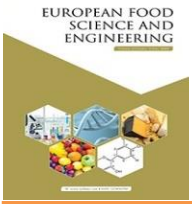

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Development of a new vegan muffin formulation: Assessing its quality and sensory characteristics

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ABSTRACT

This study aimed to develop a healthy and lactose-free muffin containing different levels of black chickpea flour (0%, 50%, 75%, and 100%, w/w) in the formulation while maintaining sensory appeal. Four different formulations were developed: while the control muffins contain cow milk, chicken egg, and wheat flour, the other three formulations include almond milk, aquafaba, and black chickpea flour at replacement ratios of 50% (M-1), 75% (M-2), and 100% (M-3), respectively. Results showed pH values ranging from 6.45 to 6.95 for batter and 6.76 to 7.10 for baked muffins, with dry matter content between 63.71% and 65.54%, and baking loss between 8.89% and 12.22%. Calorie values were highest in M-0 (330.69 kcal/100 g), reduced to 272.83-269.72 kcal/100 g with the addition of chickpea flour, aquafaba, and almond milk. Muffin height and volume decreased insignificantly in M-1, M-2, and M-3 compared to reference muffins (P>0.05). The uniformity index, volume, symmetry index, and volume index significantly decreased with chickpea flour addition (P<0.05). Sensory evaluation showed no statistically significant differences in overall acceptance among muffin samples (P>0.05). Overall, this demonstrates the potential to create sensorially pleasing vegan muffins by replacing traditional ingredients with alternatives like black chickpea flour, aquafaba, and almond milk.

1. Introduction

The quality of processed foods is directly impacted by the raw ingredients utilized. Coupled with advancements in processing technology, there has been a notable increase in processed food manufacturing. Bakery products constitute a substantial proportion of overall food consumption, with soft bakery items particularly favored despite their limited shelf life due to their delectable taste. Muffins, in particular, garner special attention due to their diverse combinations of nutritious components and sensory attributes (Dizlek, 2015; Ali et al., 2023; Shukla et al., 2024).

Chickpea (*Cicer arietinum* L.) is an annual leguminous plant belonging to the *Fabaceae* family (Rachwa-Rosiak et al., 2015). Chickpeas are valued for their high carbohydrate and protein content, with their protein quality often regarded as superior to that of other legumes (Hirdyani, 2014). When contrasted with conventional chickpeas, black chickpeas are distinguished by their black outer coat, smaller size, and irregular, wrinkled shape. They are abundant in proteins, fibers, and bioactive compounds. Several recent research findings indicate that black chickpeas hold significant promise for the creation of functional food formulations (Yaver, 2022). It holds significant promise within the consumer market, being suitable for a wide range of products such as baked goods, snacks, soups, and ready-to-eat foods (Kumar et al., 2020).

Eggs play crucial roles in food preparation due to their abilities in gelation, foaming and emulsification. They represent one of the most widely utilized food components across the globe, making them indispensable in a variety of bakery items (Mustafa et al., 2018; Boukid & Gagaoua, 2022). However, in recent times, there has been a surge in interest towards plant-based proteins as a substitute for animal-derived proteins. This trend stems from the growing vegetarian market. According to a recent report by Bloomberg Intelligence (2021), the plant-based protein market is projected to comprise up to 7.7% of the global protein market by 2030, with an estimated value exceeding $162 billion, a significant increase from $29.4 billion recorded in 2020 (Kim et al., 2022). The rise of plant-based food ingredients and products mirrors a growing effort to replicate and substitute animal-derived sources like meat, milk, and eggs. This shift aligns with the considerable expansion of vegetarian and vegan markets, driven by consumer desires for healthier and more environmentally friendly food options. Individuals are increasingly open to modifying their dietary habits and embracing accountability for climate change by minimizing their carbon emissions. This entails opting for

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plant-based alternatives over animal-based ones (He et al., 2021; Raikos et al., 2021; Ozcan et al., 2023).

Aquafaba, originating from the Latin words "aqua" meaning water and "faba" representing the *Fabaceae* family, is recognized as a valuable ingredient with functional capabilities like foaming, emulsifying, and gelling. Studies and practical applications demonstrate its potential as a substitute for eggs and milk in vegan products, offering diverse formulation options (Buhl et al., 2019; Bekiroglu et al., 2023; Viana et al., 2023; Erem et al., 2023; Erem et al., 2024). It's a viscous liquid typically extracted and discarded following the cooking of legumes, with chickpeas being the most commonly utilized source (Shim et al., 2018; Mustafa & Reaney, 2020; Echeverria-Jaramillo & Shin, 2023). Aquafaba is used in various scientific reports for the preparation of vegetable-based origin mayonnaise (Raikos et al., 2020; He et al., 2021), scrambled eggs (Dever, 2016), merengues (Fuentes-Choya et al., 2023; Tufaro & Cappa, 2023), cakes & muffins (Mustafa et al., 2018; Aslan & Ertaş, 2020; Sengar, 2021; Grossi Bovi Karatay et al., 2022; Edleman & Hall, 2023), cookies (Edleman & Hall, 2023), and mousses (Mehren et al., 2023). However, to the best of our knowledge, there is no study evaluating the effects of black chickpea flour, almond milk and aquafaba.

2. Materials and methods

2.1. Materials

Black chickpea flour (Cey Natural Foods, Istanbul, Türkiye), almond milk (Nilky Beverage and Food Industry and Trade Inc., Istanbul, Türkiye), sugar (Irmak Şeker, Ismen Food Company, İstanbul, Türkiye), commercial chickpea cans (Yayla Agro Food Industry and Transportation Inc., Mersin, Türkiye), sunflower oil (Yudum oils, Balıkesir, Türkiye), walnut (Peyman Company, Balikesir, Türkiye), cacao powder (Dr. Oetker, İzmir, Türkiye), baking powder (Dr. Oetker, Izmir, Türkiye), vanilla sugar (Dr. Oetker, İzmir, Turkiye), cinnamon powder (Bağdat Baharat, Ankara, Turkiye), UHT whole-fat cow milk (Icim, Ak Food Co., Sakarya, Türkiye), wheat flour (Söke flour, Söke Milling Industry and Trade Inc., Aydın, Türkiye) were obtained. Also, carrots and chicken eggs were purchased from a local market.

2.2. Aquafaba production

To prepare aquafaba, commercial chickpea cans were first drained using a sieve. Then, 0.5 grams of salt was added to the drained chickpea water, and it was whisked with a hand mixer for 4 min until it reached a foam consistency (similar to whipped cream, rather than stiff peaks) (Mustafa et al., 2018).

2.3. Muffin production

The block flow diagram illustrating the production process of muffins is depicted in Figure 1. At first, the sugar and chicken eggs/aquafaba were mixed in a mixing bowl for 7 min using a stainless-steel wire whisk until it reached a smooth and consistent texture. Once the sugar and egg/aquafaba mixture was ready, sunflower oil and milk were slowly added into the bowl. Then, the ingredients were thoroughly mixed for 3 min to ensure they were evenly incorporated. The grated carrot, chopped walnuts, and cinnamon were added and mixed for 1 min. Subsequently, cocoa, baking powder, vanilla, wheat flour and/or chickpea flour were added and mixed for 2 min until a uniform batter was formed. The mixture was portioned into the equal sizes (60 g portions) to promote consistent baking. Portioned batter into the muffin molds (Dolphin GG-muffin cake capsule with paper surface covered with PET film, China) were baked in the preheated countertop electric mini oven (SUF 4000 MEB, Arçelik, Türkiye) at 180 °C for 22 min. Following this procedure, 4 different muffin samples were produced, and their recipes were provided in Table 1. Also, the block flow diagram was used to produce muffins. The muffin samples, including egg (11.1%), cow milk (19.4%), and wheat flour (22.2%), were named as M-0. Meanwhile, the muffin formulations containing aquafaba (11.1%), almond milk (19.4%), and wheat flour: chickpea flour (11.1 g:11.1 g for M-1, 5.6 g:16.7 g for M-2, and 0 g:22.2 g for M-3) were coded as M-1, M-2, and M-3, respectively. Finally, the images of the produced muffins were given in Figure 2.

2.4. Chemical analysis

pH analysis

The pH values of the samples were determined using a pH meter (Ohaus AB23PH-F, China) calibrated with appropriate buffer solutions prior to analysis. 10 grams of sample was weighed using an analytical scale (readability: 0.001 g; PLJ 1200-3A-2020a, Kern & Sohn GmbH), 30 mL of distilled water was added and homogenized using a high-speed laboratory homogenizer (Model D-160, hand-held homogenizer, DLAB Scientific Co., Ltd., Beijing, China) for 3 min. Then, pH measurements and temperatures of the upper part were determined by immersing the probe into the samples (Elgün et al, 2012).

Dry matter analysis

The dry matter content of muffin samples was ascertained by using the AOAC (1990) standard technique. About 4 g of muffin samples were weighed into the weighing containers using an analytical scale (readability: 0.001 g; PLJ 1200-3A-2020a, Kern & Sohn GmbH). After they were constricted and brought to consistent weight, they were dried in a drying oven (WGL-65B, Tianjin Test Instrument Co., Ltd., Tianjin, China) at 105 ºC for 3 h. Following the procedure, they were brought to the desiccator. Using the following formula and the computed dry matter percentages, the weights of the samples that had been cooled to room temperature were ascertained.

$$Dry\ matter\ percentage\ of\ the\ sample\ (\% = \frac{((\text{Dry sample after drying} + \text{weighing container tare}) - (\text{Weighing container tare})}{((\text{Sample} + \text{weighing container tare}) - (\text{Weighing container tare}))} * 100 \quad (1)$$

Calculation of caloric value

The specific amounts of protein and carbohydrates are multiplied by the factor of 4 kcal/g, while the amount of fat is multiplied by the factor of 9 kcal/g, and as a result of these calculations, the calorie values of muffin samples determined by examining the labels of all brands individually have been calculated. The results are presented as kcal/100g.

2.5. Physical analyses

The weights of produced muffins

The weights of the produced muffins were determined in grams by weighing them on a sensitive scale after they reached room temperature.

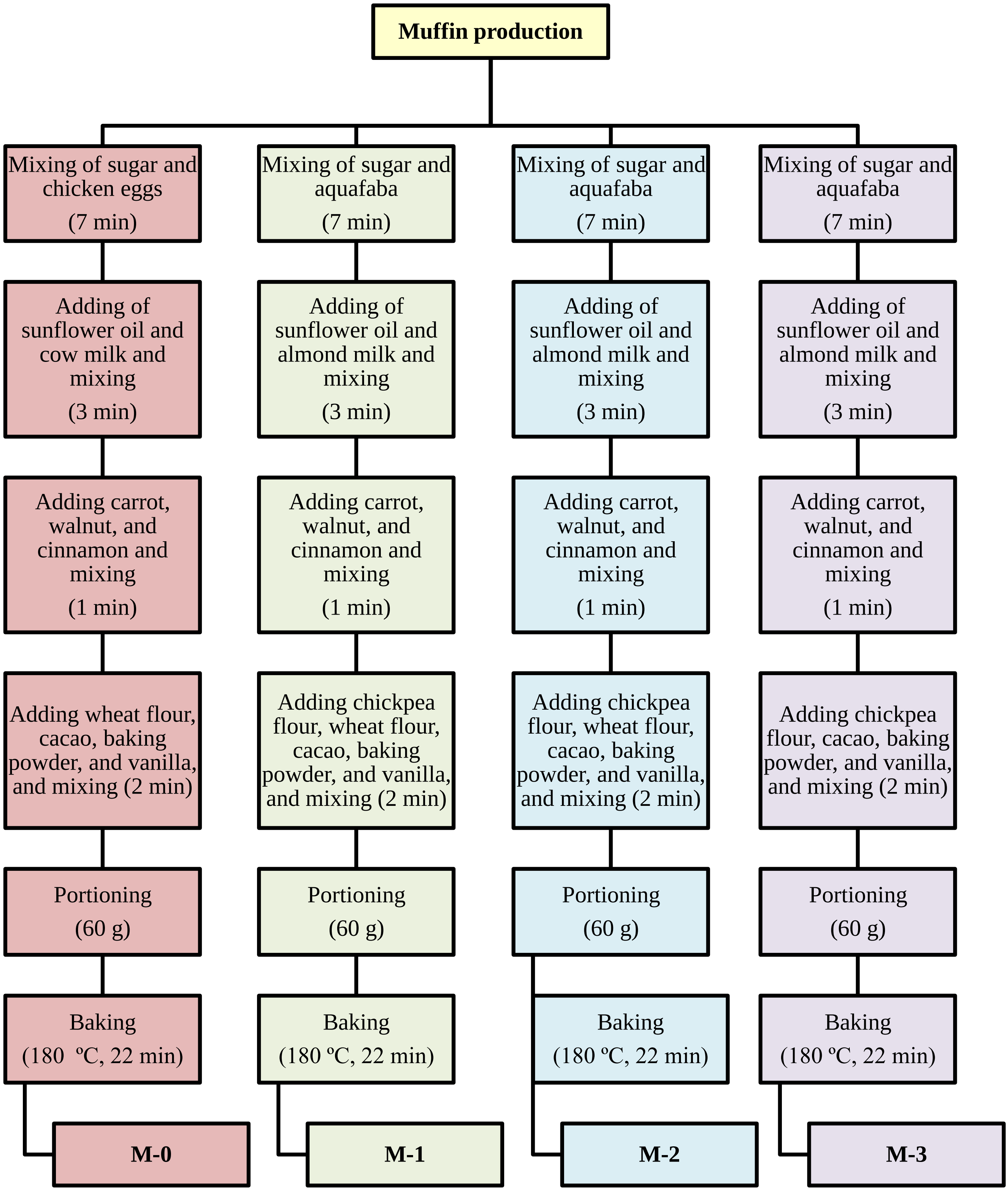

Figure 1. The block flow diagram used to produce muffins.

Table 1. The recipes utilized in the manufacturing of M-0, M-1, M-2, and M-3.

Ingredients (%)	Muffin samples			
	M-0	M-1	M-2	M-3
Wheat flour	22.2	11.1	5.6	-
Black chickpea flour	-	11.1	16.7	22.2
Milk	19.4	-	-	-
Almond milk	-	19.4	19.4	19.4
Carrot	16.7	16.7	16.7	16.7
Egg	11.1	-	-	-
Aquafaba	-	11.1	11.1	11.1
Sugar	11.1	11.1	11.1	11.1
Sunflower oil	8.3	8.3	8.3	8.3
Walnut	8.3	8.3	8.3	8.3
Cacao powder	1.9	1.9	1.9	1.9
Vanilla powder	1.4	1.4	1.4	1.4
Baking powder	1.4	1.4	1.4	1.4
Cinnamon	0.8	0.8	0.8	0.8

Figure 2. The images of produced muffins.

Muffin volume

The volume values of muffins were determined based on the displacement principle of rapeseed (AACC, Method 10-05.01). Rapeseed was poured into the container at a constant speed and distance to determine the empty volume of the container. Then, the seeds in the container were transferred to a graduated measuring cylinder to determine the container volume (V_1). Afterwards, muffin samples were placed into the container, and the seeds with volume V_1 were emptied onto them, and the top of the container was leveled using a ruler. The value obtained by transferring the seeds overflowing from the container to the graduated measuring cylinder was recorded (V_2). The value read from the graduated measuring cylinder where the overflowing seeds were placed provided the muffin volume value in milliliters (V_2).

Muffin specific volume

The specific volume values of the muffin samples (mL/g) were calculated by dividing the muffin volume by the muffin weight (Lin et al., 2017).

$$Specific\ volume = \frac{\text{Muffin volume}}{\text{Muffin weight}} \quad (2)$$

Muffin density

The density values of the produced muffins (g/cm^3) were calculated by dividing the muffin weight by the muffin volume (Gómez et al., 2008).

$$Density = \frac{\text{Muffin weight}}{\text{Muffin volume}} \quad (3)$$

Baking loss

The baking loss values of the produced muffins were calculated as a percentage using equation (Rodríguez-García et al., 2012).

$$Baking\ loss\ (\%) = \frac{(\text{Batter weight})-(\text{Muffin weight})}{(\text{Batter weight})} * 100 \qquad (4)$$

Muffin height

The height of the muffin samples was calculated by determining the highest point of the center section of the muffin and dividing it vertically with a knife. Measurements were then made with a digital caliper (Piranha PDC 1850 Digital Caliper, China) with an accuracy of 0.1 mm based on the highest point of the sample (Martínez-Cervera et al., 2012).

Determination of uniformity index (UI), upside shrinkage value (USV), symmetry index (SI), volume index (VI), and shrinkage value (SV)

VI, SI, UI, SV, and USV (shrinkage occurs on the upside portion of the muffin) of muffin samples were determined using a layer cake measurement template following the AACC 10–91.01 method, with measurements expressed in millimeters as detailed in equations (5,6,7,8, and 9; respectively). The layer cake measurement template was appropriately adjusted for a single muffin baking cup, with dimensions of 50 mm bottom diameter, 70 mm top diameter, and 35 mm height as previously modified by Dizlek (2015). In the modified muffin measurement template, the length of the template was 70 mm, and point C indicated the center. Points B and D were positioned 21 mm from both the left and right sides of the center, while points A and E were located 35 mm from both sides. Finally, the heights |BB′|, |CC′|, and |DD′|, and lengths |AE| and |A′E′| were measured from the template and utilized for the calculation of the index and shrinkage values, respectively.

To calculate the index values according to AACC Method 10–91.01, the height of the muffin was determined to the nearest 1 mm at vertical lines B, C, and D. For determining muffin SV and USV, the diameter was determined (from A to E and A' to E', respectively) to the nearest 1 mm. Then, the diameter was deductedted from 50 mm to find SV (Eq. 8), and subtracted from 70 mm to find USV (Eq. 9).

$$VI\ (mm) = |BB'| + |CC'| + |DD'| \qquad (5)$$

$$SI\ (mm) = 2|CC'| - |BB'| - |DD'| \qquad (6)$$

$$UI\ (mm) = |BB'| - |DD'| \qquad (7)$$

$$SV\ (mm) = 50\ mm - |AE| \qquad (8)$$

$$USV\ (mm) = 70\ mm - |A'E'| \qquad (9)$$

2.6. Sensory analysis

Sensory analyses were carried out by 15 female and 7 male panelists aged between 20-42 years, semi-educated, consisting of Ankara Medipol University Department of Gastronomy and Culinary Arts lecturers and third-year undergraduate students who had taken the Food Formulation and Sensory Analysis course. In these analyses, the samples were presented to the panelists at room temperature for sensory analysis. The order of presentation of the samples varied among the panelists in order not to influence their choices. Each sample was cut into two equal parts with a stainless-steel knife (Pirge ecco, 26 cm, chef knife, Türkiye). The samples were served to the panelists in plastic plates numbered (M-0:289, M-1:675, M-2:378, and M-3:743) for sensory evaluation. In addition, water was given to the panelists in disposable plastic cups as a palate cleanser during the sensory analyses. The sensory characteristics were determined by 11 different sensory parameters (crust & crumb color, softness, crumbliness, moistness, elasticity, porosity, odor, taste, volume, and overall acceptability) using a 9-point hedonic scale (1, not at all like; 9, very much like) (Yalcin et al., 2021).

2.7. Statistical evaluation

JMP 6.0 statistical analysis software (SAS Institute, Inc., Cary, NC, USA) was utilized for performing one-way ANOVA. Additionally, Student’s t-test was employed to evaluate the impacts of independent variables, including pH, dry matter, physical, and sensory analysis (*e.g.* crust & crumb color, crumbliness, softness, moistness, volume, elasticity, porosity, odor, taste, and overall acceptability). The results were analyzed at a significance level of $P<0.05$.

3. Results and Discussion

3.1. Physicochemical properties

The batter pH values were measured between 6.45 and 6.95 (Table 2). However, despite minor differences in the results, these variations were found to be insignificant ($P>0.05$). The pH values of the muffin samples ranged between 6.76 and 7.10 (Table 2). The highest pH was observed in the M-0 samples, while the lowest pH was determined in the M-2 samples. Additionally, the effect of changes in the formulation on pH was found to be statistically significant ($P<0.05$). In other words, variations in the ratios of the flours in the formulation significantly affected the pH values ($P<0.05$). The addition of black chickpea flour instead of wheat flour resulted in a decrease in pH. The pH values of flour in water suspension are crucial as certain functional properties, primarily associated with protein, such as emulsion properties and nitrogen solubility, are greatly influenced by variations in pH (Alvarez et al., 2017). Substituting wheat flour with pulse flour resulted in a higher density of cake batters. This change may be attributed to the functional properties of bean flour proteins, such as foam stability and emulsification (Singh et al., 2015). Similarly, Mustafa et al. (2018) reported that the pH of sponge cake manufactured with egg white was higher than that manufactured with aquafaba.

The dry matter values of M-0, M-1, M-2, and M-3 were determined to be 65.54%, 64.81%, 63.71%, and 65.50%, respectively (Table 2). The dry matter content of M-0 samples was slightly higher compared to the other samples; however, statistically, this difference was not significant ($P>0.05$). In other words, replacing chicken eggs with aquafaba, black chickpea flour with wheat flour, and cow milk with almond milk did not alter the moisture level of the prepared muffins. Similarly, the muffin enriched with chickpea flour has a lower pH and higher moisture content compared to muffins incorporated with wheat flour (Alvarez et al., 2017). Increased moisture levels may be linked to greater water absorption, attributable to the existence of two separate sources of protein and starch in these batters (Alvarez et al., 2017).

The reduction in bake loss holds significance in industrial settings as it directly impacts yield and product weight, with lower bake loss correlating to higher yields. Bake loss occurs due to the evaporation of water from the product during baking, a process influenced by the water retention capability of the ingredients used (Grasso & Methven, 2020). The baking loss values for muffins were found in descending order as follows: M-3 (12.22%) > M-0 (10.56%) > M-2 (10.00%) > M-1 (8.89%)

as shown in Table 2. Differences in baking loss percentages between muffin formulations were found to be significant (P<0.05). Due to lower baking loss in M-1 samples among the muffin samples, they had a higher yield.

The calorie contents of the muffins were provided in Table 2 and these values ranged from 269.72 to 330.69 kcal/100 g. The presence of chicken egg in the formulation (for M-0) increased the calorie content compared to muffins containing aquafaba (M-1, M-2, and M-3). Compared to the control samples, the reformulated vegan muffin samples showed a lower energy value, reaching a decrease in the range of 17.50% to 18.4% compared to the control muffins. Despite this quantitatively significant decrease, it was not sufficient for the product to claim "reduced energy" according to Regulation (EC) No 1924/2006 of the European Parliament and of the Council, which requires a minimum decrease of 30% (Anserona et al., 2022).

3.2. Physical attributes

The height values of the muffins vary between 35.07 and 36.11 mm (Table 3). Height was lower in muffins enriched with black chickpea flour. However, the differences in height values were not found to be statistically significant (P>0.05).

The volume values of the muffins for M-0, M-1, M-2, and M-3 were measured as 120.58, 102.52, 95.83, and 96.00 mL, respectively (Table 3). The differences between the measured values for M-1, M-2, and M-3 were found to be insignificant (P>0.05). The measured results between M-1/M-2/M-3 and control muffin samples were found to be significant (P<0.05). Several interconnected factors contribute to the final volume in baking: the rheological characteristics of the batter (which are influenced by the ingredients used), the degree of air integration, and the duration and speed of mixing and homogenization (Martínez-Cervera et al., 2012). Chickpea flour exhibited elevated protein content as well as distinct amino acid composition compared to wheat flour, factors that could potentially influence cake attributes, particularly its volume (Gómez et al., 2008). The notable decrease in muffin volume indicates a reduced amount of air retained within the cake during baking and generated denser muffins (Gómez et al., 2008; Ahmad et al., 2021; Sunwar, 2022). This could be attributed to the inability of black chickpea flour and/or aquafaba to effectively enhance air retention and promote batter aeration. The other reason could also be attributed to the elevated fiber content in chickpea flour, which potentially limits water availability for the formation of the starch-protein network during baking. Consequently, this could lead to a reduction in muffin volume (Herranz et al., 2016).

The specific volume values of the samples varied in the range of 1.77 (for M-2) to 2.25 mL/g (for M-0) (Table 3). While the differences between M-1, M-2, and M-3 samples were not statistically significant (P>0.05), the differences between the mentioned samples and the M-0 samples were found to be significant (P<0.05). Likewise, Herranz et al. (2016) observed a notable reduction in specific volume measurements in gluten-free muffins made with chickpea flour.

According to the calculated findings, the density values of the samples were determined to be in the range of 0.45-0.56 g/mL (Table 3). Since density and volume were inversely related, the M-2 muffin had the highest density. The results between M-1, M-2, and M-3 samples were found to be statistically insignificant (P>0.05). However, the differences between these samples and M-0 were found to be significant (P<0.05).

The VI values, which gave clues about the overall dimensions of the muffin (Dizlek, 2015), were ranked from smallest to largest in the tested samples as follows: M-2 (9.38 mm) < M-3 (9.68 mm) < M-1 (10.00 mm) < M-0 (12.33 mm) and these differences were statistically significant (P<0.05) (Table 3).

SI values above zero suggested an expansion in the center of bakery products, which was a desirable trait in muffin samples. Conversely, negative values indicate a concavity in the center (Moreira et al., 2023). SI values of the muffins were calculated to range from -0.14 to 1.08. Specifically, the SI values were determined as 1.08 for M-0, 0.58 for M-1, 0.54 for M-2, and -0.14 for M-3 (Table 3). While the differences between M-0 and M-1 were not found to be statistically significant (P>0.05), it was observed that the differences in SI values among the other samples were statistically significant (P<0.05).

Table 2. pH, dry matter, and baking loss content of muffin samples.

Samples	pH of batter	pH of muffin	Dry matter (%)	Baking loss (%)	Calorie content (kcal/100g)
M-0	6.95±0.01^{a}	7.10±0.01^{a}	65.54±3.10^{a}	10.56±0.96^{b}	330.69
M-1	6.81±0.01^{a}	6.94±0.01^{c}	64.81±4.34^{a}	8.89±0.96^{c}	272.83
M-2	6.45±0.59^{a}	6.76±0.01^{d}	63.71±4.42^{a}	10.00±0.00^{bc}	271.28
M-3	6.77±0.02^{a}	6.96±0.02^{b}	65.50±3.34^{a}	12.22±0.96^{a}	269.72

Columns labeled with distinct letters (*e.g.*, a, d) indicate statistically significant differences (P<0.05)

Table 3. The influences of different muffin formulations on the muffin quality.

Properties	M-0	M-1	M-2	M-3
Height (mm)	36.11±3.46^{a}	36.09±3.47^{a}	35.07±1.17^{a}	35.56±2.19^{a}
Volume (mL)	120.58±3.76^{a}	102.52±9.01^{b}	95.83±5.64^{b}	96.00±12.17^{b}
Specific volume (mL/g)	2.25±0.06^{a}	1.88±0.15^{b}	1.77±0.09^{b}	1.82±0.02^{b}
Density (g/mL)	0.45±0.01^{b}	0.54±0.05^{a}	0.56±0.03^{a}	0.55±0.07^{a}
Volume index (mm)	12.33±0.45^{a}	10.00±0.05^{b}	9.38±0.24^{c}	9.68±0.52^{bc}
Symmetry index (mm)	1.08±0.43^{a}	0.58±0.63^{a}	0.54±0.87^{ab}	-0.14±0.22^{b}
Uniformity index (mm)	0.04±0.37^{ab}	-0.23±0.09^{b}	-5.42±1.20^{b}	15.25±2.12^{bc}
Shrinkage value (mm)	-2.42±1.56^{a}	0.21±0.31^{a}	-3.75±1.94^{ab}	19.33±3.39^{a}
Upside shrinkage (mm)	13.08±1.86^{c}	-0.14±0.22^{b}	-3.18±1.82^{a}	17.33±1.75^{ab}

Rows labeled with distinct letters (*e.g.*, a, d) indicate statistically significant differences (P<0.05)

Correspondingly, Gomez et al. (2008) reported that sponge cakes with chickpea flour addition have less symmetry and consequently, less gas retention capacity and final volume. The computed UI values, serving as an indication of cake symmetry, varied between -0.23 and 0.21 mm (Table 3), with statistically significant differences between them (P<0.05). For a perfect cake, this index is ideally recorded as zero, because positive or negative values happen when one side of the cake is raised above the other (Dizlek et al., 2008).

The SV values of the muffins were calculated negatively, with the smallest value determined for M-1 (-5.42 mm) and the highest value determined for M-0 (-2.42 mm) (Table 3). The differences between these determined values were found to be statistically significant (P<0.05). Previously, Moreira et al. (2023) reported that the technological attributes of bakery goods, including firmness, SV, SI, and consistency, impact the sensory approval of the product by consumers.

The highest USV value among the samples (19.33 mm) was determined for M-2. This was followed by M-3 (17.33 mm), M-1 (15.25 mm), and M-0 (13.08 mm), respectively (Table 3). The differences in USV values arising from differences in recipes were found to be statistically significant (P<0.05).

3.3. Sensory evaluation

The sensory characteristics are significant factors in determining the approval of a product (Ahmad et al., 2021; Yavuz et al., 2022; Demirkan et al., 2024). The results of sensory evaluations are shown in Table 4. Figure 3 depicts the spider diagram illustrating the sensory evaluation of the four different muffin samples. The color of baked goods originates from two factors: the inherent color contributed by individual ingredients and the developed color that emerges from the interaction between ingredients (Sunwar et al., 2022). According to these findings, crust color values were scored in the range of 5.91-6.86 by the panelists. The crumb color of M-0 was at the lowest level, while formulations M-1, M-2, and M-3 received higher scores. However, the differences in these scores were not statistically significant (P>0.05). Additionally, odor scores for muffin samples ranged from 5.82 to 6.50. However, in formulations M-2 and M-3, a higher amount of black chickpea flour (16.7%) led to lower odor scores for muffins according to the panelists. Nevertheless, these differences were not statistically significant (P>0.05).

Table 4. Sensory properties of muffin samples.

Sensory parameters	M-0	M-1	M-2	M-3
Crust color	5.91±1.77^{a}	6.45±1.79^{a}	6.86±1.52^{a}	6.55±1.63^{a}
Crumb color	5.64±1.87^{a}	6.45±1.44^{a}	6.59±1.50^{a}	6.18±1.74^{a}
Odor	6.50±1.50^{a}	6.68±1.39^{a}	6.14±1.39^{a}	5.82±1.62^{a}
Taste	5.95±2.01^{a}	5.77±1.60^{a}	5.73±1.80^{a}	5.36±1.89^{a}
Softness	6.82±1.74^{a}	6.55±1.57^{ab}	5.55±1.87^{c}	5.64±1.43^{bc}
Moistness	5.95±2.13^{a}	6.14±1.98^{a}	5.82±1.62^{a}	5.82±1.59^{a}
Crumbliness	5.52±1.69^{a}	5.50±1.30^{a}	5.45±1.50^{a}	5.71±1.45^{a}
Elasticity	6.50±1.68^{a}	4.90±1.95^{b}	5.24±2.12^{b}	4.59±1.89^{b}
Porosity	4.86±2.17^{a}	5.32±1.70^{a}	5.59±2.06^{a}	5.14±1.88^{a}
Volume	6.23±1.57^{a}	5.00±1.63^{b}	6.41±1.71^{a}	5.86±1.61^{ab}
Overall acceptability	6.57±1.36^{a}	6.36±1.50^{a}	6.05±1.77^{a}	5.76±1.45^{a}

Rows labeled with distinct letters (*e.g.*, a, d) indicate statistically significant differences (P<0.05)

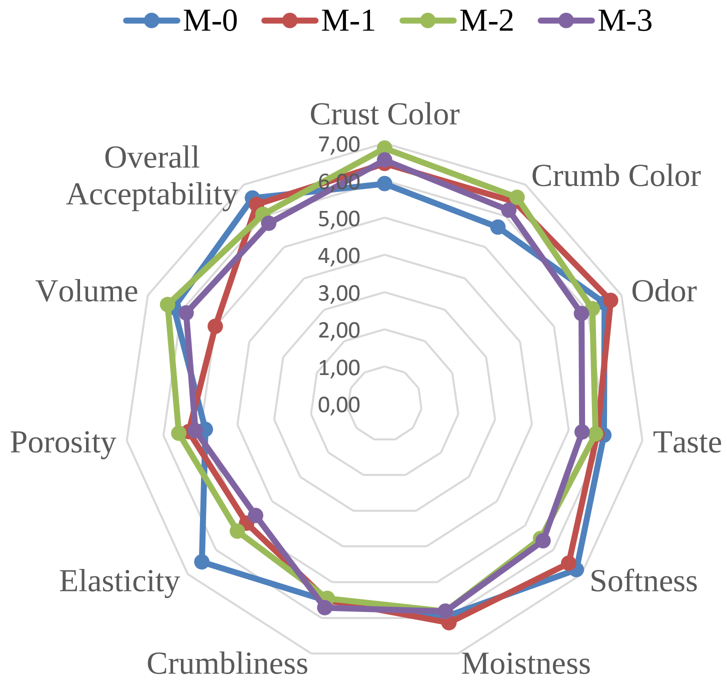

Figure 3. Spider web chart comparison of sensory analysis.

In terms of taste scores, muffin samples were found to range from 5.36 to 5.95. The highest taste score was observed in sample M-0, followed by M-1, M-2, and M-3, respectively. Hence, vegan-type produced muffins received lower scores than control muffins, but these differences were not statistically significant (P>0.05).

Softness scores ranged from 5.55 to 6.83, with sample M-2 receiving the lowest softness score and sample M-0 receiving the highest. Additionally, the differences in softness scores were found to be statistically significant (P<0.05).

The moisture parameter, which reflected the level of perceived moisture, varied between 5.82 and 6.14, which indicates that the highest moisture score was given to sample M-1 and the lowest scores were given to samples M-2 and M-3. However, these scores were not statistically significant (P>0.05). Crumbliness values ranged between 5.45 and 5.71, but no statistically significant differences were found among the crumbliness scores (P>0.05).

Elasticity values ranged from 4.90 to 6.50, with significant differences observed between samples M-0 and M-1/M-2/M-3 (P<0.05). Also, sensory evaluators rated porosity scores between 4.86 and 5.59, with no statistically significant differences found among these scores (P>0.05). Moreover, volume values were determined to range from 5.00 to 6.23. The volume scores from smallest to largest were as follows: M-1<M-3<M-0<M-2. However, the differences between the scores of M-0 and M-2 were not statistically significant (P>0.05). Additionally, overall acceptability scores ranged from 5.76 to 6.57. However, these results did not show statistically significant differences (P>0.05), showing that all muffin formulations were acceptable for the panelists.

4. Conclusions

As bakery products like muffins gain increasing popularity globally, there's a growing demand for items that are not only delicious but also low in calories and offer health benefits. Hence, the aim of this study was to assess the characteristics of muffin samples and illustrate how incorporating almond milk, aquafaba, and black chickpea flour influenced their sensory attributes and overall quality, catering to consumers who prioritize mindful eating habits. According to the findings, while the muffin formulation did not significantly affect the pH and dry matter of the muffin batter, there were notable decreases in the pH of baked muffins compared to the control. Additionally, the lowest baking loss was observed in M-1 samples. The highest calorie value was found in the control samples, whereas increasing the concentration of black chickpea flour in the formulation, substituting aquafaba for eggs, or using almond milk instead of cow's milk reduced the calorie content of the produced muffins. Moreover, height and density values were not significantly affected by the muffin formulation (P>0.05). However, compared to the control, other samples showed significantly lower values for uniformity index, volume, shrinkage value, symmetry index, volume index, and specific volume, while their density values were higher (P<0.05). Furthermore, among the sensory parameters, there was no statistically significant effect on moistness, crumb color, crust color, porosity, taste, crumbliness, odor, and overall acceptability. However, the effect was significant on other parameters (softness, elasticity, porosity, and volume) (P<0.05). Panelists rated vegan cakes lower in softness, elasticity, and volume scores. In conclusion, the muffin samples produced not only cater to individuals suffering from egg, cow milk and gluten intolerance and allergies but also offer a delightful option for those adhering to a vegan diet. This versatility underscores their potential to accommodate diverse dietary preferences and requirements while providing a tasty treat for all and aiding in the advancement of clean-label food products with the substitution of animal-based ingredients.

Author Contributions

Gozde Kutlu: Writing – original draft, review&editing, methodology, visualization, validation, supervision. Safa Yilmaz: Methodology, investigation. Ahmet Eray Karabulut: Methodology, investigation.

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Conflicts of Interest

The authors state that they have no conflicts of interest.

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