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Gluten free crackers from germinated and fermented cowpea pulses flours: Their thermal, physicochemical and consumer sensory evaluation

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ABSTRACT

Cowpea fermentation and germination improve nutrients and reduce antinutrients of resulting flours but flours of fermented or germinated cowpea pulses are not what consumers eat. Therefore, this study investigated the nutritional and consumer sensory evaluation of crackers made using fermented or germinated *Bira* and *Nakare* cowpea grain flours. Compared to common wheat crackers, cowpea crackers had a higher protein content that ranged between 21.84 and 25.14 g/100 g. The iron contents of cowpea crackers were 78 % more than those reported in common wheat crackers. The crackers' enthalpies ranged between 2.70 and 7.83 J/kg. A strong 7–9 ratings on a 9-point hedonic scale were given by 45 % of consumers for the germinated Bira crackers. At least 84 % of consumers rated at least 4–9 all the cowpea crackers. This study demonstrated the development of high protein, shelf-stable, fermented and germinated cowpea crackers, thereby diversifying the forms of consumption of the under-utilised cowpea pulses.

1. Introduction

According to FAO (2021), global cowpea (*Vigna unguiculata)* production was about 6.7 million tonnes in 2019. It is widely grown in South America, Asia, Australia and Africa (Avanza et al., 2013; Fleissner & Bagnall-Oakeley, 2001). In Africa, cowpea (CP) is commonly produced and consumed in many countries such as Nigeria, Niger, Burkina Faso, Kenya, Namibia, Zimbabwe, Botswana and South Africa (Affrifah et al., 2022; Fleissner & Bagnall-Oakeley, 2001). Dry cowpea grain comprises protein (23.28 g/100 g), fat (2.35 g/100 g), ash (2.85 g/100 g), fibre (5.82 g/100 g), total phenolics (177.8 mg GAE/100 g) (Avanza et al., 2013; Madodé, 2012; Uwaegbute et al., 2000), copper (0.54 mg /100 g), iron (6.96 mg/100 g) and zinc (4.57 mg/100 g) (Gonçalves et al., 2020).

Noteworthy is that despite cowpeas relatively high content of proteins and minerals, they also contain apparent anti-nutrients. The anti-nutrients found in cowpeas include phytate (14.0–32.39 mg/100 g) and trypsin inhibitors (6.7–9.69 units/mg), which may have a negative effect on nutrient bioavailability (Ijarotimi & Esho, 2009; Uwaegbute et al., 2000). This could be linked to the hidden hunger and its effects such as 40 % stunting (too short for age), 27 % wasting (too thin for age) and 6.7 % underweight (low weight for age) (Ahmed et al., 2020) experienced in developing nations such as in sub-Sahara Africa. The diets in these developing nations are generally high in cereals and/or grains that are apparently nutrient rich such as cowpeas but may not be appropriately processed to improve the nutrient bioavailability. For instance, in countries such as Ghana, Benin, Togo, and Nigeria, the consumption of cowpea (CP) is estimated to be between 9 – 18 kg per capita per year (Gomez, 2004).

It is consumed in various forms. These include boiled or roasted fresh pods, boiled dry seeds referred to as *Red-Red* or *Waakye* in Ghana (Affrifah et al., 2022) and canned pulses. Dry cowpea grains are also soaked and crushed to make a seasoned steamed paste called *moin moin/Alele* (Madodé et al., 2013; Uwaegbute et al., 2000) or a seasoned cooked paste/broth called *Oshigali.* It can also be milled and used to make products such as a fried fritter referred to as *acaraje* in Brazil, (Affrifah et al., 2022) or *Akara/Koose/Ata* in Niger, Nigeria, Ghana and other west African countries (Affrifah et al., 2022; Apea-Bah et al., 2017; Uwaegbute et al., 2000). It is reported that in Nigeria, snack foods such as cake, chin-chin and puff-puff are generally made from cowpea-wheat

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flour blends (Akubor, 2004). Furthermore, various studies have investigated the use of untreated cowpea in composite flours with cereals such as wheat to make noodles (Ritika et al., 2016), with plantain and wheat for biscuits (Akubor, 2003), with sorghum to make instant porridge (Pelembe et al., 2002), biscuits from cowpea-carrot blends (Ibidapo et al., 2017) and as an extender in fish nuggets (Jayasinghe et al., 2013).

Essentially, cowpeas are consumed worldwide without being subjected to any bioprocessing treatments that improves nutrient bioavailability. The conventional methods such as soaking, cooking, roasting, extrusion, fermentation and germination, along with emerging processing techniques such as high-pressure processing, ultrasound, irradiation, pulsed electric field, and microwave have been studied for their potential to improve the nutritional quality and bioavailability in legumes such as cowpea flours (Affrifah et al., 2022; Arbab Sakandar et al., 2023; Lawan et al., 2020; Ohanenye et al., 2020; Uwaegbute et al., 2000). Fermentation improves the bio-accessibility and bioavailability of nutrients of cowpea pulses (Uwaegbute et al., 2000). During fermentation, the endogenous enzymes hydrolyse the proteins into polypeptides that have bioactive properties (antioxidants, antihypertensive, anti-inflammatory) and also liberate the bound minerals such as zinc, iron and magnesium consequently increasing their bioavailability (Nkhata et al., 2018). In addition, Madodé et al. (2013) reported a reduction of flatulence-inducing compounds (e.g. stachyose and raffinose) in fermented cowpea flours. Germination of cowpea pulses improved the nutritional quality by reducing the anti-nutrients and help induce the hydrolysis of protein and carbohydrates (López-Martínez et al., 2017; Ohanenye et al., 2020). These occur through the activation of endogenous enzymes such as phytase, proteases and amylases. Phytases break phytic acid (minerals chelating compound) complexes down. This may lead to the bio-availability of iron and zinc. For instance, Souleymane et al. (2018) reported a significant increase in protein and minerals (copper, iron and zinc) contents (Devisetti & Prakash, 2020) in germinated CP flours. Similarly, the activated proteases hydrolyse protein inhibitors such as trypsin inhibitors, which may improve protein digestibility. The activation of amylases result in the hydrolysis of complex starches and oligosaccharides (López-Martínez et al., 2017; Madodé et al., 2013; Nkhata et al., 2018; Ohanenye et al., 2020).

There are, however, few studies that investigated the quality of products made using germinated or fermented cowpeas and/or their resulting flours. For instance, Ritika et al. (2016) investigated the cooking properties, functional, sensorial pasting and textural attributes of noodles made from germinated cowpea flours composited with wheat. Hallén, İbanoğlu & Ainsworth (2004), investigated the protein, gluten, α-amylase, farinograph and extensograph, loaf volume, crumb-grain structure of bread made from germinated cowpea incorporated with wheat flour. The *in vivo* and *in vitro* starch digestibility were studied on the fermented CP products (Madodé et al., 2013). Ritika et al. (2016) studied the cooking properties, functional, sensorial, pasting and textural attributes of noodles from composited wheat and fermented cowpea flour (Ritika et al., 2016). The proximate composition, minerals and sensory evaluation were studied on fermented cowpea non-dairy milk alternative (Aduol et al., 2020).

Strikingly, most of the research on the effects of bioprocessing (fermentation and germination) methods on cowpeas focused mostly on flours (Soulaymane et al., 2018; Madodé et al., 2013; Uwaegbute et al., 2000). However, cowpea flour is not the final form that people consume. There is, thus little data on the diversification and consumption of convenient, value-added food products made using fermented or germinated cowpea flours. To fill the gaps in cowpeas products diversification and quality of fermented and germinated cowpeas products, this study investigated the effects of using fermented and germinated whole grain cowpea flours to bake shelf-stable, low moisture, low sugar, crackers on the consumers sensory acceptability, nutrients' contents, physical and thermal properties of these crackers.

2. Material and methods

2.1. Cowpea varieties

About ten kilograms of each cowpea variety (*Bira* and *Nakare*) were purchased from the Omahenene research station's Northern Namibia Farmers Seeds Growers Co-operative. All seeds were harvested in July 2020 and were stored in a cool room (5°C) till processing.

2.2. Bioprocessing (germination and fermentation) of cowpea seeds

A method described by Souleymane et al. (2018) was followed to germinate cowpea seeds, except that the seeds were soaked for 6 h with one-hour air-rest. Pre-soaked seeds were then incubated and germinated at 27°C for 48 h. Cowpea seeds were fermented as described by Souleymane et al. (2018). Slight modifications were made whereby seeds were soaked in polypropylene containers filled with water at a ratio of 1:3 (seeds: water) for 72 h at 25°C. The average pH at the end of the fermentation process was 5.6. The bio-processed seeds were dried in the oven at 50°C for 24 h until their moisture content was below 14 %. The seeds were ground into flour using a Hamilton Beach commercial blender (1.8 L, SE200). Prior to milling, the seeds were partially de-hulled by hand to remove the loose hulls. The resulting flours were sieved through a universal sieve with aperture of 500 μm.

2.3. Gluten-free crackers formulation and manufacturing flow process

The formulation of gluten-free crackers is given in Table 1 and were baked following a method described in Han et al. (2010). Crackers were air-cooled and packed in zip-lock plastic bags, stored below 4°C until further analysis.

2.4. Cracker physical parameters

A Vernier caliper was used to determine the stack height, crackers length, width and thickness as outlined in Nicole et al. (2021). The crackers average weight was determined using an analytical balance (Mettler-Toledo, Switzerland, Model ME204E).

2.5. Proximate composition, Water Absorption and Solubility Indices

Moisture content (AOAC 930.15) and ash (AOAC 923.03) were determined according to the AOAC (2016) official methods. Protein ($N \times 6.25$) (AACC 46–30.01), Crude Fat (AACC 30–10.01) and crude fibre (AACC 32–10.01) contents were determined following the AACC, (2000), respectively. Total carbohydrate was calculated by difference. The water absorption index (WAI) and water solubility index (WSI) were determined as described in Adebowale et al. (2011).

2.6. Differential scanning calorimetry

A TA instruments Differential Scanning Colorimeter Q1000, v9.9, Build 303 was used to determine the thermal properties of the cowpea flours and crackers. Samples were weighed into Differential Scanning

Table 1
Crackers formulation.

Ingredient	Quantity (%)
Germinated or Fermented Cowpea Flour	67.4
Baking powder	0.5
Xantham gum	0.5
Sugar	2.4
Salt	2.4
Water	18.9
Butter	6.7
Cinnamon	1.3

Colorimeter (DSC) aluminum standard pans, sealed and left for 10–15 min to equilibrate at 40°C temperature before DSC analysis. A sample size of about 3.40–3.80 mg was used, and a water-to-sample ratio was 2:1. The DSC analysis was conducted over the temperature range of -80.16–397.82 °C at the heating rate of 9.99 °C/minute. Thermal transitions were displayed as thermographs. The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and enthalpy (H) were measured. The corrected enthalpy was expressed as the enthalpy considering the specific sample moisture content. Changes in temperature (ΔT) were calculated as the difference between the onset temperature and the conclusion temperature. Three readings were obtained per sample.

2.7. Consumer sensory evaluation

The consumer sensory evaluation was conducted at the University of Namibia's Neudamm and Main campuses following the method as described in Uukule et al. (2023). A total of 80 panelists, above the age of 18 participated in this evaluation. The participants were mostly students and staff members at these campuses. An ethical clearance approval (NEC0014) was obtaining from the University of Namibia Research Ethics Committee (REC) prior to the execution of the sensory evaluation. The panelists were given consent forms to read and voluntarily consent before taking part in the sensory evaluation. A 9-point hedonic scale was used (9 point indicated extremely like and 1 point extremely dislike). The panelists were presented with three-digit coded samples and were given water to rinse before and after each sample tasting.

2.8. Statistical analysis

Germination and fermentation were conducted once for each cultivar. Baking was done in duplicate. Analyses were performed in triplicate. One-way ANOVA was done to determine individual effects of the bio-processing methods, cultivars and products on the response variables. Post-hoc pairwise comparisons were performed following the analysis of variance (ANOVA) at the $p \leq 0.05$ level. The Least Significant Difference (LSD) test was applied to show specific group differences at 95 % confidence level. Statistical analyses were conducted using R: A Language and Environment for Statistical Computing, version 4.2.3.

3. Results and discussion

3.1. Physical properties

The pictures of crackers made from untreated, fermented and germinated cowpea flour are shown in Fig. 1. The crackers 'stack height, weight, thickness, length and width results are given in Table 2. The stack heights of crackers made from fermented flours were statistically ($p > 0.05$) the same irrespective of the cultivar. However, the stack heights of crackers made from germinated *Nakare* flour significantly ($p \leq 0.05$) decreased while that of the crackers that were made from germinated *Bira* remained the same statistically ($p > 0.05$). The stack height values of the crackers from this study were lower than the range of 68.20–69.67 mm for wheat crackers (Ahmed & Abozed, 2015), which may be due to a difference in the number of crackers used for this parameter.

The individual weights of crackers from germinated and fermented flours were statistically the same ($p > 0.05$) as those from untreated flours, irrespective of cultivars. Like the stack height, the thickness of the crackers that were made from fermented flour was statistically the same ($p > 0.05$) irrespective of cultivars. The thickness values of the crackers that were made from germinated *Nakare* flours were significantly ($p \leq 0.05$) lower compared to those of the other crackers. The crackers that were made from germinated *Bira* flours were significantly ($p \leq 0.05$) thicker than the crackers that were made from the germinated *Nakare* crackers. The cowpea crackers' thickness values in this study, irrespective of the treatments were higher than the range of 1.56–2.37 mm reported by Nicole et al. (2021) for the fermented soybean crackers enriched with wheat flour but were lower than the reported range of 4.92–5.02 mm (Kshirsagar & Jadhav, 2021) for the wheat crackers incorporated with guar meal protein. The difference in the crackers thickness findings between these studies can be attributed to the use of non-composited fermented or germinated cowpea flours as opposed to the composited legume-cereal flours used in the other studies (Nicole et al., 2021; Kshirsagar & Jadhav, 2021).

Both the length and width of crackers that were made using grains that were subjected to fermentation were statistically the same ($p > 0.05$), irrespective of cultivars. The length and width of the crackers that were made from the germinated flours were significantly ($p \leq 0.05$) higher in comparison to those of the other crackers, irrespective of cultivar. The crackers that were made from the germinated *Bira* flours were significantly ($p \leq 0.05$) longer and wider than the crackers that were made from germinated *Nakare* flours. The difference

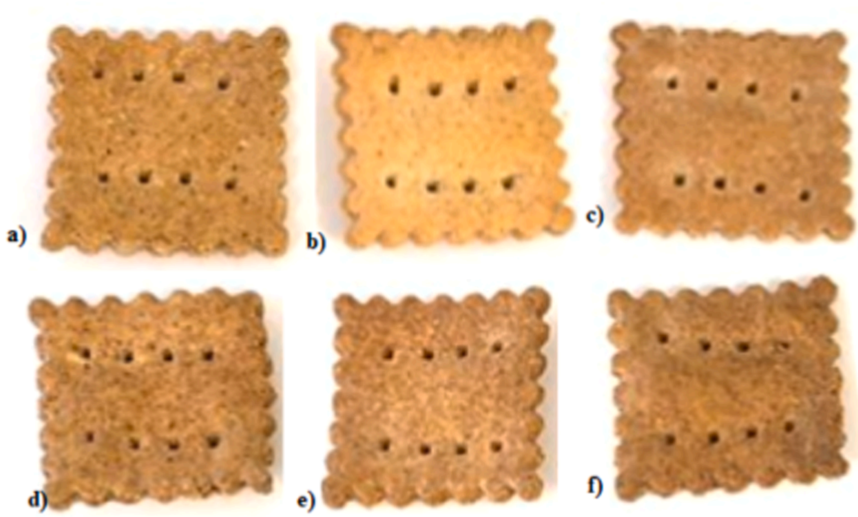

Fig. 1. Crackers developed in the study. a) cracker made from untreated Nakare flour, b) cracker made from fermented Nakare flour, c) cracker made from germinated Nakare flour, d) cracker made from untreated Bira flour, e) cracker made from fermented Bira flour and f) cracker made from germinated Bira flour.

Table 2
Physical properties of crackers made from germinated and fermented cowpea[a].

Sample	Stack height (mm)	Stack weight (g)[ns]	Cracker weight (g)[ns]	Cracker thickness (mm)	Cracker length (mm)	Cracker width (mm)
UBC	28.0 ± 0.00[bc]	11.36 ± 1.74	1.921 ± 0.19	3.93 ± 0.19[ab]	27.0 ± 0.00[b]	27.0 ± 0.00[b]
FBC	30.0 ± 0.00[ab]	9.35 ± 2.52	1.575 ± 0.43	4.00 ± 0.38[ab]	27.0 ± 0.00[b]	27.0 ± 0.00[b]
GBC	26.5 ± 0.71[c]	9.18 ± 0.57	1.639 ± 0.02	4.40 ± 0.09[a]	27.3 ± 0.14[a]	27.2 ± 0.00[a]
UNC	32.0 ± 2.83[a]	12.30 ± 0.59	2.067 ± 0.07	4.30 ± 0.24[a]	27.0 ± 0.00[b]	27.0 ± 0.00[b]
FNC	31.0 ± 0.00[ab]	10.30 ± 1.02	1.694 ± 0.14	4.21 ± 0.26[ab]	27.0 ± 0.00[b]	27.0 ± 0.00[b]
GNC	28.0 ± 1.41[bc]	10.29 ± 1.69	1.688 ± 0.33	3.70 ± 0.14[b]	26.6 ± 0.00[c]	26.6 ± 0.00[c]

[a] values = mean ± standard deviation ($n = 6$). Different lowercase letters in each column show statistically significant ($p \leq 0.05$) differences between the various treatments. Superscript *ns* indicates not statistically significant. Abbreviations: UBC (Untreated *Bira* Crackers); FBC (Fermented *Bira* Crackers); GBC (Germinated *Bira* Crackers). UNC (Untreated *Nakare* Crackers) FNC (Fermented *Nakare* Crackers) and GNC (Germinated *Nakare* Crackers)

may be attributed to different expansion capacity of each cultivar's flour.

3.2. Proximate composition

The proximate composition and carbohydrates content of crackers that were made from the flours of untreated, fermented and germinated cowpeas are shown in Table 3. The moisture contents of the crackers ranged from 5.44 to 2.86 g/100 g. These low moisture levels suggest relatively longer shelf stability. The crackers protein contents were in this order: FBC = FNC > GBC = GNC = UBC = UNC. The crackers that were made from fermented *Bira* and *Nakare* had significantly ($p \leq 0.05$) higher protein contents than those of the other crackers. The protein contents of the crackers were within the range of 21.6–28.6 g/100 g reported by Nicole et al. (2021) for the crackers that were made from wheat-fermented soybean composite flour. However, the protein contents were lower than 40.8 % of the crackers that were made from pure fermented soybean flour (Nicole et al., 2021). The crackers protein contents in this study were higher than the range of 1.68 – 16.36 g/100 g for cereal-legume crackers (Kshirsagar & Jadhav, 2021; Polat et al., 2020). Therefore, consuming these crackers can meet the recommended daily protein value of 19 g for the general population as specified by FAO/WHO (2007). The crude fibre contents of crackers were in the range of 3.31–9.36 g/100 g. The highest crude fibre was noted in the crackers that were made from untreated *Bira* flour, while the lowest was in the crackers that were made from fermented *Nakare* flour. The crude fibre contents of the crackers in this study were higher than the range of 3.63–4.05 g/100 g reported by Akeem et al. (2023), except for the crackers that were made from fermented *Nakare* flour. The fat contents in cowpea crackers ranged from 5.10 to 8.35 g/100 g, except for the crackers made from untreated and fermented *Nakare* as well as for the germinated *Bira* flours. The fat contents of the other crackers in this study fell within the range of 5.30–7.64 g/100 g reported by Ahmed and Abozed (2015) and Akeem et al. (2023). The crackers' ash contents ranged between 5.77 and 7.44 g/100 g. The crackers that were made from fermented *Nakare* flours had the lowest ash content. These were higher than those of 1.66–2.38 g/100 g reported by Polat et al. (2020).

The carbohydrate (CHO) content ranged from 32.82 to 42.25 g/100 g. The crackers that were made from the flours of the untreated and germinated *Bira* had higher carbohydrates contents that were above 40 g/100 g. Generally, the crackers that were made from germinated flours of both cultivars had higher carbohydrates contents than those of their fermented counterparts. The findings from this study were lower than the range of 68.26 – 69.76 g/100 g reported by Akeem et al., (2023).

3.3. Micronutrients (Zinc, Copper and Iron) contents and functional properties

The zinc contents of *Bira* untreated and fermented crackers were significantly ($p \leq 0.05$) higher than those of the other crackers (Table 3), whereas the zinc contents of crackers that were made from all the *Nakare* flours were statistically ($p > 0.05$) the same. The zinc contents of the crackers in this study were in the range of 2.90–3.30 mg/100 g reported by Hassan et al. (2021). However, the zinc contents of the crackers from this study were higher than the range of 1.03–1.76 mg/100 g of zinc contents that were found in the wheat crackers reported by Ahmed and Abozed (2015). The copper contents (Table 3) of the crackers were in this order UNC > FBC = FNC = GBC > GNC = UBC. The differences in the copper contents can be attributed to how different cultivars respond to the bioprocessing techniques. The crackers that were made from the fermented and germinated *Nakare* flours had significantly ($p \leq 0.05$) lower iron contents (Table 3) than all the other crackers. The iron contents of all the crackers from this study were higher than the range of 1.50–3.05 mg/100 g reported by Omar & Sonkar, (2019). A daily consumption of at least 100 g of these crackers can meet at least 60 % of the recommended daily intake (10 mg for iron;

Table 3
Proximate composition, carbohydrates, zinc, copper and iron contents of crackers made from untreated, germinated and fermented cowpea flour[a].

Sample	Moisture (g/100 g)	Protein (g/100 g db)	Crude fibre (g/100 g db)	Fat (g/100 g db)	Ash (g/100 g db)	Carbohydrates (g/100 g db)	Zinc (mg/100 g)	Copper (mg/100 g)	Iron (mg/100 g)
UBC	4.04 ± 0.47[abc]	22.44 ± 0.98[b]	9.36 ± 5.52[a]	6.40 ± 0.22[abc]	6.64 ± 0.01[b]	42.25 ± 4.49[a]	3.24 ± 0.12[a]	0.62 ± 0.03 [cd]	8.16 ± 0.19[a]
FBC	5.44 ± 0.68[a]	25.14 ± 1.14[a]	4.08 ± 0.52[b]	7.61 ± 0.14[ab]	6.70 ± 0.08[b]	34.75 ± 1.60[bc]	3.29 ± 0.10[a]	0.88 ± 0.19[b]	7.14 ± 2.40[abc]
GBC	3.55 ± 0.57[bc]	23.05 ± 0.28[b]	6.95 ± 0.43[ab]	5.10 ± 0.15[c]	7.44 ± 0.13[a]	40.02 ± 0.41[a]	2.91 ± 0.04[b]	0.80 ± 0.09[bc]	6.33 ± 0.12[bc]
UNC	2.86 ± 0.64[c]	21.84 ± 0.76[b]	5.49 ± 0.91[ab]	7.68 ± 0.51[ab]	6.83 ± 0.01[b]	38.14 ± 0.79[ab]	2.78 ± 0.15[b]	1.11 ± 0.12[a]	8.07 ± 0.46[a]
FNC	4.99 ± 1.08[ab]	24.76 ± 1.02[a]	3.31 ± 0.18[b]	8.35 ± 2.70[a]	5.77 ± 0.08[c]	32.82 ± 3.72[c]	2.91 ± 0.04[b]	0.82 ± 0.10[b]	5.82 ± 0.45[c]
GNC	3.97 ± 0.58[abc]	22.82 ± 0.23[b]	7.42 ± 2.31[ab]	5.92 ± 0.60[bc]	6.76 ± 0.12[b]	39.75 ± 1.90[a]	2.93 ± 0.03[b]	0.53 ± 0.03[d]	7.01 ± 0.22[abc]

[a] values = mean ± standard deviation ($n = 3$). Different lowercase letters in each column show statistically significant ($p \leq 0.05$) differences between the various treatments. Abbreviations: UBC (Untreated *Bira* Crackers); FBC (Fermented *Bira* Crackers); GBC (Germinated *Bira* Crackers). UNC (Untreated *Nakare* Crackers) FNC (Fermented *Nakare* Crackers) and GNC (Germinated *Nakare* Crackers)

5 mg for zinc and 0.5 mg for copper) for iron, zinc and copper for children aged 4–8 years old as per the Australian National Health and Medical Research Council (2006). Excessive contents of zinc tend to affect the absorption of iron and form complexes that lower its bioavailability (National Health and Medical Research Council, 2006 and Piskin et al., 2022). Similarly, the high contents of iron may reduce the absorption of zinc.

3.4. Functional properties

The water absorption index (WAI) of crackers ranged between 2.77 and 3.22 g/g (Table 4). The highest WAI were exhibited by the crackers that were made from the untreated and fermented *Bira* flours. The higher WAI values in these crackers suggest a relatively high presence of hydrophilic starches and other components (Guha et al., 2003). This study's findings were lower than the range of 3.31–3.52 g/g reported by Uukule et al. (2023) for the crackers that were made from pearl millet, wheat and oyster mushroom composite flours. The WSI (Table 4) of the crackers ranged between 0.021 and 0.038 g/g. The highest WSI was observed in the crackers that were made from the germinated *Bira* flours, while the lowest was noted for crackers that were made from the fermented *Nakare* flours. The relatively higher WSI values suggest that a relatively higher degree of gelatinisation and/or dextrinisation occurred (Guha et al., 2003), which presumably made the starch granules more soluble. This increased solubility may lead to a full tummy effect (feeling of satiety). The findings of this study were lower than the WSI (0.13 g/g - 0.185 g/g) reported by Uukule et al. (2023) for the crackers that were made from pearl millet, wheat and oyster mushroom composite flours. The higher WAI reported by Uukule et al. (2023) were possibly due to the presence of water-loving beta glucans in oyster mushrooms.

3.5. Differential scanning calorimetry thermal properties

The thermal behaviours (onset temperature (T_o), peak temperature (T_p) and conclusion temperature (T_c), peak width (ΔT), enthalpy (ΔH)) of the crackers that were made from the untreated, fermented and germinated *Bira* and *Nakare* cowpea varieties are shown in Table 4. The onset temperatures followed this order: GNC = UNK = FNC > FBC = UBC > GBC. The crackers that were made from all the *Nakare* flours had significantly ($p \leq 0.05$) higher onset temperatures than those of the *Bira* crackers. The relatively high onset temperatures of the crackers that were made from *Nakare* flours suggest that there was relatively less gelatinisation of starch in these crackers and thus more starch double helices were not disorganised and/or uncoiled (Li, 2022) to the same extent as for the other crackers. The relatively low onset temperatures of the crackers that were made using the germinated *Bira* flours suggest that germination led to starch hydrolysis and thus possibly resulted in a relatively low number of large molecular weight starch molecules. The peak temperatures of crackers order were as follows: GNC = FNC> UNC = FBC > UBC > GBC. The crackers that were made using the germinated and fermented *Nakare* flours had the highest peak temperatures than those of the other crackers. This suggests that the baking of these crackers left most of the interactions between long amylopectin chains themselves and/or with amylose chains in these crackers undisturbed or were the least disturbed (Wang et al., 2016). The peak widths of the crackers ranged from 12.04 – 16.78°C. The order was as follows: GNC ≥ GBC ≥ UBC ≥ FNC ≥ FBC ≥ UNC. The relatively wider peaks indicate that there were numerous but different entities that melted and recrystallised (Goldstein et al., 2010) in the crackers that were made using the germinated cowpea flours. The heat transition enthalpy values for all the crackers ranged from 2.70 to 7.83 J/g. The enthalpy values followed this order: FNC = UNC = GNC > UBC = GBC = FBC. The relatively high enthalpy values observed in all the *Nakare* crackers suggest that relatively low starch gelatinisation, protein denaturation and/or less structural changes occurred during the baking of these crackers.

3.6. Consumer sensory evaluation

The frequency of rating on the overall liking of crackers based on the 9-point hedonic scale is shown in Fig. 2. The Pearson's Chi-square test of independence revealed that there was no significant ($p > 0.05$) relation between the crackers and overall liking scores. The crackers that were made from the germinated *Bira* flours had the highest overall liking, with 45 % of consumers rating them 7–9. Most of the crackers had moderate ratings (4−6) (Nantanga et al., 2008). In general for all the crackers, 82 % of the consumers rated them from moderate liking to extreme liking. For the first time, this study revealed that consumers had a strong liking of the crackers that were made using the bioprocessed whole cowpea grain flours. Other studies found far lower levels of consumers liking of the germinated cowpeas or lentils products. For instance, lower scores of 3.9 – 4.7 were reported for the *Akara* and *Moin-moin* that were made from the cowpea that were germinated for 48 h by Uwaegbute et al. (2000) in comparison to those that were found in this study. Polat et al. (2020) reported a reduction in the overall acceptability of crackers that were made from the composite flours of wheat and germinated lentils, due to an increase in lentil incorporation level.

4. Conclusions

For the first time, the crackers were made using fermented or germinated cowpea grain flours, without the use of and composited cowpea grain flours. In comparison to common wheat crackers, the cowpea crackers had higher amounts of proteins and minerals. The iron contents of the cowpea crackers in this study were 78 % and those of zinc were 54 % more than those reported in common wheat crackers. The crackers that were made from the flours of *Nakare* cowpeas had relatively low water absorption indices and relatively high gelatinisation temperatures and enthalpies. These suggest that the *Nakare* crackers had relatively less gelatinised starch granules and thus a low digestibility potential. These crackers can thus be ideal for type 2 diabetic or pre-diabetic consumers. This study improved and diversified the forms of products of cowpea pulses by developing low sugar, low production technology, high protein, low moisture, and shelf-stable products for the market. Furthermore, the consumers sensory evaluation

Table 4
Water absorption (WAI) and Solubility indices (WSI), Thermal properties of crackers made from untreated, fermented and germinated Cowpea[a].

Sample	WAI (g/g)	WSI (g/g)	Onset Temp °C (T_o)	Peak Temp °C (T_p)	Conclusion temp °C (T_c)	Peak width (ΔT) °C	Enthalpy J/g (ΔH)
UBC	3.23 ± 0.04^{a}	0.028 ± 0.00^{b}	74.64 ± 0.38^{bc}	81.07 ± 0.91^{cd}	88.85 ± 1.07^{c}	14.21 ± 0.69^{bc}	3.82 ± 0.83^{b}
FBC	3.16 ± 0.06^{ab}	0.024 ± 0.03^{c}	74.95 ± 0.63^{b}	82.82 ± 0.94^{b}	88.05 ± 0.78^{c}	13.10 ± 0.16^{bc}	2.70 ± 0.24^{b}
GBC	2.77 ± 0.10^{d}	0.038 ± 0.18^{a}	73.80 ± 0.16^{c}	79.85 ± 0.04^{d}	88.88 ± 0.85^{c}	15.09 ± 1.01^{ab}	3.31 ± 0.60^{b}
UNC	3.06 ± 0.07^{bc}	0.028 ± 0.12^{b}	77.47 ± 0.65^{a}	82.400 ± 0.23^{bc}	89.51 ± 0.81^{bc}	12.04 ± 1.46^{c}	6.94 ± 1.00^{a}
FNC	3.02 ± 0.02^{c}	0.021 ± 0.08^{d}	77.45 ± 0.07^{a}	84.36 ± 0.23^{a}	91.35 ± 1.22^{b}	13.90 ± 1.29^{bc}	7.83 ± 0.00^{a}
GNC	2.99 ± 0.07^{c}	0.028 ± 0.12^{b}	77.55 ± 0.078^{a}	84.96 ± 0.18^{a}	94.32 ± 0.81^{a}	16.78 ± 0.73^{a}	6.68 ± 0.72^{a}

[a] values =mean ± standard deviation ($n = 3$). Different lowercase letters in each column shows statistically significant ($p \leq 0.05$) differences between the various treatments. Abbreviations: UBC (Untreated *Bira* Crackers); FBC (Fermented *Bira* Crackers); GBC (Germinated *Bira* Crackers). UNC (Untreated *Nakare* Crackers) FNC (Fermented *Nakare* Crackers) and GNC (Germinated *Nakare* Crackers).

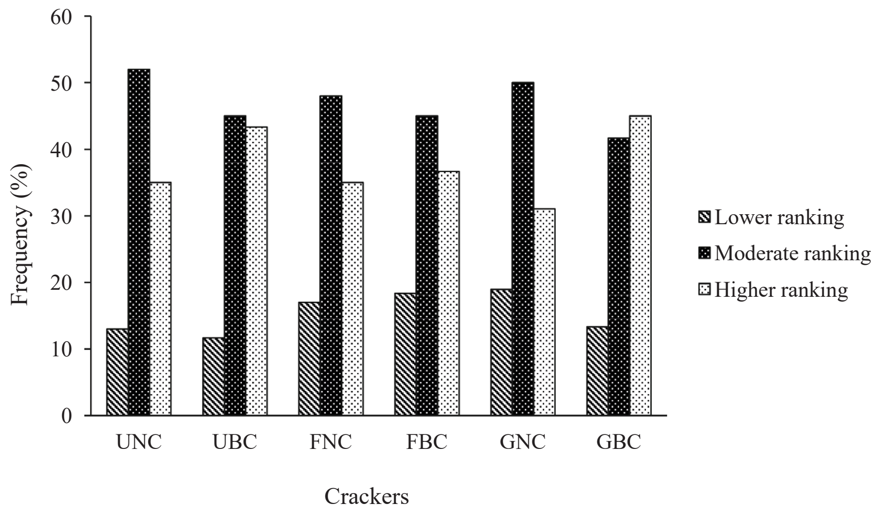

Fig. 2. Frequency percentage of Overall liking scores in the different categories (Nantanga et al., 2008) of the 9-point hedonic scale and mean ratings for crackers made from cowpea flours subjected to different treatments (n = 60). Mean values were not statistically different ($p > 0.05$), as per Pearson's Chi-square of independence. Higher rating (7 = like moderately to 9 = like extremely), Moderate rating (4 = dislike slightly to 6 = like slightly) and Lower rating (1 = dislike extremely to 3 = dislike moderately). Abbreviations: UBC (Untreated *Bira* Crackers) FBC (Fermented *Bira* Crackers); GBC (Germinated *Bira* Crackers) UNC (Untreated *Nakare* Crackers); FNC (Fermented *Nakare* Crackers) and GNC (Germinated *Nakare* Crackers).

indicated that more than 82 % of participants scored these crackers with moderate to extremely liking on the 9-point hedonic scale. The development and if accompanied by marketing of germinated or fermented cowpeas grain flour crackers have the potential (pending the bioavailability and anti-nutrients evaluation) to reduce the protein and minerals deficiencies in the diets of young children especially in the developing nations.

CRediT authorship contribution statement

Fan Zhu: Visualization, Validation, Methodology, Conceptualization. **Yiyun Wei:** Visualization, Validation, Methodology, Data curation. **Komeine Kotokeni Mekondjo Nantanga:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Conceptualization. **Werner Embashu:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Wilhelmina Vulikeni Kanime:** Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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