3 Egypt. J. Food. Sci. **Vol. 53**, No.1, pp. 35-44 (2025)

Egyptian Journal of Food Science
http://ejfs.journals.ekb.eg/

Quality Evaluation of Biscuits Made from Oat and Quinoa Composite Flour

CrossMark

Hanan A. Hussien[1], Zeinab A. Shabib[1,2] and Mokhtar H. Abd-El-Khalek[1*]
[1]Bread and Pasta Department, Food Technology Research Institute, Agricultural Research Center, Giza, Egypt.
[2]Food Science and Human Nutrition Department, College of Agriculture and Veterinary Medicine Qassim University, Saudi Arabia.

THE PRESENT study examines the incorporation of oat groat flour (OGF) and white quinoa flour (WQF) into biscuit formulations and their effects on nutritional value, physical characteristics, and sensory attributes. The biscuits prepared from oat and quinoa composite flours were analyzed for gross chemical composition, mineral content, physical properties, and sensory quality. The results indicated that supplementation of OGF and WQF significantly improved the nutritional value of biscuits by significantly increasing protein, dietary fiber, and essential minerals such as iron, calcium, magnesium, and zinc. Regression models revealed significant associations between the levels of OGF and WQF and various biscuit characteristics. The improved nutritional quality was attributed to the higher levels of dietary fiber and protein, while the richer color attributes were due to the presence of phenolic compounds in the composite flours. Sensory evaluation has also shown that even though the composite flour biscuits rated a little lower in flavor and color than the control samples, they retained an acceptable overall appeal. This study highlights oat and quinoa composite flour as a potentially viable option in developing nutrient-enriched, health-oriented biscuits that would help meet the increasing demand for functional and nutritionally rich snack foods.

Key Words: Biscuits, Oat, Quinoa, Quality, Optimization.

Introduction

Bakery products are essential in many people's diets around the world. The variability and availability of many bakery product items have made them a very important subject of innovation and continual improvement for food processors. Cereal-based bakery products are sources of many nutrients for humans, mainly carbohydrates in addition to other nutrients like fiber, minerals and vitamins (Rosell & Garzon, 2015; Carcea, 2020). Also, the incorporation of fat sources (like oil and butter) and protein ones (like eggs) in some bakery products has made them a source of these two nutrients too (Arepally et al., 2020). Codex Alimentarius has defined dietary fiber as the "carbohydrate polymers with ten or more monomeric units, which are not hydrolyzed by the endogenous enzymes in the small intestine of humans (CAC, 2017). Dietary fiber has been found to have many health benefits such as improvingt digestive health, lowering cholesterol and blood sugar levels in addition to its role in weight management as a non-caloric food ingredient and increasing satiety. Thus, the USDA has recommended a daily intake of dietary fiber of 14 grams per 1,000 calories of food (USDA, 2020). Unfortunately, the use of cereal flours with lower extraction rates has led to the production of bakery items with lower fiber content.

Oat (*Avena sativa*) is a species of cereal grain grown for its seed that is now receiving great attention for use in bakery and other cereal grain-based products (Mao et al., 2022). Oat is distinguished by its unique nutrient composition such as that in fiber, minerals, vitamins and

*Corresponding Author: Mokhtar Harb Abd-El-Khalek , mokhtarharb@yahoo.com
Received : 25/12/2024; Accepted : 6/4/2025
DOI: 10.21608/EJFS.2025.347658.1204

antioxidants which makes it a valuable food for overall health and human well-being (Rasane et al., 2015). Also, it has many health benefits including reducing the risk of heart disease, cancer and type II diabetes, lowering blood sugar levels, Improving digestion and helping in weight management (Alemayehu et al., 2023). Quinoa (*Chenopodium quinoa*) is a pseudocereal native to Latin America that belongs to the family Chenopodiaceae. It is an herbaceous plant that is grown annually as a crop for its edible seeds (Vilcacundo & Hernández-Ledesma, 2017; Ballester-Sánchez, 2019). Due to its balanced content of macronutrients (i.e., carbohydrates, protein and fats) and micronutrients (minerals and vitamins) in addition to antioxidants and other bioactive compounds, quinoa has been proposed as a strategy to improve the nutritional quality of bakery products, especially those made by using refined or low extraction rate flours (Haros & Schoenlechner, 2017; Vilcacundo & Hernández-Ledesma, 2017; Ballester-Sánchez et al., 2019).

For this reason, and to benefit from the aforementioned health advantages of oats and quinoa, several studies were conducted to investigate their use in the production of bakery items such as bread (Wang et al., 2015; Ballester-Sánchez et al., 2019; Krochmal-Marczak, 2020), cake (De La Hera et al., 2013; Abazari & Salehifar, 2022), cookies and biscuits (Wang et al., 2015, Cannas et al., 2020) and noodles (Çalışkan Koç & Pandiselvam, 2022). Response Surface Methodology (RSM) is a widely used statistical tool in vast areas of research and product quality improvement including the food industry (McCarthy et al., 2005; Dean et al., 2017). In this methodology, the effects of multiple independent variables (factors) on one or more dependent variables (responses) are evaluated, and the optimal levels of these factors are determined to achieve desired product characteristics (Khuri & Mukhopadhyay, 2010; Joshi et al., 2022). Unfortunately, the incorporation of whole-grain flours and fiber sources has been found to have a deteriorating effect on the sensory quality characteristics of bakery products including biscuits (Arepally et al., 2020), thus the present study is carried out to investigate the effect of incorporating oat groats and/or white quinoa flours on the quality characteristics of biscuits, and to obtain an optimized biscuit formula by the use of Response Surface Methodology (RSM).

Materials and Methods

Materials

Wheat flour (72% extraction) was obtained from Al-Doha Company for foodstuff, Suez, Egypt. Oat groats and white quinoa were purchased from Abu Auf Co., Cairo, Egypt. Butter ghee (Fern) was obtained from IFFCO Egypt, Suez, Egypt. Other biscuit ingredients (i.e. sugar, skim milk powder, glucose syrup, sodium bicarbonate, ammonium bicarbonate, sodium metabisulfite and vanilla extract) were provided by the Food Technology Research Institute (FTRI), Giza, Egypt.

Methods

Preparation of oat groats and white quinoa flours

Oat groats and white quinoa flours (OGF and WQF, respectively) were prepared by manually cleaning oat groats and quinoa seeds, then they were separately milled twice by using a Retsch rotor mill (type SK100, Retsch, Germany) to pass through a 60 mesh (0.250 mm) stainless steel sieve. Each flour was packed in a polyethylene bag until further usage.

Experimental design

Response surface methodology was utilized to study the effect of substituting up to 50% of the wheat flour used in the preparation of hard sweet biscuits with OGF and/or WQF on the characteristics of the produced biscuits.

The central composite design (CCD) with two independent factors (i.e. OGF and WQF) was generated with three center points and response surface methodology was applied by using Design-Exper17 Software (Stat-Ease Corporation, Minneapolis, MN). Model selection (mean, linear, 2FI, quadratic) for each response was made based on the sequential model sum of squares (SMSS), lack-of-fit tests and the coefficient of determination (R^2) by using the same Software (Stat-Ease Corporation, Minneapolis, MN) as described by McCarthy et al. (2005).

Biscuit preparation

Hard sweet biscuits were prepared for different experimental designs (central composite type) runs by using the method described by El-Sharnouby et al. (2012). The formulas of biscuits identified by the central composite design with two independent factors are shown in Table 1. Butter Ghee and sugar were creamed for 10 minutes by using a Moulinex blender (Optiblend 2000, France). Then, sodium and ammonium bicarbonate were dissolved in 100 ml of water and added to the cream with continuous mixing followed by the addition of glucose syrup. Wheat flour and/or wheat-OGF-WQF) flour mixtures were mixed with the other formula dry ingredients (i.e. skimmed milk powder and vanilla extract) were added to the above cream and were mixed until the dough was formed. The dough was then sheeted to 3.5 mm thickness, cut by using a round cutter (5 cm diameter) and baked at 205 ^{o}C for 10 minutes in an electric oven (Zanussi TS, Model: ZCOE102T2S0). After cooling, biscuits were packed in polyethylene bags for further experiments.

Chemical analysis

Chemical analysis was conducted on flours and biscuits by using the AACC (2010) methods. Moisture, protein, ether extract, dietary fiber and ash contents determinations were carried out according to the methods with the numbers (44-15.02), (46-12.01), (30-25.01), (32-05.01) and (08-01.01), respectively. Total Carbohydrates (as nitrogen-free extract, NFE) were calculated by difference.

Physical properties

Biscuits were tested for their physical properties according to the methods outlined by AACC (2010). Five biscuits were laid edge to edge and the width was measured. They were rotated 90^{o} and remeasured to obtain the average diameter (width, W). Then, they were stacked on top of one another and the thickness was measured. They were restacked in different order and remeasured to obtain the average thickness (T). The spread ratio was calculated by dividing the width (W) by the thickness (T).

The average weight of five biscuits was measured in g. The volume of five biscuits was measured in cc by the rapeseed displacement method. Specific volume was calculated by dividing the volume (in cc) by the weight (in g).

Color determinations

A Hunter Lab Color QUEST II Minolta CR-400 (Minolta Camera, Co., Ltd., Osaka, Japan) was used to determine the color parameter L* (100: white; 0: black), a* (+, red; -, green), and b* (+, yellow; -, blue) values according to the procedure outlined by (Francis, 1983). For every biscuit formula, three replicates were measured (Saricoban & Yilmaz, 2010).

Sensory analysis

For the sensory analysis of biscuits, ten trained panelists from the Food Technology Research Institute (FTRI) participated in the evaluation. To ensure standardized conditions and minimize external variables, the sensory assessment was conducted in a controlled environment within a well-lit, temperature-regulated sensory laboratory. Each panelist was asked to assess the biscuits based on five key sensory attributes (i.e., appearance, color, taste, texture, and flavor). A structured sensory evaluation sheet was provided to each panelist to maintain scoring consistency. For scoring purposes, each of the five attributes was rated on a 20-point scale, where 20 denoted the highest quality and 0 represented the lowest. In order to prevent carryover effects between samples, the panelists were requested to rinse their palates with water. The overall sensory score of each biscuit was obtained by summing the individual scores of the five attributes to provide a comprehensive and objective sensory quality measure.

TABLE 1. Central Composite Design (CCD) formulations of biscuits (g).

Treatment (Run #)	WF*	OGF*	WQF*	Sugar	Butter	Skim milk powder	Glucose syrup	Sodium bicarbonate	Ammonium bicarbonate	Sodium metabisulfite	Vanilla extract
1	50	16.7	33.3	33	15	1.5	3	0.6	1.5	0.03	0.01
2	66.7	0	33.3	33	15	1.5	3	0.6	1.5	0.03	0.01
3	87.5	0	12.5	33	15	1.5	3	0.6	1.5	0.03	0.01
4	50	25	25	33	15	1.5	3	0.6	1.5	0.03	0.01
5	50	0	50	33	15	1.5	3	0.6	1.5	0.03	0.01
6	50	25	25	33	15	1.5	3	0.6	1.5	0.03	0.01
7	87.5	12.5	0	33	15	1.5	3	0.6	1.5	0.03	0.01
8	66.7	33.3	0	33	15	1.5	3	0.6	1.5	0.03	0.01
9	50	33.3	16.7	33	15	1.5	3	0.6	1.5	0.03	0.01
10	100	0	0	33	15	1.5	3	0.6	1.5	0.03	0.01
11	50	50	0	33	15	1.5	3	0.6	1.5	0.03	0.01
12	50	25	25	33	15	1.5	3	0.6	1.5	0.03	0.01

* WF = Wheat Flour, OGF = Oat Groats Flour, WQF = White Quinoa Flour

Optimization study

For the identification of the optimized biscuit formula, RSM was employed using the Design-Expert7 Software (Stat-Ease Corporation, Minneapolis, MN) as described by McCarthy et al. (2005) with setting the following parameters as maximized: protein, ash, fiber and overall sensory acceptability, while other experimental parameters were set to be "In range".

Statistical Analysis

The obtained data were analyzed using Analysis of Variance (ANOVA) with the General Linear Model (GLM) procedure in the Statistical Analysis System (SAS, 1999). Mean comparisons were conducted using the Least Significant Difference (LSD) test at a significance level of $p \leq 0.05$.

Results and Discussion

Gross chemical composition and mineral content of flours

Gross chemical composition and mineral content of wheat, oat groat, and white quinoa flours are summarized in Table 2. Wheat flour (WF) had the highest moisture content, whereas the Oat groat flour (OGF) had a significantly higher protein content than the others ($p<0.05$). Amongst the three, white quinoa flour (WQF) had the highest ash and dietary fiber contents. For mineral content, WQF had also quite significant contents of calcium and magnesium, whereas OGF showed very high iron and zinc contents ($p<0.05$). The same Table also compares the nutritional values of OGF and WQF with those in WF, showing higher values in the first two as OGF contains about 1.5-fold more protein content, while WQF has over twice as much dietary fiber, which would positively contribute to good digestive health and enhance biscuit texture. WQF also contains almost threefold higher calcium levels and a higher level of magnesium, which isimportant for bone health. It contributes over five times the amount of iron and more than double the amount of zinc, which is very important in immune response. The addition of these flours to biscuits will increase the nutritional value of the biscuits immensely. These findings agree with those reported by Ballester-Sánchez et al. (2019) and Mao et al. (2022) on the proximate composition of oats and quinoa, respectively. Thus, quinoa and oats offer superior nutritional value compared to wheat, making them excellent candidates for enhancing wheat-based foods. Quinoa is rich in protein and minerals, while oats provide beneficial soluble fiber, which aids in cholesterol reduction. By incorporating these grains into wheat-based products, we can significantly boost their nutritional profile (Maradini-Filho, 2017; Rasane et al., 2015)

Model regression coefficients for the gross chemical composition of biscuits

The model regression analysis illustrated in Table 3 showed that there are significant relations between the gross chemical composition of biscuits and the inclusion of OGF and WQF ($p<0.05$). The coefficients demonstrated that WQF and OGF affect the chemical constituents differently for the biscuits. For example, the quadratic model for moisture content showed a noticeable increase with the addition of OGF and WQF, with coefficients suggesting a maximum value of about 4.04 and a minimum value of 3.452. Protein content was best predicted by a 2FI model, with OGF showing a positive coefficient, indicating an increase in protein levels with higher OGF content. Lipids followed a similar trend, having a maximum value of 13.89 and a minimum of 13.30, about the influence of both OGF and WQF. The ash content, as predicted by the quadratic model, increased with the addition of OGF and WQF, while the coefficients ranged from 1.25 to 2.38. Soluble dietary fiber **(**SDF**)**, insoluble dietary fiber **(**IDF**)** and total dietary fiber **(**TDF**)** also had positive coefficients which reflects a positive correlation between OGF and WQF addition, and the fiber content.

The regression analysis puts into light the significant influence of OGF and WQF on biscuit composition. Increased moisture content has indicated better hydration and improved texture (Moawad et al., 2018). A higher protein content in OGF and WQF increased the nutritional quality (Malik et al., 2022). An increase in lipid content, corresponding with the higher fat in quinoa and oats, improves palatability and energy density (Moawad et al., 2018). Another significant effect of total dietary fiber provides further evidence of intricate interactions that improve digestion and sustained energy (Nadian et al., 2021).

Model regression coefficients for the physical and color properties of biscuits

The regression models, as presented in Table 4, were used to explain the influence of OGF and WQF on the physical and color attributes of biscuits. From the high R^2 values, it is evident that these models, to a great extent, portrayed the actual correlations between flour composition and biscuit properties. The quadratic relationship of OGF to diameter suggests that there is some optimum level of OGF for maximum biscuit diameter. Going beyond this point, increasing levels of OGF may be associated with decreased diameter, possibly due to changes in dough rheology or baking spread. This agrees with the previous work by Lee & Kang (2018). The linear effects of OGF and WQF on thickness and spread ratio are as expected from these flours. Their higher protein and dietary fiber contents can strengthen the dough structure which lead to thicker and less spread biscuits. This was supported by Swapna et al. (2023). The most interesting observation is the synergistic effect of OGF and WQF on specific volumes, which suggests that combining these flours will lead to a greater improvement in specific volume than using either flour alone. This might be attributed to possible complementary effects of the two flours on dough structure and gas retention during baking.

TABLE 2. Gross chemical composition (g/100 g) and mineral content (mg/100g) of wheat, oat groat and white quinoa flours [1]

	Moisture	Protein	Ash	Lipids	Dietary fiber			Carbohydrates	Minerals (mg/100 g)					
					TDF	SDF	IDF		Ca	Mg	Fe	Mn	Zn	P
WF*	12.98^{A} ± 0.13	10.51^{C} ± 0.05	0.53^{C} ± 0.01	1.61^{C} ± 0.08	2.55^{C} ± 0.13	0.77^{B} ± 0.03	1.78^{C} ± 0.11	71.82^{A} ± 0.37	140^{A} ± 5.0	100^{C} ± 3.0	2^{C} ± 0.3	1.3^{C} ± 0.0	1.4^{C} ± 0.1	380^{B} ± 6.0
OGF*	9.63^{C} ± 0.08	15.35^{B} ± 0.17	1.42^{B} ± 0.04	6.15^{A} ± 0.16	11.86^{A} ± 0.21	2.05^{A} ± 0.08	9.81^{A} ± 0.30	55.59B ± 0.44	108^{AB} ± 4.0	160^{B} ± 5.0	4.1^{B} ± 0.1	2.2^{B} ± 0.1	4.6^{A} ± 0.1	350^{C} ± 4.0
WQF*	12.21^{B} ± 0.13	15.88^{A} ± 0.01	1.56^{A} ± 0.06	2.48^{B} ± 0.50	6.78^{B} ± 0.07	0.84^{B} ± 0.01	5.94^{B} ± 0.07	61.09C ± 0.21	100^{B} ± 3.0	210^{A} ± 3.0	4.9^{A} ± 0.1	2.8^{A} ± 0.3	3.4^{B} ± 0.0	490^{A} ± 5.0

[1] Values are expressed as mean of three replicates ± standard deviation
* WF = Wheat Flour, OGF = Oat Groats Flour, WQF = White Quinoa Flour

TABLE 3. Model regression coefficients for the gross chemical composition of biscuits containing OGF and WQF.

Chemical constituent	Model order	R^2 *	Model coefficients a						Maximum value	Minimum value
			Intercept	OGF	WQF	OGF x WQF	OGF2	WQF2		
Moisture	Quadratic	0.92	4.00	-0.01	-0.02	4.04	1.17	2.45	3.98	3.45
Protein	2FI	0.98	7.85	0.01	0.03	-2.93	-	-	9.48	7.86
Lipids	2FI	0.88	12.05	0.02	0.01	1.14	-	-	13.89	13.30
Ash	Quadratic	0.97	1.24	0.02	ns	-8.17	-1.92	-3.59	2.38	1.25
SDF	2FI	0.76	1.70	0.04	-9.88	7.92	-	-	8.09	1.20
IDF	Quadratic	0.93	2.68	0.07	-6.04	ns	ns	<0.01	55.85	55.3
TDF	2FI	0.61	4.09	0.10	0.10	<0.01	-	-	8.31	0.60
Carbohydrates	Linear	0.98	76.91	-0.11	-0.12	-	-	-	76.95	71.09

[a] OGF = Oat Groats Flour, WQF = White Quinoa Flour (%).
* R^2: Coefficient of determination.

TABLE 4. Model regression coefficients for the physical and color properties of biscuits containing OGF and WQF.

Physical properties	Model order	R^2 *	Model coefficients a						Maximum value	Minimum value
			Intercept	OGF	WQF	OGF x WQF	OGF2	WQF2		
Diameter (mm.)	Quadratic	0.65	55.85	ns	-0.04	8.97	ns	<0.01	55.85	55.3
Thickness (mm.)	Linear	0.57	10.21	0.03	0.01	-	-	-	11.76	9.97
Spread ratio	2FI	0.71	5.38	-0.01	ns	-0.01	-	-	5.60	4.74
Specific volume (cc/g)	2FI	0.97	2.38	ns	ns	<0.01	-	-	2.41	1.88
L	Quadratic	0.80	74.31	ns	0.01	ns	ns	0.01	74.38	61.93
A	Quadratic	0.99	2.72	-0.01	-0.08	ns	-0.02	0.09	4.87	2.17
B	Quadratic	0.96	30.10	-0.08	-0.05	ns	ns	0.01	30.74	25.24

[a] OGF = Oat Groats Flour, WQF = White Quinoa Flour (%).
* R^2: Coefficient of determination.

For the color properties, the non-linear relationships expressed by OGF and WQF with the color parameters L*, a*, and b* indicate a complex interplay between flour composition and biscuit color. The increasing darkness, reduced redness, and increased yellowness with higher levels of OGF and WQF likely result from the phenolic compounds and pigments contained in these flours. Similar color changes have been noted in other studies with the addition of oat and quinoa flours to baked products (Inglett et al., 2015; Demir & Kılınç, 2017). This study reveals that incorporating OGF and WQF significantly alters the physical and color properties of the biscuits. Proper regulation of levels of flour can enhance the desired characteristics including optimal size, thickness, spread, specific volume, and color of biscuits (Malik, 2022).

Model regression coefficients for the sensory attributes of biscuits

Table 5 presents the model regression coefficients of sensory attributes in biscuits with variable OGF and WQF amounts. Different models were developed for to evaluate the effects of adding OGF and WQF flours on appearance, color, taste, texture, flavor, and overall acceptability. The strength of the predictive models was represented by the coefficient of determination, R^2. For appearance, it can be seen that the linear model was identified with $R^2 = 0.48$; meanwhile, both OGF and WQF had a moderate impact on the appearance quality of biscuits. However, in WQF, changes were very minor and non-significant. The color, analyzed using the 2FI model with a higher R^2 of 0.62, revealed that both flours have an influence on color with a minor interaction effect between OGF and WQF. These findings are in agreement with other studies that found the pigments of quinoa could be responsible for the color enhancement of baked products (Cannas et al., 2020). Taste and texture data best fitted quadratic equations with R^2 values of 0.59 and 0.73, respectively. A negative coefficient for both flours indicates that at higher levels, the OGF and WQF may introduce slight bitterness, likely due to the unique compounds in quinoa flour, as evidenced by similar trends in research findings. For texture, both flours affected the biscuits' mouthfeel, probably because of the variant protein and fiber content affecting the baked goods' texture, as noticed by Sedej et al. (2011). The flavor model had a relatively lower fit, with $R^2 = 0.46$; however, positive coefficients for OGF indicated that oat enhances the flavor. Overall acceptability had the best fit, $R^2 = 0.80$, and thus presented the best predictive model, where both flours were significant contributors to consumer acceptance. This agrees with studies that propose an appropriate formulation that can result in an optimal level of sensory attributes to enhance consumer acceptance of baked goods with composite flours (Kaur and Kaur, 2017).

TABLE 5. Model regression coefficients for the sensory attributes of biscuits containing OGF and WQF.

Sensory attributes	Model order	R^2 *	Model coefficients a						Maximum value	Minimum value
			Intercept	OGF	WQF	OGF x WQF	OGF2	WQF2		
Appearance	Linear	0.48	19.16	-0.06	ns	-	-	-	20	15
Color	2FI	0.62	18.99	-0.02	0.02	-0.05	-	-	19.6	15.1
Taste	Quadratic	0.59	20.44	-0.30	-0.30	0.01	0.01	0.01	19.9	14.8
Texture	Quadratic	0.73	20.07	-0.20	-0.20	0.01	<0.01	0.01	20.0	15.7
Flavor	Quadratic	0.46	19.57	0.20	-0.02	0.01	<0.01	.01	19.0	14.5
Overall score	Quadratic	0.80	99.78	-1.03	-1.03	0.03	0.02	0.02	98.5	77.4

[a] OGF = Oat Groats Flour, WQF = White Quinoa Flour (%).

* R^2: Coefficient of determination.

Chemical composition, physical; properties and sensory characteristics of optimized biscuits

For the identification of an optimized biscuit formula, and among the different parameters studied in this work, protein, ash, fiber and overall sensory acceptability were set to be maximized while other parameters were kept as "In range". The contour surfaces obtained by the RSM method for such four parameters are shown in Fig. 1. The optimized flour blend was found by RSM methodology to contain 55.1, 19.5 and 25.4% of WF, WQF and OGF, respectively. Table 6 summarizes the chemical composition, physical properties, and sensory attributes of biscuits formulated with optimized oat and quinoa flour blends compared to control samples. The nutritional enhancements, physical characteristics, and sensory responses of the optimized biscuits were analyzed. The chemical analysis revealed that optimized biscuits exhibited a significant increase in protein, lipid, ash, and total dietary fiber (TDF) compared to the control. The notable rise in protein content aligns with the literature on the high-quality protein and amino acid profile in quinoa, enhancing the nutritional quality of composite flours (Alemayehu et al., 2023). The increased levels of soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) in the optimized biscuits support the findings of Angioloni and Collar (2013), highlighting the high fiber content of oat and quinoa as beneficial for digestive health and satiety. The optimized formulation also demonstrated increased mineral content, particularly magnesium, iron, manganese, and zinc. These results reflect the rich mineral profile of quinoa, a plant food known for its significant iron and magnesium content (Repo-Carrasco-Valencia et al., 2010). The enhanced levels of magnesium and zinc in the optimized biscuits boost their nutritional value, as these minerals are crucial for immune function, bone health, and energy metabolism (Vilcacundo and Hernández-Ledesma, 2017). The analysis of physical properties indicated minimal variation in diameter, thickness, and spread ratio between control and optimized biscuits. However, the color analysis showed significant changes in the "a" value (red-green balance), with the optimized biscuits displaying a more intense red hue. This observation is consistent with studies on quinoa-based products, where color variations are attributed to pigmentation in quinoa and the Maillard reaction during baking (Sazesh and Goli, 2020). Despite the shift in the "a" value, the stability of other physical properties suggests that oat and quinoa flour blends do not negatively impact the structural integrity of biscuits. Sensory evaluation yielded variant results. The color (as a sensory attribute) and flavor of the optimized biscuits received slightly lower ratings compared to the control, reflecting significant differences in these attributes. Similar findings were reported by Angioloni & Collar (2013), where composite flours introduced unique flavors and altered color due to natural pigments and bioactive compounds. Although flavor scores were marginally reduced, taste and texture scores remained comparable, indicating an overall acceptable sensory profile for the optimized formulation. Overall, the optimized biscuits scored marginally lower than the control, likely due to perceived differences in flavor and color. Nonetheless, the nutritional advantages of the optimized biscuits, particularly the increased protein and mineral content, make them appealing to health-conscious consumers. This trend is supported by Alemayehu et al. (2023), reflecting the growing interest in nutritious, high-fiber baked goods.

Conclusion

This study demonstrated the potential of incorporating oat groat flour and white quinoa flour into biscuit formulations to enhance their nutritional profile, physical properties, and sensory attributes. The regression models developed in this study provided valuable insights into the impact of these flours on biscuit characteristics, enabling the optimization of formulations for specific desired outcomes. The addition of OGF and WQF significantly increased the protein, fiber, and mineral content of the biscuits ($p<0.05$), making them a healthier and more nutritious option compared to traditional wheat flour-based biscuits. The physical properties, such as diameter, thickness, and spread ratio, were minimally affected by the inclusion of these flours at the optimized levels, ensuring that the biscuits maintained their desirable appearance and texture. While the sensory attributes, particularly color and flavor, were slightly altered by the addition of OGF and WQF, the overall acceptability of the optimized biscuits remained high. This suggests that a careful balance between nutritional enhancement and sensory appeal can be achieved through careful formulation and processing techniques. Future research could explore the potential of combining OGF and WQF with other functional ingredients to further enhance the nutritional and functional properties of biscuits. Additionally, investigating the effects of different processing techniques on the quality and shelf life of these biscuits could provide valuable insights for industrial applications. Overall, this study highlights the versatility of oat and quinoa flours as valuable ingredients for developing innovative and nutritious baked goods. By leveraging the knowledge gained from this research, it is possible to create a wide range of healthier and more appealing bakery products to meet the evolving needs of consumers.

TABLE 6. Chemical composition, physical; properties and sensory characteristics of optimized biscuits formula as compared to control ones.

Characteristic	Control biscuits	Optimized biscuits	Significance at 0.05
	Mean ± SD	Mean ± SD	
Chemical composition			
Moisture (%)	3.88 ± 0.08	3.43 ± 0.03	No
Protein (%)	7.87 ± 0.10	9.79 ± 0.14	Yes
Lipids (%)	9.66 ± 0.10	10.08 ± 0.12	Yes
Ash (%)	2.04 ± 0.05	2.23 ± 0.09	Yes
SDF (%)	0.87 ± 0.96	1.85 ± 1.73	Yes
IDF (%)	0.82 ± 0.67	1.79 ± 1.28	Yes
TDF (%)	1.69 ± 0.12	3.64 ± 0.17	Yes
Carbohydrates (%)	74.86 ± 0.21	7.83 ± 1.51	Yes
Ca	102.85 ± 2.30	94.15 ± 3.45	Yes
Mg	71.75 ± 3.85	109.45 ± 1.05	Yes
Fe	1.55 ± 0.05	2.15 ± 0.05	Yes
Mn	0.84 ± 0.16	1.5 ± 0.11	Yes
Zn	0.97 ± 0.02	1.77 ± 0.03	Yes
P	103.80 ± 1.76	115.35 ± 5.15	Yes
Physical properties			
Diameter	55.5 ± 0.51	54.50 ± 0.5	No
Thickness	11.2 ± 0.35	10.70 ± 0.15	No
Spread ratio	4.96 ± 0.19	5.12 ± 0.03	No
L	74.40 ± 1.13	66.95 ± 1.80	No
A	2.37 ± 0.06	3.94 ± 0.14	Yes
B	26.45 ± 1.25	29.15 ± 1.05	No
Sensory Characteristics			
Appearance	19.5 ± 0.8	18.0 ± 0.9	No
Color	19.3 ± 0.6	18.6 ± 0.5	Yes
Taste	19.0 ± 0.3	18.4 ± 0.3	No
Texture	19.7 ± 0.6	18.0 ± 0.6	No

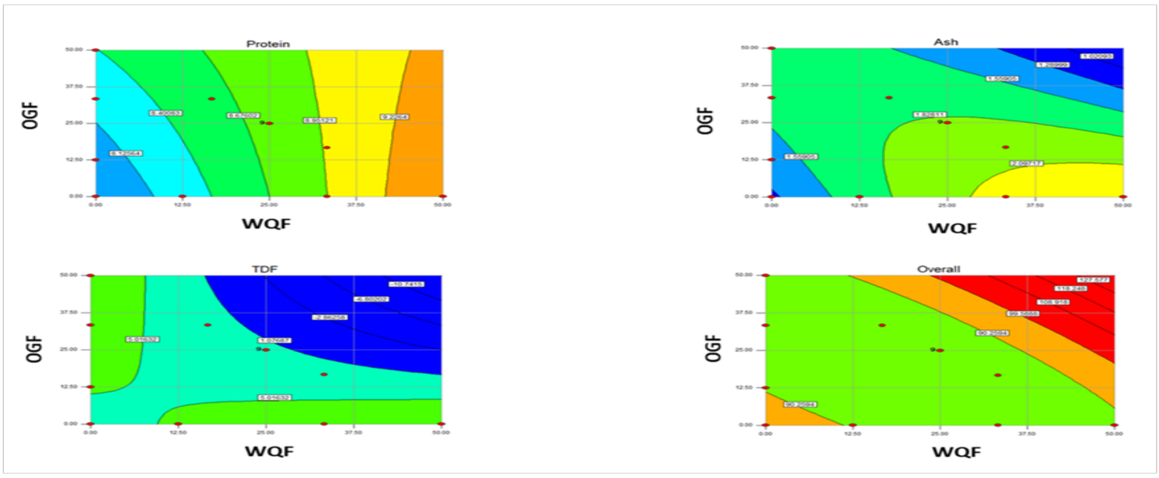

Fig. 1. Contour plots of the maximized study parameters.
OGF = Oat Groats Flour, WQF = White Quinoa Flour

References

AACC (2010) Approved Methods of Analysis of AACC International. St. Paul, MN, USA.

Abazari, A. and Salehifar, M. (2022) Production of functional cake powder using quinoa flour and isomalt. *Journal of Food Research*, **32**(1), 1-12. https://doi.org/10.22034/fr.2021.34996.1687.

Alemayehu, G. F., Forsido, S. F., Tola, Y. B. and Amare, E. (2023) Nutritional and phytochemical composition and associated health benefits of oat (Avena sativa) grains and oat-based fermented food products. *The Scientific World Journal*, 2023, 2730175, 1-16. https://doi.org/10.1155/2023/2730175.

Angioloni, A. and Collar, C. (2013) Suitability of oat, millet and sorghum in breadmaking. *Food and Bioprocess Technology*, **6**, 1486-1493. https://doi.org/10.1007/s11947-012-0786-9.

Arepally, D., Reddy, R. S., Goswami, T. K. and Datta, A. K. (2020) Biscuit baking: A review. *LWT-Food Science and Technology*, **131**, 109726. https://doi.org/10.1016/j.lwt.2020.109726.

Ballester-Sánchez, J., Millán-Linares, M. C., Fernández-Espinar, M. T. and Haros, C. M. (2019) Development of healthy, nutritious bakery products by incorporation of quinoa. *Foods,* **8**(9), 379. https://doi.org/10.3390/foods8090379.

CAC (2017) Codex Alimentarius guidelines on nutrition labelling, Joint FAO/WHO Codex Alimentarius Commission, UN. Last adopted 2021.

Çalışkan Koç, G. and Pandiselvam, R. (2022) Evaluation of physicochemical, functional, and sensorial characteristics of gluten-free Turkish noodle "Erişte" formulated with oat and quinoa flours. *Journal of Food Quality,* **2022(**1), 8622114. https://doi.org/10.1155/2022/8622114.

Cannas, M., Pulina, S., Conte, P., Del Caro, A., Urgeghe, P. P., Piga, A. and Fadda, C. (2020) Effect of substitution of rice flour with quinoa flour on the chemical-physical, nutritional, volatile and sensory parameters of gluten-free ladyfinger biscuits. *Foods,* **9**(6), 808. https://doi.org/10.3390/foods9060808.

Carcea, M. (2020) Nutritional value of grain-based foods. *Foods,* **9**(4), 504. https://doi.org/10.3390/foods9040504.

De La Hera, E., Oliete, B. and Gómez, M. (2013) Batter characteristics and quality of cakes made with wheat-oats flour blends. *Journal of Food Quality*, **36**(2), 146-153. https://doi.org/10.1111/jfq.12012.

Dean, A., Voss, D., Draguljić, D., Dean, A., Voss, D. and Draguljić, D. (2017) Response surface methodology. *Design and Analysis of Experiments*, pp. 565-614.

Demir, M. K. and Kılınç, M. (2017) Utilization of quinoa flour in cookie production. *International Food Research Journal*, **24**(6), 2394-2401.

El-Sharnouby, G. A., Aleid, S. M. and Al-Otaibi, M. M. (2012) Nutritional quality of biscuit supplemented with wheat bran and date palm fruits (*Phoenix dactylifera* L.). *Food and Nutrition Sciences*, **3**, 322-328. https://doi.org/10.4236/fns.2012.33047.

Francis, F. J. (1983) 'Colorimetry of foods', in Peleg, M. and Bagly, E. B. (Eds.) Physical Properties of Foods, pp. 105–123. Westport, Connecticut: The AVI Publishing Company Inc.

Haros, C. M. and Schoenlechner, R. (eds.) (2017) Pseudocereals: Chemistry and Technology. Hoboken, NJ, USA: John Wiley & Sons.

Inglett, G. E., Chen, D. and Liu, S. X. (2015) Physical properties of gluten-free sugar cookies made from amaranth–oat composites. *LWT-Food Science and Technology,* **63**(1), 214-220. https://doi.org/10.1016/j.lwt.2015.03.056.

Joshi, H., Awasthi, P. and Shahi, N. C. (2022) Optimization of process variables for preparation of horse gram flour incorporated high fiber nutritious biscuits. *Journal of Food Processing and Preservation*, **46**(12), 1-22. https://doi.org/10.1111/jfpp.17170.

Kaur, S. and Kaur, N. (2017) Development and sensory evaluation of gluten-free bakery products using quinoa (*Chenopodium quinoa*) flour. *Journal of Applied and Natural Science*, **9**(4), 2449-2455.

Khuri, A. I. and Mukhopadhyay, S. (2010) Response surface methodology. Wiley Interdisciplinary Reviews: *Computational Statistics*, **2**(2), 128-149. https://doi.org/10.1002/wics.73

Krochmal-Marczak, B., Tobiasz-Salach, R. and Kaszuba, J. (2020) The effect of adding oat flour on the nutritional and sensory quality of wheat bread. *British Food Journal*, **122**(7), 2329-2339. https://doi.org/10.1108/BFJ-07-2019-0493.

Lee, N. Y. and Kang, C. S. (2018) Quality improvement and antioxidant activity of sugar-snap cookies prepared using blends of cereal flour. *Preventive Nutrition and Food Science*, **23**(2), 160. https://doi.org/10.3746/pnf.2018.23.2.160.

Malik, R. A., Srivastava, S. and Shahi, N. C. (2022) Formulation of quinoa incorporated protein-rich biscuits and numerical optimization of its process parameters. *Journal of Food Processing and Preservation*, **46**(1), e16209. https://doi.org/10.1111/jfpp.16209.

Mao, H., Xu, M., Ji, J., Zhou, M., Li, H., Wen, Y., ... and Sun, B. (2022) The utilization of oat for the production of wholegrain foods: Processing technology and products. *Food Frontiers*, **3**(1), 28-45. https://doi.org/10.1002/fft2.120.

Maradini-Filho, A. M. (2017) Quinoa: nutritional aspects. *Journal of Nutraceuticals and Food Science*, **2**(1), 3.

McCarthy, D. F., Gallagher, E., Gormley, T. R., Schober, T. J. and Arendt, E. K. (2005) Application of response surface methodology in the development of gluten-free bread. *Cereal Chemistry,* **82**(5), 609-615. https://doi.org/10.1094/CC-82-0609

Moawad, E., Rizk, I. R. S., Kishk, Y. F. M. and Youssif, M. R. G. (2018) Effect of substitution of wheat flour with quinoa flour on quality of pan bread and biscuit. *Arab Universities Journal of Agricultural Sciences*, **26**(2D), 2387-2400. https://doi.org/10.21608/ajs.2018.35607.

Nadian, N., Azizi, M. H., Abbastabar Ahangar, H. and Aarabi, A. (2021) Textural and sensory characteristics of sugar-free biscuit formulated with quinoa flour, isomalt, and maltodextrin. *Food Science & Nutrition*, **9**(12), 6501-6512. https://doi.org/10.1002/fsn3.2564.

Rasane, P., Jha, A., Sabikhi, L., Kumar, A. and Unnikrishnan, V. S. (2015) Nutritional advantages of oats and opportunities for its processing as value added foods-a review. *Journal of Food Science and Technology*, **52,** 662-675. https://doi.org/10.1007/s13197-013-1072-1.

Repo-Carrasco-Valencia, R. A., Encina, C. R., Binaghi, M. J., Greco, C. B. and Ronayne de Ferrer, P. A. (2010) Effects of roasting and boiling of quinoa, kiwicha and kañiwa on composition and availability of minerals in vitro. *Journal of the Science of Food and Agriculture*, **90**(12), 2068-2073. https://doi.org/10.1002/jsfa.4053.

Rosell, C. M. and Garzon, R. (2015) Chemical composition of bakery products, in *Handbook of Food Chemistry*, pp. 191-224.

Saricoban, C. and Yilmaz, M. T. (2010) Modelling the effects of processing factors on the changes in colour parameters of cooked meatballs using response surface methodology. *World Applied Sciences Journal*, **9**(1), 14-22.

Sazesh, B. and Goli, M. (2020) Quinoa as a wheat substitute to improve the textural properties and minimize the carcinogenic acrylamide content of the biscuit. *Journal of Food Processing and Preservation*, **44**(8), e14563. https://doi.org/10.1111/jfpp.14563.

Sedej, I., Sakač, M., Mandić, A., Mišan, A., Pestorić, M., Šimurina, O. and Čanadanović-Brunet, J. (2011) Quality assessment of gluten-free crackers based on buckwheat flour. *LWT-Food Science and Technology*, **44**(3), 694-699. https://doi.org/10.1016/j.lwt.2010.11.010.

Swapna, K. S., Vijayageeta, V., Anupama, M., Mishra, D. and Kulkarni, J. (2023) Effect of oat incorporation on textural parameters of dough and sensory quality of biscuits. *Journal of Food and Dietetics Research*, **3**(1), 15-23.

USDA (2020) Dietary Guidelines for Americans 2020-2025. US Department of Health and Human Services, US Department of Agriculture.

Vilcacundo, R. and Hernández-Ledesma, B. (2017) Nutritional and biological value of quinoa (Chenopodium quinoa Willd). *Current Opinion in Food Science,* **14**, 1-6. https://doi.org/10.1016/j.cofs.2016.11.007.

Wang, S., Opassathavorn, A. and Zhu, F. (2015) Influence of quinoa flour on quality characteristics of cookie, bread and Chinese steamed bread. *Journal of Texture Studies*, **46**(4), 281-292. https://doi.org/10.1111/jtxs.12128.