



Sensory Evaluation of Chickpea Aquafaba as an Egg Substitute in Vegan Cupcake Formulation **

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Abstract

This study aimed to investigate the use of aquafaba, a plant-based ingredient, as an alternative to eggs in cupcake production. Two formulations, traditional and vegan, were prepared and their sensory properties were comparatively evaluated. Sensory analysis was carried out with 30 semi-trained panelists in two replicates, using difference-from-control, scoring, and hedonic scale tests. In the difference-from-control test, the vegan cupcake was perceived as moderately different from the control. According to the scoring test, statistically significant differences were found in appearance attributes, as the vegan cupcake was rated with a darker crust color and a less uniform crumb structure, while no significant differences were observed in aroma, texture, or flavor attributes. In the hedonic scale test, both samples received high overall liking scores, with the vegan cupcake receiving slightly higher ratings than the traditional one. Overall, these findings suggest that aquafaba presents a favorable sensory profile and holds potential as a viable egg substitute in cupcake formulations.

Article Type

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INTRODUCTION

In recent years, the adoption of vegan diets has increased worldwide (Koeder & Perez-Cueto, 2022). This dietary pattern has gained particular popularity in Western countries and has attracted growing interest from both consumers and the scientific community (Bakaloudi et al., 2021; Janssen et al., 2016). A vegan diet excludes all animal-derived products and is primarily adopted for ethical reasons related to animal welfare and animal rights (Bakaloudi et al., 2021; Ghaffari et al., 2022; Janssen et al., 2016). In addition to ethical motivations, health considerations, environmental concerns, religious or philosophical beliefs, and personal preferences also influence the decision to follow a vegan diet (Ghaffari et al., 2022; Janssen et al., 2016). Several studies have reported positive health outcomes associated with vegan diets, further contributing to their increasing popularity (Dinu et al., 2017; Qian et al., 2019; Selinger et al., 2023).

The growing demand for vegan and other plant-based diets has driven increased investment in plant-based food products within the food industry (Fehér et al., 2020). Vegan products, in particular, have shown steady growth in both sales and consumption (Martinelli & De Canio, 2022). The global vegan food market was valued at 16.55 billion USD in 2022 and is projected to grow at a compound annual growth rate of 10.7% between 2023 and 2030 (Grand View Research, 2022). This rapid market expansion has intensified efforts to develop alternative vegan products (Gallagher, 2022). Consequently, food manufacturers have introduced substitutes for a wide range of animal-based products to meet consumer demand for plant-based options (Fuentes & Fuentes, 2017). Despite these developments, producing plant-based foods that are both sensorially acceptable and sustainable alternatives to animal protein sources remains a challenge (Pointke & Pawelzik, 2022).

In this context, the development of new formulations relies either on the identification of novel ingredients or on the innovative use of existing ones. Aquafaba, obtained from the cooking water of legumes, has emerged as a promising plant-based ingredient and is widely used as an egg substitute in vegan formulations due to its nutritional composition and functional properties (Raikos et al., 2020). Over the past decade, aquafaba has gained increasing attention, and several studies have investigated its applicability in vegan food products (Aslan & Ertaş, 2020; Buhl et al., 2019; Mustafa et al., 2018; Raikos et al., 2020).

This study aimed to develop a vegan cupcake formulation using chickpea aquafaba as an alternative to eggs traditionally used in cake production. In addition, the sensory performance of the vegan cupcake was evaluated and compared with that of a traditional formulation to assess its potential as a comparable alternative.

Aquafaba

Viscous liquids obtained from cooking legumes in water are referred to as aquafaba (Raikos et al., 2020). Although the term is most commonly associated with chickpeas, it also encompasses the cooking water of other legumes, including beans, green lentils, and yellow peas. Aquafaba was first described by French vegan Joël Roessel, who identified its foaming ability while seeking an egg-white substitute for a “floating island” dessert (Roessel, 2014). Following this discovery, aquafaba gained wider recognition through its use in products such as chocolate mousse and vegan meringue (He et al., 2021). In 2015, Goose Wohlt optimized a meringue formulation using chickpea aquafaba and sugar and introduced the term “aquafaba,” derived from the Latin words aqua (water) and faba (bean) (He et al., 2021). The term rapidly gained international acceptance and was subsequently included in major

dictionaries, including the Oxford English Dictionary, Merriam-Webster, and Scrabble (Mustafa & Reaney, 2020).

Aquafaba first appeared in scientific literature in the study by Bird et al. (2017), in which chickpea cooking water was used to improve the structure of gluten-free bread, although it was not explicitly referred to as aquafaba. The first study to formally use the term was conducted by Shim et al. (2018), who investigated the chemical composition of aquafaba obtained from different commercial chickpea brands. Since then, scholarly interest in aquafaba has increased steadily, particularly within food science, resulting in a growing body of research on its functional and technological properties.

Aquafaba production generally involves soaking chickpeas followed by cooking through boiling, pressure cooking, or canning (Echeverria-Jaramillo & Shin, 2023). During this process, soluble proteins, carbohydrates, saponins, and phenolic compounds migrate into the cooking water, thereby determining its composition and functional potential (Stasiak et al., 2023). Aquafaba quality is influenced by several factors, including chickpea genotype, seed-to-water ratio, cooking method, and processing conditions (He et al., 2019; Alsalman et al., 2020; Crawford et al., 2023). Notably, higher solid content obtained through boiling or pressure cooking increases protein concentration, which is closely associated with enhanced foaming and emulsifying capacities (Alsalman et al., 2020; Lafarga et al., 2019). Consequently, standardization of processing parameters is essential to ensure consistent quality and functionality in aquafaba-based products (He et al., 2021).

From a functional perspective, aquafaba exhibits foaming, emulsifying, gelling, and water- and oil-binding properties, primarily attributed to its proteins, polysaccharides, saponins, and phenolic compounds (Mustafa & Reaney, 2020; He et al., 2021). These characteristics make aquafaba a suitable egg substitute in a variety of food products, including mayonnaise (Raikos et al., 2020; Ozcan et al., 2023), meringues (Stantiall et al., 2018; Meurer et al., 2020), cakes (Aslan & Ertaş, 2020; Crawford et al., 2023), and gluten-free breads (Bird et al., 2017; Roozen & Serventi, 2022). In addition, recent studies have explored technological interventions such as ultrasound and high-pressure processing, which have been shown to improve foaming stability, emulsifying capacity, and overall textural quality (Meurer et al., 2020; Alsalman & Ramaswamy, 2021). Overall, these findings underline aquafaba's versatility and its growing potential as a sustainable plant-based ingredient for both industrial and artisanal food applications.

Material and Method

Material

Cake flour, powdered sugar, sunflower oil, milk, coconut milk, vanilla extract, and baking powder were purchased from local markets in Sivas, Türkiye. Gypsophila extract (Tito, Türkiye) and cream of tartar (Arifoğlu, Türkiye) were supplied by specialized food ingredient companies. Dried chickpeas (*Cicer arietinum* L.) (Mill & More, Türkiye) used for aquafaba preparation were purchased online. According to the manufacturer's label, 100 g of dried chickpeas contained 1240 kJ/295 kcal energy, 31 g of carbohydrates (2.6 g sugar), 2.8 g of fat (0.5 g saturated fat), 22 g of protein, and 0.14 g of salt.

Method

Preparation of Research Samples

Preparation of Aquafaba

In this study, chickpea aquafaba was produced following the protocol described by De Barros Miranda et al. (2024). Dried chickpeas were first soaked at 4°C for 10 hours at a chickpea-to-water ratio of 1:4 (w/v). After soaking, the water was drained, and the chickpeas were cooked in a pressure cooker for 30 minutes at a hydrated chickpea-to-water ratio of 2:3 (w/v). The cooked chickpeas with the cooking water were cooled to room temperature and stored for 24 hours at 4°C. Subsequently, the cooking water (aquafaba) was separated from the chickpeas by draining.

Cupcake Production Process

The control sample was prepared using a traditional cake recipe, which was subsequently modified to develop the vegan formulation. In the vegan recipe, aquafaba was used as an egg substitute, while milk was replaced with coconut milk as a plant-based alternative. Previous studies have reported that aquafaba exhibits improved foaming capacity and stability under relatively low pH conditions (Lafarga et al., 2019; Lima et al., 2024). Therefore, cream of tartar, an acid salt, was incorporated into the vegan formulation to enhance aquafaba's foaming properties. In addition, during the recipe development process, it was determined that Gypsophila extract, a plant-derived ingredient, further improved the foaming ability of aquafaba. Kablan et al. (2022) demonstrated that saponins, which are abundantly present in Gypsophila extract, act as potent surfactants and contribute to the formation of stable foam structures. Consequently, Gypsophila extract was included in limited amounts in the vegan cupcake formulation as a supplementary agent to reinforce the foaming performance of aquafaba. The ingredients and their quantities for both formulations are listed in Table 1.

Table 1. Cupcake formulations

Traditional Formulation		Vegan Formulation	
Ingredients	Amount (g)	Ingredients	Amount (g)
Cake flour	40	Cake flour	40
Powdered sugar	27	Powdered sugar	27
Egg	35	Aquafaba	35
Sunflower oil	17	Sunflower oil	17
Milk (3% fat)	16	Coconut milk	16
Vanilla extract	0,5	Vanilla extract	0,5
Baking powder	0,5	Baking powder	0,5
		Gypsophila extract	1,5
		Cream of tartar	0,2

Traditional Formulation

In the traditional formulation, egg and sugar were placed into a mixing bowl and whipped with a hand mixer (Tefal, Mastermix) at speed level 4 for 5 minutes. Sunflower oil, milk, and vanilla extract were then added and mixed at speed level 1 for 20 seconds. Cake flour and baking powder were sifted into the mixture, followed by mixing at speed level 1 for 1 minute. The batter was portioned into baking molds (20 g each) and placed on a baking tray. Baking was carried out in a preheated oven at 165 °C (conventional mode) for 30 minutes, after which the temperature was increased to 180 °C and baking continued for an additional 5 minutes.

Vegan Formulation

In the vegan formulation, aquafaba and cream of tartar were placed into a mixing bowl and whipped with a hand mixer (Tefal, Mastermix) at speed level 4 for 3 minutes. Gypsophila extract and one-third of the sugar (9 g) were then added and whipped at speed level 2 for 2 minutes. The second one-third of the sugar (9 g) was incorporated and whipped at speed level 3 for 1 minute, followed by the remaining sugar (9 g) at speed level 4 for 1 minute. Sunflower oil, coconut milk, and vanilla extract were subsequently added and mixed at speed level 1 for 20 seconds. Cake flour and baking powder were sifted into the mixture and mixed at speed level 1 for 1 minute. The batter was portioned into baking molds (20 g each) and baked under the same conditions as the traditional formulation.



Figure 1. Traditional cupcake sample



Figure 2. Vegan cupcake sample

Data Collection

Sensory Analysis

Primary data for this study were collected using structured sensory evaluation forms developed in line with the research objectives. The forms comprised standardized sections for difference-from-control, scoring, and hedonic scale tests, allowing for a comprehensive assessment of the sensory characteristics of the cupcake samples. The measurement criteria for each sensory test were defined as follows:

Difference-from-Control Test: To determine the degree of difference between the samples, the perceived difference between the vegan cupcake and the traditional (control) sample was rated on a scale ranging from 0 (no difference) to 10 (extreme difference).

Scoring Test: Four main sensory attributes were evaluated through eight sub-parameters: crust color and pore uniformity (appearance); vanilla aroma and egg odor (aroma); softness and chewiness (texture); and sweetness and off-flavor (flavor). Each sub-parameter was rated for intensity on a 5-point scale (1 = not at all intense, 5 = extremely intense).

Hedonic Scale Test: The overall acceptability of the samples was rated on a 5-point hedonic scale (1 = dislike extremely, 5 = like extremely) to compare the preference levels between the traditional and vegan cupcakes.

The panel size was determined based on recommendations reported in previous studies (Carpenter et al., 2000; Rogers, 2010; Onoğur & Elmacı, 2019). A total of 30 semi-trained assessors were recruited from academicians and students of the Department of Gastronomy and Culinary Arts at Sivas Cumhuriyet University. Assessors were required to be in good general health, have no known food allergies, and refrain from smoking. All evaluations were performed in two replicates (n = 60 evaluations per test).

To ensure blind evaluation, samples were presented with distinct identification codes (e.g., C34 for the control

cupcake and C45 for the vegan cupcake). Prior to each panel session, assessors received an information sheet and the procedure was explained by the researcher. Written informed consent was obtained from all participants. Ethical approval was granted by the Ethics Committee for Social Sciences Research at Sivas Cumhuriyet University (decision no. 2023/3, dated 23 November 2023).

Data Analysis

Statistical Analysis

The data obtained through the sensory evaluation tests were subjected to statistical analysis using IBM SPSS Statistics (v.23.0). Descriptive statistics, including mean \pm standard deviation, minimum, and maximum values, were used to summarize the findings. Data normality was assessed via the Kolmogorov–Smirnov test; variables with skewness and kurtosis values within ± 2 were considered to meet the normality assumption (George & Mallery, 2020). To identify significant differences in sensory attribute intensities between traditional and vegan cupcake samples, paired-samples t-test was applied to normally distributed variables (crust color, pore uniformity, vanilla aroma, softness, chewiness, and sweetness), while the Wilcoxon signed-rank test was used for non-normally distributed variables (egg odor and off-flavor). Statistical significance was set at $p < 0.05$.

Results and Discussion

The results from the difference-from-control test are presented in Table 2.

Table 2. Difference from control test results

Sample Code	Sample	n	Min.	Max.	Mean \pm Sd
C45	Vegan Cupcake	60	0	7	3.58 \pm 1.69

As shown in Table 2, the vegan cupcake was perceived as moderately different from the control. While the wide range of scores reflects individual differences in perception, the average score remained below the midpoint of the scale, indicating that the overall difference was relatively low.

The results from the scoring test are presented in Table 3.

Table 3. Scoring test results

Evaluation Parameters	Sub-parameters	Traditional Sample		Vegan Sample		p-value
		Min. Max.	Mean \pm Sd	Min. Max.	Mean \pm Sd	
Appearance Attributes	Crust Color	1 5	3.16 \pm 0.92	1 5	3.50 \pm 0.94	0.01
	Pore Uniformity	3 5	4.31 \pm 0.65	2 5	3.13 \pm 1.01	< 0.001
Aroma Attributes	Vanilla Aroma	1 5	3.60 \pm 1.07	1 5	3.63 \pm 1.11	0.83
	Egg Odor	1 2	1.06 \pm 0.25	1 2	1.03 \pm 0.18	0.15
Texture Attributes	Softness	2 5	3.81 \pm 0.81	2 5	4.10 \pm 0.91	0.08
	Chewiness	2 5	4.25 \pm 0.79	2 5	4.31 \pm 0.81	0.53
Flavor Attributes	Sweetness	2 5	3.71 \pm 0.78	2 5	3.65 \pm 0.81	0.57
	Off-flavor	1 3	1.11 \pm 0.45	1 3	1.18 \pm 0.50	0.15

The results of the scoring test (Table 3) revealed significant differences between traditional and vegan cupcakes for appearance-related attributes, including crust color ($p < 0.05$) and pore uniformity ($p < 0.001$). The vegan cupcakes exhibited a significantly darker crust than the control. This finding contrasts with Aslan and Ertaş (2020), who reported lighter crust colors as aquafaba substitution levels increased in cake formulations. Regarding pore uniformity, the traditional sample was perceived as significantly more homogeneous. This aligns with Mustafa et al. (2018), who observed less uniform structures in aquafaba-based sponge cakes and attributed this to heat-resistant proteins that limit the stabilization of expanding air bubbles during baking.

No significant differences were detected between the formulations with respect to aroma attributes ($p > 0.05$). Both samples demonstrated comparable vanilla aroma intensity and minimal egg odor perception, indicating that aquafaba effectively replicated the aromatic profile of the egg-based control. Although negative effects on odor have been reported at high aquafaba substitution levels in earlier studies (Aslan & Ertaş, 2020), such effects were not observed in the present formulation.

Regarding textural attributes, the vegan cupcakes tended to be perceived as slightly softer than the traditional sample; however, this difference did not reach statistical significance ($p > 0.05$). This tendency is in line with previous instrumental and sensory studies reporting reduced hardness and softer texture in aquafaba-based cakes (Konal et al., 2025; Yazici et al., 2025). Chewiness perceptions were also comparable between the two formulations ($p > 0.05$), suggesting similar textural resilience, despite some reports indicating lower chewiness in aquafaba-based cakes (Konal et al., 2025).

Flavor-related attributes showed no notable differences between the two cupcake formulations. Sweetness and off-flavor perceptions were comparable ($p > 0.05$), with both samples exhibiting minimal off-flavor intensity. These findings indicate that the plant-based formulation did not introduce undesirable sensory notes. Although previous studies have reported reduced flavor and aroma ratings in aquafaba-based formulations (Aslan & Ertaş, 2020; Konal et al., 2025; Yazici et al., 2023), the present formulation achieved flavor acceptance comparable to that of the control sample.

The results from the hedonic scale test are presented in Table 4.

Table 4. Hedonic scale test results

Sample Code	Sample	n	Min.	Max.	Mean ± Sd
C34	Traditional Cupcake	60	3	5	4.05±0.81
C45	Vegan Cupcake	60	2	5	4.11±0.80

As shown in Table 4, both the traditional and vegan cupcake samples received high hedonic scores, indicating strong overall acceptance among panelists. The vegan cupcake achieved a numerically higher mean score than the traditional control, suggesting it is highly competitive in terms of consumer preference. The low standard deviations for both formulations further reflect a high level of consistency in the evaluations. These findings are consistent with previous studies reporting similar sensory acceptance between aquafaba-based and egg-based baked products. Konal et al. (2025) observed that cakes prepared with white chickpea aquafaba closely resembled the control sample in terms of appearance, texture, and overall acceptability, while Yazici et al. (2023) reported the highest overall acceptability scores for chickpea aquafaba among various legume-based aquafaba formulations used in gluten-free cakes.

Conclusion

This study investigated the use of aquafaba, a plant-based ingredient, as an egg substitute in vegan cupcake production. Two formulations, traditional and vegan, were prepared and comparatively analyzed in terms of sensory properties. Sensory evaluations with 30 semi-trained panelists in two replicates revealed that the vegan cupcake was perceived as moderately different from the traditional control, yet showed substantial similarities in aroma, texture, and flavor attributes. Differences were more evident in appearance, as the vegan sample was evaluated with a darker crust color and a less uniform crumb structure. No significant differences were observed in vanilla aroma, egg odor, softness, chewiness, sweetness, or off-flavor perception, with the vegan sample positively evaluated for the near absence of off-flavor. Furthermore, the hedonic test results indicated that the vegan cupcake received slightly higher mean liking scores than the traditional sample. Overall, these findings suggest that aquafaba provides a favorable sensory profile and holds strong potential as a viable egg alternative in cupcake production.

Limitations and Future Direction

The present study has several limitations. Due to the methodological requirements of the applied sensory tests, the evaluation was carried out with a limited number of semi-trained panelists, and vegan consumers were deliberately excluded. As a result, potential differences in perception and preference among vegan consumers could not be assessed. Future studies should therefore include vegan participants and employ larger consumer panels to improve the generalizability of the findings, particularly in relation to consumer behaviors such as purchase intention.

Although the vegan formulation received relatively high levels of sensory acceptance, it differed from the traditional sample in appearance attributes, suggesting that recipe modifications may be applied to improve these characteristics. Moreover, the present study relied exclusively on sensory evaluation; subsequent research should incorporate instrumental analyses, such as physical and chemical measurements, to provide objective support for sensory data.

Finally, the limited incorporation of soapwort extract to enhance the functional characteristics of aquafaba warrants further systematic investigation, particularly regarding its effects on foam capacity and stability, as well as its potential applications in diverse product development processes.

Declaration

All authors have contributed equally to the article process. The authors declare that there are no conflicts of interest to report. Ethical approval was granted by the Ethics Committee for Social Sciences Research at Sivas Cumhuriyet University (decision no. 2023/3, dated 23 November 2023).

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