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POTENTIAL OF USING PULSES FLOURS AND AQUAFABA IN GLUTEN-FREE AND VEGAN CAKES

BAKLİYAT UNLARININ VE AQUAFABANIN GLUTENSİZ VE VEGAN KEKLERDE KULLANIM POTANSİYELİ

Burcu SARI GENÇAĞ[1*] (ORCID: 0000-0002-2847-297X)
Ezgi DEMİR ÖZER[1] (ORCID: 0000-0002-3525-5172)
Cem Okan ÖZER[2] (ORCID: 0000-0002-2030-1412)
Elif KÜTAHNECİ[1] (ORCID: 0000-0003-2241-5787)

[1] Department of Gastronomy and Culinary Arts, Cappadocia University, Nevşehir 50240, Türkiye
[2] Department of Food Engineering, Engineering Faculty, Nevsehir Haci Bektas Veli University, Nevsehir 50300, Türkiye

*Sorumlu Yazar / Corresponding Author: Burcu SARI GENÇAĞ, burcu.sari@kapadokya.edu.tr

ABSTRACT

Aquafaba, the viscous liquid obtained from cooking legumes, has gained popularity as a vegan egg substitute due to its foaming and moisture-retention properties. This study aimed to evaluate the potential of chickpea and lentil aquafaba, along with their respective flours, as egg and wheat-flour substitutes in gluten-free, vegan cakes. The foaming capacity of egg white, chickpea aquafaba, and lentil aquafaba was determined as 666.67%, 133.33%, and 116.67%, respectively, indicating superior foaming performance of chickpea aquafaba compared to lentil aquafaba. Physicochemical analyses revealed that cakes prepared with chickpea aquafaba had significantly higher moisture content (31.39–30.92%) and lower hardness than lentil-based formulations ($p < 0.05$). Lentil flour incorporation resulted in increased gumminess and lower overall sensory acceptability scores (2.71) compared to chickpea-based cakes and the control group (>3.50). Chickpea aquafaba and chickpea flour demonstrated sensory and textural attributes comparable to the control group, with no significant differences in texture perception ($p > 0.05$). The darker colours and unique texture associated with legume-based flours, particularly lentil flour, were linked to Maillard and caramelization reactions during baking. These results indicate that chickpea aquafaba and chickpea flour can successfully replicate the functional and sensory properties of traditional ingredients, providing a sustainable solution for gluten-free and vegan cake production.

Keywords: Aquafaba, chickpea flour, lentil flour, gluten-free cakes, egg substitutes

ÖZET

Aquafaba, baklagillerin pişirilmesiyle elde edilen viskoz bir sıvı olup, köpürme ve nem tutma özellikleri sayesinde vegan beslenmede yumurta ikamesi olarak yaygın bir şekilde kullanılmaktadır. Bu çalışmada, nohut ve mercimek aquafabaları ile bunlara ait unların, glutensiz ve vegan keklerde yumurta ve buğday unu yerine kullanılabilirliği araştırılmıştır. Nohut aquafabasının köpürme kapasitesi ve stabilitesinin mercimek aquafabasından daha yüksek olduğu belirlenmiş, bu durum keklerde daha yumuşak doku ve daha yüksek duyusal kabul edilebilirlik sağlamıştır. Fizikokimyasal analizler, nohut aquafabasının nem tutmayı artırdığını ve sertliği azalttığını ortaya koyarken, mercimek bazlı formülasyonların daha yapışkan yapı sergilediği ve genel kabul edilebilirliğinin düşük olduğu saptanmıştır. Nohut aquafabası ve unu, kontrol grubu ile karşılaştırılabilir duyusal ve tekstürel özellikler göstermiş ve glutensiz ile vegan kek üretiminde umut verici alternatifler olarak öne çıkmıştır. Baklagil unları, özellikle mercimek unu, pişirme sürecinde meydana gelen Maillard ve karamelizasyon reaksiyonlarına bağlı olarak daha koyu renk ve farklı doku özellikleri kazandırmıştır. Elde edilen bulgular, nohut aquafabası ve nohut ununun fonksiyonel ve duyusal açıdan geleneksel bileşenleri başarıyla taklit edebildiğini ve sürdürülebilir glutensiz-vegan kek üretimi için uygun çözümler sunduğunu göstermektedir.

Anahtar Kelimeler: Aquafaba, nohut unu, mercimek unu, glutensiz kekler, yumurta ikameleri

INTRODUCTION

A growing number of individuals are demonstrating sensitivities to the consumption of egg and gluten-containing products. Egg intolerance, defined as an exaggerated immune response to egg proteins, is a prevalent condition. It has been demonstrated that both the albumen and the yolk of the egg contain proteins capable of triggering allergic reactions. Nevertheless, it is crucial to acknowledge the nutritional significance of eggs in the human diet, as they serve as a crucial source of proteins, lipids, vitamins, and minerals that are essential for embryonic development. Furthermore, eggs possess immune factors that provide protection against bacterial and viral infections (Kovacs-Nolan et al., 2005). In addition to their high nutritional value, eggs exhibit functional properties such as coagulation, binding, foaming, gelation, and emulsification, which are integral in various food products (Baldwin, 1986; Yazici & Ozer, 2021).

The substitution of eggs in food products has proven to be a significant challenge. A variety of plant- and animal-based protein sources, including casein, milk powder, whey powder, hydrocolloids, emulsifiers, chia seeds, and flaxseeds, have been utilized as complete or partial substitutes for eggs in the production of cakes. However, the findings of most studies indicate that these alternatives are inadequate for producing stable foams, making the search for a suitable egg substitute a persistent issue (Mustafa et al., 2018; Yazici & Ozer, 2021).

A similar challenge arises with gluten consumption. Gluten sensitivity, including celiac disease, which is a genetic disorder resulting in malabsorption (McAllister et al., 2019), is triggered by exposure to gluten proteins found in grains and grain-based products. In response to these dietary sensitivities, alternative flours derived from buckwheat, chickpeas, beans, lentils, peas, carob, coconut, and almonds are increasingly being evaluated as potential substitutes for wheat flour due to their high nutritional profiles (Foschia et al., 2017).

The increasing demand for food products that meet specific dietary requirements and preferences has prompted the food industry to explore novel ingredients and technologies. Legume-derived components, due to their high protein content and functional properties, have shown potential as substitutes for traditional ingredients such as wheat flour and eggs. Chickpeas (*Cicer arietinum L.*), which belong to the Leguminosae family, have gained attention as a promising alternative (Fişek, 2021; Hedayati et al., 2022). Green lentils (*Lens culinaris Medik.*), another legume, are a rich source of protein (23-31%), vitamins, and minerals, and contain essential amino acids such as leucine, isoleucine, lysine, phenylalanine, and valine, contributing to their high protein quality (Shevkani et al., 2024).

Aquafaba, the viscous liquid obtained from boiling legumes, has recently emerged as a promising alternative to egg. Conventionally regarded as a by-product, aquafaba consists of water-soluble starch, amylose, amylopectin, protein, and sugar released during boiling (Aslan & Ertaş, 2020). The term "aquafaba" is derived from the Latin words "aqua" (water) and "faba" (bean) (Buhl et al., 2019). Its potential as a foaming agent was first proposed by Loël Roessel, a French vegan musician, in 2014 (He et al., 2021). Since then, aquafaba, particularly from boiled chickpeas, has gained popularity within the vegan community as a substitute for eggs and milk in various food applications (Mustafa et al., 2018).

The aim of the present study is to develop a plant-based egg substitute using aquafaba, with a potential application as an alternative for individuals with egg allergies or those adhering to a vegan diet. Furthermore, the objective is to formulate a gluten-free cake option to meet the dietary needs of individuals with coeliac disease. In addition, the study seeks to address food waste by utilising boiled legume water, which is commonly wasted. The incorporation of these innovations is expected to contribute to the production of more inclusive and sustainable food products.

MATERIAL AND METHOD

Materials

The present project was conducted in the kitchens and laboratory of the Department of Gastronomy and Culinary Arts at Cappadocia University. The following ingredients were obtained from a local market in Nevşehir: chickpeas and green lentils, eggs, flour, baking powder, sugar, vanilla, chia seeds, and sunflower oil. The other ingredients utilized in the cake were xanthan gum (Alfasol, China) and tapioca starch (Vegrano, Thailand), lecithin (Alfasol, India), chickpea flour (Ipek Degirmen, Türkiye), and lentil flour (Ipek Degirmen, Türkiye).

Preparation of Aquafaba

Chickpeas and lentils were heated in tap water at 100 °C for 35 and 25 min, respectively. Thereafter, the legumes were allowed to cool to room temperature and stored at 4°C for 24 hours. After the refrigeration period, the water used to boil the legumes was separated to obtain aquafaba (Lafarga et al., 2019; Ozcan et al., 2023). The difference in heating times is due to the variation in the structural composition and hardness of chickpeas and lentils, with chickpeas requiring longer cooking times to soften adequately and release soluble components into the boiling water.

Production of Cakes

The recipe utilized 180 g of sucrose, 60 ml of oil, 10 g of vanillin, and 10 g of baking powder, with these ingredients being common to all cake groups. In the control group and other treatment groups, all ingredients were used in the amounts specified in Table 1. In cake production, firstly sugar and eggs or aquafaba were whipped at high speed for 5 minutes (Öztiryakiler Gurmeaid Mixer) until a foamy and slightly firm consistency was achieved. Then, the liquid ingredients were added, and the mixing continued for an additional 5 min. Afterward, the dry ingredients were gradually incorporated, ensuring a homogeneous consistency with a spatula. The chia seeds in the formulation were first ground (10 g) and mixed with water (45 ml), and kept for approximately 10 min, and used after reaching a gel consistency. The resulting batters were evenly distributed to fill half of each lightly greased silicone cake mold (12-count) and baked in a preheated oven at 180°C for 13 minutes. After baking, the cakes were left in the oven for an additional 7 minutes with the oven door closed.

Table 1. Formulation of the Cake Samples

Ingredients	C	EF-CF	EF-LF	CAF-CF	CAF-WF	LAF-LF	LAF-WF
Wheat flour (g)	360	-	-	-	360	-	360
Egg (pieces)	3	3	3	-	-	-	-
Chickpea flour (g)	-	300	-	300	-	-	-
Lentil flour (g)	-	-	300	-	-	300	-
Tapioca starch (g)	-	60	60	60	-	60	-
Xanthan gum (g)	-	6	6	6	-	6	-
Water (ml)	60	60	60	-	-	-	-
Aquafaba (ml)	-	-	-	430	430	430	430
Chia seed (g)	-	-	-	10	10	10	10
Lecithin (g)	-	-	-	30	30	30	30

C: Control, EF-CF: Egg and Chickpea Flour, EF-LF: Egg and Lentil Flour, CAF-CF: Chickpea Aquafaba and Chickpea Flour, CAF-WF: Chickpea Aquafaba and Wheat Flour, LAF-LF: Lentil Aquafaba and Lentil Flour, LAF-WF: Lentil Aquafaba and+ Wheat Flour.

Foam Capacity and Stability Analysis of Aquafabas

The foaming capacity (FC) and foam stability (FS) of aquafaba and egg whites were determined according to a previously described method (Mustafa et al., 2018). Specifically, 5 mL of aquafaba or egg white was diluted with 10 mL of water in a 150 mL graduated measuring cup. The mixture was then subjected to a whipping process using a mixer (Öztiryakiler Gurmeaid, Türkiye) at a speed setting of 10 for a duration of 2 min within a fixed 4.3 L container. Subsequently, the volume of the foam of the whipped samples was measured at the 0th minute (VF0) and the 30th minute (VF30). The foaming capacity (FC) and foam stability (FS) were calculated using the appropriate equations, namely Equations 1 and 2, respectively.

$$FC\% = \frac{V_{F0}}{V_{sample}} \times 100 \quad (1)$$

$$FS\% = \frac{V_{F30}}{V_{F0}} \times 100 \quad (2)$$

Physicochemical Analysis of Cakes

Protein, ash, fat, and moisture contents of the cakes were determined according to the AACC (Karaoglu, 2011).

Additionally, the total carbohydrate content of cake mixtures was calculated by differences among total proximate compositions.

The pH of the samples was determined using a portable and digital pH meter with a penetration probe (Milwaukee, MW102-F, USA).

Baking Loss

The baking loss ($BL\%$) of the cake samples was determined according to a previously described method (Erkoc, 2022). Specifically, the weight of the dough was measured prior to baking (W_p), and the weight of the baked sample was recorded immediately after baking (W_a). Subsequently, the baking loss ($BL\%$) was calculated using the appropriate equation, as shown in Equation 3.

$$BL\% = \frac{W_a - W_p}{W_p} \times 100 \quad (3)$$

Colour Parameters of Cakes

After the cakes were baked and allowed to cool, colour measurements of both the crust and interior were conducted. Colour values were determined by a colorimeter (PCE-CSM 3, PCE Instruments, Germany). At room temperature, L^* (lightness), a^* (green to red), and b^* (blue to yellow) were measured from at least 3 different points of the samples.

Texture Profile Analysis of Cakes

Texture analyses of cake samples were performed using a 100 mm probe (P-100) on a TA-XT2 Plus texture analyser (Stable Micro System Ltd., Surrey, UK). After baking and cooling at room temperature, samples with a diameter of 3 cm and a height of 3 cm were removed from the cakes for texture analysis using a cylinder probe. The parameters of the TPA method were set as follows: pre-test speed 1 mm s-1, test speed 2 mm s-1, post-test speed 1 mm s-1, waiting time 5 s, trigger force 20 g (automatic), and compression ratio 30%. Hardness, elasticity, cohesiveness, and chewiness values were calculated from the graph drawn under these conditions (Gerçekaslan & Boz, 2018).

Sensory Evaluation

Sensory evaluation of the cakes was conducted by 24 untrained panelists aged between 20 and 35 years, who were informed beforehand. The assessment included external and internal colour, internal pore structure, texture, moistness and stickiness, aroma, swallowability, chewiness, and overall acceptability, using a 5-point hedonic scale (1 = extreme dislike, 5 = extreme like).

Statistical Analysis

The study was conducted in duplicate, with each measurement performed at least twice for all analyses. Statistical analysis was conducted using SPSS 22.0.0 (SPSS Inc., USA). A completely randomized design was employed, involving a control group and six experimental groups, each with two replications. Treatment groups were considered fixed effects, while replications were treated as random effects. The data were analyzed using the general linear model (GLM). The physicochemical properties, sensory attributes, and textural parameters of the cakes were assessed using one-way ANOVA followed by Duncan's post-hoc test. Statistically significant differences between means were considered to be present when P-values were less than 0.05. The results obtained are expressed as mean values along with their standard deviations.

RESULTS AND DISCUSSION

Foam capacity and stability

The foaming property of eggs, one of the main elements in cake production, plays a crucial role in achieving the desired texture in baked products like cakes (Aslan & Ertaş, 2020). Moreover, the stability of air bubbles within the protein network structure of egg albumin during foaming can be increased due to the film that forms around the bubbles. This film results from protein denaturation, a process in which globular proteins partially unfold (Aslan & Ertaş, 2020; Lomakina & Mikova, 2018). The foaming properties of aquafaba in food processing are directly associated with its content of low-molecular-weight proteins, polysaccharides, and saponins. Aquafaba's variations in foaming capacity may partly be attributed to modifications of albumin, a low-molecular-weight protein. Additionally, cross-linking between polysaccharides and proteins can significantly enhance aquafaba's foam stability. Saponins, which contribute to its emulsifying properties, also affect this trait by increasing aquafaba's foaming capacity (Erem et al., 2023).

The foaming capacity varied, showing rates of 666.67%, 133.33%, and 116.67% for the C, AC, and AL groups, respectively. In a study examining the properties of aquafaba obtained from commercial canned chickpeas, the foaming capacity and foam stability of the samples were found to range from 182% to 476% and from 77% to 92%, respectively. In the same study, the foaming capacity of egg whites was determined to be 311.11% (Mustafa et al., 2018). The foaming capacity of aquafaba samples derived from chickpeas ranged from 133% to 200%, while foam stability values were between 59.8% and 86.5% (Crawford et al., 2023). In a study investigating the substitution of egg with varying proportions of chickpea water in cake formulations, the foaming capacities of egg white and chickpea aquafaba were determined to be 200% and 126.67%, respectively, while their foam stabilities were found to be 93.33% and 94.74%, respectively (Aslan & Ertaş, 2020).

The results of foam capacity and stability align with the observed physical, textural, and sensory properties of the cakes. The significantly higher foam capacity of the control group compared to chickpea aquafaba and lentil aquafaba underscores the superior foaming and air retention ability of egg whites. This directly contributed to the control group achieving the highest internal pore structure score and softer texture, as stable foams are critical for incorporating air and creating a uniform cake crumb. On the other hand, the relatively lower foam capacity of aquafaba, particularly from lentils, resulted in denser structures and lower sensory scores for internal pore structure and overall acceptability in the LAF-LF group. The foam stability values also support these findings; although chickpea aquafaba exhibited comparable stability to eggs, lentil aquafaba demonstrated a less stable foam structure, which may explain its weaker performance in textural and sensory assessments.

Moreover, the gelling properties and protein-polysaccharide interactions of aquafaba contributed to enhanced moisture retention, which mitigated the negative effects of lower foam capacity to some extent, particularly in the CAF-CF and CAF-WF groups. These samples exhibited softer textures and higher sensory scores compared to lentil-based formulations, highlighting the importance of both foam capacity and moisture retention in achieving desirable cake characteristics. In contrast, the higher hardness and gumminess of lentil flour-containing cakes can be attributed to their low foam capacity and stability, coupled with reduced moisture retention. This indicates that foam properties, in conjunction with textural and sensory evaluations, play a pivotal role in determining the quality of legume-based cake formulations.

Baking Loss

The results demonstrated that the EF-CF group exhibited the lowest baking loss, with a value of 5.78%. This is believed to be a consequence of the combined effect of the binding properties of egg (Yazici & Ozer, 2021) and the high water retention capacity of chickpea flour (Mohammed et al., 2014). The highest baking loss was observed in the CAF-WF and LAF-WF groups. This is believed to be due to the low fibre content of white flour and the restricted binding capacity of aquafaba. No statistically significant difference was observed between the EF-LF, CAF-CF, LAF-LF, and C groups ($p > 0.05$). A comparison of chickpea and lentil flours revealed that the groups utilising chickpea flour exhibited a lower baking loss. This was attributed to the superior water retention capacity of chickpea flour in comparison to lentil flour. Additionally, a higher baking loss was observed in the groups employing aquafaba in comparison to egg. This is postulated to be due to the lower protein content of aquafaba in comparison to egg. Overall, the baking loss values of the cake samples are summarized in Table 2.

In a study investigating the use of chickpea juice at different ratios in place of eggs in cake formulation, it was stated that the observed changes in baking loss values can be explained by the fact that cake formulations containing eggs have a higher water-binding capacity than formulations prepared with egg substitute (Aslan & Ertaş, 2020). In another analogous study, the researchers reported that the baking loss values of aquafaba cakes were higher than those of egg-containing cakes. This was attributed to the higher water-binding capacity of eggs (Helal & Nassef, 2021). In a different study, the baking loss values of cakes containing egg white and aquafaba were reported as 10.52% and 11.99%, respectively (Mustafa et al., 2018).

Table 2. Baking Loss Values of Cake Samples

Samples	Baking Loss (%)
C	7.51 ± 0.12^{ab}
EF-CF	5.78 ± 0.23^{b}
EF-LF	7.29 ± 0.54^{ab}
CAF-CF	8.03 ± 2.11^{ab}
CAF-WF	8.91 ± 0.59^{a}
LAF-LF	7.95 ± 2.02^{ab}
LAF-WF	8.42 ± 0.80^{a}

C: Control, EF-CF: Egg and Chickpea Flour, EF-LF: Egg and Lentil Flour, CAF-CF: Chickpea Aquafaba and Chickpea Flour, CAF-WF: Chickpea Aquafaba and Wheat Flour, LAF-LF: Lentil Aquafaba and Lentil Flour, LAF-WF: Lentil Aquafaba and+ Wheat Flour
The mean values followed by different letters in the same column are significantly different ($p < 0.05$).

Determination of Physicochemical Composition of Cakes

The physicochemical composition of cakes is presented in Table 3. The pH values of the samples showed statistically significant differences ($p < 0.05$), mainly due to the effect of legume flours and aquafaba on the acidity of the formulations. Previous studies have similarly reported that the inclusion of aquafaba in cake recipes results in lower pH values compared to cakes produced with egg whites, which typically have a pH of around 8 (Aslan & Ertaş, 2020). This change in pH can be attributed to the natural acidity of aquafaba and its unique composition, including saponins and proteins, which affect pH during baking. These components not only affect the pH but could also play a role in determining the texture, moisture content, and overall quality of cakes made with aquafaba as an egg replacement.

Significant differences were also observed in the protein content of the samples ($p < 0.05$). The differences in aquafaba and protein content arise from its inherent low protein composition, processing conditions that affect extraction efficiency, and variations in legume types used. These factors collectively contribute to the observed statistical differences in protein content when comparing aquafaba to traditional egg whites. Groups containing lentil and chickpea flour had higher protein levels than those containing wheat flour, reflecting the higher protein content of legume flours. In addition, higher water ratios during preparation may dilute the protein and carbohydrate concentrations, resulting in lower overall protein content (Thomas-Meda et al., 2023). The physicochemical analyses also confirmed that the composition of the ingredients and the processing conditions significantly influenced the final product characteristics ($p < 0.05$).

Table 2. The Physicochemical Composition of Cakes

Groups	pH	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Carbohydrate (%)
C	8.30±0.04^{a}	24.19±0.23^{c}	1.27±0.03^{e}	10.32±0.04^{e}	7.75±0.10^{c}	56.48±0.33^{b}
EF-CF	7.15±0.03^{d}	21.60±0.04^{d}	3.22±0.03^{b}	21.03±0.16^{a}	7.93±0.06^{a}	46.21±0.16^{e}
EF-LF	7.39±0.02^{c}	20.58±0.24^{e}	1.92±0.03^{c}	18.30±0.07^{b}	7.89±0.05^{ab}	51.30±0.29^{d}
CAF-CF	6.78±0.02^{f}	31.39±0.13^{a}	3.30±0.01^{a}	16.39±0.02^{c}	7.80±0.05^{bc}	41.12±0.17^{g}
CAF-WF	7.56±0.02^{b}	30.92±0.13^{b}	1.30±0.04^{de}	6.04±0.15^{f}	7.96±0.05^{a}	53.79±0.03^{c}
LAF-LF	6.94±0.01^{e}	31.43±0.15^{a}	1.97±0.05^{c}	14.41±0.03^{d}	7.91±0.03^{a}	44.28±0.10^{f}
LAF-WF	7.56±0.03^{b}	18.91±0.32^{f}	1.35±0.03^{d}	5.22±0.06^{g}	7.75±0.06^{c}	66.78±0.30^{a}

C: Control, EF-CF: Egg and Chickpea Flour, EF-LF: Egg and Lentil Flour, CAF-CF: Chickpea Aquafaba and Chickpea Flour, CAF-WF: Chickpea Aquafaba and Wheat Flour, LAF-LF: Lentil Aquafaba and Lentil Flour, LAF-WF: Lentil Aquafaba and+ Wheat Flour
The mean values followed by different letters in the same column are significantly different ($p < 0.05$).

The moisture content of cakes was found to be significantly affected by the use of legume flours or aquafaba from these legumes as substitutes for wheat flour and eggs ($p < 0.05$). The utilization of legume flours as an alternative to wheat flour led to a substantial reduction in moisture content, while the incorporation of legume aquafaba instead of eggs resulted in a notable increase in moisture levels ($p < 0.05$). The lower water-binding capacity of legume flours in comparison to wheat flour may have resulted in reduced water retention in cake batter. The increase in moisture noted with aquafaba ($p<0.05$) is because aquafaba is essentially a concentrated solution of soluble proteins (albumins) and saponins. These act as powerful emulsifiers and foaming agents. They create a fine, stable film around air bubbles that acts as a moisture barrier, significantly reducing evaporation compared to whole legume flour or eggs (Náthia-Neves et al.,2025). Also, aquafaba is characterized by a high-water content and notable gelling properties (Büker & Karaça, 2024). This property has the capacity to enhance moisture retention in cake batter through its ability to retain water (Aslan & Ertaş, 2020; Madhavi et al., 2025). Furthermore, the protein and polysaccharide content of aquafaba has been demonstrated to reduce moisture loss and to enhance the moisture retention capacity of cake batter during the baking process. Thus, it was reported that cakes made with treated chickpea aquafaba had the highest moisture content compared to control samples made with egg white (Nguyen & Tran, 2021).

The utilization of legume flours and aquafaba also resulted in significant alterations to the ash content of cakes ($p < 0.05$). The primary reason for this is the higher mineral content of legume flours in comparison to wheat flour (Ndovie et al., 2025). Chickpea flour, in particular, contributed to the highest ash content observed in the CAF-CF sample (3.30%), compared to the CAF-WF sample (1.30%), which utilized wheat flour. Notably, the CAF-CF sample exhibited the highest ash content (3.30%), which is attributed to the higher mineral density of chickpea flour compared to both wheat and lentil flour (1.92–1.97% in lentil-based groups). While both legumes are nutrient-dense, the specific concentration of minerals in chickpea flour significantly elevated the inorganic residue (ash) in the final product. Aquafaba is not a mineral itself, but rather a complex aqueous solution containing water-soluble minerals—such as potassium and magnesium—that leach from legumes during cooking (He et al., 2021). Consequently, it acts as a mineral-rich functional ingredient that contributes to the total ash content.

Regarding the carbohydrate content, the incorporation of legume flours led to a significant decrease in the overall carbohydrate percentages compared to wheat-based formulations ($p < 0.05$). For instance, the carbohydrate content of CAF-CF (41.12%) was notably lower than that of CAF-WF (53.79%). This reduction is attributed to the higher protein concentration in chickpeas and lentils, which replaces a portion of the starch typically found in wheat flour. The change in the fat content of the cakes is considered an insignificant proportional variation resulting from the shifts in moisture, protein, and ash levels.

The colour parameters of the cakes are presented in Table 4. Cakes containing lentil and chickpea flours generally exhibited lower L^* values and higher a^* and b^* values in both the inside and crust of the cake compared to other groups. This finding is consistent with previous studies, which reported that legume flours contribute to darker and more intense colour profiles due to their higher protein content and natural pigments, such as carotenoids and anthocyanins (Aslan & Ertaş, 2020; Thomas-Meda et al., 2023). In contrast, the control group exhibited lighter and more neutral colour characteristics, consistent with findings that wheat-based products typically exhibit higher L* values due to the lighter colour of wheat flour (Pinel et al., 2025).

The significant impact of aquafaba and legume flours on colour parameters can also be linked to the Maillard and caramelization reactions that occur during baking. Legume flours, being rich in reducing sugars and amino acids, intensify these reactions, resulting in increased browning and enhanced a* and b* values (Lazou, 2024). Furthermore, aquafaba, which contains saponins and other surface-active compounds, may influence the thermal and chemical dynamics of the baking process, contributing to the unique colour development observed in these samples.

The findings suggest that the choice of flour and the incorporation of aquafaba not only affect the nutritional and functional properties of baked products but also play a crucial role in their visual quality. The darker and more vibrant colours associated with legume flours may enhance consumer appeal for specific product types, such as whole-grain or health-oriented baked goods. However, further studies are needed to evaluate the sensory acceptability of these colour changes, as consumer preferences for colour intensity can vary across different markets.

Table 3. Colour Parameters of Cakes Prepared with Different Formulations

Groups	**Inside of cakes**			**Crust of cakes**		
	L^*	a^*	b^*	L^*	a^*	b^*
C	64.22±0.42^{a}	3.29±0.20^{e}	20.85±0.67^{c}	61.26±0.64^{a}	13.53±1.04^{bc}	29.98±1.61^{ab}
EF-CF	63.23±0.68^{ab}	7.52±0.23^{a}	32.89±0.50^{a}	58.79±3.97^{a}	12.38±0.71^{bc}	30.81±1.39^{a}
EF-LF	51.74±3.07^{d}	6.90±0.20^{b}	22.41±2.32^{c}	52.20±1.60^{b}	12.01±0.89^{c}	27.51±0.99^{bc}
CAF-CF	61.50±1.88^{bc}	6.10±0.37^{c}	28.78±1.26^{b}	49.16±2.46^{bc}	17.29±0.81^{a}	29.37±1.83^{ab}
CAF-WF	63.95±0.72^{ab}	4.82±0.15^{d}	19.52±0.38^{c}	48.56±6.73^{bc}	14.22±0.80^{b}	28.37±1.56^{ab}
LAF-LF	45.91±0.36^{e}	5.66±0.38^{c}	21.10±3.10^{c}	43.66±1.25^{c}	14.51±0.90^{b}	26.58±1.07^{cd}
LAF-WF	59.02±0.20^{c}	5.82±0.57^{c}	20.80±1.01^{c}	43.37±0.39^{c}	14.81±0.19^{b}	24.91±0.09^{d}

C: Control, EF-CF: Egg and Chickpea Flour, EF-LF: Egg and Lentil Flour, CAF-CF: Chickpea Aquafaba and Chickpea Flour, CAF-WF: Chickpea Aquafaba and Wheat Flour, LAF-LF: Lentil Aquafaba and Lentil Flour, LAF-WF: Lentil Aquafaba and+ Wheat Flour
The mean values followed by different letters in the same column are significantly different ($p < 0.05$).

The use of legume flour instead of wheat flour in cakes significantly increased the hardness and gumminess of the cakes. The increase was considerably higher with lentil flour than with chickpea flour. On the other hand, the use of aquafaba significantly decreased the hardness value. These results are also closely related to the change in the moisture content of the cakes. The use of legume flours in cakes increased the hardness and gumminess values due to their lower water binding capacity and higher protein and fiber content compared to wheat flour. It was observed that lentil flour in particular formed a denser structure, and therefore, the increase in hardness was more pronounced compared to chickpea flour. In contrast, the high moisture retention and gelling properties of aquafaba reduced moisture loss during baking, resulting in a softer cake texture. Fig. 1 shows the texture profile of the cake samples.

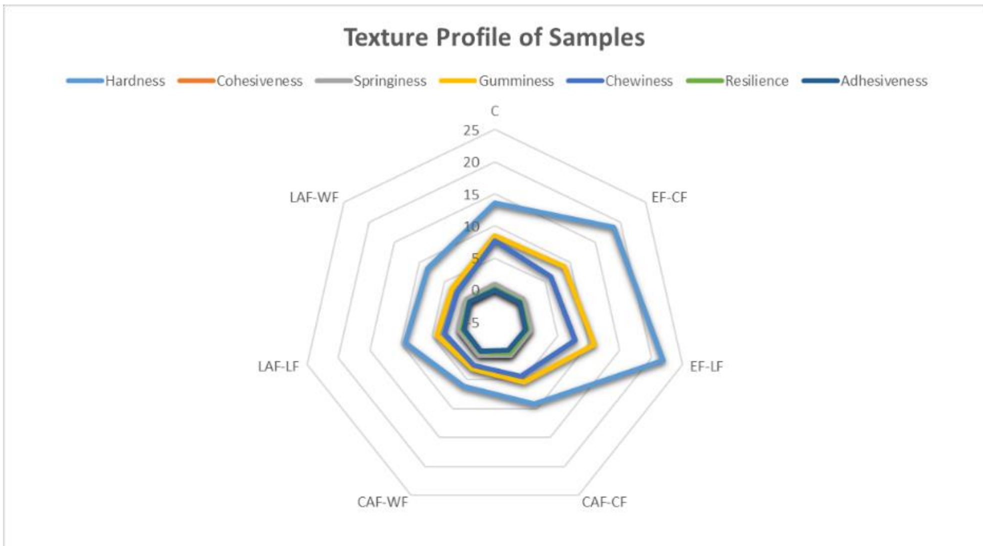

Figure 1. Texture Profile Analysis of Vegan and Gluten-Free Cakes Prepared with Different Substitutes

Sensory Evaluation

The sensory properties of the cake samples are presented in Figure 2. The EF-CF, CAF-CF, and CAF-WF samples exhibited internal and external colour outcomes comparable to the control group. In contrast, the LAF-LF and EF-LF samples received low scores, indicating that lentil flour had a negative effect on the cake's colour. In terms of internal pore structure scores, the control group achieved the highest value, which was statistically significantly higher than those of all other groups ($p < 0.05$). CAF-CF exhibited superior internal pore structure in comparison to LAF-LF. This finding indicates that the utilization of lentil aquafaba and lentil flour exerts a detrimental influence on the pore structure of the cake, in contrast to the use of chickpea aquafaba and chickpea flour. In terms of texture, CAF-CF and CAF-WF samples gave statistically similar results with the control ($p > 0.05$). This shows that the use of chickpea flour and chickpea aquafaba does not have a negative sensory effect on texture. The EF-LF, LAF-LF, and LAF-WF groups exhibited significantly lower values for moisture and stickiness compared to the control group.

The highest aroma values were observed in the control and CAF-WF groups. The utilization of chickpea aquafaba as a substitute for egg did not result in a statistically significant negative impact on flavor. While all other groups attained acceptable scores in flavor (>3.00), LAF-LF fell below the acceptable limit with 2.71 points. This can be ascribed to the incorporation of both aquafaba and lentil flour, which led to a prominent lentil odor. The highest values in the swallowability assessment were observed in the control and CAF-WF groups, while the chewability scores were highest in the control and EF-LF groups. The swallowability and chewability values for LAF-LF were both below the acceptable limit, with a score of 2.88. The highest overall acceptability scores were observed in the control and CAF-CF groups. Although all other groups achieved scores above the acceptable value (>3.00), the LAF-LF group recorded the lowest score of 2.71, falling below the acceptable range.

In general, the control and CAF-CF groups produced the best sensory results, indicating that chickpea aquafaba and chickpea flour are successful alternatives in cake production. In the present study, a range of legume aquafaba samples, including white chickpea, black chickpea, white bean, and red bean, were utilised as egg substitutes in the context of cake production. The sensory evaluation results indicated that white chickpea aquafaba exhibited potential as an effective alternative in cake production by providing sensory attributes comparable to those of the control sample (Konal et al., 2025).

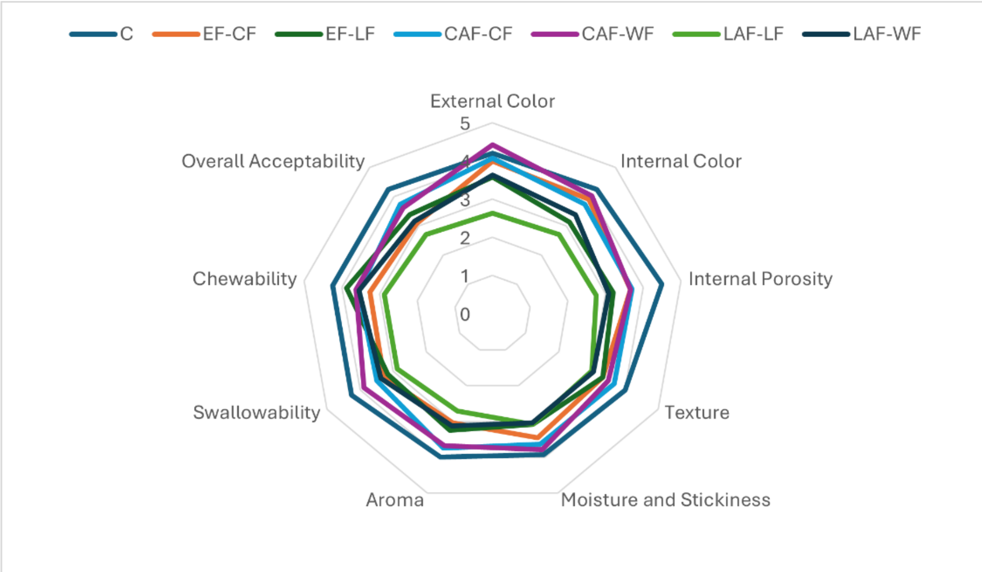

Figure 2. Sensory Evaluation Results of Cake Samples.

Studies have demonstrated that cakes containing up to 50% aquafaba can exhibit comparable physical properties to those prepared with eggs, without adversely affecting sensory qualities (Aslan & Ertaş, 2020; Crawford et al., 2024).Vegan/gluten-free cakes prepared with different formulations are shown in Figure 3.

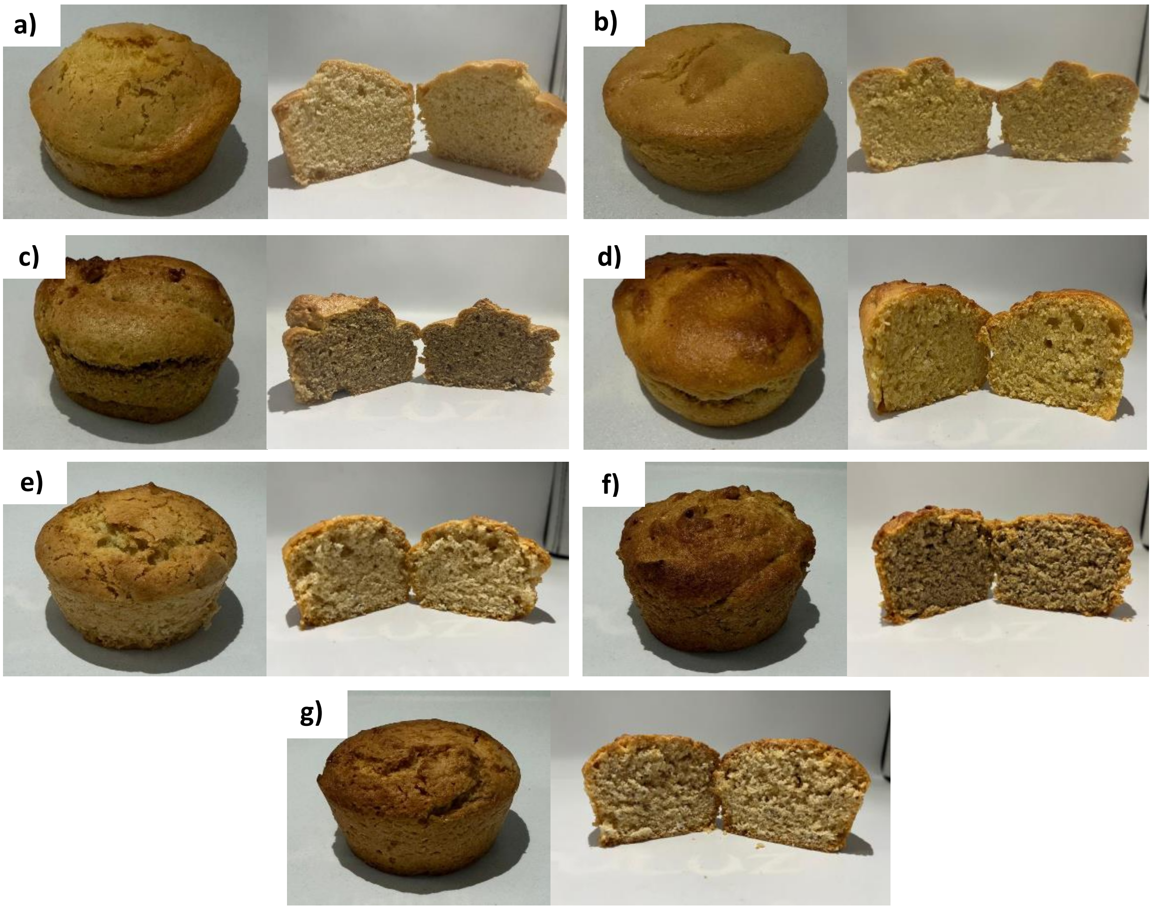

Figure 3. Vegan and Gluten-Free Cakes Prepared with Different Formulations. a) C, b) EF-CF, c) EF-LF, d) CAF-CF, e) CAF-WF, f) LAF-LF, and g) LAF-WF.

CONCLUSION

This study demonstrated the potential of legume-derived ingredients, particularly chickpea aquafaba and chickpea flour, as effective substitutes for eggs and wheat flour in cake formulations. The findings revealed that chickpea aquafaba significantly enhanced moisture retention, reduced hardness, and maintained favorable sensory qualities, making it a promising plant-based egg alternative. Conversely, lentil-based ingredients, especially lentil flour, negatively impacted foam capacity, textural properties, and sensory characteristics, emphasizing the importance of careful formulation adjustments when incorporating these components. Physicochemical analyses highlighted the significant influence of legume flours and aquafaba on moisture, ash, protein, and carbohydrate content, with chickpea aquafaba contributing to improved functional and nutritional characteristics of cakes. The darker and more vibrant colours associated with legume flours, driven by Maillard and caramelization reactions, provide opportunities for niche market applications but may require further sensory acceptability evaluations. In conclusion, chickpea aquafaba and chickpea flour were identified as successful alternatives to traditional ingredients in the production of gluten-free and vegan cakes. These findings contribute to the development of more inclusive, sustainable, and nutritionally enriched baked goods. Further research is recommended to optimize formulations and explore consumer preferences for legume-based cake products in diverse market segments.

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ARTIFICIAL INTELLIGENCE CONTRIBUTION STATEMENT

Artificial intelligence tools were used solely for language editing purposes. The content, analysis, and interpretation are entirely the authors' responsibility.

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