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Sensory Characteristics Are More Pronounced in Baked Cookies than in Thin Porridges Made from Flours Obtained from Cassava Tubers Developed via Gamma Irradiation

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Abstract

In recent years, gamma irradiation has been adopted as one of the plant breeding approaches to ensuring food and nutrition security for the ever-growing global population in the face of unprecedented climate change. However, the sensory characteristics and acceptability of the products made from either pure or composite flours of the developed varieties have not been fully investigated. This is timely as cassava flour can be used to make thin porridges or used in baking when fortified with wheat flour. This study evaluated the sensory attributes of flour, thin porridges, and cookies made from developed cassava varieties (CAS 1, CAS 2, CAS 3) developed from KME 4 through gamma irradiation at a rate of 15, 20, and 30 Grays (Gy) at 2 Gy/min, respectively. The cassava flour of the CAS 1 variety, which had the least setback viscosities, was fortified with wheat flour. A consumer acceptability panel of 62 persons was conducted using 9-point Likert scale. Cassava flour exhibits high lightness (L^*) and whiteness, with low redness (a^*) and yellowness (b^*). In the preparation of porridge and cookies, colour characteristics varied depending on the flour blend. Porridge exhibited a lightness (L^*) value that indicated a bright and appealing appearance, with a consistent yellowish hue (b^*) suggesting the presence of carotenoids inherent in cassava. The cookies displayed distinct lightness (L^*) values, with the top of the cookies generally exhibiting higher lightness compared to the bottom, attributed to increased browning from direct heat exposure during baking. The Browning Index (*BI*) values indicated a greater degree of browning in the bottom of the cookies, reflecting the influence of heat transfer and temperature on colour development. Consumer acceptability for porridge was moderately liked across all the varieties, while for cookies, the V5 variety

(50% cassava-50% Wheat) was the most liked.

Subject Areas

Food Science & Technology

Keywords

Cassava, Gamma Irradiation, Sensory Evaluation, Colour, Browning Index

1. Introduction

Intensifying and out-scaling diets that focus on food crops resilient to climate change and capable of yielding adequately during harsh climatic conditions is a critical pathway toward achieving food security in sub-Saharan Africa [1]. This approach emphasizes the need for sustainable agricultural practices that enhance productivity while minimizing environmental impacts. Cassava (*Manihot esculenta*), a starch-rich root crop, has a significant potential for enhancing food security in Kenya due to its resilience to drought and poor soil fertility, which are prevalent challenges in the Kenyan agricultural sector [2]. Despite its adaptability and the ability to thrive under poor climatic conditions, cassava consumption remains low, particularly among urban populations. Studies indicate that urban consumers often prefer other staple foods such as maize and rice over cassava, which can be attributed to factors such as price, quality, and cultural preferences [3]. Consequently, efforts to diversify cassava-based recipes are crucial, as they can help elevate its status from a traditional staple to a more versatile ingredient in modern cuisine.

Gamma irradiation can significantly impact the physicochemical properties of starch, including changes in amylose content, molecular size, water solubility, and gelatinization parameters [4]. Additionally, irradiation affects starch's swelling power, solubility index, and rheological properties, which ultimately influence the texture and quality of baked products such as cookies [5]. This enhancement of functional properties highlights the potential of gamma irradiation in improving cassava flour quality to meet the demands of modern food processing.

Moreover, irradiation is recognized as an effective method for ensuring food safety and extending shelf life without compromising nutritional value. For example, [6] has demonstrated that ready-to-eat meals remain acceptable up to irradiation doses of 10 kGy, although higher doses may cause noticeable changes in appearance and texture. Despite these benefits, the industrial use of cassava flour in pastry and baking remains limited due to insufficient data on the quality of gamma-irradiated cassava flour, its blending potential with wheat and other cereals, and consumer acceptance of products made from improved cassava varieties.

To address these gaps, this study evaluates consumer acceptability of thin porridge and cookies made from new cassava varieties CAS 1, CAS 2, and CAS 3, which were developed through gamma irradiation at doses of 15, 20, and 30 Gy, respectively, from the parent variety KME 4. This approach aims to generate insights into optimizing cassava flour quality for use in thin porridge and cookies formulated by blending wheat flour with these improved cassava varieties, thereby supporting their wider utilization in modern cuisine and value-added food products.

2. Materials and Methods

2.1. Materials

Cassava tubers from four varieties of cassava were obtained from the University of Eldoret, Uasin Gishu County. Cassava variety KME 4 was selected among previously developed mutant varieties [7] based on its good agronomic quality, such as high tuber yield and resistance to pests and diseases. CAS 1, 2, and 3 were developed from KME 4 using gamma irradiation on the stem cuttings using 15, 20, and 30 grays, respectively, at 2 Gy/min.

Commercially available wheat flour (EXE all-purpose flour, Unga Limited, Kenya), sugar (Kabras Limited, Kenya), margarine (Prestige, Bidco, Kenya), and baking powder (Chapa Mandashi, Bidco, Kenya) were procured from the local supermarket in Eldoret, Kenya.

CAS 1 and KME 4 were selected in preparation of cookies based on their physicochemical properties specifically pasting properties that indicated CAS 1 having a lowest setback viscosity compared to the other varieties and KME 4 having the highest trough viscosity compared to the daughter varieties as highlighted by Chebitok *et al.* (2024), "Irradiation influences physicochemical, functional properties and shifts in functional groups in cassava flour" (In press).

2.2. Preparation of Cassava Flour

Freshly harvested roots were washed to remove accumulated dirt using running tap water, peeled manually using a kitchen knife, and then washed using distilled water. They were sliced using a kitchen knife into small pieces for easier processing. The chopped pieces of cassava were grated using a motorized cassava grater and oven-dried at 60˚C (Memmert-854, Memmert GmbH + Co, Germany) for 48 h. The dehydrated grits were processed into flour using a disc attrition miller (Munson Machinery Model SK-30-SS, USA). The flours obtained from CAS 1, CAS 2, CAS 3, and KME 4 were placed in air-tight containers and stored at room temperature (25˚C).

2.3. Preparation of Cassava Thin Porridge

Cassava flours from all the varieties were used to prepare porridge. Complementary porridges (10% solid) were prepared as described by [8] with some modifications. One (1) liter of water was boiled in a stainless steel cooking pot. Next, 100 ml of cold water was added to the flour to make a slurry, which was then added to the boiling water while stirring. Cooking was continued for 15 minutes, stirring every 5 minutes. After preparation, the porridges were kept warm in a thermos flask (40˚C - 50˚C).

2.4. Preparation of Cassava Cookies

2.4.1. Composites Formulation Using Mixture Model Design

A three-component augmented simplex centroid mixture design was employed to formulate composite flour for cookie preparation, with KME 4 and CAS 1 having a high trough viscosity, and wheat flour as the mixture components. The design involved systematic variation of the proportions of each flour, expressed as percentages of the total 200 g mixture. Experimental runs were conducted using Design-Expert software version 8.0.3 (State-Ease, Inc., 2010, Minneapolis, USA). A total of six runs were performed for each cassava variety blend to evaluate the effects of different flour ratios on cookie quality. (See Equation (1) and Table 1)

Table 1. A mixture model design used to determine flour composites used to make cookies.

Sample	CAS 1 (C1)	WHEAT (X2)	KME 4 (K1)	WHEAT (X2)
V1	50	50		
V2	60	40		
V3	40	60		
V4			50	50
V5			60	40
V6			40	60

CAS 1 was developed from KME 4 by exposure to 15 Gy. KME 4 parent variety. Wheat as control. The measurements are in (g). The formulation of cassava and wheat for the preparation of cookies was; V1-50% CAS 1flour 50% Wheat flour, V2-60% CAS 1 flour 40% Wheat flour, V3-40% CAS 1 flour 60% Wheat flour, V4-50% KME 4 flour 50% Wheat flour, V5-60% KME 4 flour 40% Wheat flour, V6-40% KME 4 flour 60% Wheat flour. Control-Wheat.

$$\sum X_i = C_1 + X_2 = 100 \text{ g or Where: } \sum X_i = K_1 + X_2 = 100 \text{ g} \quad (1)$$

where C_1 is the CAS 1 cassava flour,

X_2 is wheat flour;

K_1 is KME 4 Cassava flour;

X_1 is the total formulation of the cassava and wheat flour of either CAS 1 or KME 4.

2.4.2. Preparation of the Cookies

Cookies were prepared according to the method proposed by [9]. First, 100 g of margarine was creamed with 100 g of sugar until it became fluffy. This was then followed by adding an egg and other dry ingredients (1/2 tsp salt, 1/2 tsp baking powder, and 200 g flour). The dough was thoroughly kneaded for five minutes and then rolled manually to a thickness of 5 mm using a rolling pin. The sheeted dough was cut with a star-shaped cookie cutter and baked on a greased tray for 15 min at 160˚C in an oven (Memmert-854, Memmert GmbH + Co, Germany). The cookies were cooled at room temperature for 30 minutes before being placed in an airtight plastic container awaiting the sensory evaluation panel. Cookies made from 100% wheat flour with the same processes and quantities of ingredients as above served as a control.

2.5. Colour Measurement of Cassava Flour, Thin Porridges and Cassava-Wheat Blend Cookies

The colour of the cassava flour, porridge, and cookies was determined using a handheld colorimeter (PCE-TCR 200, PCE Instrument, China). The colorimeter was calibrated using standard white and black tiles. Five (5 g) of each flour sample were accurately weighed into the sample cup. For the porridge, half a cup of porridge from each variety was left to cool to room temperature before evaluation. For the cookies, five samples from each variety were used to measure color. The colour measurements were taken for the values of L^* (lightness), a^* (changes from green to red), and b^* (changes from blue to yellow). Colour readings of each sample were measured at six distinct locations, and the average for each colour attribute was calculated.

2.6. Browning Index

The colour measurement of cassava flour, thin porridge, and cookies that were obtained from section 2.5 was used to calculate the browning index, using the following general formula derived from the CIE-Lab values in the handheld Colorimeter [10]. (See Equation (2))

$$\text{Browning index (BI)} = [100(x - 0.31)]/017,$$
$$\text{Where } x = a^* + 1.75L^*/(5.645L^* + a^* - 3.012b^*) \quad (2)$$

where:

L^* = Lightness value (0 = black, 100 = white)

a^* = Red-green value (positive values indicate red, negative values indicate green)

$b*$ = Yellow-blue value (positive values indicate yellow, negative values indicate blue)

2.7. Sensory Evaluation

The sensory evaluation was conducted using a nine-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) as described by [11] to assess key attributes, including taste, texture, aroma, appearance, and overall acceptability. The evaluation of porridge and cookies was conducted on separate days by consumer panels drawn from the University of Eldoret main campus in Eldoret, Kenya. The porridge evaluation involved 54 participants on the first day, while the cookie evaluation included 62 participants on the second day. The sensory panel comprised 62 participants, with females representing a majority (35) over males. The age of panelists ranged from 23 to 35 years, reflecting a young adult demographic. Participants were moderately familiar with cassava, with most having previous experience consuming cassava products. This demographic distribution ensures an adequate representation of gender, age, and familiarity, supporting the validity and reliability of the sensory evaluation data. The consent form was signed by participants before the testing. Participants were fully informed about the nature and purpose of the study, and their participation was entirely voluntary.

Both panels assessed the sensory attributes of the products, such as appearance, aroma, taste, texture, and overall acceptability. To ensure unbiased results, the samples were labeled with random three-digit code numbers and presented in a randomized order to the panelists. Participants were instructed to cleanse their palates with water between samples and were asked not to make comments during the evaluation process to avoid influencing the opinions of other panelists. This controlled setup aimed to provide accurate and reliable insights into the sensory characteristics and overall acceptability of the products tested.

2.8. Data Analysis

The data collected was subjected to descriptive statistics using R version 4.3.2. To evaluate cassava as a source of variation, the data were analyzed using one-way Analysis of Variance (ANOVA). Statistical significance between mean values was determined at a threshold of $p < 0.001$, and results are presented as mean ± Standard Deviation (SD). Tukey's Honest Significant Difference (HSD) multiple comparison method was employed to distinguish the means for flour, porridge, and cookies colour and consumer acceptability.

3. Results and Discussions

3.1. Colour of the Cassava Flour

The colour values of the cassava flours are presented in **Table 2**. The data indicate that there are no significant differences in lightness (L^*) among the cassava varieties tested ($p < 0.001$). This finding implies that the intrinsic lightness of the cassava roots remains relatively stable despite exposure to varying levels of gamma radiation. This study disagrees with the findings of [12] as their study reported a significant difference in the lightness as gamma irradiation increased from 0 to 15 Gy on the Indian Chestnut. The change in lightness involves radiation-induced free radical formation. Gamma radiation breaks chemical bonds in pigments and other compounds, producing reactive free radicals that cause oxidation and degradation of color compounds such as carotenoids and phenolic [13]. This leads to alterations in the molecular structure and color intensity, resulting in a significant decrease in lightness as irradiation dose increases [14]. This study indicates that consistent lightness across the varieties may be advantageous for consumer acceptance, as brightness is often associated with freshness and quality in food products.

Table 2. Colour of the flours.

Variety	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Hue angle (H^*)	Chroma (C^*)
KME 4	79.24 ± 1.78^a	2.32 ± 2.13^a	13.32 ± 4.03^a	81.18 ± 5.00^b	13.57 ± 4.36^a
CAS 1	77.62 ± 5.18^a	4.96 ± 0.74^{ab}	15.55 ± 3.11^a	71.79 ± 4.83^a	16.37 ± 2.89^a
CAS 2	82.34 ± 2.50^a	3.71 ± 0.93^{ab}	11.83 ± 3.30^b	72.29 ± 2.45^a	12.41 ± 3.39^a
CAS 3	78.60 ± 1.17^a	5.09 ± 0.68^b	16.52 ± 1.28^a	72.91 ± 1.03^a	17.29 ± 1.41^a

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.001$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy, respectively, at 2 Gy/min.

Redness (a^*) quantifies the extent of red coloration in the flour. CAS 3 had the highest redness value, significantly different from KME 4 ($p < 0.001$) and indicating a more pronounced red hue. The increased redness in CAS 3 may be attributed to the formation of new pigments, such as carotenoids, as a result of gamma irradiation. The energy from gamma rays can enhance enzymatic activity that converts precursors into carotenoids. Irradiation may promote the synthesis or stabilization of carotenoids, leading to increased red pigment content in the flour [15]. A study by [16] agrees with these findings as it shows that gamma irradiation at 10 Gy significantly increased the levels of carotenoids and anthocyanins, leading to enhanced red pigmentation in the roots. This finding supports the notion that gamma radiation can effectively enhance the red pigmentation in cassava roots, aligning with the observations that radiation treatments can modify the biochemical composition of plants to improve colour intensity [16].

The yellowness value (b^*) indicates the degree of yellow pigmentation in the cassava roots. The data show that CAS 2 has the lowest yellowness values, which were significantly different from the other varieties ($p < 0.001$). The irradiation doses in CAS 1 and CAS 3 may have led to significant chlorophyll degradation, allowing carotenoids to become more prominent and thus increasing yellowness. Gamma irradiation can lead to the degradation of chlorophyll, the green pigment found in plants. As chlorophyll breaks down, it can release various chromophores and precursors that contribute to the formation of yellow pigments, such as carotenoids. The breakdown of chlorophyll reduces green coloration, allowing the yellow hues from carotenoids to become more prominent, thereby increasing the yellowness value in the flour [17]. In contrast, the 20 Gy dose applied to CAS 2 may not have been sufficient to induce significant chlorophyll breakdown. A study by [18] agrees with these findings as it found that gamma irradiation led to significant degradation of chlorophyll in carrot juice, which in turn allowed the carotenoids to become more visible. Higher yellowness is often associated with the presence of carotenoids, which are known for their health benefits, including antioxidant properties [19]. The increased yellowness in CAS 1 and CAS 3 may indicate a higher concentration of these beneficial pigments, which could enhance the nutritional profile of the flour. Yellow hues are also associated with certain desirable flavors and can enhance the overall sensory experience for consumers. This could enhance the visual appeal of cassava products from CAS 1 and CAS 3, making them more attractive to consumers.

The hue angle (H^*) represents the overall colour perception, with lower values indicating a shift towards red and yellow hues and higher values indicating greener hues. KME 4 had the highest hue angle, significantly different from the other varieties ($p < 0.001$), suggesting a greener hue, while CAS 1, CAS 2, and CAS 3 exhibited lower hue angles, indicating a shift towards more yellowish and reddish tones. Gamma irradiation can induce the degradation of chlorophyll. As chlorophyll degrades, the green colour diminishes, allowing other pigments, such as carotenoids and anthocyanins, to become more prominent. This degradation results in a lower hue angle, indicating a shift towards yellow and red hues [17]. The breakdown of chlorophyll reduces the green component of the colour profile, which is reflected in the higher hue angle of KME 4 compared to the lower hue angles of CAS 1, CAS 2, and CAS 3. KME 4, with its higher hue angle, suggests a greener hue that may be associated with freshness but could also lead to lower appeal in certain contexts, especially in baked products like cookies. In contrast, CAS 1, CAS 2, and CAS 3, with their lower hue angles, indicate a shift towards more vibrant yellow and red hues, enhancing visual appeal and potentially increasing consumer attraction and expectations of high-quality products.

3.2. Colour of the Thin Porridge

The colour attributes of the porridge varieties are shown in **Table 3**. Lightness (L^*) measures the brightness of the porridge. KME 4 exhibited the highest lightness value, significantly different from the other varieties ($p < 0.001$). CAS 1, CAS 2, and CAS 3 all had lower lightness values, indicating a trend toward darker colors in these irradiated varieties. The lower lightness values in CAS 1, CAS 2, and CAS 3 compared to KME 4 suggest that gamma irradiation and subsequent cooking can lead to a darkening of cassava porridge color. This effect may be attributed to the Maillard reaction, which involves the interaction between amino acids and reducing sugars under the influence of irradiation and cooking. The Maillard reaction can produce brown pigments, contributing to the reduced lightness observed in the irradiated varieties [20]. A study by [21] aligns with this study as it reported a significant decrease in luminosity (lightness) in whole sorghum flours subjected to gamma irradiation. The variation in lightness can significantly influence consumer choices, as lighter colors are typically preferred in food products [22].

The redness values show a significant range, with CAS 3 having the highest redness (5.50 ± 0.29) and KME 4 the lowest (3.20 ± 0.37). This indicates that CAS 3 has a more pronounced red hue, which could be appealing in certain culinary contexts. The increased redness in CAS 1, CAS 2, and CAS 3 compared to KME 4 suggests that gamma irradiation can enhance the red pigmentation in cassava porridge. This effect may be due to the formation of carotenoids or other red pigments as a result of the irradiation process [15]. A study by [23] suggests that gamma irradiation can lead to the formation of new pigments through the interaction of radiation with food components. This can occur through oxidation processes or reactions between amino acids and sugars [17]. The pronounced red hue in CAS 3 may enhance the visual appeal of the porridge, as red hues are often associated with good flavor. This could positively influence consumer preferences, making CAS 3 more attractive compared to KME 4, which has a more muted colour profile.

Table 3. Colour of the cassava thin porridge.

Variety	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Hue angle (H^*)	Chroma (C^*)
KME 4	16.42 ± 0.30^b	3.20 ± 0.37^a	4.83 ± 0.09^a	56.58 ± 2.68^a	5.80 ± 0.27^a
CAS 1	14.01 ± 0.99^a	4.42 ± 0.66^b	6.52 ± 0.41^b	55.99 ± 3.02^a	7.89 ± 0.65^b
CAS 2	13.83 ± 0.15^a	4.34 ± 0.54^b	6.44 ± 0.72^b	55.89 ± 5.98^a	7.80 ± 0.39^b
CAS 3	13.42 ± 0.17^a	5.50 ± 0.29^c	7.14 ± 0.48^b	52.34 ± 2.85^a	9.02 ± 0.34^c

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.001$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy, respectively. The Hue angle (H^*) was derived from the tangent angle between a^* and b^*. Chroma (C^*) was calculated using the formula: $(a^{*2} + b^{*2})^{1/2}$.

Yellowness (b^*) measures the yellow hue of the porridge. CAS 1, CAS 2, and CAS 3 exhibited significantly higher yellowness values compared to KME 4 ($p < 0.001$). The higher yellowness values in the irradiated varieties indicate that gamma irradiation can promote the formation of yellow pigments, such as carotenoids, in cassava porridge [17]. This effect may enhance the visual appeal and perceived nutritional quality of the porridge, as yellow hues are often associated with the presence of beneficial compounds like antioxidants [19]. A study by [5] agrees with this finding as it shows the yellowness value increased from 9.14 for the non-irradiated sample to 12.28 at 10 Gy.

The Hue angle values range from 52.34 ± 2.85 (CAS 3) to 56.58 ± 2.68 (KME 4) with no significant difference. The relatively narrow range of hue angles indicates that the overall colour tone of these varieties remains similar, primarily falling within the yellow-red spectrum. The variation in the hue angle shift may be due to chemical changes in pigments [24], although the overall tone remains within the yellow-red spectrum. [25] study disagrees with these findings as they reported gamma irradiation can alter the chemical structure of food components, affecting their colour properties. For instance, the Maillard reaction, which occurs during heating, can be influenced by irradiation, leading to browning and changes in hue.

Chroma values indicate the intensity of the color, with CAS 3 showing the highest chroma and KME 4 the lowest, which was significantly different. The higher chroma values in the irradiated varieties may be due to gamma irradiation, as it can stimulate the biosynthesis of carotenoids. The energy from gamma irradiation can activate metabolic pathways that enhance the production of these pigments, leading to increased chroma in the porridge [24]. For example, carotenoids like beta-carotene contribute to the yellow coloration, and their increased synthesis can significantly enhance the chromaticity of the porridge [19]. The higher chroma values in CAS 3 suggest a more saturated color, enhancing the sensory experience of the porridge.

3.3. Colour of the Cassava-Wheat Blend Cookies

The data presented in Table 4 and Table 5 show the colour characteristics of different flour blends, including varying proportions of CAS 1 flour and wheat flour, as well as KME 4 flour and wheat flour. The lightness values of the top and bottom range from 51.23 ± 1.70, 61.26 ± 1.34, and 43.80 ± 1.83, 53.47 ± 2.86, respectively, with V2 being the lightest and V3 the darkest. Higher L^* values in V2 suggest a lighter color, which is often associated with freshness and quality. Cassava flour exhibits distinct functional properties compared to wheat flour, including higher water absorption capacity, swelling power, and solubility index [26]. These functional differences influence the dough behavior and final product texture, with cassava flour's gelatinization and retrogradation properties contributing to changes in moisture retention and product density. Such functional attributes affect light scattering and can result in higher lightness (L^*) values in products fortified with cassava flour [27].

Redness values are relatively consistent, with V5 showing the highest redness at 8.10 ± 0.63 and 3.53 ± 1.34 (V4), the lowest at the top and bottom at 12.12 ± 0.52 (V6), and the lowest V4 at 9.95 ± 1.12. Redness (a^*) is primarily influenced by the presence of red pigments, such as anthocyanins or other colored compounds. In the cassava-wheat blends, the relatively consistent redness values suggest that the addition of cassava flour does not significantly introduce or alter these pigments [28]. The similar levels of redness across the blends suggest that the addition of cassava flour does not significantly alter the red hue. This consistency may be beneficial for maintaining a uniform appearance in the final product.

Table 4. Colour of the top of wheat-cassava blend cookies.

Variety	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Hue angle (H^*)	Chroma (C^*)
V1	52.63 ± 2.55^{abc}	8.06 ± 1.07^{d}	27.82 ± 0.77^{a}	73.83 ± 2.31^{a}	28.98 ± 0.60^{abc}
V2	61.26 ± 1.34^{e}	2.95 ± 1.74^{a}	27.51 ± 0.95^{a}	84.00 ± 3.31^{d}	27.71 ± 1.15^{ab}
V3	55.78 ± 2.21^{bcd}	5.88 ± 1.50^{bcd}	28.94 ± 0.60^{a}	78.56 ± 2.79^{abc}	29.56 ± 0.76^{bc}
V4	58.06 ± 2.24^{de}	3.53 ± 1.34^{ab}	27.32 ± 0.58^{a}	82.69 ± 2.65^{cd}	27.57 ± 0.71^{a}
V5	52.43 ± 2.99^{ab}	8.10 ± 0.63^{d}	28.89 ± 1.26^{a}	74.29 ± 1.78^{a}	30.01 ± 1.07^{c}
V6	56.82 ± 1.50^{cd}	5.35 ± 0.69^{abc}	28.55 ± 0.30^{a}	79.39 ± 1.35^{bcd}	29.06 ± 0.32^{abc}
Control	51.23 ± 1.70^{a}	7.28 ± 1.13^{cd}	27.50 ± 1.79^{a}	75.11 ± 2.63^{ab}	28.48 ± 1.68^{abc}

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p \le 0.05$ as assessed by Tukey's HSD. The Hue angle (H^*) was derived from the tangent angle between a^* and b^*. Chroma (C^*) was calculated using the formula: $(a^{*2} + b^{*2})^{1/2}$. CAS 1 variety was developed from KME 4 by exposure to gamma rays (15Gy) with a low dosage of 2 Gy/min.

Table 5. Colour of the bottom of wheat-cassava blend cookies.

Variety	Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Hue angle (H^*)	Chroma (C^*)
V1	47.81 ± 3.30^{ab}	10.08 ± 1.60^{a}	25.74 ± 1.10^{a}	68.61 ± 3.52^{a}	27.69 ± 0.92^{a}
V2	53.47 ± 2.86^{c}	10.42 ± 5.89^{a}	26.80 ± 1.90^{ab}	69.68 ± 9.23^{a}	29.07 ± 3.87^{a}
V3	43.80 ± 1.83^{a}	11.41 ± 0.99^{a}	25.44 ± 1.02^{a}	65.86 ± 1.51^{a}	27.89 ± 1.22^{a}
V4	50.35 ± 4.82^{bc}	9.95 ± 1.12^{a}	27.14 ± 0.68^{ab}	69.85 ± 2.53^{a}	28.93 ± 0.27^{a}
V5	45.27 ± 1.51^{ab}	11.65 ± 0.70^{a}	27.93 ± 0.52^{b}	67.35 ± 1.46^{a}	30.27 ± 0.41^{a}
V6	44.8 ± 1.04^{ab}	12.12 ± 0.52^{a}	26.41 ± 0.70^{ab}	65.34 ± 1.25^{a}	29.06 ± 0.59^{a}
Control	47.62 ± 2.04^{ab}	9.99 ± 1.02^{a}	25.64 ± 0.92^{a}	68.21 ± 2.98^{a}	27.54 ± 1.02^{a}

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p \leq 0.05$ as assessed by Tukey's HSD. The Hue angle (H^*) was derived from the tangent angle between a^* and b^*. Chroma (C^*) was calculated using the formula: $(a^{*2} + b^{*2})^{1/2}$. CAS 1 variety was developed from KME 4 by exposure to gamma rays (15 Gy) with a low dosage of 2 Gy/min.

Yellowness values show that V5 exhibits the highest yellowness. The increase in yellowness in V5 indicates that the blend with a higher proportion of KME 4 flour may enhance the visual appeal of V5, which has a higher proportion of KME 4 flour. The increased yellowness suggests that this variety may contain more carotenoids or other yellow pigments that contribute to its visual appeal. The breakdown of chlorophyll allows these pigments to become more pronounced, enhancing the overall yellowness of the blend [25]. The narrow range of hue angles suggests that the overall colour tone remains similar across the blends, primarily falling within the yellow-red spectrum. This consistency can help in branding and consumer recognition.

The higher chroma in blends like V5 (30.27 ± 0.41) suggests a greater concentration of pigments, making them appear more vibrant. This vibrancy can be attributed to the interaction between the pigments present in the cassava and wheat flours, as well as the overall structure of the flour matrix, which enhances light absorption and reflection [25]. Flour blends with a higher proportion of cassava flour often exhibit the highest lightness (L^*), resulting in a brighter color. This is likely due to the partial substitution of wheat flour with cassava flour, which dilutes the gluten content and slows the rate of gluten network formation, leading to a lighter color. [29] agree with this finding as the incorporation of cassava flour into wheat flour would lead to increased lightness resulting in an increase in lightness in the final product. Additionally, the fiber content from the cassava flour may have increased the fiber-water interactions, contributing to the lighter appearance. Cassava flour contains a significant amount of fiber, which absorbs water and swells. This swelling can lead to a more open structure in the dough, allowing light to scatter more effectively, thus increasing the perceived lightness [30]. Also, the presence of fiber can disrupt the formation of a dense gluten network, which is typically responsible for a darker, more opaque appearance in wheat-based products. By diluting gluten content with cassava flour, the resulting product tends to be lighter [31]. Vivid colors are more appealing to consumers because they stimulate emotions, enhance perceived taste and quality, and align with consumer preferences for freshness and naturalness [32].

In contrast, the flour blends with higher proportions of wheat flour, such as V3 (40% CAS 1 flour, 60% wheat flour) and V6 (40% KME 4 flour, 60% wheat flour), had lower lightness (L^*) values and higher redness (a^*) values, indicating a darker and more reddish color. This can be attributed to the higher protein and ash content in wheat flour, which can contribute to a darker colour through the Maillard reaction and the presence of minerals that catalyze browning reactions [33] [34]. During baking, the amino acids from the proteins in wheat flour can react with the reducing sugars, producing a wide range of brown-colored melanoidin compounds that darken the crust and crumb of the baked goods [33] [35]. In addition, the higher mineral content in the ash of wheat flour can also contribute to a darker colour in baked products. The minerals present in the ash can catalyze Maillard reactions and caramelization, leading to the formation of brown colored compounds that darken the overall appearance [34]. The colour characteristics of the flour blends were significantly influenced by the proportion of cassava flour and wheat flour, with the 60% CAS 1 flour blend exhibiting the brightest and most yellow color.

The bottom of the cookies, which is typically in direct contact with the baking surface, experiences higher temperatures and longer exposure to heat. This can result in more pronounced browning due to the Maillard reaction and caramelization processes, darkening the color. In contrast, the top of the cookies may not experience the same level of heat exposure, especially if they are covered or if the heat source is primarily from below, leading to a lighter colour [36].

3.4. Browning Index

Table 6 shows the browning index of flour, porridge, and cookies of new cassava varieties. The Browning Index (BI) is a measure used to assess the degree of browning in food products, often associated with enzymatic reactions and non-enzymatic browning processes such as the Maillard reaction [25]. The browning index for the cassava flour showed no significant difference ($p < 0.001$), while that of the porridge showed a significant difference ($p < 0.001$). CAS 3 variety exposed to the highest gamma irradiation dose exhibits the most pronounced browning effect. The significant increase in BI suggests that the Maillard reaction and other browning processes are enhanced at this irradiation level. The presence of naturally occurring sugars such as glucose and fructose from proteins in cassava provides the necessary reactants for the Maillard reaction to occur, as some enzymes involved in the breakdown of sugars may be activated by irradiation, further facilitating the availability of reactants for the Maillard reaction [28]. The irradiation process may also lead to the breakdown of certain proteins, releasing free amino acids that participate in the Maillard reaction. The presence of more free amino groups facilitates the formation of brown pigments, as these groups react with reducing sugars under heat [28]. The increased reaction of amino acids enhances the overall browning process, resulting in a higher BI. As the control variety with no irradiation, KME 4 has the lowest BI, indicating minimal browning. This serves as a baseline for comparison, showing that without the influence of gamma irradiation, the natural browning processes are limited [28]. The results show that the BI of flour is lower than that of porridge; the key difference between flour and porridge regarding browning lies in the cooking process. While raw flour lacks the necessary conditions for the Maillard reaction to occur, *i.e.*, heat and moisture, cooking porridge introduces heat that allows the reducing sugars and amino acids in the flour to react and moisture to facilitate the interaction between reducing sugars and amino acids, promoting the reaction and resulting in a higher Browning Index [37].

Table 6. Browning index.

Variety	Flour	Porridge	Top of the cookies	Bottom of the cookies
KME 4	1.70 ± 1.2^{a}	76.74 ± 0.21^{a}	N/A	N/A
CAS 1	1.71 ± 0.1^{a}	121.05 ± 0.12^{b}	N/A	N/A
CAS 2	1.72 ± 0.4^{a}	118.84 ± 0.32^{b}	N/A	N/A
CAS 3	1.72 ± 0.4^{a}	146.05 ± 0.66^{c}	N/A	N/A
V1	N/A	N/A	1.74 ± 1.35^{b}	1.80 ± 1.2^{b}
V2	N/A	N/A	1.63 ± 2.65^{a}	1.74 ± 0.9^{a}
V3	N/A	N/A	1.68 ± 1.22^{a}	1.86 ± 0.87^{c}
V4	N/A	N/A	1.76 ± 0.5^{b}	1.78 ± 0.34^{b}
V5	N/A	N/A	1.73 ± 1.0^{b}	1.84 ± 1.34^{ab}
V6	N/A	N/A	1.67 ± 2.34^{a}	1.86 ± 2.98^{c}
V7 (control)	N/A	N/A	1.73 ± 1.07^{b}	1.80 ± 1.65^{b}

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p < 0.001$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy, respectively.

The results indicate that the browning index of the cookies is significantly different ($p < 0.001$) and is mainly contributed to by the ratio of wheat and cassava. Composites with higher wheat flour content (V3, V4, V5, V6) tend to exhibit greater browning. Wheat flour contains higher levels of reducing sugars and proteins, which play a crucial role in the Maillard reaction, a chemical process that occurs during baking [38]. This reaction involves the interaction between reducing sugars, such as glucose and fructose, and amino acids from proteins when exposed to heat, which results in the browning of the baked products [38]. The differences in Browning Index values between the top and bottom of the cookies can be attributed to variations in heat transfer. The bottom of the cookies may have experienced more direct heat, leading to increased browning reactions. Additionally, the Browning Index values for the cookies are generally higher than those reported for the flour and porridge samples, indicating that the baking process enhanced the browning reactions. The degree of browning can significantly impact the sensory perception and acceptability of food products [25], while moderate browning can enhance flavor and aroma, excessive browning may be undesirable, especially in products where a lighter colour is preferred. For this study, the increased browning observed in the irradiated varieties may be acceptable or even desirable, depending on consumer preferences.

3.5. Sensory Evaluation

3.5.1. Consumer Acceptability of the Cassava Thin Porridge

Consumer acceptability of the cassava porridge from the new varieties and parents was evaluated through sensory evaluation. Table 7 shows that the cassava porridge from three varieties (CAS 1, CAS 2, and CAS 3) sensory attributes, including appearance, taste, texture, aroma, and overall acceptability, had no significant difference ($p < 0.001$). This suggests that consumers perceive these varieties similarly regarding these sensory characteristics, which may imply that the processing methods (gamma irradiation) or the inherent qualities of the cassava itself contribute to a consistent sensory profile across these varieties. For instance, research on cassava porridge aligns with this study as it highlights that sensory attributes such as taste and texture are critical for consumer preference, but when varieties are processed similarly, their sensory profiles can be quite similar, leading to no significant differences in acceptability scores among them [39]. Gamma irradiation did not affect consumer acceptability, and this aligns with the studies by [39] and [40] that highlight the effectiveness of this processing method without compromising sensory qualities. The lack of significant differences ($p < 0.05$) in sensory attributes among the cassava porridge varieties suggests that they may be equally acceptable to consumers, which can be advantageous for product development and marketing strategies. This study supports the conclusion that gamma irradiation can be effectively utilized in food processing without compromising consumer acceptability, particularly when consumers are well-informed about the benefits and safety of irradiated products.

Table 7. Sensory evaluation of the cassava thin porridge.

Variety	Appearance	Taste	Texture	Aroma	Acceptability
KME 4	6.93 ± 1.73^a	6.29 ± 2.38^a	7.16 ± 2.25^a	6.98 ± 1.81^a	7.11 ± 2.04^a
CAS 1	6.95 ± 2.09^a	6.78 ± 1.94^a	7.42 ± 2.11^a	6.95 ± 1.98^a	7.22 ± 1.95^a
CAS 2	7.16 ± 1.87^a	7.25 ± 1.65^a	7.53 ± 1.73^a	7.20 ± 1.97^a	7.36 ± 1.74^a
CAS 3	7.15 ± 1.68^a	7.18 ± 1.89^a	7.58 ± 1.69^a	7.40 ± 1.77^a	7.53 ± 1.72^a

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p \le 0.05$ as assessed by Tukey's HSD. CAS 1, CAS 2, and CAS 3 were developed from KME 4 by exposure to 15, 20, and 30 Gy, respectively.

3.5.2. Consumer Acceptability of Cassava-Wheat Blend Cookies

The results in Table 8 show the sensory scores for cookies produced at different levels of composite flours and compared to the control. Appearance is a major factor in determining the consumer acceptance of the food product. The scores rated for V5 and V6 were significantly ($p < 0.001$) lower than the other samples. The low rating might be attributed to the brightness of colour that might not be visually appealing to the consumers, as cookies with a golden brown colour and a uniform shape are considered the best, which enhances their overall attractiveness, which was the case with V7, resulting in having the highest appearance score [41] [42].

Table 8. Sensory evaluation of cassava-wheat blend cookies.

Variety	Appearance	Aroma	Taste	Texture	Overall acceptability
V1	7.94 ± 0.89^{b}	7.66 ± 0.90^{cd}	8.04 ± 0.93^{d}	7.96 ± 0.90^{cd}	7.82 ± 1.02^{cd}
V2	7.58 ± 1.07^{b}	7.24 ± 1.10^{bc}	7.20 ± 1.28^{bc}	7.20 ± 0.90^{ab}	7.24 ± 1.10^{bc}
V3	7.58 ± 0.73^{b}	7.42 ± 0.97^{c}	7.64 ± 0.90^{cd}	7.4 ± 0.88^{bc}	7.54 ± 0.79^{cd}
V4	7.96 ± 0.97^{b}	7.14 ± 1.31^{bc}	7.80 ± 1.34^{cd}	7.72 ± 0.93^{bcd}	7.80 ± 1.14^{cd}
V5	6.86 ± 1.85^{a}	6.42 ± 1.31^{a}	6.34 ± 1.79^{a}	6.58 ± 1.57^{a}	6.50 ± 1.46^{a}
V6	7.46 ± 1.32^{a}	6.76 ± 1.15^{ab}	6.80 ± 1.51^{ab}	7.16 ± 1.33^{ab}	6.72 ± 1.42^{ab}
Control	8.12 ± 0.72^{b}	8.10 ± 0.81^{d}	7.96 ± 1.00^{cd}	8.08 ± 0.88^{d}	7.94 ± 0.98^{d}

Values are means ± standard deviation. Means with different superscript letters along the same column are significantly different at $p \leq 0.05$ as assessed by Tukey's HSD. CAS 1 variety was developed from KME 4 by exposure to gamma rays (15Gy) with a low dosage of 2 Gy/min. V1-50% CAS 1 flour, 50% Wheat flour, V2-60% CAS 1 flour, 40% Wheat flour, V3-40% CAS 1, flour 60% Wheat flour, V4-50% KME 4 flour, 50% Wheat flour, V5-60% KME 4 flour, 40% Wheat flour, V6-40% KME 4 flour, 60% Wheat flour and Control-100% Wheat.

Taste is a key sensory attribute that affects the insight into the food to be consumed. Cookies from V5 were significantly lower than the other varieties, as cookies from V1 recorded the highest score, which was significantly different ($p < 0.001$) compared to all varieties, including V7 (Control). This could be because the combination of CAS 1 flour and Wheat flour in V1 may have created a unique and appealing flavor profile that resonated well with the sensory panel, leading to a higher taste score compared to the control (V7). Also, the 50% blend of CAS 1 flour and wheat flour in V1 could have resulted in a balanced taste that complemented the other sensory attributes of the cookies, enhancing the overall taste experience for the judges [43]. Also, the interaction between the ingredients in the CAS 1 and the Wheat flour blend in V1 could have created a harmonious flavor profile that stood out during the sensory evaluation, resulting in a higher taste score [44]. The low scores from V5 and V6 in the taste of the cookies might be associated with the aftertaste reported by the respondent. The attribute of a "root crop" aftertaste in these samples has significantly impacted the taste perception of the cookies, leading to lower likability scores for these specific samples. Several studies have reported that higher substitution of wheat flour with cassava flour in biscuits was associated with a beany flavor "root" aroma and aftertaste [45]. This flavor is not literally "beany" as in legumes, but rather an earthy, raw root-like note typical of cassava products. These sensory attributes arise from natural compounds in cassava roots, including cyanogenic glucosides and other volatiles released during processing [45]. Consequently, varieties with higher cassava flour proportions (such as V5 and V6) tend to score lower in aroma acceptability, likely due to this distinct root flavor impacting consumer preference. Wheat flour contains more proteins and other compounds that can contribute to the development of desirable aroma and flavor compounds during baking through Maillard reactions and caramelization [35] [36].

In contrast, cassava flour has a relatively bland and neutral aroma profile, lacking the complex aromatic compounds found in wheat flour [46]. As the proportion of cassava flour increases in the cookie formulations, the overall aroma and flavor profile become more muted and less appealing to the sensory panelists. Cassava flour has a relatively bland and neutral aroma profile, lacking the complex aromatic compounds found in wheat flour [36]. This is evident in the lower aroma scores for the cookie varieties with higher cassava flour content (V5, V6) compared to those with a higher wheat flour content (V1, V2, V3, V4). This is likely due to the inherent flavor characteristics of cassava, which do not complement the typical wheat-based aroma and taste profile that consumers expect in baked goods [43].

V5 and V6, with higher cassava flour content, scored lower for overall acceptability compared to the other varieties. This can be attributed to the off aftertaste, aroma, and potentially less appealing colour and appearance compared to the varieties with a more balanced blend of cassava and wheat flour or those made entirely with wheat flour [43]. Additionally, the high acceptance of V1, V4, and V7 can be attributed to the balanced flavor profile, texture and mouthfeel, colour and appearance, and the rich aroma and flavor profile of wheat flour [9].

The control cookies made with 100% Wheat flour (V7) scored well in appearance, aroma, and texture, with an overall acceptability of 7.94. This could be because cookies from wheat flour are a common and familiar product, and the panelists may have had higher expectations for their taste and quality compared to cookies made with cassava flour or blends. This finding is in agreement with the study by [46] that the control (wheat flour Biscuits) were highly acceptable overall compared to the other cassava-wheat blend biscuits. From the results, it is evident that cookies made from KME 4 flour scored less in all aspects compared to CAS 1. Cookies made from CAS 1 flour showed a softer, more brittle, and crisp texture compared to those made from KME 4 flour, which were firmer and less crisp. These textural differences likely arise from the unique pasting properties and starch gelatinization behavior of the CAS 1 variety, which favor a tender cookie structure. Such texture attributes contributed to the higher overall acceptability of CAS 1 cookies.

4. Conclusion

Gamma irradiation increased the browning across all varieties and products. Sensory evaluations highlighted that cookies made with CAS 1 flour achieved high acceptability scores, particularly in taste and texture, outperforming those made with KME 4. Control cookies made with 100% wheat flour scored the highest overall acceptability, but consumers moderately liked all the cassava porridge. V5 was the most liked cookie. This suggests that cassava varieties, particularly CAS 1, can serve as effective alternatives to traditional wheat flour, providing unique sensory attributes and potentially enhancing the nutritional profile of baked goods.

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Conflicts of Interest

The authors declare no conflicts of interest.

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