5 °C/minute; a 5-min holding at 95 °C; followed by a cooling to 25 °C at the rate of 5 °C/minute; and a 5-min holding at 25 °C. The pasting properties of the sample were acquired in the personal computer system through the Thermocline software.

Proximate composition and gross food energy determination

The flour and biscuit samples' proximate (moisture, ash, crude protein, total carbohydrate, and crude fat) compositions (%) were analyzed as per AOAC (2005) method. Moisture level was analyzed by oven-drying 3 g of sample in a clean and pre-weighed moisture can in a Fisher hot-air oven (Fisher Scientific Co., 655F, USA) at 100 – 105 °C for 24 hr. Afterwards, the sample was cooled to ambient temperature in a desiccator; the final weight was recorded, and its moisture level was calculated.

Total nitrogen (N) level was analyzed by micro-Kjeldahl method, using a Tecator digestion system and distillation unit (Kjeltec 2300, Hilleroed, Denmark). For this purpose, 0.5 g of sample in a digestion tube, to which 4 mL each of concentrated H_2SO_4, and H_2O_2, and a Kjeldahl catalyst tablet were added, was digested on a digestion block at 420 °C for 2 hr. After cooling to ambient temperature, the digestate was distilled by adding 40% NaOH solution and heating to liberate ammonium hydroxide. The ammonium hydroxide was trapped as ammonium borate in a 4% boric acid receiver solution (containing 1 mg/mL bromocresol green and 1 mg/mL methyl red in ethanol). Next, the total nitrogen content of sample was determined by titrating with a standardized 0.1 M HCl and the crude protein level was computed as N × 6.25.

The samples' ash content was analyzed by incinerating the samples (2 g) in a clean and pre-weighed porcelain crucible at 600 °C for 6 hr. in a muffle furnace (Fisher Scientific Co., m186A, USA). After cooling the sample to ambient temperature in a desiccator, the final weight was recorded, and its ash content was calculated.

The crude fat level of the samples was analyzed by extracting the fat with normal hexane using a Soxtec extractor (Soxtec HT unit). To accomplish this, 3 g of sample in a dried thimble was plugged with cotton wool. Next, the thimble was loaded in the extraction unit and fat was extracted with 50 mL of hexane contained in a clean, dried and pre-weighed extraction cup. The extraction ran for 15 minutes in a boiling mode and 45 min in a rinsing mode. Thereafter, the hexane was evaporated, and the cup containing the fat was oven-dried at 100 °C for 30 min. Finally, the cup was cooled in a desiccator, and the final weight was taken to calculate the sample's fat content.

The samples' total carbohydrate level was computed by subtracting the sum of ash, moisture, protein, and fat from 100 (that is, 100 – [%ash + %moisture + %protein + %fat]).

The samples' gross food energy value was calculated thus:

Gross food energy (kCal/100 g) = (%crude protein × 4) + (%total carbohydrate × 4) + (%Fat × 9).

Starch content determination

The flour and biscuit samples were analyzed for their starch content by adopting the method described by Elemosho et al. (2020). This was achieved by mixing the sample (0.02 g), 80% ethanol (1 mL), distilled water (2 mL), and hot 80% ethanol (10 mL), and centrifuging the mixture for a period of 10 min at 2000 x g. Thereafter, the residue was subjected to acid hydrolysis for 1 hr. with concentrated perchloric acid (7.5 mL). The resulting hydrolysate was diluted to a total volume of 25 mL with distilled water and filtered using a No. 2 Whatman filter paper. Afterward, the filtrate (0.05 mL), 5% phenol solution (0.5 mL), and concentrated H_2SO_4 (2.5 mL) were mixed in a test tube. Next, the reaction mixture was left to cool to ambient temperature and the absorbance reading was taken at 490 nm in a UV-Vis spectrophotometer (Shimadzu Scientific Instruments, 2450, Columbia, MD). The concentration of starch in the sample was computed using a calibration curve of D-glucose and a conversion factor (0.9).

Amylose and amylopectin concentration determination

The samples' (flours and biscuits) amylose concentration were analyzed according to Elemosho et al. (2020) method. To gelatinize the starch in each sample, 100 mg of the sample was mixed with 1 mL of ethanol (95%) and 9.2 mL of NaOH (1 N), and heated at 100 °C in a water bath for a period of 10 min. Following cooling to ambient temperature, 0.05 mL of the gelatinized sample was diluted to a total volume of 0.5 mL with distilled water in a test tube. Afterwards, 0.1 mL of acetic acid solution (1 N), 0.2 mL of iodine solution (0.2% I_2 in 2% KI), and 9.2 mL of distilled water were sequentially dispensed into the test tube. This was followed by the reaction mixture's incubation at ambient temperature for a period of 20 min, and absorbance reading at 620 nm in a UV-Vis spectrophotometer (Shimadzu Scientific Instruments, 2450, Columbia, MD). Amylose concentration in each sample was computed using corn starch amylose as a reference.

Amylopectin concentration in each sample was computed as per the following formula:

$$\%\text{Amylopectin} = 100 - \%\text{amylose}.$$

In vitro starch digestibility and estimated glycaemic index (eGI) determination

The method of Goni et al. (1997) was adopted to determine the samples' (flours and biscuits) in vitro starch digestibility rate and hydrolysis index (HI). Briefly, 50 mg of sample, HCl-KCL buffer (10 mL; pH 1.5) and pepsin solution (0.2 mL; 1 g pepsin dissolved in HCl-KCl buffer (10 mL; pH 1.5) were mixed in conical tubes. The mixture was incubated for 1 h at 40 °C in a mechanically shaking water bath. Subsequently, Tris-maleate buffer (pH 6.9) was added to bring the mixture volume to 25 mL. This was followed by adding 5 mL of pancreatic α-amylase solution (2.6 UI) prepared in a Tris-maleate buffer and the mixture was incubated in a mechanically shaking water bath at 37 °C. Thereafter, 0.1 mL aliquot of the hydrolyzed sample was collected from each tube from 0 to 180 min at 30 min interval and dispensed into another tube at 100 °C. The content of the tube was vigorously shaken for a period of 5 min to inactivate the α-amylase and refrigerated until the incubation time completed. Next, 1 mL of sodium acetate buffer (0.4 M; pH 4.75) and 30 μL of amyloglucosidase were sequentially added to each aliquot. The resulting mixture was incubated for 45 min at 60 °C in a shaking water bath, during which the digested starch was hydrolyzed into glucose. Then, the hydrolyzed glucose level was determined using glucose oxidase-peroxidase reagent. The glucose was later re-converted into starch by multiplying with a conversion factor of 0.9. Starch hydrolysis rate was expressed in terms of the starch hydrolyzed (in percentage) per unit time. The reference used was 50 mg of glucose.

The starch hydrolysis index (%) was computed thus:

$$\text{Hydrolysis index}(\%) = \text{AUC}_{\text{sample}} \times 100/\text{AUC}_{\text{ref}};$$

where $\text{AUC}_{\text{sample}}$ and AUC_{ref} represent the areas under the sample's and reference's (50 mg glucose) hydrolysis curves, respectively.

The estimated glycaemic index (eGI) of the samples was computed as per the formula reported by Granfeldt et al. (1992) thus:

$$\%eGI = 8.198 + 0.862HI;\ \text{where HI is hydrolysis index}(\%).$$

Sensory qualities evaluation of biscuit samples

The protocol for the sensory qualities evaluation of the biscuits was reviewed and duly approved by the Kwara State University Research Ethics Board (Ref: KWASU/CR&D/REA/2021/0020). Informed consent was also obtained from each panelist before their participation in the study. Freshly baked biscuits (M-b, MC-b1, MC-b2, MC-b3 and C-b) and the control biscuit (W-b) were evaluated for their sensory qualities according to Ranasalva and Visvanathan (2014) procedure, with a little modification. Thirty-five panelists (comprising 15 male and 20 female students of Kwara State University, Nigeria), within the age of 18 – 25 years, evaluated the biscuits' appearance, taste, colour, flavour, crispiness, and overall acceptability. This was done in a laboratory having individual sensory booths equipped with white light. A hedonic-scale questionnaire on a 9-point scale, in which "1″ represented "dislike extremely" and "9″ represented "like extremely", was used for the evaluation. The biscuit samples were randomly labeled with a three-digit code, and offered to the panelists in one session. The panelist were served fresh potable water between different biscuits' evaluations. Also, the panelists were requested to comment freely on the individual biscuit's overall acceptability. The limit of acceptability for all the sensory qualities was a score 5.

Data analysis

One-way analysis of variance (ANOVA) was carried out on the results of triplicate analyses. The mean values of different treatments were compared by Tukey's post hoc test at $p < 0.05$, using version 17 of SPSS statistical software. Pearson correlation test was also performed on the results data.

Results and discussion

Pasting characteristics of flours

The pasting characteristics of the flour samples are presented in Table 2 in terms of peak, trough, breakdown, final, and setback viscosities, as well as peak time, and pasting temperature. The samples' representative amylographs are depicted in Fig. 2. All the pasting parameters varied significantly ($p < 0.05$) among the flours. Among the native flours (M-f, C-f, and W-f), W-f (refined wheat flour), followed by C-f (cowpea flour), consistently had the highest levels of peak, trough, and breakdown viscosities; M-f (provitamin A yellow maize flour) had the highest setback viscosity (127.62 ± 0.41 RVU), peak time (7.02 ± 0.03 min), as well as pasting temperature (93.55 ± 0.07 °C). Furthermore, the final viscosities of W-f (159.12 ± 1.12 RVU) and M-f (157.36 ± 0.20 RVU) were comparable ($p > 0.05$); however, these were higher ($p < 0.05$) than that of C-f (93.15 ± 0.39 RVU). Among the composite flours (MC-f1, MC-f2 and MC-f3), MC-f3 (comprising 25% M-f and 75% C-f) had the highest peak (65.52 ± 0.03 RVU) and breakdown (4.15 ± 0.10 RVU) viscosities, while MC-f2 (comprising 50% M-f and 50% C-f) had the highest trough (62.95 ± 0.18 RVU), final (175.43 ± 0.81 RVU) and setback (112.98 ± 0.08 RVU) viscosities. Also, MC-f1 (comprising 75% M-f and 25% C-f) had the highest peak time of 6.64 ± 0.04 min and pasting temperature of 95.13 ± 0.11 °C, among the composite flours.

Table 2 Pasting characteristics of flour samples

Samples	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback Viscosity (RVU)	Peak time (min)	Pasting temperature (°C)
M-f	36.47± 0.64^{f}	29.74± 0.61^{e}	6.73± 0.05^{c}	157.36± 0.20^{b}	127.62± 0.41^{a}	7.02± 0.03^{a}	93.55± 0.07^{b}
MC-f1	27.80± 0.31^{e}	27.03± 0.28^{f}	0.78± 0.04^{f}	48.55± 1.02^{e}	21.53± 0.74^{f}	6.64± 0.04^{b}	95.13± 0.11^{a}
MC-f2	64.18± 0.22^{d}	62.95± 0.18^{b}	1.23± 0.04^{e}	175.43± 0.81^{a}	112.98± 0.08^{b}	5.31± 0.06^{d}	87.15± 0.21^{d}
MC-f3	65.52± 0.03^{c}	61.37± 0.07^{c}	4.15± 0.10^{d}	154.50± 0.24^{c}	93.13± 0.17^{c}	5.03± 0.04^{e}	84.78± 0.04^{e}
C-f	82.83± 0.36^{b}	58.53± 0.08^{d}	24.30± 0.28^{b}	93.15± 0.39^{d}	34.62± 0.30^{e}	4.92± 0.02^{f}	83.15± 0.07^{f}
W-f	157.80± 0.30^{a}	76.67± 0.48^{a}	81.13± 0.18^{a}	159.12± 1.12^{b}	82.45± 0.64^{d}	5.96± 0.04^{c}	88.25± 0.35^{c}

Results are presented as mean ± SD of triplicate analyses. Mean values with varying superscript letters along the same column are significantly different at $p < 0.05$. Flours and biscuits acronyms are as defined in the "Wholemeal composite flours preparation" and "Biscuit-baking process" sections, respectively

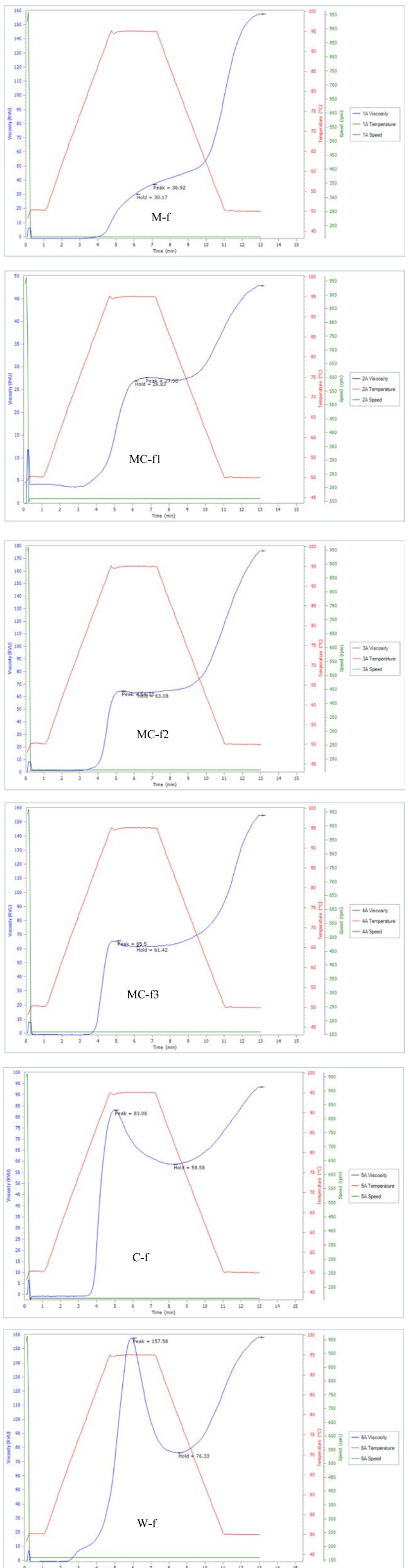


Fig. 2 Representative amylographs of M-f (100% biofortified yellow maize), MC-f1 (75:25 biofortified yellow/cowpea composite, %), MC-f2 (50:50 biofortified yellow/cowpea composite, %), MC-f3 (25:75 biofortified yellow/cowpea composite, %), C-f (100% cowpea), and W-f (100% refined wheat) flour samples

Pasting properties represent changes in starch following its gelatinization in excess water, after a definite cycle of heating and cooling under shear forces (Alcázar-Alay and Meireles 2015). Among the pasting characteristics, final viscosity is the index used most commonly to ascertain the suitability of a given starch/flour for food and industrial applications. It represents the alteration in viscosity following the holding of cooked starch sample at 50 °C, indicating the stability of the cooked starch sample and the paste's resistance to shear force, when being stirred (Irondi et al. 2019; Elemosho et al. 2020). Thus, the higher final viscosities of refined wheat (W-f) and provitamin A yellow maize (M-f) flours suggest that they may have technological advantage over cowpea flour (C-f) for the development of food products requiring a high viscosity starch (Irondi et al. 2021). This may partly explain why refined wheat is considered as the gold standard flour for baking. The functional superiority of refined wheat flour over gluten-free cereals' flours in baked products has also been ascribed to its gluten's unique propensity to form a viscoelastic network in a dough (Cappelli et al. 2020; Irondi et al. 2022; Parenti et al. 2020).

Among the composite flours MC-f2 (comprising 50% M-f and 50% C-f) had the highest final viscosity (175.43 ± 0.81 RVU), suggesting that food products made from MC-f2 may be of a better technological quality than those made from MC-f1 and MC-f3. Meanwhile, peak viscosity indicates the capacity of a given flour sample to bind water, reflecting the starch granules' propensity to freely swell prior to their physical breakdown (Alamu et al. 2017). Overall, the differences in the pasting profiles of the native and composite flours might be due to the variations in their starch composition, as previously reported (Ortiz et al. 2019; Elemosho et al. 2020). For instance, it has been documented earlier that a flour containing a low level of amylose swelled easily, resulting in an increased viscosity at a lower temperature during heating, due to a weaker binding force in the granules of starch (Hoover et al. 1996). However, a recent study (Irondi et al. 2022) demonstrated that in addition to starch, endogenous lipids and proteins in the flour matrix also influence its pasting properties. Other previous studies also reported that endogenous proteins and lipids

Table 3 Proximate composition and energy value of flours and biscuits

Samples	Moisture (%)	Protein (%)	Ash (%)	Fat (%)	Total CHO (%)	Food energy (kCal/100 g)
Flours						
M-f	5.40 ± 0.01^f	10.07 ± 0.30^j	1.15 ± 0.02^i	6.87 ± 0.05^g	76.52 ± 0.24^b	408.16 ± 0.24^g
MC-f1	4.81 ± 0.01^g	14.09 ± 0.19^g	1.88 ± 0.01^g	5.03 ± 0.03^h	74.20 ± 0.15^c	398.39 ± 0.13^h
MC-f2	4.36 ± 0.02^h	17.64 ± 0.02^e	2.50 ± 0.02^e	3.65 ± 0.13^i	71.86 ± 0.14^d	390.88 ± 0.49^i
MC-f3	4.14 ± 0.01^h	22.01 ± 0.56^c	2.94 ± 0.01^c	2.44 ± 0.01^j	68.48 ± 0.57^e	383.93 ± 0.06^j
C-f	5.81 ± 0.05^e	26.88 ± 0.39^a	3.27 ± 0.03^b	1.18 ± 0.03^k	62.87 ± 0.28^f	369.59 ± 0.17^l
W-f	5.17 ± 0.02^{fg}	12.12 ± 0.35^h	0.64 ± 0.02^k	0.28 ± 0.01^l	81.80 ± 0.33^a	378.21 ± 0.24^k
Biscuits						
M-b	8.49 ± 0.45^b	8.92 ± 0.24^k	1.31 ± 0.03^h	19.02 ± 0.45^a	62.27 ± 0.27^{fg}	455.91 ± 3.90^a
MC-b1	7.73 ± 0.28^c	12.02 ± 0.13^h	2.14 ± 0.06^f	16.58 ± 0.33^b	61.54 ± 0.78^g	443.44 ± 0.30^b
MC-b2	7.11 ± 0.08^d	15.19 ± 0.17^f	2.72 ± 0.05^d	15.20 ± 0.37^c	59.79 ± 0.66^h	436.69 ± 1.39^c
MC-b3	6.86 ± 0.19^d	18.87 ± 0.22^d	3.21 ± 0.06^b	14.05 ± 0.29^d	57.03 ± 0.20^i	430.00 ± 0.93^d
C-b	9.02 ± 0.08^a	23.15 ± 0.37^b	3.73 ± 0.11^a	13.07 ± 0.16^e	51.03 ± 0.49^j	414.33 ± 0.91^f
W-b	7.85 ± 0.11^c	10.96 ± 0.11^i	0.77 ± 0.03^j	12.15 ± 0.41^f	68.27 ± 0.45^e	426.29 ± 1.51^e

Results are presented as mean ± SD of triplicate analyses. Mean values with varying superscript letters along the same column are significantly different at $p < 0.05$. Flours and biscuits acronyms are as defined in the "Wholemeal composite flours preparation" and "Biscuit-baking process" sections, respectively

affect the rheology of flours by limiting starch granule's expansion during gelatinization, and retarding amylopectin's retrogradation (Yu et al. 2012).

Proximate composition and energy values of flours and biscuits

The flours' and biscuits' proximate compositions and energy values are presented in Table 3. The moisture, crude protein, crude fat, ash, and total carbohydrate levels, as well as the energy values of the flours differed significantly ($p < 0.05$). Biofortified yellow maize flour (M-f) displayed the highest crude fat (6.87 ± 0.05%) and energy value (408.16 ± 0.24 kCal/100 g); cowpea flour (C-f) had the highest moisture (5.81 ± 0.05%), crude protein (26.88 ± 0.39%), and ash (3.27 ± 0.03%) contents; while the refined wheat flour (W-f) had the highest total carbohydrate level (81.80 ± 0.33%). Expectedly, the levels of total carbohydrate, crude fat and food energy value in the composite flours (MC-f1, MC-f2 and MC-f3) increased with increasing proportion of M-f, while the crude protein and ash contents increased with an increasing proportion of C-f.

The moisture, ash, crude fat, and food energy values were significantly ($p < 0.05$) higher, while the levels of crude protein and total carbohydrate were significantly ($p < 0.05$) lower in the biscuits, relative to their counterpart flours. In trends similar to those of the composite flours, yellow maize biscuit (M-b) had the highest crude fat (19.02 ± 0.45%) and energy value (455.91 ± 3.90 kCal/100 g); cowpea biscuit (C-b) had the highest moisture (9.02 ± 0.08%), crude protein (23.15 ± 0.37%) and ash (3.73 ± 0.11%) contents; while refined wheat biscuit (W-b) had the highest total carbohydrate (68.27 ± 0.45%). The total carbohydrate, crude fat levels, and energy values of the composite biscuits (MC-b1, MC-b2 and MC-b3) also increased with an increasing proportion of M-f, while the crude protein and ash contents increased as the level of C-f increased. The increase in the composite biscuits' protein content with increasing level of C-f is consonant with the finding of Sparvoli et al. (2016), who also reported an increase in the protein content of soft wheat, maize, and common bean composite biscuit with an increasing addition of the common bean flour. In addition, other previous studies reported that incorporating protein-rich flours from different sources, such as buckwheat, soya, lentil and amaranth grain, could improve the protein content of the final product (Filipčev et al. 2011; Yang et al. 2019; Di Cairano et al. 2022).

The proximate composition (moisture, protein, crude fat, ash, and total carbohydrate) and energy value of the flours and biscuits samples (Table 3) represent their nutritional values. Thus, M-f, with the highest crude fat (6.87 ± 0.05%) and energy value (408.16 ± 0.24 kCal/100 g) may be a richer source of fats and energy in human nutrition than C-f and W-f. Similarly, C-f, with the highest crude protein (26.88 ± 0.39%) and ash (3.27 ± 0.03%) contents may be a richer protein and minerals source in human nutrition. The observed increase in the composite flours' and biscuits' total carbohydrate, crude fat, and energy values with an increasing proportion of M-f reflects the richness of the M-f in these nutrients. Also, the increase in the composite flours' and biscuits' ash and crude protein levels, with an

Table 4 Levels of starch, amylose, amylopectin, starch hydrolysis index (HI), and estimated glycaemic index (eGI) of flours and biscuits

Samples	Starch (%)	Amylose (%)	Amylopectin (%)	Amylose/Amylopectin	HI (%)	eGI (%)
Flours						
M-f	70.58 ± 0.24^{b}	19.79 ± 0.11^{b}	80.21 ± 0.11^{i}	0.25 ± 0.00^{b}	70.54 ± 0.37^{c}	69.01 ± 0.32^{b}
MC-f1	68.66 ± 0.39^{c}	18.19 ± 0.18^{c}	81.82 ± 0.18^{h}	0.22 ± 0.00^{c}	72.33 ± 0.43^{b}	66.07 ± 0.32^{c}
MC-f2	60.43 ± 0.47^{d}	17.21 ± 0.17^{d}	82.80 ± 0.19^{g}	0.21 ± 0.00^{d}	56.74 ± 0.29^{d}	57.10 ± 0.26^{d}
MC-f3	54.64 ± 0.10^{f}	15.93 ± 0.12^{e}	84.07 ± 0.12^{f}	0.19 ± 0.00^{e}	47.31 ± 0.22^{g}	48.98 ± 0.19^{g}
C-f	51.87 ± 0.53^{g}	13.22 ± 0.13^{g}	86.78 ± 0.11^{d}	0.15 ± 0.00^{g}	38.22 ± 0.14^{i}	41.15 ± 0.12^{i}
W-f	80.68 ± 0.26^{a}	21.81 ± 0.29^{a}	78.20 ± 0.30^{j}	0.28 ± 0.00^{a}	74.20 ± 0.33^{a}	72.16 ± 0.29^{a}
Biscuits						
M-b	61.05 ± 0.29^{d}	15.91 ± 0.01^{e}	84.09 ± 0.01^{f}	0.19 ± 0.00^{e}	53.62 ± 0.29^{e}	54.42 ± 0.25^{e}
MC-b1	57.23 ± 0.49^{e}	14.04 ± 0.07^{f}	85.96 ± 0.07^{e}	0.16 ± 0.00^{f}	50.93 ± 0.28^{f}	52.10 ± 0.25^{f}
MC-b2	50.20 ± 0.43^{h}	12.05 ± 0.35^{h}	87.95 ± 0.35^{c}	0.14 ± 0.01^{h}	44.81 ± 0.54^{h}	46.83 ± 0.47^{h}
MC-b3	46.20 ± 0.44^{i}	10.15 ± 0.23^{i}	89.86 ± 0.23^{b}	0.11 ± 0.00^{i}	37.80 ± 0.51^{i}	40.78 ± 0.44^{i}
C-b	41.02 ± 0.24^{j}	7.82 ± 0.24^{j}	92.19 ± 0.24^{a}	0.09 ± 0.01^{j}	31.09 ± 0.25^{j}	34.99 ± 0.21^{j}
W-b	68.01 ± 0.66^{c}	18.27 ± 0.18^{c}	81.73 ± 0.18^{h}	0.23 ± 0.01^{c}	56.84 ± 0.50^{d}	57.19 ± 0.45^{d}

Results are presented as mean ± SD of triplicate analyses. Mean values with varying superscript letters along the same column are significantly different at $p < 0.05$. Flours and biscuits acronyms are as defined in the "Wholemeal composite flours preparation" and "Biscuit-baking process" sections, respectively

increasing C-f proportion, reflects the richness of the C-f in protein and minerals. The complementary role of legumes and cereals in meeting the protein requirement in human nutrition is well-known (Sparvoli et al. 2016). Rich sources of protein and minerals, such as cowpea, are nutritionally important for the alleviation of protein and minerals deficiencies, respectively, in human nutrition (Olatoye et al. 2023). Thus, with an increased protein content, the biofortified yellow maize-cowpea composite biscuit formulated in this study may be beneficial for alleviating protein deficiency among consumers. Further, proteins function as hormones, enzymes and antibodies, and provide structural materials for the human body (Hounsome et al. 2008). On the other hand, available carbohydrates (starch and sugars) are the primary sources of energy to the cells (Elemosho et al. 2020).

Starch profile, amylose/amylopectin ratio, starch hydrolysis index (HI), and estimated glycaemic index (eGI) of flours and biscuits

The flours' and biscuits' starch, amylose, amylopectin, amylose/amylopectin ratio, starch hydrolysis index (HI), and estimated glycaemic index (eGI) levels are presented in Table 4. Significant ($p < 0.05$) variations were observed in the levels of starch, amylopectin, amylose, amylose/amylopectin ratio, HI and eGI among the native flours. These parameters ranged from 51.87 ± 0.53% in C to 80.68 ± 0.26% in W-f (starch); 13.22 ± 0.13% in C-f to 21.81 ± 0.29% in W-f (amylose); 78.20 ± 0.30% in W-f to 86.78 ± 0.11% in C-f (amylopectin); 0.15 ± 0.00 in C-f to 0.28 ± 0.00 in W-f (amylose/amylopectin ratio); 38.22 ± 0.14 in C-f to 74.20 ± 0.33 in W-f (HI); and 41.15 ± 0.12 in C-f to 72.16 ± 0.29 in W-f (eGI). The levels of starch, amylose, amylose/amylopectin ratio, HI and eGI in the composite flours increased with increasing proportion of M-f, but decreased with increasing proportion of C-f. In contrast, the amylopectin level of the composite flours decreased with an increasing level of M-f, but increased as the level of C-f increased. The trends of starch, amylopectin, and amylose levels, amylose/amylopectin ratio, HI, and eGI in the biscuits were similar to those of their counterpart flours. Thus, W-b had the highest contents of starch, amylose, amylose/amylopectin ratio, HI and eGI, while C-b had the lowest levels of these parameters. Additionally, it was observed that amylopectin level was consistently higher than amylose level in all the flour and biscuit samples. This is consonant with previous reports that amylopectin is predominant over amylose in most starches (Elemosho et al. 2020).

Furthermore, an increasing proportion of M-f in the composite biscuits consistently resulted in an increase in the concentrations of starch and amylose, as well as amylose/amylopectin ratio, HI, and eGI; while an increasing proportion of C-f led to their decrease. The decrease in the biofortified yellow maize-cowpea composite biscuits' HI and eGI, with an increasing C-f addition, is consistent with the findings of previous studies in which adding protein-rich flours, such as chickpea, buckwheat, and lentil, reduced the starch digestibility of biscuits (Di Cairano et al. 2022; Lu et al. 2022). Starch comprises amylose and amylopectin, and their levels in flours have effect on the functional characteristics of the flour, impacting their food and industrial products applications (Irondi et al. 2017). It is well-known that amylose is a linear molecule, comprising c ~ (1,4)-linked D-glucopyranosyl units, having a degree of polymerization that range from 500 to 600 glucose residues. On the other hand, amylopectin is a highly-branched and very large polysaccharide, having a degree of polymerization in the range of 3×10^5 to 3×10^6 glucose units, and consisting of chains of o ~ (1,4)-linked D-glucopyranosyl residues that are interlinked by oL(1,6)-bonds (Arendt et al. 2008).

The amylose/amylopectin ratio of flours and food products influences their blood glucose response/glycaemic index, with a smaller amylose and a larger amylopectin concentration resulting in a larger glycaemic index value (Shanita et al. 2011; Irondi et al. 2019). According to Birt et al. (2013), this is due to the relative ease of amylose and amylopectin digestion by α-amylase in the human duodenum. Moreover, a previous study indicated that a higher amylose content resulted in a decreased starch digestibility (Zhu et al. 2011). Part of the reasons for this is the higher propensity of amylose than amylopectin to form double helices after cooking (retrogradation), due to its linear and more flexible structure. This makes amylose more resistant than amorphous starch to amylase hydrolysis. Consequently, the digestion rate of starch with a higher amylose level is slower than that with a lower level of amylose (Syahariza et al. 2013; Irondi et al. 2022). This may account for the lower starch hydrolysis (HI) and estimated glycaemic (eGI) indices recorded for C-f, C-b, and the composite flours and biscuits (Table 4).

In addition, the higher levels of phenolics (Irondi et al. 2021) and crude protein in C-f, C-b, and the composite flours and biscuits, relative to M-f, M-b, W-f, and W-b, may have contributed to their lower HI and eGI. Phenolics are known to decrease the rate of starch digestion in vitro and in vivo (Amoako and Awika 2016) and glycemic response (Hanhineva et al. 2010) through the inhibition of starch-hydrolyzing enzymes. Proteins, on their part, form a barrier around the granules of starch, foreclosing their access to amylase, with a concomitant reduction in starch digestibility. Moreover, the various hydrophilic groups ($-NH_2$, $-COOH$, $-OH$, and -SH) contained in the structure of proteins are capable of binding with starch via hydrogen bond, leading to an adhesion of starch to the protein. As a consequence of this adhesion, the rate of enzyme-catalyzed starch hydrolysis could be retarded (Chen et al. 2015; Irondi et al. 2022). Further, the pattern of diffraction and/or crystallinity of starch granule in cereal and legume may have contributed to the variations in the HI and eGI of the various flours and biscuits in this study. In this context, the A-type power diffraction of cereal starch, with its open structure, makes it highly digestible. In contrast, the C-type crystallinity in legume starch has close-packed structure that renders it more resistant to digestion (Biliaderis 1991; Sparvoli et al. 2016).

Glycaemic index represents a relative ranking of carbohydrate in foods in terms of how they impact blood glucose concentration (Venn and Green 2007). The lower the GI of a particular food, the lesser the impact the food will have on blood sugar level. Thus, foods having a GI of 55% or less are categorized as low-GI foods; those having a GI of 56 – 69% are classified as moderate/medium GI foods, while those having a GI above 70% are classified as high-GI foods (Atkinson et al. 2008). Therefore, based on the eGI of the biscuits, C-b, M-b, and their composites can be classified as low-to-moderate GI foods, suggesting that they may be beneficial for obese and type 2 diabetic patients. This corroborates a previous report by Garsetti et al. (2005) that plain sweet biscuits had either a low or moderate GI, mainly due to their limited starch digestibility, occasioned by the low degree of starch gelatinization in biscuits (Sozer et al. 2014). It is already well-known that low-GI foods may enhance weight control and lower the risk of diabetes mellitus by enhancing satiety, reducing postprandial secretion of insulin, and maintaining insulin sensitivity (Flores-Silva et al. 2015).

Correlations of the chemical constituents, estimated glycaemic index (eGI) and starch hydrolysis index (HI) of flours and biscuits

Table 5 presents the correlations among the chemical constituents (crude protein, fat, starch, amylose, and

Table 5 Correlations among chemical constituents, estimated glycaemic index (eGI) and starch hydrolysis index (HI) of flours and biscuits

Parameter	Crude fat	Starch	Amylose	Amylopectin	eGI	HI
Crude protein	−0.378	−0.673**	−0.594**	0.594**	−0.715**	−0.696**
Crude fat		−0.403	−0.496*	0.496*	−0.365	−0.371
Starch			0.969**	−0.969**	0.966**	0.954**
Amylose				−1.000**	0.947**	0.931**
Amylopectin					−0.947**	−0.931**
eGI						0.995**

** : Significant correlation at $p \leq 0.01$; *: Significant correlation at $p \leq 0.05$

Table 6 Sensory characteristics of biscuits

Biscuits	Appearance	Taste	Colour	Crispiness	Flavour	Overall Acceptability
M-b	4.46 ± 0.02^{c}	2.89 ± 0.92^{e}	4.86 ± 0.28^{c}	3.71 ± 0.00^{e}	2.86 ± 0.01^{e}	3.71 ± 0.02^{d}
MC-b1	5.13 ± 0.70^{bc}	3.31 ± 0.92^{de}	3.89 ± 0.28^{d}	3.69 ± 0.10^{b}	3.60 ± 0.62^{de}	4.46 ± 0.01^{cd}
MC-b2	5.49 ± 0.98^{b}	4.00 ± 0.00^{cd}	5.23 ± 0.97^{bc}	4.91 ± 0.10^{b}	3.97 ± 0.18^{cd}	4.49 ± 0.52^{cd}
MC-b3	5.89 ± 0.62^{b}	4.71 ± 0.01^{c}	5.80 ± 0.31^{bc}	4.82 ± 0.15^{b}	4.69 ± 0.02^{c}	4.91 ± 0.90^{c}
C-b	6.86 ± 0.01^{a}	5.60 ± 0.01^{b}	6.17 ± 0.05^{b}	5.51 ± 0.00^{b}	5.77 ± 0.00^{b}	6.43 ± 0.00^{b}
W-b	7.51 ± 0.00^{a}	7.49 ± 0.00^{a}	7.20 ± 0.00^{a}	6.42 ± 0.00^{a}	7.31 ± 0.00^{a}	8.00 ± 0.00^{a}

Results are presented as mean ± SD of replicate evaluations. Mean values with varying superscript letters along the same column are significantly different at $p < 0.05$. Biscuits acronyms are as defined in the "Biscuit-baking process" section

amylopectin), eGI, and HI of flours and biscuits. Crude protein (r = − 0.715, − 0.696), starch (r = 0.966, 0.954), amylose (r = 0.947, 0.931) and amylopectin (r = − 0.947, − 0.931) were all significantly correlated ($p < 0.01$) with the eGI and HI, respectively. However, whereas the crude protein and amylopectin had negative correlations, starch and amylose had positive correlations with both eGI and HI. The negative correlations between crude protein and each of eGI and HI further affirms the report of Chen et al. (2015) that proteins retard starch digestion rate. This negative correlation could be ascribed to the formation of amylose-protein complex, thereby retarding starch hydrolysis and reducing the foods glycaemic index. Some previous studies reported that protein matrix could entrap starch granules, hindering their gelatinisation and amylolytic attack by amylase (Ezeogu et al. 2008; Chi et al. 2018; Irondi et al., 2022). Similarly, it has been explained that protein could be embedded within the internal matrix of starch, partly due to the gelatinized starch granule's cracking and swelling, allowing the dispersion of a continuous protein matrix with a discontinuous starch inclusions (Fitzsimons et al. 2008; Yang et al. 2019). Taken together, these may explain the significant negative correlation observed between protein content and each of HI and eGI in this study. Further, the positive correlations between amylose and each of eGI and HI corroborate a recent report by Tuaño et al. (2021) that also indicated a positive correlation between amylose content and HI. Overall, the correlations observed in this study might provide an insight into optimizing the formulation of biofortified yellow maize and cowpea composite biscuits to obtain a low-GI biscuit, which may be useful in obese and type 2 diabetic conditions.

Sensory attributes of biscuits

The sensory characteristics (appearance, taste, colour, flavour, crispiness, and overall acceptability) of the biscuits are presented in Table 6. Relative to W-b, M-b, C-b and their composite biscuits displayed significantly lower ($p < 0.05$) sensory ratings. Further, C-b was rated higher than M-b in all the sensory attributes. This translated to a manifest improvement in the appearance, taste, colour, flavour, and overall acceptability of the composite biscuits, as the proportion of C-f in the biscuits increased. Thus, MC-b3 (comprising 25% yellow maize and 75% cowpea) was adjudged the best among the composite biscuits. This trend contradicts the report of Sparvoli et al. (2016), who noted that the sensory (liking) scores of composite biscuit formulated with soft wheat, maize, and common bean flours decreased with increasing proportion of the bean flour. Further, the higher sensory ratings of W-b, when compared to M-b, C-b, and their composites, corroborate a previous report by Parenti et al. (2020), affirming consumers' preference of refined wheat products to those made from other wholemeal cereals flours. However, considering the accompanying health benefits of M-b, C-b, and their composites over W-b, consumers may accommodate the loss in their sensory quality (Arp et al. 2020). As part of such health benefits, our recent study (Irondi et al. 2021) demonstrated that M-b, C-b, and their composites had a stronger antioxidant and digestive enzymes (pancreatic lipase, α-glucosidase, and α-amylase) inhibitory capacities than W-b.

Conclusions

The physicochemical qualities, as well as in vitro starch digestibility of biofortified yellow maize and cowpea composite flours and biscuits were affected by the proportions of the native flours. The composite flours' and biscuits' crude protein and ash concentrations increased as the level of cowpea flour increased, suggesting that the biscuits may be beneficial for alleviating protein and minerals deficiencies among consumers. An increased proportion of cowpea flour led to a decrease in the starch, amylose levels, amylose/amylopectin ratio, starch hydrolysis index, and estimated glycaemic index in the composite flours and biscuits. The sensory qualities of the composite biscuits also improved with an increase in the level of cowpea flour in them. Crude protein, starch, amylose, and amylopectin correlated with eGI and HI. Overall, the results indicate that the biofortified yellow maize-cowpea composite flours and biscuits formulated in this study had an improved nutritional quality and a reduced eGI. Hence, the composite flours and biscuits of biofortified yellow maize and cowpea may serve as good sources of nutrients with a low-to-moderate glycaemic index. Therefore, the biscuits may be suitable as diets for a diabetic condition, requiring low-to-moderate glycaemic index foods.

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Authors' contributions
Emmanuel A. Irondi: Conceptualization, Funding acquisition, Supervision, Writing – original draft & editing. Kazeem Koledoye Olatoye: Resources, Investigation, Formal analysis, Writing – original draft. Hassan Taiye Abdulameed: Resources, Investigation, Formal analysis. Olawale Mashood Aliyu and Emmanuel Oladipo Ajani: Resources, Supervision, Writing - review & editing, Validation. Osayame Funmilayo Ogbebor: Resources, Investigation.

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Availability of data and materials
The data supporting the findings reported in this paper are included in the manuscript. More information about the data and materials are available from on request from the corresponding author.

Declarations

Ethics approval and consent to participate
Ethics approval to conduct the sensory qualities evaluation of the biscuits was reviewed and approved by the Kwara State University Research Ethics Board (Ref: KWASU/CR&D/REA/2021/0020). Informed consent was also duly obtained from each panelist before their participation in the sensory evaluation.

Consent for publication
Not applicable.

Competing interests
The authors have no competing interest.

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