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CHEMICAL COMPOSITION, ANTIOXIDANT PROPERTIES, AND SENSORY ASPECTS OF GINGERBREAD ENRICHED WITH GREEN COFFEE AND CASCARA

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ABSTRACT

Background. With growing consumer health consciousness, there is an increasing demand for value-added food products that offer greater nutritional benefits and improved sensory profiles. Enhancing traditional foods with functional ingredients provides a vital avenue for meeting this demand.

Materials and methods. This study describes the preparation and analysis of gingerbread enriched with 10% green coffee and 10% cascara. The formulated samples were analysed to determine their nutritional composition, antioxidant characteristics, chlorogenic acid content, and caffeine content, and they were subjected to a sensory evaluation.

Results. The ash content in the gingerbread samples ranged from 1.16% to 1.34%, with the sample containing 10% green coffee exhibiting the highest crude protein level at 10.57%. The antioxidant capacity was between 0.91 mg TEAC/g and 1.5 mg TEAC/g, with the green coffee sample containing the highest total polyphenol content at 1.38 mg GAE/g. Caloric values remained consistent across all samples at approximately 45.700 kcal/100 g. Additionally, minerals including copper, zinc, manganese and iron were detected in the enriched gingerbread samples, while no detectable levels of risk elements (cadmium, lead or mercury) were observed. The addition of green coffee and cascara significantly ($p < 0.005$) increased the concentrations of chlorogenic, neo-chlorogenic and crypto-chlorogenic acids. The green coffee had a caffeine concentration of 303.67 μg/g. The sensory evaluation generated positive feedback, especially regarding aroma and taste, indicating that the addition of green coffee and cascara enhanced the product's nutritional and sensory properties.

Conclusions. This study suggests that gingerbread enriched with green coffee and cascara presents an appealing option for health-conscious consumers, offering a pastry that maintains its freshness with the added

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benefit of a mild, natural stimulant effect from caffeine. This enrichment not only contributes to the product's nutritional profile but also aligns with current consumer trends favouring functional and health-promoting foods.

Keywords: stimulating plants, enriched food, caffeine, phenolic acids, antioxidant

INTRODUCTION

Coffee ranks as the second most traded commodity after petroleum and is one of the most consumed beverages worldwide (Mussatto et al., 2011). In the initial phase of the coffee production process, mature coffee berries are harvested. They subsequently undergo one of two treatments – either a wet process, or a dry process – to separate the pulp from the bean, leaving the green coffee bean (Klingel et al., 2020). The parchment residue is retained in cascara, which is produced in the dry process. This method offers a more traditional way to obtain cascara with a pleasant flavour and aroma. The parchment is a by-product that can also be utilized in various applications (Klingel et al., 2020; Littardi et al., 2020). Disinfection in rural coffee fields is unfeasible, rendering the production of cascara through the wet method a meticulous undertaking.

The fermentation process and unmanaged bacteria may induce off-flavours. Contamination and the subsequent development of harmful substances like ochratoxin A and aflatoxins are thus highly likely (Buck et al., 2021). Dried cascara can also be used to produce an aqueous infusion for use in beverages, as a base ingredient for other foods (for example, as a flour replacement in gluten-free cookies; Rosas-Sánchez et al., 2021), or as a flavouring for foods and alcoholic beverages (Neupane et al., 2021). The European Food Safety Authority (EFSA) has evaluated two notifications for cascara as a traditional food from a third country and one complete application (Lachenmeier et al., 2021). They did not find any safety concerns associated with putting dried cherry pulp on the market within the EU (Turck et al., 2022).

Following the removal of skin, pulp, mucilage and parchment from coffee cherries through dry or wet processing, green coffee beans are produced and then sold on the international market. These beans are still mostly covered by their silver skin, which can be removed in a further, optional polishing step (Joët et al., 2010). Green coffee has a mild, bean-like aroma (Madhava Naidu et al., 2008). The main constituents of green coffee are insoluble polysaccharides (~50%) such as celluloses and hemicelluloses. In addition to complex carbohydrates, it contains mono- and oligosaccharides, oils, and waxes (8%–18%), proteins and amino acids (9–12%), minerals (3–5%), and polyphenolic compounds (Anthony et al., 1993; Arya and Rao, 2007). The most common alkaloid in green coffee is caffeine (1–4%), whose concentration strongly depends on the variety and growing conditions, followed by trigonelline (~0.8%) (Dessalegn et al., 2008). Trigonelline is partially degraded during coffee roasting, forming *N*-methyl pyridinium ions by decarboxylation and nicotinic acid by demethylation (Lang et al., 2008).

Green coffee is categorized as a novel food within the realm of coffee by-products, as end consumers generally only consume roasted coffee. However, green coffee can be marketed unroasted, and an infusion can be prepared from the chopped beans through non-selective water extraction (Onakpoya et al., 2011; Macheiner et al., 2019). Extracts tailored to the requirements of the food industry can typically be obtained through extraction using hot water (Suzuki et al., 2002), alcohol (Thom, 2007), or a combination of the two (Madhava Naidu et al., 2008). Such extracts require independent evaluation as novel foods. They are offered in tablet form as dietary supplements or utilized in the production of beverages or chewing gum. The extracts are marketed for their possible health benefits, attributed to their high chlorogenic acid concentration, which may be slightly diminished by roasting; however, some of these effects remain unverified (Klingel et al., 2020).

Caffeine is known to affect the central nervous system and is popular for its stimulant effect (Vaclavik et al., 2013). Currently, a great deal of research is focused on waste material recovery, recycling, and optimization, especially in the food processing industry, where valuable by-products and residues can be turned into beneficial products and value-added dietary supplements, such as those containing bioactive compounds and dietary fibre (Laufenberg et al., 2003; Elleuch et al., 2011). The utilization of food processing by-products to encourage a varied diet has significantly expanded opportunities for waste reduction, indirect income generation and the lowering of raw material expenses (Sharma et al., 2016), leading such by-products to be considered novel foods with beneficial properties (Klingel et al., 2020). Cereal-based food products have been the basis of the human diet since ancient times. Cereals are an excellent source of all three macronutrients essential for daily bodily functions: protein, fat, and carbohydrates (Borneo and León, 2012). However, they naturally contain only low levels of micronutrients, most of which are lost during food processing (Poletti et al., 2004), presenting opportunities to incorporate additional micronutrient-rich ingredients. Coffee waste has been documented as a potential source of bioactive components, primarily secondary metabolites like phenolic acids, including hydroxycinnamic acids and flavonoids, which are valued for their advantageous antioxidant qualities (Abdeltaif et al., 2018). However, the benefits of recycling should not be undermined by the environmental impact of new production processes (Mirabella et al., 2014). The combination of gingerbread, green coffee, and cascara in cereal technology is a novelty because it integrates novel ingredients into traditional formats (such as cereals and snack bars), offering not only a unique taste experience but also functional benefits and sustainability. This innovative approach taps into the health-conscious, sustainability-driven market while challenging traditional cereal flavour profiles, making it an exciting development in the food industry. Consequently, this study aims to elucidate the chemical composition, antioxidant properties, and sensory aspects of gingerbread enriched with green coffee and cascara.

MATERIALS AND METHODS

Chemicals

All the chemicals used were of analytical grade and were purchased from Sigma-Aldrich (St. Louis, USA) and Central Chem (Bratislava, Slovak Republic).

Preparation of gingerbread

The ingredients were purchased from the local market and included: wheat flour (T 550), powdered beet sugar, sodium bicarbonate, flower honey, butter, eggs, and spices (mixture for gingerbread – cinnamon, clove, nutmeg, coriander, star anise, anise, nutmeg flower, fennel). Altogether, two variants of gingerbread were prepared: one supplemented with 10% green coffee and the other with 10% cascara (Tab. 1). Preliminary sensory analyses (data not shown) conducted at the Institute of Food Sciences (Nitra, Slovakia) indicated that supplementation at 10% was optimal, which is why this level of additive was used in this study. After kneading, the dough was allowed to rest for 60 min at 4°C. It was then rolled with a hand roller to obtain a thickness of about 6–7 mm. The desired shapes were cut out of the dough and formed by hand. Later, they were baked at 160°C for 20 minutes in a traditional brick oven. After cooling for 30 minutes, the gingerbread was packed in polyethylene zipper resealable food bags and stored at 21°C and 50% relative humidity before the analysis of its chemical, antioxidant, and sensory characteristics.

Table 1. The ingredients of the green coffee, cascara and control gingerbread

Ingredients	Gingerbread 10% green coffee	Gingerbread 10% cascara	Control
Wheat flour T 550	200 g	200 g	200 g
Powdered beet sugar	70 g	70 g	70 g
Egg	80 g	80 g	80 g
Butter	70 g	70 g	70 g
Green coffee	20 g	–	–
Cascara	–	20 g	–
Flower honey	50 g	50 g	50 g
Spices	2 g	2 g	2 g
Sodium bicarbonate	1 g	1 g	1 g

Dry matter, ash, crude protein, and fat content

Dry matter, ash, and protein content were determined following the standard AACC Approved Methods (Cereals & Grains Association, 2023). The nitrogen content was measured by the semi-micro-Kjeldahl method. Nitrogen was converted to protein using the conventional factor of 5.7 for wheat. The fat content was determined with an Ancom XT15 Fat Extractor (USA) in line with the manufacturer's instructions – the sample (1.5 g, W1) was weighed in a special filter bag (XT4, Ancom, USA) and dried for 3 hours in an oven (WTB, Binder, Germany) at 105°C to remove moisture before the extraction. The samples were placed in a desiccant pouch for 15 minutes, re-weighed (W2), and the fat was extracted for 60 minutes at 90°C using petroleum ether. After the process, the samples were removed, dried in an oven at 105°C for 30 minutes, placed in a desiccant pouch, and re-weighed (W3). The fat content (%) was calculated using the following formula (1):

$$\text{Fat content} = [(W2 - W3)/W1] \times 100 \qquad (1)$$

Mineral compound composition

The analysis of mineral compounds was performed with a Varian model AA 240 FS equipped with a D2 lamp background correction system using an air-acetylene flame (air 13.5 L/min, acetylene 2.0 L/min, Varian, Ltd., Mulgrave, Australia). The results were compared with multi-elemental standards for GF AAS (CertiPUR®, Merck, Germany). A 1 g sample was digested with a mixture of HNO_3:redistilled water (1:1). Samples were digested in a closed-vessel high-pressure microwave digester (MARS X-press, USA) for 55 min. After cooling to room temperature, the suspension was filtered through Munktell filter paper (grade 390.84 g/m^2, Germany) and diluted to 50 mL with distilled water. The sample extracts were subsequently analysed for Cd, Pb, Cu, Zn, Co, Cr, Ni, Mn, and Fe. The wavelengths at which the heavy metals were analysed following the calibration process were as follows: Cd – 228.8 nm, Pb – 217.0 nm, Cu – 324.8 nm, Zn – 213.9 nm, Co – 240.7 nm, Cr – 357.9 nm, Ni – 232.0 nm, Mn – 279.5 nm, Fe – 241.8 nm.

Calorific value

The calorific values of the samples were determined with a bomb calorimeter IKA C 5000 (IKA Works, Inc., Wilmington, USA). The adiabatic method was used for the measurement, as it is more suitable for loose samples. The samples were placed in the crucible of the bomb calorimeter and were electrically ignited to burn in the presence of pure oxygen. The samples were weighed using external scales (Libra Axis AG1000C, Poland), and their masses ranged from 0.63 mg to 0.89 mg. Cotton threads were used to ignite the samples, which had been placed in quartz crucibles with a diameter of 20 mm and a height of 20.5 mm. During combustion, heat was released, and the increase in temperature was measured. Dry benzoic acid was used to calibrate the effective heat capacity of water in the calorimeter.

Antioxidant characteristic

Preparation of extracts

20 mL of 80% ethanol was used to extract one gram of homogenized material (IKA, A10, Germany, Mesh 8) over two hours at room temperature. The supernatant from centrifugation at 3000×g (Himac CT 6E, Hitachi Ltd., Japan) for 20 min was used to determine total polyphenols, phenolic acids and the DPPH. 20 mL of 96% ethanol was used to extract one gram of homogenized material (IKA, A10, Germany, Mesh 8) over 24 hours at room temperature. The supernatant from centrifugation at 3000×g (Himac CT 6E, Hitachi Ltd., Japan) for 20 min was used to determine the HPLC.

DPPH – free radical scavenging capacity

According to the steps outlined by Yen and Chen (1995), with slight modifications, the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay was used to measure the samples' capacity to scavenge free radicals. 0.012 g of DPPH was dissolved in 100 mL of ethanol, and 4 mL of the DPPH solution was added to the extracts (1 mL). At 510 nm, the absorbance of the extracts was measured using a BioTek Microplate Reader (ELx800). The samples' ability to neutralize free radicals was measured in terms of mg of Trolox Equivalent Antioxidant Capacity (TEAC) per gram of dry matter.

Total polyphenol content

The total polyphenol content of the samples was determined spectrophotometrically using Folin-Ciocalteu reagent with slight modifications (Singleton et al., 1999). 0.1 mL of Folin-Ciocalteau reagent, 0.1 mL of sample extract, and 1 mL of 20 % sodium carbonate were combined. A BioTek Microplate Reader (Elx800) was used to detect absorbance at 700 nm. The total amount of polyphenols was reported as mg/g of dry matter in terms of Gallic Acid Equivalent (GAE).

Chlorogenic acid and caffeine content determination by the HPLC-DAD method

The chlorogenic acid content and caffeine content were determined using the separation gradient method RP-HPLC/UV-DAD on an Agilent 1260 Infinity high-performance liquid chromatograph (Agilent Technologies, Waldbronn, Germany). Separation was achieved on a Purosphere reverse phase C18 column (4 mm × 250 mm × 5 μm) (Merck, KgaA, Darmstadt, Germany). The mobile phase consisted of HPLC methanol (B) and 0.1% formic acid in HPLC water (C). The following gradient program was employed: 0–2 min, isocratic elution (20 % B and 80% C); 2–15 min, linear gradient elution (40% B and 60% C); 15–20 min, isocratic elution (40% B and 60% C). The flow rate was 1 mL/min. The column oven temperature was set to 25°C and the samples were kept at 4°C in the Peltier sample manager. The DAD monitored the eluate over a wavelength range of 210–400 nm, with a preferred wavelength of 330 nm for quantification and a data acquisition rate of 5 Hz (Demianová et al., 2021).

Sensory characteristic

A sensory panel of 40 evaluators – 20 women and 20 men, aged 22 to 62 – determined the organoleptic qualities of the gingerbread. The panellists were asked to assess its appearance, aroma, taste, aftertaste, and overall acceptability. The samples were rated on a 9-point hedonic scale, with values ranging from 9 (like very much) to 1 (strongly dislike).

Statistical analysis

All tests were carried out in triplicate, and the results are reported as means with standard deviations. The experimental data were analysed using SAS 2009 software, applying analysis of variance with Duncan's test at a 0.05 confidence level.

RESULTS AND DISCUSSION

Nutritional composition

There were significant differences between the three gingerbread samples in terms of ash content, crude protein, and fat content. Gingerbread enriched with cascara had a significantly ($p < 0.0001$) higher ash content, specifically 15.2% compared to the control and 4.1% compared to the sample enriched with green coffee. Cascara, a coffee industry by-product, is potentially beneficial to health due to its fibre and bioactive components (Setiaboma et al., 2024). The addition of 10% cascara flour (which is rich for mineral compounds) into bread increased the ash content (4.91%) compared to the control sample (3.02%) (Utami et al., 2021; Setiaboma et al., 2024). Similarly, a bread sample enriched with 10 % green coffee had a higher ash content (1.287 ±0.021%) than the control (0.93%), as reported by Dawi et al. (2024). The increase in ash content in the fortified samples suggests that the addition of green coffee and cascara can improve the mineral profile of baked goods. Moreover, the ash content was higher than the ash content of bread made with additional quinoa flour (0.75–0.82%) (Coţovanu et al., 2023). The mineral content of such products is important for meeting daily nutritional requirements, as minerals are crucial for various bodily functions, including bone health, nerve function, and enzyme activation (Gharibzahedi and Jafari, 2017). Therefore, the fortification of gingerbread with green coffee and cascara offers a viable means of increasing the dietary intake of essential minerals.

A notable difference in crude protein content was observed across the samples (Tab. 2). The gingerbread enriched with green coffee exhibited a significant increase in crude protein content (10.567 ±0.435%) compared to the control (8.027 ±0.015%) and the cascara-enriched sample (8.497 ±0.021%). The higher protein content in green coffee-enriched gingerbread is consistent with the previous findings of Dawi et al. (2024) regarding enriched bread: WFG12 (88:12%), WFG16 (84:16%), and WFG20 (80:20%), in which wheat flour was replaced with green coffee bean at levels of 8.55%, 8.15%, and 6.24%, respectively. The increase in protein content through green coffee fortification is particularly relevant for enhancing the nutritional value of baked goods, especially in addressing

Table 2. Nutritional composition and caloric value of gingerbread enriched with green coffee and cascara

Samples	Control	With green coffee, 10%	With cascara, 10%
Ash, %	1.163 ±0.006^{c}	1.287 ±0.021^{b}	1.340 ±0.010^{a}
Crude protein, %	8.027 ±0.015^{b}	10.567 ±0.435^{a}	8.497 ±0.021^{b}
Fat, %	13.103 ±0.021^{b}	13.267 ±0.057^{a}	13.170 ±0.046^{b}
Caloric value, kcal/100 g	45.630 ±1.001^{c}	45.829 ±1.300^{b}	45.8595 ±1.401^{a}

Note: values are means ±SD; n = 3. Different superscript letters (a, b, c) in the same row represent mean values that are statistically different ($p < 0.05$) from one another.

dietary protein requirements essential for muscle repair, immune function, and hormone production (Poletti et al., 2004; Gharibzahedi and Jafari, 2017). The fat content was relatively consistent across the gingerbread samples, with slight variations among the different formulations. The green coffee-enriched sample contained 13.267 ±0.057% fat, while the cascara-enriched sample had 13.170 ±0.046%, and the control had 13.103 ±0.021%. These differences, though present, were not statistically significant ($p > 0.05$). The fat content of the treatment was comparatively higher than the 9.84–10.60% reported by Setiaboma et al. (2024). This result contrasts with the findings of Rios et al. (2020), who studied gluten-free products made with isolated cascara dietary fibre. In their study, fat content did not exhibit significant differences, whereas protein content did. Fat is an essential macronutrient that provides energy, aids in the absorption of fat-soluble vitamins (A, D, E, and K), and contributes to the texture and flavour of food products (Sharma et al., 2016).

The caloric value (Tab. 2) of the gingerbread samples also showed only slight variations, with the cascara-enriched sample exhibiting the highest caloric value (45.8595 ±1.4001 kcal/100 g), followed closely by the greencoffee-enriched samples (45.829 ±1.300 kcal/100 g) and the control (45.630 ±1.001 kcal/100 g).

The minor increase in caloric value in the samples is likely due to the higher ash and protein content, as both protein and minerals contribute to the overall caloric value of food products (Utami et al., 2021).

Mineral composition

Table 3 presents the mineral content of the control and gingerbread samples enriched with 10% green

Table 3. Mineral composition of gingerbread enriched with green coffee and cascara

Samples	Control	With green coffee, 10%	With cascara, 10%
Cu, mg/kg	1.630 ±0.046^{c}	2.127 ±0.021^{a}	1.847 ±0.021^{b}
Zn, mg/kg	5.130 ±0.020^{b}	5.690 ±0.053^{a}	5.197 ±0.042^{b}
Mn, mg/kg	6.630 ±0.020^{c}	7.723 ±0.118^{a}	6.870 ±0.040^{b}
Fe, mg/kg	12.403 ±0.070^{c}	13.820 ±0.118^{a}	12.853 ±0.097^{b}
Cr, mg/kg	0.030 ±0.020^{b}	0.130 ±0.020^{a}	0.030 ±0.010^{b}
Ni, mg/kg	0.140 ±0.026^{c}	0.177 ±0.006^{b}	0.323 ±0.015^{a}
Co, mg/kg	0.013 ±0.006^{c}	0.053 ±0.015^{b}	0.073 ±0.006^{a}
Pb, mg/kg	0.000 ±0.000^{b}	0.103 ±0.012^{a}	0.000 ±0.000^{b}

Note: values are means ±SD; n = 3. Different superscript letters (a, b, c) in the same row represent mean values that are statistically different ($p < 0.05$) from one another.

coffee and cascara. According to the Food and Nutrition Board, minerals are categorized as bone-related nutrients (Ca, Mg) and trace elements (Cr, Cu, Fe, Mn, Mo, Zn, Ni, V). Metals in foods and beverages are further classified as essential (e.g., Fe, Zn, Cu, Mn, Cr, Co, V) or toxic at certain levels (e.g., Pb, Cd, Ni, As, Hg). Based on human nutritional requirements, minerals are also divided into bulk minerals (e.g., Ca, Mg, K, Na) with a Recommended Dietary Allowance (RDA) > 200 mg/day and trace minerals (Gure et al., 2019). Green coffee is known to contain a variety of trace elements, including iron (Fe), aluminium (Al), copper (Cu), iodine (I), fluoride (F), boron (B), and manganese (Mn), with potassium (K) being its most abundant mineral, constituting nearly 40% of its dry weight (Gure et al., 2019). The addition of green coffee significantly ($p < 0.05$) elevated the copper content to 2.127 ±0.015 mg/kg, the highest among the samples. The zinc (Zn) concentration in the green coffee-enriched sample (5.690 ±0.053 mg/kg) was significantly ($p < 0.05$) higher than the concentrations in the control and cascara-enriched samples. The manganese (Mn) content increased notably in both enriched samples, to 7.723 ±0.118 mg/kg in green coffee-enriched gingerbread and 6.870 ±0.040 mg/kg in cascara-enriched gingerbread, compared to 6.630 ±0.020 mg/kg in control. Manganese plays a crucial role in bone development and metabolic processes, particularly enzyme activation in glucose metabolism (Ding et al., 2020). Prior studies confirm the high manganese content of green coffee, explaining the significant increase in the fortified samples (Farah et al., 2006). This supports the idea that cascara and green coffee can improve the functional properties of baked goods (Rozali et al., 2024). Iron (Fe) levels were also higher in the green coffee-enriched (13.820 ±0.118 mg/kg) and cascara-enriched (12.853 ±0.097 mg/kg) samples than in the control (12.403 ±0.070 mg/kg). For adults, the recommended daily doses of manganese, iron and zinc are 2.3 mg, 8.7 mg and 11 mg, respectively (Ding et al., 2020). Consumption of 50 g of gingerbread enriched with 10% green coffee can cover 16.95 % of the recommended daily dose of manganese, 5.91 % of the recommended daily dose of iron and 3.22% of the recommended daily dose of zinc. Chromium (Cr) levels were significantly elevated in green coffee-enriched gingerbread (0.130 ±0.020 mg/kg), in contrast to the control and cascara-enriched samples, both of which had 0.030 mg/kg. Nickel (Ni) content was highest in the cascara-enriched sample (0.323 ±0.015 mg/kg), followed by the green coffee-enriched sample (0.177 ±0.006 mg/kg) and the control (0.140 ±0.026 mg/kg). This increase in nickel content aligns with previous findings that cascara contains notable amounts of nickel (Esquivel and Jiménez, 2012), underscoring the need for caution, particularly for individuals sensitive to this element. Cobalt (Co) levels were also highest in cascara-enriched gingerbread (0.073 ±0.006 mg/kg), followed by green coffee-enriched gingerbread (0.053 ±0.015 mg/kg) and the control sample (0.013 ±0.006 mg/kg). Lead (Pb) was undetectable in both the control and cascara-enriched samples, though it was present at 0.103 ±0.012 mg/kg in the green coffee-enriched sample. Overall, the highest mineral levels – except for Cr, Ni, Co, and Pb – were recorded in the 10% green coffee and cascara-enriched gingerbread, but all remained within acceptable regulatory limits.

Antioxidant characteristics

DPPH radical scavenging capacity

As shown in Table 4, the gingerbread enriched with green coffee exhibited the highest radical scavenging capacity (1.500 ±0.085 mg TEAC/g), followed by the cascara-enriched sample (1.330 ±0.020 mg TEAC/g) and the control (0.913 mg TEAC/g). The DPPH inhibition level in bread with 10% green coffee was 1.64 times higher than for the control sample and 1.128 times higher than for the sample with 10% cascara. These results are consistent with those of Butt and Sultan (2011), who observed a significant increase in DPPH inhibition in bread with 12% GCB.

The polyphenol content was highest (1.377 mg ±0.051TEAC/g) in the green coffee-enriched sample. The polyphenols from the green coffee, particularly chlorogenic acids, may account for the increased polyphenol content in the enriched gingerbread (Dawi et al., 2024). The high polyphenol content in green coffee-enriched gingerbread can be attributed to the tendency of unroasted green coffee to retain more bioactive compounds. Cascara is also a rich source of polyphenols, primarily flavonoids and phenolic acids (Budryn et al., 2015). The lower polyphenol content in the cascara-enriched gingerbread sample can be explained by the fact that cascara has a different

Table 4. Antioxidant characteristics of gingerbread enriched with green coffee and cascara

Samples	Control	With green coffee, 10%	With cascara, 10%
DPPH, mg TEAC/g	0.913 ±0.021[c]	1.500 ±0.085[a]	1.330 ±0.020[b]
Polyphenols, mg GAE/g	0.760 ±0.010[c]	1.377 ±0.051[a]	0.887 ±0.045[b]
Phenolic acids, mg CAE/g	0.043 ±0.006[c]	0.193 ±0.015[b]	0.253 ±0.040[a]

Note: values are means ± SD; n = 3. Different superscript letters (a, b, c) in the same row represent mean values that are statistically different ($p < 0.05$) from one another. GAE (Gallic Acid Equivalent), CAE (Caffeic Acid Equivalent), TEAC (Trolox Equivalent Antioxidant Capacity), DPPH (2,2-diphenyl-1-picrylhydrazyl).

polyphenol profile to green coffee, with lower chlorogenic acid levels (Butt and Sultan, 2011). Nevertheless, cascara still significantly increased the polyphenol content of gingerbread.

The phenolic acid content in the gingerbread enriched with cascara (0.253 mg ±0.040CAE/g) was significantly higher than gingerbread enriched with green coffee. This suggests that cascara is particularly rich in phenolic acids, corroborating findings from prior studies (Butt and Sultan, 2011). Cascara is abundant in hydroxycinnamic acids, including chlorogenic, caffeic, and ferulic acids, which are potent antioxidants (Torres-Mancera et al., 2011). These compounds have exhibited a capacity to reduce oxidative stress by scavenging free radicals and chelating metal ions, thus protecting cells from damage (Ayik et al., 2023). The higher phenolic acid content of the cascara-enriched gingerbread aligns with the results of Abduh et al. (2023), who ascribed the antioxidant potential of cascara to its high phenolic acid concentration. The green coffee-enriched sample also showed a significant increase in phenolic acid content compared to the control. Cheynier (2005) observed that phenolics are highly heat-sensitive and reactive compounds, and the baking process might have resulted in a reduction in phenolic compounds. Although the green coffee-enriched gingerbread had lower phenolic acid content than the cascara-enriched sample, it still exhibited a higher antioxidant capacity relative to the control.

HPLC-DAD

Caffeine is a stimulant found predominantly in coffee beans and some tea varieties (Esquivel and Jiménez, 2012). In the current study, the green coffee-enriched gingerbread had a substantial caffeine concentration of 303.667 ±3.215 mg/g. The absence of caffeine in the cascara sample is consistent with studies showing that cascara, derived from the husk of coffee cherries, typically contains little to no caffeine (Esquivel and Jiménez, 2012). On the other hand, green coffee is known for its significant caffeine content, which remains largely intact before roasting (Farah et al., 2006). This explains the high caffeine levels observed in the green coffee-enriched sample. Thus, the green coffee-enriched gingerbread delivers a substantial caffeine boost, which could appeal to consumers seeking an energy-boosting snack.

Based on the data shown in Table 5, the green coffee-enriched sample exhibited the highest concentration (462.000 ±2.646 mg/g) of chlorogenic acids. This aligns with a previous study reporting that green coffee is rich in chlorogenic acid, while cascara contains significantly lower levels of this compound (Wale et al., 2024). Chlorogenic acid is a major bioactive compound of green coffee beans that has numerous health benefits including weight reduction by the inhibition of fat absorption and activation of fat metabolism in the liver (Shimoda et al., 2006). The incorporation of green coffee into gingerbread may offer health benefits due to the presence of chlorogenic acid (Mukkundur Vasudevaiah et al., 2017).

Neo-chlorogenic acid and crypto-chlorogenic acid, two isomers of chlorogenic acid, were present in the green coffee-enriched gingerbread at concentrations of 81.333 ±2.328 mg/g and 291.333 ±1.528 mg/g, respectively. These isomers contribute to the overall antioxidant capacity of green coffee (Farah et al., 2006). The control and cascara-enriched samples exhibited no detectable levels of these compounds, which is consistent with a report that suggests cascara contains fewer chlorogenic acid derivatives than green coffee (Esquivel and Jiménez, 2012).

Table 5. Caffeine and chlorogenic acids (mg/g) in gingerbread enriched with green coffee and cascara

Samples	Control	With green coffee, 10%	With cascara, 10%
Caffeine	0.000 ±0.000^{b}	303.667 ±3.215^{a}	0.000 ±0.000^{b}
Chlorogenic	0.000 ±0.000^{c}	462.000 ±2.646^{a}	32.000 ±2.646^{b}
Neo-chlorogenic	0.000 ±0.000^{b}	81.333 ±2.328^{a}	0.000 ±0.000^{b}
Crypto-chlorogenic	0.000 ±0.000^{b}	291.333 ±1.528^{a}	0.000 ±0.000^{b}
3,5-dicaffeoylquinic acid	0.000 ±0.000^{b}	29.667 ±0.577^{a}	0.000 ±0.000^{b}
4,5-dicaffeoylquinic acid	0.000 ±0.000^{b}	30.000 ±1.000^{a}	0.000 ±0.000^{b}

Note: values are means ± SD; n = 3. Different superscript letters (a, b, c) in the same row represent mean values that are statistically different ($p < 0.05$) from one another.

The presence of dicaffeoylquinic acids, specifically 3,5-dicaffeoylquinic acid and 4,5-dicaffeoylquinic acid, was also notable in the green coffee-enriched gingerbread, with concentrations of 29.667 ±0.577 mg/g and 30.000 ±1.000 mg/g, respectively. These compounds are known for their potent antioxidant properties, helping to protect cells from oxidative stress and inflammation (Farah et al., 2008). The absence of dicaffeoylquinic acids in both the control and cascara-enriched samples supports the idea that green coffee is the primary source of these bioactive compounds. Comparatively, studies have shown that dicaffeoylquinic acids are present in much higher concentrations in unroasted coffee beans, such as green coffee, compared to roasted beans or other coffee by-products (Farah et al., 2006). Roasting significantly reduces the levels of these beneficial compounds due to thermal degradation (Daglia et al., 2002). Thus, the high levels of dicaffeoylquinic acids in green coffee-enriched gingerbread suggest that the addition of green coffee can significantly improve the health benefits of the final product.

Sensory characteristics

Gingerbread is a popular product consumed in different countries, especially at Christmas and Easter. Nowadays, this product is especially popular among younger generations due to its long shelf-life, as well as its taste. Enriching gingerbread with materials abundant in bioactive ingredients therefore seems to be a well-targeted approach. The overall appearance of gingerbread with cascara received a significantly higher score of 8.2 (Fig. 1). However, a study by Setiaboma et al. (2024) reported that increasing the concentration of cascara flour significantly decreased the colour, taste, texture, and overall appearance scores of cascara enriched bread. In our study, cascara's rich pigmentation may have contributed to this enhancement in appearance, aligning with findings by Arya et al. (2022) that highlighted the visual appeal of baked goods enriched with natural colorants from fruit skins (Iriondo-DeHond et al., 2020). The increased score for gingerbread with cascara suggests that consumers may prefer food products with a more visually striking appearance, potentially due to their associations with natural ingredients and perceived health benefits (Riandani et al., 2022). The sensory properties of gingerbread can be significantly influenced by Maillard

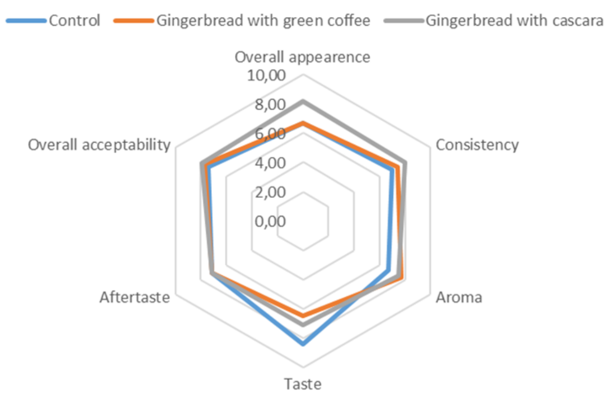

Fig. 1. Sensory characteristics of samples (sum of all evaluators)

reaction products, such as lysine, furosine and melanoidins. These compounds contribute to browning, which affects the colour and visual appeal of the gingerbread. They also produce flavour compounds, impacting the aroma, bitterness, and overall taste of the product. Melanoidins, for example, contribute to the characteristic roasted flavour, while furosine is a marker of more advanced glycation, potentially affecting bitterness and texture. These Maillard reaction products can be directly linked to sensory perception and the overall eating experience of gingerbread (Starowicz and Zieliński, 2019).

The consistency scores varied across samples, with the control scoring around 6.0, while the gingerbread enriched with green coffee and cascara scored between 7.0 and 8.0. This indicates that the introduction of both green coffee and cascara improved the texture of the gingerbread (Littardi et al., 2020). Moreover, Littardi et al. (2020) found that functional ingredients such as cascara can positively influence the water-holding capacity of baked products, contributing to a moister and more desirable texture. The slight improvement observed with green coffee may be linked to its potential to alter the dough's matrix (Ibrahim et al., 2020).

This study showed a significant increase in aroma from 6.7 to 7.7. The enhanced aroma in gingerbread with green coffee can be linked to the volatile compounds present in unroasted coffee beans, which are rich in aromatic compounds like chlorogenic acids (Farah et al., 2008). Cascara, with its fruity and floral scent, may also have contributed positively to the aroma, though its impact did not surpass that of green coffee (Arpi et al., 2021). This is consistent with the results of Abduh et al. (2023), who reported that cascara introduces a unique fruity aroma that complements a variety of food products.

The taste score was highest for the control (8.4), while the gingerbread enriched with green coffee and cascara had lower scores, ranging from 6.0 to 7.0. This suggests that while green coffee may enhance aroma, its flavour profile may not be a good match for gingerbread, possibly due to its bitterness, as noted by Wibowo et al. (2024). Cascara, on the other hand, had a moderate impact on taste, which may be due to its fruity and somewhat acidic flavour profile (Komaria et al., 2021). The relatively lower score for green coffee suggests that while its health benefits are well-documented, its taste profile may require further modification to achieve greater consumer acceptance in baked goods.

There were no significant differences ($p > 0.05$) in the aftertaste of the samples. The overall acceptability scores of the control and fortified gingerbread samples ranged from 7.4 to 7.9. The higher score for cascara could be due to its balanced contributions to appearance, consistency, and aroma, even though its taste score was lower than that of the control (Pua et al., 2021). This suggests that while green coffee and cascara may introduce distinct flavour and texture changes, these ingredients are generally well-received by consumers (Das et al., 2024).

CONCLUSION

The increased ash content observed in cascara-enriched gingerbread signifies an improvement in the mineral composition of baked goods, potentially addressing common dietary mineral deficiencies. The fortification of gingerbread with green coffee also enhances its protein content, presenting a viable strategy to compensate for the low protein levels in traditional baked items. These nutritional benefits are compounded by a minor increase in fat content from green coffee, contributing to the energy density and overall flavour profile of gingerbread. This balanced caloric enhancement positions both green coffee and cascara as practical solutions for developing energy-dense, nutritious food products that meet contemporary dietary needs. Mineral analysis reveals substantial increases in essential minerals such as copper, zinc, and manganese in green coffee-enriched gingerbread, with cascara contributing significantly to this enhancement as well. Therefore, the inclusion of these coffee by-products offers a feasible strategy to improve the nutritional profile of cereal-based foods, which often lack these essential micronutrients. The high levels of chlorogenic acids and other phenolic compounds inherent in green coffee bolster antioxidant capacity, which may mitigate oxidative stress, offering functional health benefits that extend beyond mere nutrition. The sensory analysis provides valuable insights into consumer perceptions, with cascara-enriched gingerbread receiving the highest score for overall appearance (8.2) and improvements in consistency (from 7.0 to 8.0) when compared to control samples. The aroma also significantly improved with green coffee (7.7), which is essential given the importance of sensory attributes in consumer acceptance. Although taste scores varied (control gingerbread scored highest at 8.4, while cascara and green coffee scored 7.1 and 6.5, respectively) these findings suggest that while taste is critical, aspects such as appearance, aroma, and consistency heavily influence consumer preferences.

AUTHOR CREDIT STATEMENT

Conceptualization, E.I. methodology, E.I., L.H., K.D.; Data analysis, K.D., L.H., M.C., and J.A.; writing – original draft preparation, E.I., E.D.O., and A.A.-B.; writing – review and editing, E.I, E.D.O, J.J.K., P.Ł.K. and A.A.-B.; visualization, E.I., J.A., and M.C.; supervision, E.I.; funding acquisition, E.I. All authors have read and agreed to the published version of the manuscript.

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DECLARATIONS

Data statement
Data will be made available on request.

Ethical Approval
Not applicable.

Competing Interests
The authors declare that they have no conflicts of interest.

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