Please cite the Published Version

Robinson, Iberedem E and Tas, Ayten A (2025) Effect of Cassava Flour and Ginger Powder Addition on Physicochemical and Antioxidant Properties of Bread. Applied Sciences, 15 (7). 3762

DOI: https://doi.org/10.3390/app15073762

Publisher: MDPI AG

Version: Published Version

Data Access Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

applied sciences

Article

Effect of Cassava Flour and Ginger Powder Addition on Physicochemical and Antioxidant Properties of Bread

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Abstract: This study explored the enhancement of antioxidant properties in bread by incorporating ginger powder while reducing wheat flour utilisation through partial replacement with cassava flour, addressing the issue that bread produced from refined wheat flour is low in antioxidants due to the removal of the aleurone layer during processing. The study investigated the effect of cassava flour and ginger powder addition on physicochemical properties (moisture content, water activity, firmness, crumb structure, density, volume, specific volume, and colour), antioxidant capacity (AC) using Ferric reducing antioxidant potential (FRAP), and total phenolic content (TPC) (by using the Folin Ciocalteu method) of bread. Seven bread samples were produced using the Chorleywood method (220 ± 1 °C at 25 min) using cassava flour (10 and 40%) only and with the combination of ginger powder (1 and 3%). The volume, specific volume, and firmness of the bread with 10% cassava flour and ginger powder were similar to the control (100% wheat flour). Breads containing 40% cassava flour had reduced volume and specific volume and increased firmness and density. The TPC and AC increased significantly ($p < 0.05$) with ginger powder addition. The study showed that 10% cassava flour and 3% ginger powder could be added to bread formulations to improve their phenolic content and antioxidant capacity without significantly affecting their quality.

Keywords: bread; cassava flour; ginger powder; antioxidant capacity; total phenolic content; physicochemical properties

Academic Editor: Chiara Cavaliere

Received: 3 March 2025
Revised: 21 March 2025
Accepted: 26 March 2025
Published: 29 March 2025

Citation: Robinson, I.E.; Tas, A.A. Effect of Cassava Flour and Ginger Powder Addition on Physicochemical and Antioxidant Properties of Bread. *Appl. Sci.* **2025**, *15*, 3762. https://doi.org/10.3390/app15073762

1. Introduction

Bread is a staple food produced from various ingredients (flour, yeast, salt, butter, and water) [1]. Wheat flour is a major ingredient in bread and is a source of protein, carbohydrates, B vitamins, and some minerals [2–4]. The gluten it contains imparts desirable physical attributes to bakery products, such as increasing loaf volume, providing dough elasticity and strength, and influencing dough hydration and consistency [5,6]. Partial and/or full replacement of wheat flour in bread has proven to be a challenge due to undesirable loaf volume and crumb structure, which are attributed to an insufficient amount or lack of gluten [7,8]. There has been a surge in wheat consumption in the last decade. The consumption is expected to increase further in the future due to global population growth, and this could potentially increase the cost of bakery products [9]. This calls for a sustainable wheat flour substitute that could replicate the desirable physicochemical parameters of bread [10], reducing reliance on a single staple, enhancing food security, and mitigating price volatility in the wheat market, potentially stabilising costs over time.

Cassava (*Manihot esculenta*) is a drought-tolerant and staple food crop that could potentially be a sustainable remedy for food security, especially in developing countries [11].

It is cultivated in Africa, Asia, and North America, providing a source of valuable nutrients [11,12]. Its roots and leaves have various applications in food (such as starch, vegetable sauce, and flour production) and feed industries (i.e., animal feed for monogastric animals) [12,13]. Cassava has a post-harvest short shelf life of 24–48 h due to its fresh root moisture content (65%), which constitutes tissue softening and rotting after exposure to the atmosphere within a few days [14]. The high perishability of cassava significantly reduces its economic value and contributes to food loss. This has shown the need for the further utilisation of cassava in different forms, such as granulated and pre-gelatinised starch (obtained from toasting grated and fermented cassava roots with a slightly sour taste) [15], starch [16], cassava chips, fufu (i.e., soured paste obtained from soaked and grated cassava roots after sieving and boiling of the mashed cassava) [17], and flour [14,18]. The high-water absorbing capacity (205%) of cassava flour could improve the baked product density and yield in comparison to wheat flour [19,20]. Furthermore, regarding the production cost and consumer purchasing ability of bread (using cassava flour), a study showed a profitable result and a positive purchasing cost in areas where cassava is domestically cultivated [21]. The nutritional properties of cassava flour compared to wheat and corn flour are highlighted in Table 1.

Table 1. Nutritional profile of cassava flour in comparison to other flours [19,22–25].

	Nutritional Composition (%)			
	Carbohydrate	**Starch**	**Crude Fibre**	**Protein**
Cassava flour	79	73	6	7
Wheat flour	73	70	3	21
Corn flour	71	69	2	11

The replacement of wheat flour in bread production can have various effects on the final product's quality and nutritional value, and this is dependent on the substituted flour percentage [26–28]. Bread samples in which 10% of wheat flour was replaced with different varieties of cassava flour showed acceptable qualities (loaf volume, specific volume, and bread density) similar to 100% wheat flour bread [29]. Similarly, cassava flour addition at 20% resulted in bread with acceptable sensory properties (i.e., colour, taste, texture, and general acceptability) similar to the control sample [26]. Breads developed with the incorporation of cassava flour (up to 30%) were shown to have a reduced loaf volume, specific volume, and density when compared with wheat bread with no cassava flour, due to the latter being gluten-free [30,31]. The reduced loaf quality associated with the inclusion of cassava flour at higher concentrations (such as 30%) can be overcome by the incorporation of additives such as hydrocolloids, which can improve dough rheological properties (through stabilising emulsions and retaining moisture), and the overall finished product structure [32]. The literature has shown that the addition of carboxymethyl cellulose at 2% in addition to cassava flour (18%) developed bread with an improved loaf volume, specific volume, and firmness compared to bread with 100% wheat flour [32]. To further advance the utilisation of cassava flour in bread development, there is a need to identify a balance between cassava flour and wheat flour concentration to achieve high-quality bread comparable to commercially available bread [33].

Cassava flour is used to develop other bakery products, such as cookies and biscuits. A study conducted using 100% cassava flour in addition to xanthan gum and inulin showed that gluten-free biscuits had desirable physical qualities (hardness and brittleness) that were similar to commercially available biscuits [34]. Another study showed that cookies made from 50% cassava flour had higher sensory acceptability, low moisture (5.63%) and low fat

(24.87%) content, a higher spread ratio (8.15), and low breaking strength in comparison to wheat flour cookies [35].

Refined wheat flour used in white bread production is low in antioxidants due to the removal of the aleurone layer during milling. However, incorporating functional ingredients such as ginger, turmeric, and coriander can enhance the antioxidant capacity of breads [28,36,37]. Ginger is a flowering plant with its root used extensively as a spice and it tends to contain more than 400 different compounds [38] such as carbohydrates, lipids, terpenes, and phenolic compounds (gingerols, paradols, shogaol). It is a functional food because its ingredients have anti-inflammatory, anti-apoptotic (i.e., preventing cell death), antioxidant, and antibacterial capacities [39,40]. Ginger has a bitter taste, which could be attributed to gingerols and shogaols, which are released during the heat process because of the dehydration of gingerols. However, this does not pose a serious drawback to ginger application in food (such as tea, bread, snacks, or stew) [41,42]. A relevant study has shown that ginger powder addition (0.5%) improved the sensory properties (such as crispiness, flavour, and colour) of bread, and its general acceptability was similar to the control sample (100% wheat flour bread) [28].

Ginger is utilised in different forms, including fresh, dried, extracts, or powder [42]. The processing of dried ginger powder has been reported to decrease the total phenolic content (TPC), antioxidant capacity (AC), and vitamin C content [43]. Some studies have shown that the addition of ginger powder in white bread production increased the flavonoid content and the TPC of the bread samples [28,37,44]. There has been limited information on ginger powder's effect on bread's texture and physicochemical properties.

The global population is expected to increase, which could increase food costs and demand. Using cassava flour in bread formulation may reduce food waste and contribute to sustainable diets. Bread is a staple food in many countries, and the nutritional enhancement of such an important food commodity with antioxidant compounds can contribute to better health. Therefore, this study developed different bread formulations by partially replacing wheat flour with cassava flour and adding ginger powder to improve the antioxidant properties of bread. The study examined the effect of different bread formulations on their physicochemical properties (moisture content, water activity, colour, firmness, crumb structure, density, loaf volume, and specific volume) and total phenolic content and antioxidant capacity.

2. Materials and Methods

2.1. Materials

Bread ingredients (strong white bread flour, sugar, salt, margarine, ginger powder, and yeast) were purchased from a local supermarket. Cassava flour and diamond improver were supplied by Buy Whole Foods Online (Ramsgate, Northeast Kent, UK) and Baking Beauty and Beyond Ltd. (Mildenhall, UK), respectively. Seven bread samples were produced using different concentrations of cassava flour (10% and 40%) only and with the addition of ginger powder (1% and 3%), including the control sample (containing 100% wheat flour) (Table 2). Chemicals (Folin Ciocalteu, sodium carbonate, gallic acid, ethanol, sodium acetate trihydrate, glacial acetic acid, 2,4,6-tripyridyl-s-triazine (TPTZ), hydrochloric acid (HCl), ferric chloride, and ferrous sulphate) for the determination of the total phenolic content and antioxidant capacity were supplied by Merck Life Science Limited (Gillingham, UK).

Table 2. Recipe for the development of bread enriched with cassava flour and ginger powder [26,28].

	Samples						
Ingredients (g)	**WF**	**CW10**	**CWG11**	**CWG13**	**CW40**	**CWG41**	**CWG43**
Wheat flour	600	540	534	522	360	354	342
Cassava flour	0	60	60	60	240	240	240
Ginger powder	0	0	6	18	0	6	18
Sugar	60						
Salt	6						
Diamond improver	12						
Margarine	60						
Yeast	12						
Water	220						

WF (100% wheat flour), CW10 (90% wheat flour: 10% cassava flour), CWG11 (89% wheat flour: 10% cassava flour: 1% ginger powder), CWG13 (87% wheat flour: 10% cassava flour: 3% ginger powder), CW40 (60% wheat flour: 40% cassava flour), CWG41 (59% wheat flour: 40% cassava flour: 1% ginger powder), CWG43 (57% wheat flour: 10% cassava flour: 3% ginger powder).

2.2. Methods

Bread Making

Breads were produced according to the Chorleywood method [45]. Wheat flour was sieved using a stainless-steel hand sieve (470 µm) to remove any impurities and obtain clump-free flour. Yeast was mixed with 30 mL water (22 ± 1 °C). Cassava flour, wheat flour, and other ingredients were weighed using a top-pan balance (Sartorius Balance, European Instruments Limited, Oxford, UK), were placed into the mixer bowl, and mixed using a Tweedy mixer (Tweedy of Burnley Limited, Burnley, UK). These ingredients were mixed for 3 min, and 42 kJ/kg of energy was imparted into the dough. The dough was covered with clingfilm and left for 10 min at room temperature (22 ± 1 °C). The dough was weighed and divided into 300 g pieces and placed in greased tins (11 cm depth, 16 cm length, and 8.6 cm width) in the prover at 43 °C for 30 min. The divided dough was baked at 220 ± 1 °C for 25 min. The bread was de-tinned, cooled (22 ± 1° C), and frozen (−20 °C) to maintain freshness for subsequent analysis.

2.3. Moisture Content (MC)

Bread samples were ground using a laboratory blender (Waring Commercial Blender, Torrington, USA) and oven-dried (Heraeus Function Line, Hanau, Germany) at 65 ± 1°C overnight (n = 3).

2.4. Water Activity (a_w)

The water activity was determined using Rotronic Hygrolab (Crompton Fields, West Sussex, UK) at room temperature (22 ± 1 °C) (n = 3).

2.5. Firmness

The firmness of the bread slices (25 mm thick) was determined using the AACC (74-09) standard method [46] with a TA-TXT Texture Analyser (Stable Micro System Godalming, Surrey, UK) at room temperature (22 ± 1 °C) with a load cell of 30 kg. The test speed of 33 mm/s with a 5 g trigger force and 40% compression strain of the bread height were used for the analysis (n = 3).

2.6. Crumb Structure

The crumb structure was determined using a C-Cell (Caliber Control International Limited, Warrington, UK). The breads were sliced at 25 mm thickness using a knife to obtain a neat surface. The slice was measured for cell volume, number, and area of holes (n = 3).

2.7. Volscan Measurement

The bread density, volume, and specific volume were analysed using a Volscan Profiler (Stable Microsystem Godalming, Surrey, UK) (n = 3). The bread loaves were placed on a Volscan stand and scanned by the laser for 60 s, producing the bread's 3D view (height, width, and depth) on the software (Exponent Connect Lite, Version 6.1).

2.8. Colour Measurements

Colour measurement was conducted on ground samples (n = 3) using a calibrated Data-color 800 colourimeter (Datacolor, Newport, UK). The results were presented in the CIE LAB system as L* (lightness or brightness), a* (red or green), and b* (blue or yellow). The secondary colour parameters, including the hue angle (H°), chroma (C*), and total colour difference (E*), were calculated using the equations below. The standard values used for the analysis were L* (65.18), a* (1.59), b* (10.31), C* (10.43), and H° (81.25), respectively.

$$\mathrm{C}* = \sqrt{\mathrm{a}^2 + \mathrm{b}^2} \tag{1}$$

$$\mathrm{H}^\circ = \tan^{-1}(\mathrm{b}^* \div \mathrm{a}^*) \tag{2}$$

$$\mathrm{E}* = \sqrt{\mathrm{dL}^{*2} + \mathrm{dC}^{*2} + \mathrm{dH}^{*2}} \tag{3}$$

2.9. Chemical Analysis

2.9.1. Extraction of Antioxidants

Two grams of ground bread was added to 20 mL methanol–water (70:30 *v*/*v* %) solution and placed on a shaking bath with orbital stirring at 100 rpm at room temperature (22 ± 1°C) for 3 h. The solution was placed in the dark for 21 h to extract the antioxidant compounds. The extract was centrifuged (Eppendorf Centrifuge, Hamburg, Germany) at 4700 rpm for 10 min. Thereafter, the supernatant was filtered using Whatman filter paper no. 5 and made up to 25 mL methanol–water (70:30 *v*/*v* %) solution. The extracts were covered with aluminium foil to protect them from light and stored in the refrigerator at 5 ± 1 °C for subsequent analysis.

2.9.2. Total Phenolic Content (TPC) Analysis

The TPC of the extracts was determined spectrophotometrically using the Folin Ciocalteu method [47]. A total of 500 µL of the antioxidant extract was mixed with diluted Folin Ciocalteu (2.5 mL) solution and placed in the dark for 5 min. After adding 2 mL of sodium carbonate, the solution was kept at 50 ± 1 °C for 5 min. The contents were cooled to room temperature (22 ± 1 °C) before the absorbance was read at 760 nm (Cole-Parmer SP-200, Jenway 63 Series, Cambridgeshire, UK) (n = 3). The total phenolic content was calculated using a standard calibration curve plotted using gallic acid concentration (50 mg/L to 250 mg/L). The mean values were presented as gallic acid equivalent (GAE) in g/100 g on a dry weight basis (dwb).

2.9.3. Determination of Antioxidant Capacity (AC)

Distilled water (300 µL), 3 mL of FRAP (ferric reducing antioxidant potential) reagent, and 100 µL of antioxidant extract were added and mixed briefly in a vortex mixer. The solution was transferred to a cuvette, and absorbance was read on the spectrophotometer at 593 nm (Cole-Parmer SP-200, Jenway 63 Series, Cambridgeshire, UK) at time zero, and, after, the samples were kept at 50 ± 1 °C for 4 min. The standard curve was prepared using a 0.01 mM to 0.5 mM Fe^{2+} solution. The AC was expressed as an Fe^{2+} equivalent in mmol/100 g dwb.

2.10. Statistical Analysis

The data were analysed using one-way analysis of variance (ANOVA) in the IBM Statistical Package for Social Science (SPSS), Version 29. The Duncan multiple range test (DMRT) determined significant differences in the mean score. The significant differences were determined at $p < 0.05$.

3. Results

3.1. Moisture Content and Water Activity

The moisture content was significantly reduced with increased cassava flour concentration (Table 3). The sample WF (control) and CWG13 had the highest moisture content (approximately 28%).

Table 3. Moisture content, water activity, crumb structure (cell volume, area of holes, and number of holes), and firmness values.

Parameters	**WF**	**CW10**	**CWG11**	**CWG13**	**CW40**	**CWG41**	**CWG43**
Moisture content (%)	28.60 ± 0.14 ^{a}	25.04 ± 0.38 ^{b}	26.37 ± 0.15 ^{c}	28.20 ± 0.47 ^{a}	24.57 ± 0.07 ^{d}	26.61 ± 0.11 ^{e}	25.19 ± 0.19 ^{b}
Water activity	0.843 ± 0.006 ^{c}	0.866 ± 0.007 ^{d}	0.878 ± 0.004 ^{e}	0.868 ± 0.001 ^{d}	0.870 ± 0.001 ^{d}	0.867 ± 0.001 ^{d}	0.867 ± 0.001 ^{d}
Cell volume	23.67 ± 1.15 ^{e}	29.00 ± 1.00 ^{e,f}	31.33 ± 1.15 ^{f}	29.00 ± 5.00 ^{e,f}	30.33 ± 2.31 ^{f}	32.00 ± 1.00 ^{f}	30.67 ± 5.03 ^{f}
Area of holes	0.52 ± 0.79	0.91 ± 1.57 ^{g}	0.72 ± 0.87 ^{g}	0.37 ± 0.65 ^{g}	1.74 ± 1.45	0.04 ± 0.06 ^{g}	1.89 ± 1.64 ^{g}
Number of holes	1.14 ± 1.74 ^{h}	1.03 ± 1.78 ^{h}	0.75 ± 0.84 ^{h}	0.34 ± 0.58 ^{h}	1.48 ± 0.06 ^{h}	0.04 ± 0.06 ^{h}	1.14 ± 1.02 ^{h}
Firmness (g)	1518 ± 381 ^{i}	1644 ± 163 ^{i}	1912 ± 161 ^{i}	2098 ± 141 ^{i}	4538 ± 388 ^{j}	4381 ± 417 ^{j}	6676 ± 482 ^{k}

Different letters indicate significant differences ($p < 0.05$) among breads in the same row. WF (100% wheat flour), CW10 (90% wheat flour: 10% cassava flour), CWG11 (89% wheat flour: 10% cassava flour: 1% ginger powder), CWG13 (87% wheat flour: 10% cassava flour: 3% ginger powder), CW40 (60% wheat flour: 40% cassava flour), CWG41 (59% wheat flour: 40% cassava flour: 1% ginger powder), CWG43 (57% wheat flour: 10% cassava flour: 3% ginger powder).

The water activity changed between 0.84 ± 0.01 (WF) and 0.88 ± 0.01 (CWG11). The control (WF) had significantly lower water activity ($p < 0.05$) compared to the other breads (Table 3).

3.2. Crumb Structure

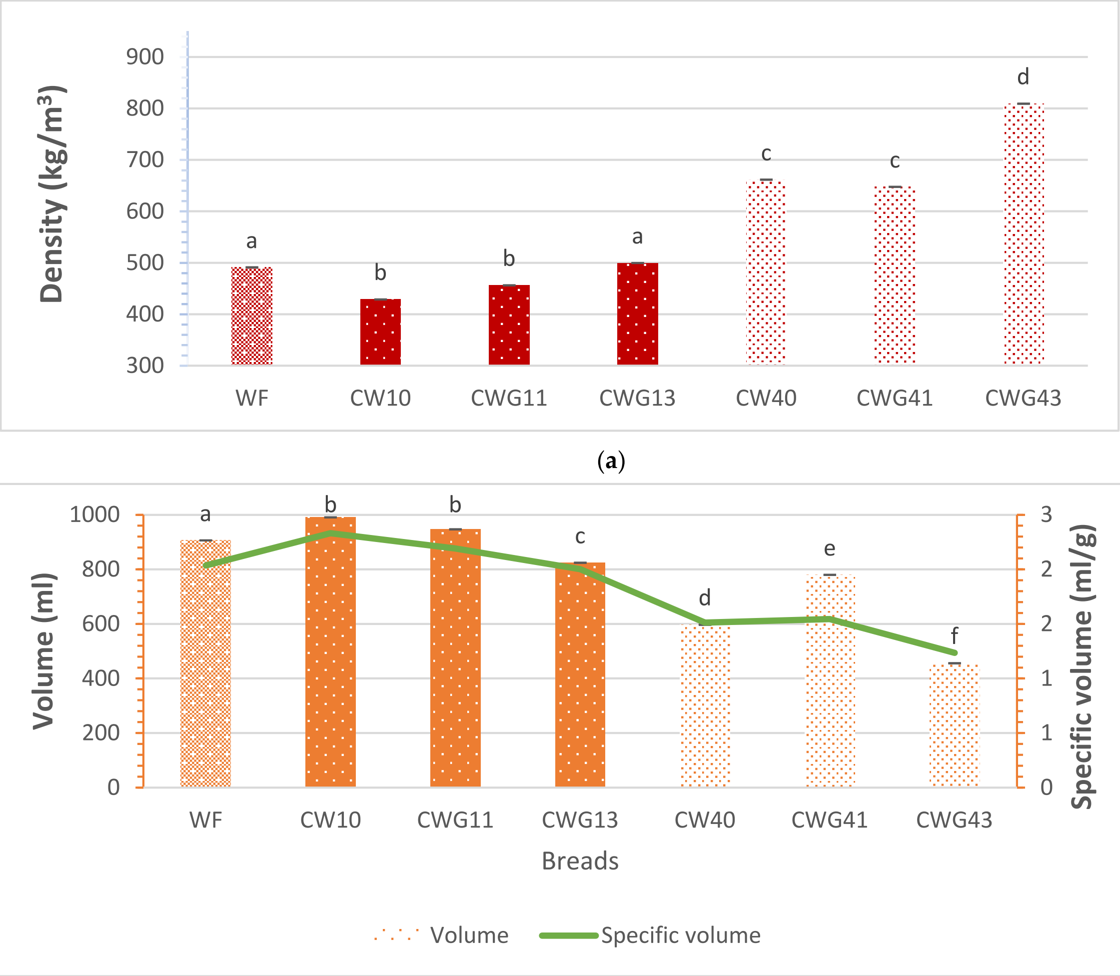
The crumb structure of the developed breads is shown in Table 3. WF had the lowest cell volume (23.67 ± 1.15), while CWG41 had the highest cell volume (32.00 ± 1.00). This implied that adding cassava flour and ginger powder significantly increased the bread cell volume ($p < 0.05$). The values obtained for the number and area of holes were not significantly different across the bread samples.

3.3. Firmness

Cassava flour addition at 40% increased firmness significantly (Table 3). The control (WF) had the lowest firmness value (1518 ± 381 g), like the bread samples with 10% cassava flour. Sample CWG43 registered the highest firmness value (6676 ± 482 g).

3.4. Density, Volume, and Specific Volume

The density of the bread samples is shown in Figure 1a. Values ranged from 428.92 (CW10) to 809.36 kg/m^3 (CWG43). Bread density increased as the amount of cassava flour and ginger powder increased ($p < 0.05$). As shown in Figure 1b, compared to WF, specific volume and volume decreased markedly in bread with 40% cassava flour (CW40, CW41, and CW43). The volume of the samples varied from 455.92 (CWG43) to 990.86 mL (CW10), and the specific volume varied from 1.24 (CWG43) to 2.33 mL/g (CW10). The inclusion of 10% cassava flour did not reduce the volume and specific volume of breads compared to the control.



(a)

(b)

Figure 1. Physical properties of breads (**a**) Density, (**b**) Volume, and specific volume. Different small case letters correspond to significant differences ($p < 0.05$).

3.5. Colour Measurements

Lightness (L*) values varied from 57.02 ± 1.72 to 76.53± 0.52, and there were no significant differences between the samples ($p > 0.05$) (Table 4). This implied that adding cassava flour and ginger powder did not affect the lightness values. However, the addition of cassava flour and ginger powder increased the bread's red and yellow colour. There was a noticeable increase in the total colour difference ($p > 0.05$) in bread incorporated with ginger powder and cassava flour compared to the control.

Table 4. Colour measurements.

Colour Value	WF	CW10	CWG11	CWG13	CW40	CWG41	CWG43
L*	66.09 ± 1.00 ^{a}	57.02 ± 1.72 ^{a}	76.53 ± 0.52 ^{a}	72.34 ± 1.38 ^{a}	71.89 ± 1.02 ^{a}	71.59 ± 1.93 ^{a}	68.35 ± 0.50 ^{a}
a*	1.61 ± 0.05 ^{b}	1.92 ± 0.06 ^{b}	2.41 ± 0.07 ^{c}	3.72 ± 0.31 ^{d}	4.90 ± 0.31 ^{e}	4.20 ± 0.31 ^{f}	5.76 ± 0.23 ^{g}
b*	9.87 ± 0.50 ^{h}	15.47 ± 0.20 ^{i}	16.65 ± 0.18 ^{j}	18.79 ± 0.66 ^{k,m}	18.18 ± 0.25 ^{k}	15.71 ± 0.60 ^{l}	19.27 ± 0.53 ^{m}
C*	10.00 ± 0.49 ^{n}	15.59 ± 0.20 ^{o}	16.83 ± 0.18 ^{p}	19.16 ± 0.63 ^{q}	18.83 ± 0.31 ^{q}	16.26 ± 0.63 ^{o,p}	20.11 ± 0.56 ^{r}
H°	81.16 ± 0.09 ^{s}	81.63 ± 0.03 ^{t}	81.37 ± 0.07 ^{t}	80.65 ± 0.25 ^{u}	79.71 ± 0.19 ^{v}	78.89 ± 0.19 ^{v}	79.26 ± 0.11 ^{s}
E*	1.03 ± 1.10 ^{t}	14.51 ± 0.44 ^{u}	13.03 ± 0.45 ^{u,v}	11.32 ± 1.34 ^{v,w}	10.89 ± 0.53 ^{w}	8.81 ± 1.79 ^{x}	10.39 ± 0.67 ^{w,x}

Different letters indicate significant differences ($p < 0.05$) among breads in the same row. WF (100% wheat flour), CW10 (90% wheat flour: 10% cassava flour), CWG11 (89% wheat flour: 10% cassava flour: 1% ginger powder), CWG13 (87% wheat flour: 10% cassava flour: 3% ginger powder), CW40 (60% wheat flour: 40% cassava flour), CWG41 (59% wheat flour: 40% cassava flour: 1% ginger powder), CWG43 (57% wheat flour: 10% cassava flour: 3% ginger powder).

3.6. Total Phenolic Content and Antioxidant Capacity

Ginger powder addition significantly increased the total phenolic content of the bread ($p < 0.05$), as evident at both cassava flour concentrations (i.e., 10 and 40%) (Table 5). The highest TPC was observed with the sample CWG13 (4.54± 0.35 g GAE/100 g dwb), followed by CWG43 (3.95 ± 0.18 mg GAE/100 g dwb).

Table 5. Total phenolic content (TPC) and antioxidant capacity of bread samples.

Parameters	WF	CW10	CWG11	CWG13	CW40	CWG41	CWG43
TPC (GAE in g/100 g dwb)	3.42 ± 0.19 ^{a}	3.04 ± 0.02 ^{b}	3.58 ± 0.03 ^{a}	4.54 ± 0.35 ^{c}	3.04 ± 0.05 ^{b}	3.21 ± 0.08 ^{a}	3.95 ± 0.18 ^{d}
FRAP (mmol/100 g dwb)	2.04 ± 0.26 ^{e}	5.07 ± 0.61 ^{f}	5.48 ± 0.24 ^{f}	4.68 ± 0.50 ^{f}	3.07 ± 0.24 ^{g}	7.94 ± 0.79 ^{h}	4.74 ± 0.24 ^{f}

Different letters indicate significant differences ($p < 0.05$) among breads in the same row. WF (100% wheat flour), CW10 (90% wheat flour: 10% cassava flour), CWG11 (89% wheat flour: 10% cassava flour: 1% ginger powder), CWG13 (87% wheat flour: 10% cassava flour: 3% ginger powder), CW40 (60% wheat flour: 40% cassava flour), CWG41 (59% wheat flour: 40% cassava flour: 1% ginger powder), CWG43 (57% wheat flour: 10% cassava flour: 3% ginger powder).

The AC of the formulated breads was higher than that of the control (WF). Increased values were observed when cassava flour was added alone or combined with ginger powder.

4. Discussion

4.1. Moisture Content and Water Activity

Moisture content is an essential food quality parameter and contributes to bread's freshness (excess water could affect the length of time bread could stay fresh), weight (could impact cost), and product shelf life (excess moisture could promote microbial activities) [48]. The standard range of moisture in bread varies from 35 to 45% [49,50]. The MC obtained in the current study (24 to 28%) is lower than this range, and this could potentially increase the bread shelf life [48]. Furthermore, the MC is lower than what was obtained in other studies (31 to 37%) that featured ginger-wheat flour bread [28] and cassava-wheat flour bread (35 to 39%) [26]. The lower MC obtained in the current study could be attributed to the higher baking temperature (220 °C) compared to 180 °C used in a previous study (Ozcan, 2022) [28].

The addition of cassava flour significantly reduced the MC. Cassava flour has a relatively lower MC (10%) in comparison to wheat flour (13%) [35]. This could have contributed to the lower MC observed in samples with cassava flour and no ginger powder (CW10 and CW40).

The addition of cassava flour and ginger powder increased the water activity of the breads (Table 3). Cassava flour has a higher water-absorbing capacity in comparison to wheat flour due to its higher starch content (73%) [22] compared to wheat flour (70%) [23]. Furthermore, cassava flour is hydrophilic, and its fibre could have bound to more free water during dough formation and increased the availability of unbound water, leading to an increase in water activity [22]. On the other hand, the low water activity observed in WF (0.84 ± 0.01) could be due to the low water absorption capacity in wheat flour and gluten network formation, which could have reduced free water in the bread [51]. The water activity range (0.84 to 0.88) obtained in this study is lower than previously reported in white bread (0.95) and whole wheat bread (0.97) [51].

4.2. Firmness

Firmness showed a consistent increase with cassava flour and ginger powder concentration (Table 5). Bread firmness depends on several factors, such as moisture migration and water distribution [52], the interaction of gluten and starch [53], and starch retrogradation [54]. During bread cooling, starch can retrograde and fill the intergranular spaces and provide rigidity, leading to loaf firmness [55].

The inclusion of cassava flour could produce higher firmness values in bread since increased dough viscosity values were reported with such bread samples [56]. Also, cassava flour addition at 20% has been reported to reduce dough extensibility and elasticity in cassava-wheat flour composite bread [57]. In the current study, bread samples with 40% cassava flour (CW40, CWG41, and CWG43) required more water during the mixing process and registered firmness values more than twice as much as the control sample. A similar result was reported in bread incorporated with 6% ginger powder, which was reported to have more than twice the firmness of bread with 100% wheat flour (control) [37]. The values obtained corroborated previous studies of increased firmness with cassava flour and ginger powder addition in bread [37,56,58]. Additionally, the results showed it is possible to replace 10% wheat flour with cassava flour and ginger powder (1 and 3%) without significantly impacting the firmness of bread.

4.3. Crumb Structure

The addition of up to 40% cassava flour significantly ($p < 0.05$) increased the cell volume of the bread (Table 3). Cell volume could occur in bread due to gas pressure arising from the rate of carbon dioxide (CO_2) intake within gas cells in dough and the repulsion that arises from the bi-extension of the gas cell wall [31,59]. Having partially replaced wheat flour with cassava flour (gluten-free), the resistance of the dough gas cell wall could have been reduced (due to a weaker gluten network formation), leading to the formation of a larger cell volume in bread [60]. A similar result of increased cell volume (18 to 78) was obtained previously, where wheat flour (10 to 30%) was replaced with different varieties of cassava flour in breads [31].

The gluten strength and concentration in the total flour used influences the holes in bread [61]. The results obtained were consistent with a previous study where no significant difference was observed in the number of holes (17,885 to 25,445) and area of holes (1.58 to 1.70) of bread developed with different varieties of wheat flour [61]. The results for the number and area of holes could suggest that cassava flour (10 and 40%) and ginger powder (1 and 3%) addition was not sufficient to disrupt the gluten functionality of forming a stable network to trap gas efficiently, preventing significant differences in the hole structure [61].

4.4. Density, Volume, and Specific Volume

The bread density increased with a higher concentration of cassava flour and ginger powder (Figure 1a). The high density observed in breads with 40% cassava flour could be attributed to low gluten strength in the composite flour [62]. A high carbohydrate content in cassava flour (79%) compared to wheat flour (73%) reported in previous studies [19,20] could contribute to increased water-absorbing capacity, and the lack of internal structure (due to no glutenin and gliadins) leads to less gas retention and denser loaves [29,62,63]. The density of bread with 10% cassava flour was similar to the control (WF). This was consistent with another study where no significant changes in bread density were found with 10% cassava flour addition compared to the bread containing 100% wheat flour [56].

The volume and specific volume values agreed with a previous study using different varieties of cassava flour (10 to 50%) reporting values of 680 mL to 1110 mL (volume) and 1.28 mL/g to 2.59 mL/g (specific volume) [33]. The current study showed a significant reduction in the specific bread volume with an increased concentration of cassava flour. Reduced loaf volume and specific volume in bread with 40% cassava flour were consistent with previous studies where varied concentrations of cassava flour (10 to 40%) were used with wheat flour-based breads [31,56,64]. Some studies have attributed the change in specific volume and bread volume developed from different cassava flour sample varieties to proofing time, baking temperature, baking time, protein quality, and quantity of the flour used [56,60]. However, the developed breads in this study were treated the same (including baking temperature and time). Therefore, the reduction in specific bread volume and volume could be attributed to the low protein content (7%) and the lack of gluten in cassava flour in comparison to wheat flour [19]. The increased concentration of cassava flour (at 40%) reduced the overall concentration of gluten. This possibly resulted in a weaker dough and reduced its leavening capacity upon hydration, leading to bread with a reduced loaf volume and increased density [29,56].

Ginger powder addition was reported to reduce bread volume and specific volume due to the increased resistance of dough to deformation, and the higher fibre content of ginger powder (7% vs. 2% in wheat flour) was proposed as a reason for this [37]. The current study obtained a similar result, as bread with 3% ginger powder had reduced volume and specific volume compared to the control and bread with cassava–wheat flour and no ginger powder (35).

4.5. Colour Measurements

Colour is an essential visual tool that could improve or discourage consumer demand for a particular product [28]. The crumb colour can be influenced by the colour of the flour and ingredients [60]. In the present study, lightness was similar across the samples, which was in line with a previous study where ginger powder added at different concentrations (3, 4.5, and 6%) did not result in noticeable changes [44]. Other studies reported improved red and yellow colour in bread samples enriched with ginger powder at 2 to 6% [37] and 0.5 to 3% [28], and cassava flour (10 to 30%) [31,60]. Similarly, increased red (a*) values were obtained in the present study (1.61 to 5.76) in the samples containing ginger powder and cassava flour. The increased red colour observed in the bread could be ascribed to the carotenoids in cassava flour [65], ginger powder [66], and wheat flour [29,67]. In the current study, the yellow colour increased with the concentration of ginger powder. The high b* values (9.87–19.27) could be due to curcumin, desmethoxycurcumin, and 6-dehydrogingerdione, responsible for ginger powder's characteristic pale-yellow colour [68,69]. There was a noticeable increase in the total colour difference (E*) with increasing ginger powder concentration. This could be due to the oxidation of phenolic compounds in ginger powder and nonenzymatic browning during baking [28,70]. A similar colour difference was reported previously in breads developed with 0.5, 1, and 1.5% ginger powder [28].

4.6. Total Phenolic Content (TPC)

Phenolic compounds are reported to be one of the major antioxidants in plants (including cassava and ginger) [43,71]. Quantifying the concentration of phenolic compounds in food is essential due to their health benefits (such as antiviral, antimicrobial, and anti-inflammatory properties) [72]. There was a significant increase in the TPC of bread with ginger powder addition (Table 5). The findings in this study corroborated the existing literature, which demonstrated that the TPC of bread could be increased with ginger powder addition at 0.5 to 1.5% [28], and 2 to 6% [37], possibly due to the presence of phenolic compounds in the ginger rhizome (gingerol, catechins, gallic acid, rutin, quercetin, and 3,4-dihydroxybenzoic acid). One study has shown an increase in these compounds with the increased levels of ginger powder in the bread formulations [28].

Another study attributed the increase in the phenolic content of breads enriched with ginger powder to gingerols and diarylheptanoids [37]. However, gingerol is heat labile (i.e., stable at temperatures below 70 °C), and can convert to another compound called shogaol during heat processing [28,73,74]. The values obtained in the present study were higher than what was reported on crust and crumbs of bread developed with ginger powder addition (0.14 and 0.71 mg GAE/g dwb, respectively) [75]. These variations could have occurred due to genetic and/or physiological factors pertaining to ginger from which the rhizome powder is obtained [76].

One limitation of the study was that it did not include nutritional analysis. However, theoretical nutrient calculations using a UK nutrient database [77] indicated a considerable increase in carbohydrate, fibre, and starch content in the bread samples containing 40% cassava flour. A similar trend was reported previously in cassava-wheat bread formulations (i.e., 10 to 40% cassava flour) [26], and the changes could be attributed to the higher content of these nutrients in cassava flour, as highlighted in Table 1.

4.7. Antioxidant Capacity (AC)

Antioxidant capacity measures the ability of phenolic compounds to donate hydrogen atoms or molecules and capture free radicals [71]. The addition of ginger powder and cassava flour increased the AC of the bread samples. The higher AC in bread samples enriched with ginger powder could be attributed to gingerol, shogaol, zingerone, and diarylheptanoid compounds [37,75]. Similar findings of increased AC were previously reported in breads developed with ginger powder addition [28,37]. It was noticed that bread with 1% ginger powder (CWG11 and CWG41) had a higher AC than bread with 3% ginger powder (CWG13 and CWG43). The reason for this was unclear.

Some of the phenolic compounds in ginger may degrade because of thermal processing [73,74]. This degradation has been elucidated through a study that reported a decrease in AC in dried ginger due to the formation of zingerone, a compound formed via the conversion of shogaol during heating [78]. Zingerone has a lower AC than shogaol [79]. Since the current study did not measure any of these phenolic compounds, it was not possible to confirm this finding.

5. Conclusions

This study examined the effect of cassava flour and ginger powder addition on bread’s physicochemical and antioxidant properties. Ginger powder addition improved the bread samples’ antioxidant properties and red and yellow colour. Incorporating cassava flour at 40% produced bread with reduced volume, specific volume, and increased density and firmness. The study has shown that up to 10% cassava flour and 3% ginger powder could be added to bread to improve its antioxidant properties without significantly affecting its quality (firmness, loaf volume, and crumb structure). Future work may include nutritional analysis including starch digestibility, the determination of shelf life, and flavonoid content. Lastly, conducting sensory analysis to ascertain consumer acceptability can provide useful information.

Author Contributions: Conceptualisation: I.E.R. and A.A.T.; Methodology: I.E.R.; Validation: I.E.R. and A.A.T.; Formal Analysis: I.E.R.; Investigation: I.E.R.; Project administration: I.E.R. and A.A.T.; Resources: I.E.R.; Data curation: I.E.R.; Visualisation: I.E.R.; Writing—original draft preparation: I.E.R.; Writing—Review and Editing, A.A.T.; Supervision, A.A.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors appreciate the technical assistance of Pamela Flint and Eimear Tubritt.

Conflicts of Interest: The authors declare no conflicts of interest.

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