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Investigating the effect of emulsifier gel on the physicochemical and sensory properties of cupcake containing processed (roasted) quinoa flour

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ABSTRACT

Quinoa is a semi-grain rich in essential amino acids and B vitamins, and is high in protein and fiber. Therefore, in order to enrich cupcakes, different levels of wheat flour (0, 10, and 20%) were replaced with roasted quinoa flour, and emulsifier gel (0, 0.5, and 1%) were used to improve the quantity and quality of this type of cake, and the textural and sensory characteristics of the produced samples were evaluated. The results showed that in the time interval of 2 hours and 1 and 2 weeks after cooking, the moisture content of the control (without quinoa flour and emulsifier gel) was 17.03, 13.17 and 11.30%, respectively, and the moisture content of the sample containing 20% quinoa flour and 1% emulsifier gel (the highest consumption levels) was 18.61, 17.65 and 17.04%, indicating the positive performance of quinoa flour and emulsifier gel in maintaining moisture during shelf life. The sample containing 10% quinoa flour and 0.5% emulsifier gel had the highest specific volume (3.74 ml/g) and porosity (25.11%) and the lowest texture hardness during 2 weeks of storage (5.17 N). Based on the results obtained from the crust color evaluation of the produced samples, it was determined that the presence of roasted quinoa flour in the cupcake formulation caused darkening (decrease in the color components L* and b* and increase in the color component a*) and the presence of emulsifier gel caused the color to become lighter. Finally, based on the findings obtained from the sensory parameters, especially overall acceptance, the sample containing 10% roasted quinoa flour and 0.5% emulsifier gel is introduced as the best sample in this study.

1-Introduction

Quinoa is a pseudo cereal with unique nutritional characteristics. This seed contains essential amino acids, including methionine, lysine, and cysteine, as well as B vitamins such as B6, niacin, folate, and riboflavin. The protein content of quinoa ranges from 12% to 23%, which is, on average, higher than that of wheat, rice, barley, corn, rye, and sorghum [1]. With the presence of phytoestrogens among its compounds, quinoa has the potential to prevent various cancers, osteoporosis, and cardiovascular diseases [2]. The functional properties of quinoa include water-holding capacity, solubility, gelatinization, foaming, and emulsifying capabilities [3]. In the 21st century, quinoa stands out as one of the most promising agricultural crops due to its nutritional attributes and its tolerance to drought and salinity. Furthermore, NASA (National Aeronautics and Space Administration) recognizes the nutritional value of quinoa as a component of the Controlled Ecological Life Support System (CELSS) [4]. Cake is a widely consumed product in the baking industry, typically prepared from wheat flour. Cakes come in various types and are calorie-dense. The caloric content of this baked product is dependent on the amount of oil, eggs, and sugar in the formulation [5]. Cake presents a suitable option for enrichment with quinoa flour. Emam et al. (2023) investigated the application of quinoa flour (0% to 50%) in cupcake formulations. Through the examination of physicochemical, textural, and sensory properties of the produced samples, these researchers reported that the presence of quinoa flour and increased consumption levels led to an increase in protein, fat, fiber, and ash content in the cake samples. Moreover, based on their findings, the sample containing 25% quinoa flour exhibited the largest volume and lowest texture hardness. This sample was identified as the optimal one, receiving the highest scores for sensory attributes, particularly in terms of aroma, taste, and texture [6].

Hamzacebi and Tacer-caba (2021) utilized quinoa flour in muffin formulations. These researchers reported that the presence of quinoa flour increased cake volume and fiber content while reducing the texture hardness of the produced samples. The results also indicated that adding quinoa flour to the muffin formulation played a role in improving the quantity and quality of the cake samples, and these samples exhibited enhanced shelf life. However, a notable point is that replacing a portion of wheat flour with quinoa flour, especially at levels exceeding 30%, decreases the gluten content of the final product, weakening the gluten network [7]. This leads to detrimental technological consequences that can be mitigated with the aid of emulsifiers. Emulsifiers used in cake production include mono- and diglycerides and their derivatives, stearoyl lactylates, propylene glycol monostearate, sorbitan monostearate, polysorbates, and lecithin [8]. Most emulsifiers possessing a linear fatty acid in their molecule are capable of forming a complex with the amylose of soluble starch. This characteristic is highly significant in retarding the staling of bread and cakes and reducing dough stickiness [9]. Emulsifiers also contribute to the stabilization of water activity in cakes during storage, which consequently reduces the dryness of the produced goods over time [10]. The use of oils containing emulsifiers in cake preparation not only facilitates the mixing of cake components but also increases the amount of water consumed, thereby delaying the staling process. When emulsifiers are in gel form and used in cake production, they are referred to as cake gels. Generally, the incorporation of cake gel into cake batter leads to a more uniform distribution of air bubbles, resulting in increased viscosity and a more desirable texture and volume in cakes, particularly those made with weak flour [11].

Vyakhaya and David (2020) employed emulsifier gel to enhance the quantity and quality of cakes. Their research indicated that the emulsifier gel strengthened cake volume by improving aeration, increasing cake viscosity, and preventing the coalescence of air bubbles. Furthermore, dough stability was improved as a result of the emulsifier gel's presence in the formulation [12]. Gunadi and Pamungkaningtyas (2022) investigated and reported the beneficial and key effects of lactem, mono- and diglycerides, and polyglycerol ester emulsifiers (at levels of 0% to 3%) in sponge cake formulations. The presence of emulsifiers in the formulation, by reinforcing the gluten network to hold air bubbles more effectively and uniformly, and by thickening the walls of these bubbles, proved instrumental in increasing the crumb, porosity, and volume of the produced samples, while also reducing cake crumb firmness and the staling rate [13]. Therefore, considering the societal demand for new and enriched baked products, the nutritional benefits of quinoa flour, and the positive impact of emulsifier gel on the technological and visual characteristics of bakery products, this study utilized quinoa flour at levels of 0%, 10%, and 20% (replacing wheat flour) and emulsifier gel at levels of 0%, 0.5%, and 1% in cupcake formulations.

2- Materials and Methods

2.1. Materials

White quinoa seeds (moisture: 6.80%, protein: 16.78%, fat: 3.53%, and ash: 2.69%), wheat flour with an extraction rate of 78% (moisture: 9.16%, protein: 8.92%, fat: 1.40%, ash: 0.46%, and wet gluten: 29.60%), oil, powdered sugar, baking powder, and salt were procured from reputable suppliers of raw materials and confectionery equipment in Mashhad. The emulsifiers used were purchased from Pars Behbood Company. Chemical reagents were obtained from reputable brands such as Sigma, Merck, etc.

2.2. Method for Preparing Roasted Quinoa Flour

A combined microwave-hot air system was employed for roasting the quinoa seeds. Initially, the seeds were pre-treated using a microwave at 600 W for 3 minutes [14]. Subsequently, the final drying stage was completed in a convection oven at 150°C [15 and 16]. The roasted seeds were then ground into powder and passed through a sieve with a particle size of 250 micrometers. The moisture, protein, fat, and ash content of the quinoa seeds after roasting were 6.65%, 15.52%, 3.89%, and 2.82%, respectively.

2.3. Method for Preparing Emulsifier Gel

To prepare the emulsifier gel, the formulation ingredients, comprising 60 parts monoglyceride, 6 parts monoglyceride acetic acid ester, 7 parts sodium stearoyl-2-lactylate, 20 parts polyglycerol polyricinoleate (PGPR), 56 parts water, 5 parts DATEM, and 10 parts polyglycerol esters, were initially mixed. The mixture was then heated to 70°C under continuous stirring. The emulsifier gel formed upon cooling [9].

2.4. Preparation Method for Cupcakes

For the preparation of the control sample (sample without roasted quinoa flour and emulsifier gel), 100 parts wheat flour, 45 parts egg, 50 parts powdered sugar, 57 parts oil, 2 parts baking powder, 1 part salt, and 30 parts waters were used. To prepare the cake samples, in the first step, sugar and eggs were mixed at high-speed using a laboratory mixer for 1 minute. Then, oil and water were added to the sugar and egg mixture. Subsequently, flour and baking powder were added in several stages to the other ingredients, and mixing continued until a smooth and uniform batter was achieved. After preparing the batter, it was molded, and baking was performed in a laboratory oven at 180°C for 20 minutes. The prepared cake samples were packaged in ziplock bags and stored at ambient temperature (25°C). It should be noted that in this study, 9 treatments were prepared with three levels of quinoa flour (0%, 10%, and 20%) and three levels of emulsifier gel (0%, 0.5%, and 1%).

2.5. Moisture Content

Moisture content was measured using the oven-drying method according to standard AACC (2000) No. 16-442 [17]. This test was conducted at 3 intervals: 2 hours, 1 week, and 2 weeks post-baking.

2.6. Specific Volume

Specific volume was calculated as the ratio of volume (in milliliters) to weight (in grams). To evaluate cake volume, standard AACC (2000) Method 72-10 (volume displacement method using millet seeds) was employed [17].

2.7. Porosity

The porosity of the internal texture of the cake samples was assessed using image processing techniques with ImageJ software. For this purpose, the cake crust was removed using an electric serrated knife, and images of the internal texture were captured using a scanner. The captured images of the internal cake texture were processed by the software, and the ratio of light to dark points (porosity) was calculated [18].

2.8. Texture Hardness

Texture hardness of the internal cake was evaluated using a texture analyzer (Model TA plus, UK). The maximum force required for probe penetration was reported as cake texture hardness in Newtons. The probe had a cylindrical end with a diameter of 2 cm and a height of 2.3 cm. The instrument settings for probe speed through the center of the cake were set at 60 mm/min [19].

2.9. Crust Color ($L^*a^*b^*$)

To evaluate the crust color of the cake samples, digital photography was performed in a chamber with a white background. The color components (L*, a*, b*) were calculated in the Hunterlab color space using image processing software [20].

2.10. Sensory Properties

For this evaluation, 10 untrained panelists were selected. Sensory evaluation was based on a five-point hedonic scale, ranging from very bad (1) to very good (5). The sensory attributes of the cupcakes examined included form and shape, appearance of the top and bottom surfaces, crumb and porosity, texture hardness and softness, chewiness, aroma and flavor, and overall acceptability [21 and 22].

2.11. Statistical Analysis

The experimental design of this study was a completely randomized factorial design with two factors. Factor 1 was roasted quinoa flour at three levels (0, 10, and 20%), and Factor 2 was emulsifier gel at three levels (0, 0.5, and 1%), resulting in 9 treatments. The data obtained from the experimental section were analyzed using Mini-Tab 17 software. The mean of three replicates was considered for all tests. Mean comparison was performed using the Tukey test.

3-Results and Discussion

3.1. Moisture

The results of moisture evaluation of cupcakes containing different levels of roasted quinoa flour and emulsifier gel during 2 weeks of storage are presented in Table 1. The findings obtained from the moisture measurements showed that, at 2 hours after baking, the highest moisture content was observed in the sample containing 1% emulsifier gel and no quinoa flour, while at 1 and 2 weeks after baking, the highest moisture content belonged to the sample containing 10% roasted quinoa flour and 1% emulsifier gel. Overall, quinoa flour and emulsifier gel played an effective role in retaining cake moisture during the storage period. The moisture contents of wheat flour and roasted quinoa flour were 9.16% and 6.65%, respectively (physicochemical properties of the flours are presented in the Materials section). Therefore, it was expected that replacing wheat flour with quinoa flour would lead to a decrease in the moisture content of the produced samples, due to the lower moisture level of quinoa flour; however, this did not occur, and similar moisture levels were observed in all cake samples. This indicates the superiority of the components present in quinoa flour—particularly its higher fiber content compared with wheat flour—in maintaining higher moisture during and after baking (throughout storage). In this regard, Patricia et al. (2018) replaced part of the rice flour in a gluten-free muffin formulation with quinoa flour. They reported that, despite the similar moisture contents of rice and quinoa flours and the expectation of no difference in the moisture levels of the two types of flour used, the moisture content of the samples containing quinoa flour was higher. The researchers attributed this to the higher fiber content of quinoa flour compared with rice flour [23]. Alavi et al. (2022) used quinoa flour in the formulation of "Nokhodchi" cookies and replaced part of chickpea flour with quinoa flour. Their results showed that the moisture content of samples containing quinoa flour was higher than that of the sample containing 100% chickpea flour [24]. Javaheripour et al. (2021) considered the higher protein and fiber contents of quinoa flour compared with wheat flour as two key factors responsible for the higher moisture in sponge cake samples containing quinoa flour compared with other produced samples [25]. Furthermore, Haghayegh and Zavezad (2019) used processed (sprouted) quinoa flour in pan bread formulation. These researchers identified the higher protein content of quinoa flour compared with wheat flour as a key factor in moisture retention of bread samples during and after baking, stating that the polar groups present in protein peptide bonds possess hydrophilic capacity and consequently enhance water-holding capacity [26]. Ghanadrezaee et al. (2018) reported that the use of cake gel (emulsifier gel) in cupcake formulations contributed to moisture retention during and after baking [9]. The presence of both hydrophilic and hydrophobic groups in emulsifier chains imparts functional properties to these compounds. This means that their molecular structure simultaneously tends to interact with oily components due to the nonpolar end, and bind to water molecules due to the polar head. Accordingly, the addition of emulsifiers to food systems causes them to localize at the oil–water interface within the product matrix. The hydrophilic groups of the emulsifier chain, by binding to free water, increase water-holding capacity and, in turn, exert an inhibitory effect on moisture loss during baking and subsequent storage [27 and 28].

Table 1: The effects of quinoa flour and gel emulsifier on the moisture of cake during 3 times

Treatments	Quinoa Flour (%)	Gel Emulsifier (%)	Moisture (%)		
			2 hours	1 week	2 weeks
1	-	-	17.03 ± 0.32^{ab}	13.17 ± 0.39^{d}	11.30 ± 0.90^{f}
2	-	0.5	17.57 ± 0.70^{ab}	15.19 ± 0.61^{bcd}	14.24 ± 0.29^{de}
3	-	1	19.03 ± 0.97^{a}	16.83 ± 1.01^{abc}	15.64 ± 0.28^{bcd}
4	10	-	16.83 ± 0.45^{b}	14.99 ± 0.79^{bcd}	13.64 ± 0.37^{e}
5	10	0.5	17.43 ± 0.88^{ab}	16.52 ± 0.94^{abc}	15.99 ± 0.58^{abc}
6	10	1	18.78 ± 0.11^{ab}	17.86 ± 0.90^{a}	17.24 ± 0.34^{a}
7	20	-	17.17 ± 0.69^{ab}	14.81 ± 0.45^{cd}	14.83 ± 0.18^{cde}
8	20	0.5	17.93 ± 0.68^{ab}	17.07 ± 0.30^{ab}	16.04 ± 0.79^{abc}
9	20	1	18.61 ± 0.65^{ab}	17.65 ± 0.76^{a}	17.04 ± 0.16^{ab}

Different letters represent a significant difference from one another ($p<0.05$).

3.2. Specific Volume

According to the results of specific volume evaluation of the samples containing different levels of roasted quinoa flour and emulsifier gel (Table 2), the sample containing 10% roasted quinoa flour and 0.5% emulsifier gel exhibited the highest specific volume compared with the other produced samples. As the results indicated, at the intermediate level of quinoa flour substitution (10%), an increase in specific volume was observed. In this regard, Elgeti et al. (2014) reported that the use of quinoa flour at levels below 20% in bakery formulations led to improvements in texture and volume. These researchers attributed this effect to the presence of the enzyme α-glucosidase in quinoa flour [29]. It has also been reported that quinoa flour exerts a positive effect on cake batter aeration and thereby contributes to an increase in cake volume [30]. Miranda-Villa et al. (2018) examined the effect of quinoa flour and its malted form (up to 30% replacement) on the quality of gluten-free rice-based muffins. Their results showed a reduction in muffin specific volume, which was attributed to decreased batter consistency [31]. El-sohaimy et al. (2020), by incorporating quinoa flour into pan bread, observed reductions in bread height, diameter, weight, and volume. These effects were attributed to decreased gluten content and a weakened gluten network, which reduced the ability to retain gas cells during baking [32]. On the other hand, several hypotheses have been proposed regarding the increase in baked product volume resulting from the addition of various emulsifiers and emulsifier gels to bakery formulations as permitted additives. For example, Kurek, M. and Wyrwisz (2015) associated increased volume under the influence of emulsifiers with the enhanced availability of water provided by these additives within the flour matrix. They stated that this increased water availability facilitates the formation of cross-links between proteins and starch, resulting in a stronger gluten network with higher gas-retention capacity during baking [33]. Gunadi and Pamungkaningtyas (2022), by adding lactem emulsifier, mono- and diglycerides, and polyglycerol esters at concentrations of 0, 1.5, 2, 2.5, and 3% to sponge cakes, reported that emulsifiers, by reducing surface tension between liquid and gas phases, enhance the ability of air to enter the batter, and these air bubbles expand during baking, playing a key role in increasing product volume [13]. Yanan et al. (2020) used emulsifiers including soy lecithin, sodium stearoyl-2-lactylate, diacetyl tartaric acid esters, and monoglycerides in steam-leavened potato-enriched bread. Their results showed that adding emulsifiers to the bread formulation increased dough strength and viscoelastic properties, which enhanced gas-retention capacity during fermentation and baking, ultimately leading to increase bread volume [34].

Table 2: The effects of quinoa flour and gel emulsifier on the specific volume and porosity of cake

Treatments	Quinoa Flour (%)	Gel Emulsifier (%)	Specific volume (ml/g)	Porosity (%)

1	-	-	2.66 ± 0.47^{bcd}	23.26 ± 0.83^{ab}
2	-	0.5	2.85 ± 0.11^{bc}	23.32 ± 0.81^{ab}
3	-	1	2.41 ± 0.29^{cd}	21.94 ± 0.86^{bc}
4	10	-	3.22 ± 0.35^{ab}	23.59 ± 0.66^{ab}
5	10	0.5	3.74 ± 0.22^{a}	25.11 ± 0.594^{a}
6	10	1	3.09 ± 0.16^{abc}	24.56 ± 0.51^{a}
7	20	-	1.96 ± 0.08^{d}	21.05 ± 0.85^{c}
8	20	0.5	2.40 ± 0.32^{bcd}	23.40 ± 0.48^{ab}
9	20	1	3.20 ± 0.21^{ab}	24.91 ± 0.31^{a}

Different letters represent a significant difference from one another (p<0.05).

3.3. Porosity

Table 2 presents the findings of the porosity evaluation of cupcake samples formulated with different levels of roasted quinoa flour and emulsifier gel. The results showed that the sample containing 10% roasted quinoa flour and 0.5% emulsifier gel, as well as the sample containing 10% roasted quinoa flour and 1% emulsifier gel, jointly exhibited the highest specific volume compared with the other samples. Shahsavan Tabrizi et al. (2024) reported that incorporating more than 20% quinoa flour into pan bread formulation reduced product volume; the researchers attributed this to the weakening of the gluten network and its inability to retain and uniformly distribute gases [35]. On the other hand, the findings of the present study indicated that the use of emulsifier gel had a positive effect on the porosity of the samples. Emulsifiers, by reducing the surface tension between the liquid and gas phases, promote the distribution of small, uniformly sized air bubbles throughout the cake batter. During baking, air escapes from these bubbles in a controlled manner, resulting in a cake with appropriate porosity [36]. Dudu et al. (2020), in their investigation of emulsifier incorporation into baked product formulations, concluded that emulsifiers increase the number of pores, their surface fraction, and the internal porosity of such products. This effect corresponds to the high water-binding capacity of emulsifiers, as well as improvements in dough stability and increased gas-retention capacity [37]. Similarly, Pourfarzad et al. (2012) reported that sodium stearoyl-2-lactylate had a significant effect on increasing cell size and crumb porosity in bread. These researchers attributed the observed effects to interactions between the emulsifier and flour components, which enhanced gas-retention capacity within the gluten network [38]. Anvarinejad and Javadi (2017), by incorporating agar gum and glycol monostearate emulsifier into sponge cake formulations, also reported increased porosity. They explained that during baking, small gas cells tend to merge into larger ones, which reduces internal porosity. However, the use of hydrocolloids and emulsifiers can create a protective layer around small emulsion droplets, preventing their coalescence and aggregation, thereby increasing porosity [39].

Table 2: The effects of quinoa flour and gel emulsifier on the specific volume and porosity of cake

Treatments	Quinoa Flour (%)	Gel Emulsifier (%)	Specific volume (ml/g)	Porosity (%)
1	-	-	2.66 ± 0.47^{bcd}	23.26 ± 0.83^{ab}
2	-	0.5	2.85 ± 0.11^{bc}	23.32 ± 0.81^{ab}
3	-	1	2.41 ± 0.29^{cd}	21.94 ± 0.86^{bc}
4	10	-	3.22 ± 0.35^{ab}	23.59 ± 0.66^{ab}
5	10	0.5	3.74 ± 0.22^{a}	25.11 ± 0.594^{a}
6	10	1	3.09 ± 0.16^{abc}	24.56 ± 0.51^{a}
7	20	-	1.96 ± 0.08^{d}	21.05 ± 0.85^{c}
8	20	0.5	2.40 ± 0.32^{bcd}	23.40 ± 0.48^{ab}
9	20	1	3.20 ± 0.21^{ab}	24.91 ± 0.31^{a}

Different letters represent a significant difference from one another (p<0.05).

3.4. Texture Hardness

The results of the texture hardness evaluation of cupcake samples produced with different levels of roasted quinoa flour and emulsifier gel are presented in Table 3. As the findings indicate, replacing wheat flour with quinoa flour up to the 10% substitution level led to a decrease in texture hardness, meaning that the cake hardness followed a downward trend at lower substitution levels. However, with further replacement (from 10% to 20%), hardness increased, and the samples containing 20% quinoa flour exhibited firmer textures than those with 10% quinoa flour. This suggests that careful attention must be paid to the substitution level of quinoa flour, as using levels above 20% in cake formulation is likely to result in higher hardness compared with the control sample (without quinoa flour). A number of studies have investigated this trend. For instance, Kim et al. (2021) and Nesliha et al. (2018) found that substituting wheat flour with quinoa flour at levels exceeding 15% disrupted the gluten network in cake batter, impairing its ability to retain air bubbles during mixing and fermentation, which consequently increased cake hardness compared with the control [40, 41]. Jan et al. (2018) reported that incorporating quinoa flour at levels below 50% in cookie formulations resulted in softer textures due to improved dispersion of sugar and fat within the formulation [42]. Adriana et al. (2015) used rice–quinoa flour blends in cookie formulations at quinoa levels of 10, 25, and 45%. Their results showed that the sample containing 10% quinoa flour and 90% rice flour had the lowest hardness (i.e., the softest texture). Higher percentages of quinoa flour increased hardness because of higher fiber content, while lower substitution levels led to reduced hardness due to the presence of the α-glucosidase enzyme and better distribution of ingredients in the formulation [43]. Some researchers have attributed the superior performance of quinoa compared with other grains such as wheat and rice in enhancing the textural properties of baked goods—especially bread—to its higher contents of protein, fiber, and oil [44]. Consistent with these findings, the present study also showed that the inclusion of emulsifier gel in the cupcake formulation containing roasted quinoa flour improved texture by reducing hardness and increasing softness. Emulsifiers act as dough-strengthening agents in baked products, forming a layered structure at the gluten–starch interface that contributes to gluten network development. By improving the rheological characteristics of the dough—such as stability and extensibility—they reduce product firmness [45]. Marudova et al. (2020) used polyglycerol monostearate esters, sucrose stearate esters, and inulin palmitate esters as emulsifiers in cake formulations. According to their results, emulsifiers and emulsifier gels effectively reduced cake hardness through two main mechanisms: (a) By positioning themselves at the oil–water interface and interacting with gluten and starch components to improve texture characteristics, and (b) By retaining more moisture during baking and storage, delaying starch retrogradation and staling, and thereby maintaining cake softness [46]. Sheikholeslami et al. (2021) reported that the use of DATEM and sodium stearoyl-2-lactylate emulsifiers reduced the staling rate and maintained the softness of whole-grain bread during storage. The observed decrease in hardness was attributed to improved water absorption within the gluten–starch network. The researchers further explained that emulsifiers can lower the surface tension of the liquid phase surrounding gas cells, facilitating air incorporation and retention in the cake batter. This leads to a more uniform air-cell distribution and consequently a softer crumb texture [47].

Table 3: The effects of quinoa flour and gel emulsifier on the hardness of cake during 3 times

Treatments	Quinoa Flour (%)	Gel Emulsifier (%)	Hardness (N)		
			2 hours	1 week	2 weeks
1	-	-	2.91 ± 0.35^{bc}	6.45 ± 0.59^{a}	8.15 ± 0.98^{a}
2	-	0.5	2.47 ± 0.20^{c}	3.93 ± 0.24^{cd}	5.04 ± 0.20^{bc}
3	-	1	3.79 ± 0.28^{a}	3.92 ± 0.29^{cd}	4.57 ± 0.50^{c}
4	10	-	2.41 ± 0.35^{c}	4.67 ± 0.71^{bc}	6.78 ± 0.79^{ab}
5	10	0.5	2.21 ± 0.19^{c}	3.30 ± 0.61^{d}	5.17 ± 0.38^{bc}
6	10	1	2.77 ± 1.23^{bc}	2.84 ± 0.35^{d}	4.76 ± 0.49^{c}
7	20	-	2.39 ± 0.51^{ab}	5.56 ± 0.39^{ab}	6.01 ± 0.87^{bc}
8	20	0.5	2.61 ± 0.26^{bc}	4.77 ± 0.24^{bc}	5.71 ± 0.74^{bc}

9	20	1	2.34 ± 0.17^{c}	3.60 ± 0.45^{cd}	5.49 ± 0.77^{bc}

Different letters represent a significant difference from one another ($p<0.05$).

3.5. Crust Color Values ($L^*a^*b^*$)

Table 4 presents the results of the color attribute analysis (L^* a^* b^*) of cupcake crusts formulated with different levels of roasted quinoa flour and emulsifier gel. According to the findings, the inclusion of roasted quinoa flour in the cupcake formulation caused crust darkening, as evidenced by decreases in L^* (lightness) and b^* (yellowness) values and an increase in a^* (redness). Conversely, the presence of emulsifier gel in the formulation lightened the crust color, reflected by increases in L^* and b^* values and a decrease in the perceived redness of the baked product. Similar studies have also reported color darkening when quinoa flour was added to food formulations. Cannas et al. (2020), in their investigation of substituting rice flour with quinoa flour in biscuit formulations, found that increasing the substitution level led to a drop in lightness (L^*) and a rise in redness (a^*), indicating darker biscuit color. The researchers attributed this effect to the presence of reducing sugars (e.g., glucose) and the amino acid lysine in quinoa flour, which promote the Maillard reaction during baking—a key factor enhancing the a^* parameter. Moreover, they noted that the polyphenolic compounds of quinoa flour directly affect product color by reducing lightness (L^*) and yellowness (b^*) and increasing redness (a^*) [48]. Moawad et al. (2018) similarly reported that partial substitution of wheat flour with quinoa flour in biscuits resulted in darker product coloration. They explained that this was due to intensified non-enzymatic browning caused by the higher protein content and the abundance of essential amino acids, particularly lysine, in quinoa flour compared with wheat flour [49]. Larissa et al. (2017) ascribed the darker appearance of pasta containing quinoa flour to its higher ash content, mineral levels, and phenolic compounds relative to semolina flour [50]. On the other hand, the present study found that the incorporation of emulsifier gel into the cupcake formulation containing roasted quinoa flour lightened the crust color. Emulsifiers, owing to their strong water-binding capacity, increase dough hydration; this dilutes the concentrations of available amino acids and reducing sugars, lowering the intensity of the Maillard browning reaction and thereby enhancing crust lightness [51]. Furthermore, emulsifiers can reduce protein–sugar interactions by coating flour particles with lipids, which restricts protein accessibility to reducing sugars and thus suppresses browning. They can also affect starch behavior by decreasing dextrinization and the amount of sugars available for the browning reaction, which results in decreased color intensity [52]. It has also been proposed that combinations of emulsifiers such as sodium stearoyl-2-lactylate (SSL) and diacetyl tartaric acid esters of mono- and diglycerides (DATEM) promote the formation of a homogeneous and cohesive structure in baked products, wherein starch granules interact closely with gluten proteins—leading to a lighter overall color [47]. Similarly, Ghanadrezaee et al. (2018) reported an increase in cake lightness upon incorporating emulsifier gel into cake formulations, attributing this to improved aeration during batter preparation, which enhances the brightness of the final baked product [9].

Table 4: The effects of quinoa flour and gel emulsifier on the crust color values of cake during 3 times

Treatments	Quinoa Flour (%)	Gel Emulsifier (%)	Crust color values		
			L^*	a^*	b^*
1	-	-	64.54 ± 1.11^{bc}	11.65 ± 0.69^{bc}	40.42 ± 1.59^{a}
2	-	0.5	71.25 ± 0.97^{a}	7.22 ± 0.72^{d}	38.81 ± 1.71^{a}
3	-	1	66.71 ± 1.20^{b}	3.59 ± 0.84^{e}	37.58 ± 1.74^{abc}
4	10	-	60.03 ± 1.94^{d}	13.76 ± 0.97^{ab}	38.47 ± 1.47^{ab}
5	10	0.5	64.83 ± 1.14^{bc}	9.42 ± 0.75^{cd}	37.14 ± 1.38^{abc}
6	10	1	62.61 ± 1.58^{bcd}	7.52 ± 0.54^{d}	33.89 ± 1.35^{bcd}
7	20	-	53.67 ± 1.73^{e}	15.07 ± 1.38^{a}	33.65 ± 1.96^{cd}
8	20	0.5	61.66 ± 1.66^{cd}	10.46 ± 0.87^{c}	30.19 ± 1.96^{d}
9	20	1	64.04 ± 1.28^{bc}	9.46 ± 0.49^{cd}	29.35 ± 1.69^{d}

Different letters represent a significant difference from one another ($p<0.05$).

3.6. Sensory Properties

Table 5 presents the results of the sensory evaluation of the produced cupcake samples, influenced by varying levels of roasted quinoa flour and emulsifier gel. The findings indicate that substituting wheat flour with roasted quinoa flour, particularly at the 10% level, led to improvements in sensory attributes. These included overall form and shape, top and bottom surface characteristics, crumb porosity and texture, firmness and softness, chewiness, aroma and flavor, and ultimately, the overall acceptability score (which represents the average score of other sensory attributes after applying their respective effective weights). The results also demonstrated a positive effect of the emulsifier gel on enhancing sensory properties. Specifically, a 0.5% emulsifier gel level was found to be most effective in improving the quality and market acceptability of cupcakes when 10% of the wheat flour was replaced with roasted quinoa flour. Similarly, when replacing 20% of the wheat flour with roasted quinoa flour, a 1% emulsifier gel level yielded the greatest positive impact on the samples. Supporting these findings, Hamzehpour and Ahmadi Dastgerdi (2023) utilized different levels of quinoa flour (0% to 30%) in cupcake formulations and assessed the sensory and quality attributes of the resulting products. Their research clearly showed that the presence of just 10% quinoa flour in the formulation improved aroma and flavor, top and bottom surface characteristics (especially color), form and shape, texture (porosity, crumb firmness/softness, and chewiness), and consequently increased overall acceptability [53]. However, they reported that two other samples (those with 20% and 30% quinoa flour) were rejected during sensory evaluation, failing to achieve an acceptable score (minimum 2.5 out of 5) [53]. In a related study, Cannas et al. (2020) investigated the effect of substituting rice flour with quinoa flour on the quality characteristics of biscuits. They noted that incorporating quinoa flour (below 30%) improved the color of the biscuits. However, using quinoa flour at levels above 10% introduced a bitter taste and reduced the aroma and flavor scores. The texture of samples containing low levels of quinoa flour was also deemed acceptable in sensory evaluations [48]. El-sohaimy et al. (2019) examined the substitution of wheat flour with quinoa flour at various levels (0%, 5%, 10%, 15%, 20%, and 30%) in white bread formulations, evaluating the physicochemical and sensory properties of the produced samples. Their findings revealed that substituting wheat flour with quinoa flour up to the 15% level (specifically, samples containing 5%, 10%, and 15% quinoa flour) resulted in increased overall acceptability scores compared to the control sample (100% wheat flour). Notably, the samples containing 10% and 15% quinoa flour were jointly identified as the best performing samples in their study [32]. Conversely, the sensory evaluation results from the present study also indicated that the inclusion of emulsifier gel in the cupcake formulation containing roasted quinoa flour had a positive effect on sensory attributes. Numerous studies have investigated this aspect and reported favorable outcomes. Gunadi and Pamungkaningtyas (2022) added a mixture of emulsifiers (Lactem, mono- and diglycerides, and polyglycerol esters) in gel form at levels ranging from 0% to 3% to a sponge cake formulation. They concluded that the use of emulsifier gels improved the qualitative characteristics and overall acceptability score of the cake [13]. Lauren et al. (2022) utilized an emulsifier gel containing mono- and diglycerides, DATEM, and sodium stearoyl-2-lactylate in bread, observing improvements in sensory characteristics such as volume, crumb firmness and softness, porosity and texture, chewiness, and color [54]. In their study, Yanan et al. (2020) employed various emulsifiers in a steamed white bread formulation. They reported that the presence of emulsifiers enhanced the quality of the final product, including appearance, color, and texture, by strengthening the gluten network (affecting proteins) and mitigating staling (affecting starch). These researchers noted that the emulsifiers did not significantly impact the aroma and flavor [34].

Ghanadrezaee et al. (2018) used an emulsifier gel containing monoglycerides, acetic acid esters of monoglycerides, sodium stearoyl-2-lactylate, DATEM, polyglycerol esters, polyol, and water in a cupcake formulation. They found that the presence of monoglyceride and DATEM emulsifiers, by strengthening the gluten network, and polyols, by increasing water absorption, improved crumb firmness and softness, chewiness, porosity and texture, volume, appearance, and color. The cupcake samples containing the emulsifier gel achieved a higher overall acceptability score in sensory evaluations compared to the control sample (without emulsifier gel) [9].

Table 5: The effects of quinoa flour and gel emulsifier on the sensory properties of cake

Treatments	Quinoa Flour (%)	Gel Emulsifier (%)	Sensory properties			
			Form & Shape	Upper surface	Lower surface	Porosity
1	-	-	4.20±0.42^{a}	3.60±0.52^{ab}	3.80±0.63^{ab}	3.20±0.42^{bc}
2	-	0.5	3.40±0.52^{b}	3.80±0.798^{a}	4.00±0.67^{ab}	3.20±0.63^{bc}
3	-	1	2.60±0.52^{c}	3.60±0.52^{ab}	3.50±0.53^{b}	2.60±0.52^{bc}
4	10	-	3.70±0.48^{ab}	3.60±0.53^{ab}	3.90±0.57^{ab}	3.00±0.67^{bc}
5	10	0.5	4.20±0.42^{a}	4.30±0.48^{a}	4.50±0.53^{a}	4.30±0.48^{a}
6	10	1	3.60±0.51^{ab}	3.50±0.70^{ab}	3.80±0.63^{ab}	3.30±0.48^{bc}
7	20	-	3.60±0.52^{ab}	2.90±0.57^{b}	3.60±0.52^{b}	3.40±0.70^{bc}
8	20	0.5	3.60±0.52^{ab}	3.60±0.52^{ab}	4.10±0.74^{ab}	3.70±0.82^{ab}
9	20	1	3.80±0.42^{ab}	3.70±0.48^{ab}	4.00±0.66^{ab}	3.80±0.78^{ab}
Treatments	Quinoa Flour (%)	Gel Emulsifier (%)	Sensory properties			
			Texture	chewiness	Odor &Taste	Acceptance
1	-	-	3.60±0.52^{abcd}	3.90±0.32^{ab}	3.50±0.71^{abc}	3.74±0.13^{bc}
2	-	0.5	3.40±0.51^{bcd}	3.10±0.57^{bc}	3.30±0.80^{bc}	3.39±0.25^{cd}
3	-	1	3.10±0.88^{cd}	2.90±0.74^{c}	2.90±0.87^{c}	2.94±0.37^{d}
4	10	-	3.50±0.53^{bcd}	3.80±0.42^{ab}	4.10±0.74^{ab}	3.67±0.27^{bc}
5	10	0.5	4.20±0.63^{ab}	4.50±0.53^{a}	4.40±0.52^{a}	4.33±0.40^{a}
6	10	1	3.70±0.48^{abcd}	3.50±0.52^{bc}	3.80±0.63^{abc}	3.59±0.39^{bc}
7	20	-	3.00±0.67^{d}	3.40±0.52^{bc}	4.40±0.84^{bc}	3.53±0.30^{bc}
8	20	0.5	4.00±0.82^{abc}	3.70±0.67^{abc}	4.30±0.82^{ab}	3.83±0.46^{abc}
9	20	1	4.50±0.70^{a}	3.70±0.66^{abc}	4.00±0.67^{ab}	3.90±0.44^{ab}

Different letters represent a significant difference from one another ($p<0.05$).

4- Conclusion

This research was conducted with the aim of enriching cupcakes using roasted quinoa flour. To achieve this, different levels of wheat flour (0%, 10%, and 20%) were substituted with roasted quinoa flour. Furthermore, given that roasted quinoa flour lacks gluten protein and a potential reduction in the quality of the produced samples existed, emulsifier gel was used at varying levels (0%, 0.5%, and 1%) in the formulation of cupcakes containing roasted quinoa flour. The results indicated that the highest moisture content within 2 hours post-baking was observed in the sample containing 1% emulsifier gel and no roasted quinoa flour. The highest moisture content at 1- and 2-weeks post-baking was found in the sample containing 10% roasted quinoa flour and 1% emulsifier gel. The sample containing 10% quinoa flour and 0.5% emulsifier gel exhibited the highest specific volume and porosity, along with the lowest texture hardness compared to other produced samples. Moreover, the crust color evaluation results showed that the presence of roasted quinoa flour and emulsifier gel led to a darker crust color and lighter color in the produced samples, respectively. The sensory evaluation results suggested that substituting wheat flour with roasted quinoa flour, particularly at the 10% level, improved sensory characteristics. These improvements included form and shape, top and bottom surface properties, crumb porosity and texture, firmness and softness, chewiness, aroma and flavor, and ultimately, the overall acceptability score (which is the average score of other sensory attributes after applying their respective effective weights). Additionally, the results demonstrated the positive performance of the emulsifier gel in enhancing sensory properties. Based on the findings of this study, it was determined that when replacing 10% of the wheat flour with roasted quinoa flour, a 0.5% level of emulsifier gel was most effective in improving quality and market acceptability. Similarly, when replacing 20% of the wheat flour with roasted quinoa flour, a 1% level of emulsifier gel showed the greatest impact on enhancing the quality and market acceptability of the cupcake samples. In conclusion, the sample containing 10% roasted quinoa flour and 0.5% emulsifier gel, and the sample containing 20% roasted quinoa flour and 1% emulsifier gel can be proposed as the optimal samples from this research for the functional baked goods industry.

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چکیده

کینوا یک شبه غله سرشار از اسیدهای آمینه ضروری و ویتامین‌های گروه ب وحاوی پروتئین و فیبر بالا است. از این رو به منظور غنی‌سازی کیک فنجانی، سطوح متفاوت آرد گندم (صفر، ۱۰ و ۲۰ درصد) با آرد کینوای برشته شده جایگزین شد و از ژل امولسیفایر (صفر، ۰/۵ و ۱ درصد) برای بهبود کمیت و کیفیت این نوع کیک استفاده و ویژگی‌های بافتی و حسی نمونه‌های تولیدی ارزیابی گردید. نتایج نشان داد در بازه زمانی ۲ ساعت و ۱ و ۲ هفته پس از پخت رطوبت نمونه شاهد (فاقد آرد کینوا و ژل امولسیفایر) به ترتیب ۱۷/۰۳، ۱۳/۱۷ و ۱۱/۳۰ درصد و رطوبت نمونه حاوی ۲۰ درصد آرد کینوا و ۱ درصد ژل امولسیفایر (بیشترین سطح مصرف ژل امولسیفایر) ۱۸/۶۱، ۱۷/۶۵ و ۱۷/۰۴ درصد بود که نشان‌دهنده عملکرد مثبت آرد کینوا و ژل امولسیفایر در حفظ رطوبت در زمان ماندگاری بود. نمونه حاوی ۱۰ درصد آرد کینوا و ۰/۵ درصد ژل امولسیفایر دارای بیشترین حجم مخصوص (۳/۷۴ میلی‌لیتر بر گرم) و تخلخل (۲۵/۱۱ درصد) و کمترین سختی بافت پس از ۲ هفته نگهداری (۵/۱۷ نیوتن) بود. براساس نتایج بدست آمده از ارزیابی رنگ نمونه‌های تولیدی مشخص شد حضور آرد کینوای برشته شده در فرمولاسیون کیک فنجانی سبب تیرگی (کاهش مولفه رنگی L^* و b^* و افزایش مولفه رنگی a^*) و حضور ژل امولسیفایر در سبب روشن‌تر شدن رنگ شد. در نهایت براساس یافته‌های بدست آمده از پارامترهای حسی به ویژه پذیرش کلی، نمونه حاوی ۱۰ درصد آرد کینوای برشته شده و ۰/۵ درصد ژل امولسیفایر به عنوان بهترین نمونه این پژوهش معرفی می‌گردد.