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Makhrouta, A Traditional Egyptian Food Product: Production and Enrichment of Nutritional Value

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ABSTRACT

Wheat was the first crop cultivated in Egypt and remains highly important today. Physical examination, extraction rate, and gluten content determination of the Giza 155 and Sakha 8 wheat varieties were conducted to select the type of wheat best suited for Makhrouta dough. This study aims to evaluate the development and enhancement of the nutritional value of Makhrouta made from Egyptian wheat flour as an alternative to instant noodles, corn flakes, and ready-to-eat breakfast cereals. Physical, nutritional, technological, cooking, and sensory characteristics were evaluated in triplicate. The rheological characteristics of flour samples were assessed using Mixolab indices. Different levels of sweet lupin flour (SLF) (0, 5, 10, 15, 20, and 25%) were added to produce composite flour and assess its impact on the chemical composition, physical properties, cooking quality, and sensory evaluation of the product (dry and steamed Makhrouta). Results showed that Sakha 8 outperformed Giza 155 in all aspects, particularly in flour yield (%). In terms of rheological indices, the sweet lupin flour-wheat flour (SLF-WF) composites' water absorption, dough development time, and C4 torque increased as the SLF level rose, whereas their flour moisture, dough stability, and C2, C3, and C5 Mixolab decreased. Makhrouta generated by the SLF-WF composites had greater volume, harder texture, and a darker color. greater antioxidant activity as well as greater protein and mineral content were also demonstrated by makhrouta with SLF. Panelists liked the color, flavor, texture, taste, and overall acceptance of Makhrouta samples enhanced with SLF (5, 10, 15, 20, and 25%). In comparison to other samples, the addition of 20% SLF produced the best acceptance.The economic evaluation for producing Makhrouta with 20% SLF at an industrial scale proves the cost-effectiveness and potential profitability of this addition.

1. Introduction

Wheat (*Triticum aestivum* L.) is a strategically important cereal crop worldwide, and it is the most significant one in Egypt (Farid et al., 2023; Abd El-Aty et al., 2024). Wheat production in Egypt is around 9622993 tons (Bulletin of Agricultural Statistics, 2022). Due to its gluten protein content, wheat flour is a vital ingredient in pastries and bakery products. The characteristics of wheat flour products vary based on the wheat variety, milling rate, and particle size. The technological properties of flour result from specific quality parameters, such as protein content, wet gluten content, gluten strength, Zeleny index, falling number, extensibility, and resistance. Although gluten content and protein content are correlated, protein content alone does not always indicate quality. Recently, there has been growing interest in using composite flours in bread-making, Either to take advantage of the unique

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nutritional properties of non-wheat flours or to address wheat flour shortages (Eduardo et al., 2014). Wheat flour is rich in energy, dietary fiber, minerals, vitamins, and various bioactive compounds. Although no other cereal flour can fully match wheat's dough and baking characteristics, wheat flour is deficient in essential amino acids like lysine and threonine. Efforts to improve wheat flour by incorporating protein-rich ingredients from cereal and non-cereal sources have been explored in previous studies (Amir et al., 2013 and Ogur, 2014). Consumer acceptance of newly developed products is crucial to their success (Abdel-Samie & Abdulla, 2016). Legume seeds are an excellent source of proteins, minerals, vitamins, and sugars, making them highly beneficial for human nutrition (Bojňanská et al., 2012). Lupine (*Lupinus albus L.*) is an underappreciated legume despite its high protein and dietary fiber content and its potential health benefits (Arnoldi et al., 2015). It's production in Egypt is estimated to be 158 tons (Bulletin of the Agricultural Statistics, 2022). According to Estivi et al. (2023), lupine is widely cultivated due to the excellent nutritional composition of its seeds, which include a high protein content (28–48g/100g), a substantial lipid content (4.6–13.5g/100g, or up to 20.0 g/100g in Andean lupine) with a focus on unsaturated triacylglycerols, and an abundance of antioxidant compounds such as carotenoids, tocols, and phenolics. Particularly noteworthy is the amount of free phenolics, which are highly bioaccessible in the small intestine. Lupine protein has a well-balanced amino acid profile, with lysine, isoleucine, leucine, phenylalanine, and tyrosine present in proportions suitable for adults (FAO/WHO/ONU, 1985). Additionally, lupine seeds contain significant amounts of minerals like calcium, magnesium, and phosphorus, as well as trace amounts of copper, iron, manganese, and zinc (Ruiz-López et al., 2019). Lupine can be incorporated into high-carbohydrate foods, leading to significant increases in protein and fiber content, reductions in refined carbohydrates, and minimal impact on product acceptability. Replacing refined carbohydrates with protein in the diet may have beneficial effects on blood pressure. Additionally, lupine contains lower levels of anti-nutritional factors, such as trypsin inhibitors and saponins, compared to many other legumes. Studies have shown that lupine flour can be used to develop acceptable baked products (Ahmed, 2014; Lopez and Goldner, 2015; Guardianelli et al., 2023) and pasta (Martínez-Villaluenga et al., 2010). Makhrota is a traditional dry and/or steamed product native to some regions of Egypt, typically handmade from wheat flour and water. On an industrial scale, Makhrota is a type of pasta product that can serve as a substitute for instant noodles, cornflakes, and ready-to-eat breakfast cereals. The objective of this study was to produce and evaluate Makhrouta using Egyptian wheat flour (72% extraction) and five levels of sweet lupine flour (SLF) as a functional food ingredient on the flour's mixing characteristics, as well as the quality and nutritional properties of Makhrota.

2. Materials and Methods

Materials

Wheat varieties (Giza 155 and Sakha 8) and sweet lupin (*Lupinus albus*) seeds (Giza 2) variety were obtained from the Field Crops Research Institute, Agricultural Research Center, Giza, Egypt. Salt was purchased from a local market and used in this study. All analytical-grade reagents were procured from Sigma-Aldrich S.r.l. (Milan, Italy), unless otherwise specified.

Methods

Physical characteristics of wheat grains

The thousand-grain weight and hectoliter weight of the two wheat varieties were determined using standard procedures as outlined by AACC (2010). Grains were sliced using a farinograph, and the vitreous grains were counted. The flour extraction rate was calculated as the percentage of flour obtained from the total mass of grains milled. Gluten content, including both wet and dry gluten, was measured in accordance to AACC methods (2010).

Preparation of wheat flour and composite flour

Wheat grain samples (Giza 155 and Sakha 8) were cleaned and washed, then conditioned to 14% moisture content. The grains were milled using a

Quadrumat Senior Laboratory Mill, following the procedures outlined in AOAC (2019). The extraction rates of wheat flour for the two varieties were determined to be 75.23% and 77.23%, respectively. The flour was sieved through a 60-mesh sieve to obtain a 72% extraction rate, and the suitable flour (Sakha 8, 72%) was selected for making dough for Makhrouta. Sakha 8 wheat flour was then replaced with Sweet Lupin Flour (SLF) at levels of 5%, 10%, 15%, 20%, and 25% for Makhrouta preparation.

Preparation of Sweet Lupin Flour (SLF)

Lupin seeds were cleaned and soaked in tap water (1:3) at 25 ± 1°C for 12 hours. The soaked seeds were boiled in tap water (1:3) at 100°C for 25 minutes, then ground for 10 minutes. The ground seeds were dried in an oven at 60°C for 8 hours, followed by dry grinding using a Brabender laboratory mill. The resulting sweet lupin seed flour was sieved through a 60-mesh screen to obtain a fine powder, which was stored in polyethylene bags under freezing conditions at -18°C until use.

Rheological Properties

Mixo Lab analysis

The rheological behavior of wheat flour (WF) and composite flour (a mixture of 25% sweet lupin flour with wheat flour, SLF-WF) was analyzed using a Mixo Lab (Chopin+, Tripette et Renaud, Paris, France). The Mixo Lab instrument simultaneously determines the dough properties during mixing at a constant temperature and throughout the subsequent heating and cooling phases (Ozturk et al., 2009).

Makhrouta Production

Preparation of Makhrouta

To identify a suitable recipe for this study, various formulations were tested, and one was selected for optimal results. The final product incorporated Sweet Lupin Flour (SLF) at six different levels to enhance nutritional value and health benefits, along with a control sample (without Sweet Lupin Flour).

1. Dough Preparation:

The dry ingredients (1kg) were mixed first. Then, 500–550 ml of water per kilogram of flour was added to achieve a suitable dough texture. The dough was allowed to rest for 5 minutes before being portioned into smaller pieces. These pieces were then formed into rolls using a professional home pasta machine (Model Lillodue, Bottene, Marano Vicentino, Italy). About 10–15g of additional flour was used to prevent sticking.

2. Forming Makhrouta

The Makhrouta dough was passed through a 0.22 cm diameter stainless steel Makhrouta die and cut into 25 cm lengths. This process yielded six different samples, named T0 (control), T1, T2, T3, T4, and T5, following the method described by Rocchetti et al. (2020). Six batches of Makhrouta were produced for each sample.

3. Drying and seaming

- **Drying**

Each Makhrouta sample was divided into two parts. The first part was placed on a clean tissue for sun drying for 5–6 hours to reduce moisture content, followed by drying in an oven at 50–60°C for 3 hours to obtain dried Makhrouta.

- **Steaming**

The second part of each sample was placed in the upper section of a couscoussière. The lower section contained approximately 1.5 L of boiling water, and the junction between the two sections was sealed with a damp cloth to ensure steam passage. Steaming continued for 10 minutes. The steamed Makhrouta was then transferred to a dish. This method allowed for the preparation of both dried and steamed variations of Makhrouta, each with unique textural and nutritional characteristics.

Table 1. Ingredients of Makhrouta samples

Ingredients	T0	T1	T2	T3	T4	T5
Wheat flour (Sagha 8, 72% extraction)	99	94	89	84	79	74
Sweet Lupin Flour (SLF)	0	5	10	15	20	25
Salt	1	1	1	1	1	1
Total	100	100	100	100	100	100

Analytical Methods

1. Proximate Composition

- The moisture, ash, protein, crude fiber, and fat content of the raw materials and Makhrouta samples were determined following the AOAC (2019) methods.

- Total carbohydrates were calculated by difference. Total caloric value (Kcal) was computed using James' (1995) formula:

[(4×Protein) + (4×carbohydrate) + (9×fat)]

2. **Mineral Analysis**

- Minerals were analyzed on a dry weight basis, extracted from the samples using the dry ashing method (Chapman & Pratt, 1982).

3. Amino Acid Determination

- The amino acid profile was analyzed using a High -Performance Amino Acid Analyzer, following AOAC (2019) guidelines.

- The daily requirement of amino acids for individuals aged 31 to 50 years was referenced from FAO/ WHO (2007).

4. Carotenoid content

Cartenoid levels in raw materials and Makhrouta were measured using the method of Okonkwo (2009), with absorbance readings taken at 450 nm on a spectrophotometer.

5. Antioxidant Activity

Antioxidants were analyzed on a wet basis. Antiradical activity was assessed using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical-scavenging assay, as described by Mansouri et al. (2005).

6. Total Phenolic Content

The total phenolic content was measured using the method of Cosmulescu et al. (2015). Absorbance was recorded at 765 nm using a GENESYS 10S UV -Vis spectrophotometer (Thermo Scientific, USA), and results were expressed as milligrams of gallic acid equivalents per gram of sample (mg GAE/g).

These methods ensured a comprehensive analysis of the nutritional and bioactive properties of the Makhrouta samples, highlighting the effects of incorporating sweet lupin flour on the product's nutritional quality.

Physical Properties

Color Parameters

The external color of the grains, as well as dry uncooked and steamed Makhrouta samples, was measured using a hand-held chromameter (model CR-400, Konica Minolta, Japan). The color parameters were recorded as:

L: Lightness (ranging from 0 = black to 100 = white), a: Red/green value (-a indicates greenness, +a indicates redness), b: Blue/yellow value (-b indicates blueness, +b indicates yellowness)

The total color difference (ΔE\Delta EΔE) between uncooked, steamed, and control Makhrouta samples was calculated using the formula:

$$\Delta E = \sqrt{}\,(L0 - L^*)2 + (a_0 - a^*)2 + (b0 - b^*)2$$

Each measurement was taken in triplicate, and the procedure followed the guidelines of Francis (1983).

Water Activity (a_w)

Water activity (a_w) was determined at 25 ± 2°C using a Decagon Aqualab meter series 3TE (Pullman, WA, USA). Before measurement, Makhrouta samples were broken into small pieces to ensure accurate readings, following the method described by Shahidi et al. (2008). These measurements provided important data on the physical properties of the Makhrouta samples, essential for understanding their stability and shelf life.

Texture Profile Analysis

The firmness of steamed and dry Makhrouta was measured using a Texture Analyzer (Brookfield Engineering Lab. Inc., Middleboro, MA, USA). Three uncooked Makhrouta pieces were aligned perpendicularly to the probe so they touched each other along their entire length. The samples were compressed twice at a speed of 2mm/s, with a compression ratio of 70%, in accordance with AACC (2010) guidelines. Each measurement was performed in triplicate, and the average values were recorded.

Technological Parameters

Water Absorption Capacity (WAC)

The Water Absorption Index was determined as follows: 2.5g of Makhrouta powder was mixed with 30 mL of ultrapure water in a centrifuge tube. The tube was shaken for 30 minutes and then centrifuged at 2200 rpm for 10 minutes. The supernatant liquid was carefully drained into a container and dried in an oven at 105 °C for 4 hours before weighing it on an analytical balance. The remaining material in the centrifuge tube was also weighed, and the WAI was calculated based on the procedure described by Oliveira et al. (2015).

Cooking quality assessment

The cooking quality of Makhrouta samples, including weight increase (WI), volume increase (VI), and cooking loss (CL), was assessed as important technological quality parameters. These cooking properties were evaluated following the method outlined in AACC (2002), using the respective equations to determine the values.

WI (%) = 100 × (weight of cooked Makhrouta - weight of raw Makhrouta)/ weight of raw Makhrouta

VI (%) = 100× (volume of cooked Makhrouta - volume of raw Makhrouta)/ volume of raw Makhrouta

The cooking loss of Makhrouta was determined using a procedure reported by Ounane et al. (2006). Ten grams of Makhrouta (dried or steamed) was placed in 200 mL of distilled water at 25 °C. The mixture was agitated for 4 minutes, and 10 mL of the supernatant was then collected. The recovered supernatant was incubated in an oven at 105 °C for 15 hours to measure the extent of solids lost during cooking.

CL (%) = 100× (weight of residue in cooking water) / (weight of raw Makhrouta)

Sensory evaluation

A sensory evaluation was conducted with 10 panelists who were each given approximately 50g of the six different cooked Makhrouta samples containing 0%, 5%, 10%, 15%, 20%, and 25% sweet lupin flour. The samples were randomly numbered, and the panelists rated their preference using a 9-point Hedonic scale, where 1 = dislike extremely and 9 = like extremely, following the method described by Bashir et al. (2012).

Nutritional Attributes

Nutritional value for the products

The nutritional values of both the control and modified Makhrouta samples were computed using and The Food Nutrition Board, Institute of Medicine (2004)guidelines to assess the extent of nutrient enrichment and determine how they align with the Recommended Daily Allowance (RDA).

Economic indices

The economic indicators for producing one ton of Makhrouta from Egyptian wheat flour (Sagha 8, 72% extraction) and 20% lupine at an industrial level were estimated based on various economic factors and the added value. Variable costs were calculated by considering the quantities and average unit prices of wheat flour, lupine, equipment, electricity, labor, and other production-related expenses. All costs and returns were calculated using average market prices in Egyptian Pounds (EGP). The economic indicators were determined using the following equations:

$$TR = P \times Q \,,\ NR = TR - VC,\ \ AV = TR - IC,$$
$$RVA = VA/TR$$

where TR is the total return, P is the commodity price and Q is the quantity of the commodity, NR is the net return, VC is the variable costs, IC is the intermediate costs, VA is the value-added, and RVA is the ratio of value-added to the value of production (Vukoje et al., 2013).

Statistical analysis

The collected data were presented as means ± standard deviation (SD) and analyzed using analysis of variance (ANOVA) according to Steel et al., 1996. Means were compared using Duncan's multiple range test at the 5% significance level.

3. Result and Discussion

Wheat quality can be broadly categorized into physical, chemical, rheological, and technological properties. Physical grain quality attributes include thousand-grain weight, hectoliter weight, vitreousness, and color profiles, all of which can influence chemical and processing characteristics (Marcheva, 2021; Giunta et al., 2019).

Table 2 presents the mean values of the physical qualities, flour yield (%), and gluten content of two Egyptian wheat varieties, Sakha 8 and Giza 155.

The results showed that Sakha 8 outperformed Giza 155 in terms of thousand-grain weight (61.54–59.74 g), hectoliter weight (81.44–79.24 kg/hl), and vitreousness (86.67%–71.74%), respectively. These findings align with Mpofu et al. (2006), who reported hectoliter values for some wheat varieties ranging from 74.1 to 83.8 kg/hl. This suggests that Sakha 8, having greater thousand-grain weight and hectoliter weight, would likely yield more flour, achieving a significantly higher flour yield (77.23%) compared to Giza 155 (75.23%). The color profile of the wheat grains, also shown in Table 2, indicates that Giza 155 recorded the highest L* value (73.19) compared to Sakha 8 (72.10). However, the a* and b* values were lower for Giza 155 (5.40 and 22.91) than for Sakha 8 (5.90 and 23.96). Gluten content, a measure of gluten strength and gas retention, is also reported in Table 2, showing that Sakha 8 had higher wet and dry gluten contents than Giza 155. This trend indicates that both wet and dry gluten contents increased in line with protein content, as is well established in studies on wheat (Ionescu et al., 2010).

Table 2. Physical characteristics of two Egyptian wheat varieties

Item	Sakha 8	Giza 155
1000 Kernel weight (g)	61.54±0.92	59.74±0.02
Hectoliter (kg/hl)	81.44±0.04	79.24±0.16
Vitreousness (%)	86.67±0.96	71.74±1.41
L*	72.10±2.49	73.19±2.55
a*	5.90±0.52	5.40±0.27
b*	23.96±1.34	22.9±1.12
Extraction percentage of two Egyptian wheat varieties		
Flour yield (%)	77.22±0.10	75.23±0.09
Bran (%)	4.06±0.14	5.20±0.11
Red pollard	12.22±0.11	14.94±0.16
White pollard	6.50±0.10	4.62±0.13
Gluten content		
Wet gluten (%)	32.02±0.99	26.23±0.01
Dry gluten (%)	10.63±0.57	8.20±0.10

Values are means of three replicates ±SD

Characteristics of flour

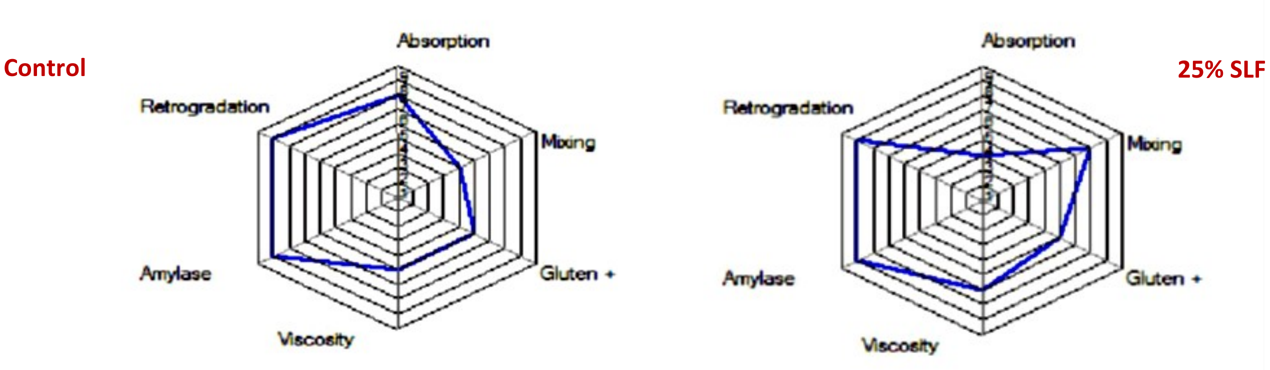
The Mixolab was used to analyze dough behavior during mixing and heating in a single test, effectively simulating the mixing and baking processes. The parameters measured by the Mixolab included: dough consistency during mixing (C1), mixing stability, protein weakening due to mechanical work and temperature (C2), starch gelatinization (C3), amylase activity and hot gel stability (C4), and starch retrogradation during the cooling phase (C5). Detailed results from the Mixolab data are presented in Table 3, along with Figure 1 and the corresponding curves. A comparative analysis between the control dough (base formulation) and dough containing 25% SLF is shown in Figure 1. Protein quality was assessed using the initial phase of the Mixolab curve, with indicators such as dough development time (DDT), dough stability, and the C2 value. DDT represents the time required to reach the maximum torque of 1.1 Nm (C1) (Sedej et al., 2011). The extraction rate of wheat flour influences its water absorption, protein (gluten) content, starch properties (including damaged and gelatinized starch particles), and particle size (Perten, 1990). Changes in pasting and mixing properties of lupin-wheat flour composites can be attributed to the chemical composition of lupin flour, its lack of gluten, and its distinct fiber composition.

The water absorption of control wheat flour was measured at 52.3%. With the proportional addition of SLF to wheat flour, water absorption increased, reaching a maximum value of 53.1% with 25% SLF. Flour that absorbs a greater amount of water is often preferred, as it yields higher quantities of Makhrouta during manufacturing. Dough development time (DDT) was optimal (1.48 minutes) for control flour (wheat flour without SLF), while the addition of SLF gradually increased DDT, peaking at 1.52 minutes with 25% SLF. This increase may be due to gluten weakening, as SLF is gluten-free, and the composition of SLF compared to wheat flour. This finding aligns with Doxastakis et al. (2002) and Sedej et al. (2011), who reported that adding high-fiber ingredients increased DDT levels. Dough stability, the duration over which dough resists deformation, decreased with the addition of SLF, from 9.12 minutes in the control flour to 8.43 minutes with 25% SLF. This reduction could be attributed to the decreased gluten content with the addition of gluten-free lupin flour. Dough consistency (C2) represents the minimum torque achieved after heating, reflecting protein aggregation and denaturation. The control wheat flour, which retained gluten integrity, maintained higher dough consistency (0.56Nm) than SLF-substituted samples. With 25% SLF, dough consistency (C2) decreased to 0.53Nm. Similarly, Antanas et al. (2013) observed a decrease in C2 with increased triticale levels in whole-wheat flour. Control samples had a higher C3 value, indicating a greater starch content, with a torque of 1.92 Nm, compared to 1.86 Nm in 25% SLF samples. This reduction in viscosity peak (C3) with lower starch addition is consistent with findings from Hadnadev (2011), which associated lower starch content with reduced viscosity peaks. The torque at C4 indicates the rate of enzymatic hydrolysis and the stability of the hot gel. A lower value signifies reduced stability. The control sample had a C4 value of 1.85 Nm, indicating a stable hot-phase gel, while the 25% SLF sample had a value of 1.78 Nm. The torque at C5 measures the structural reorganization of starch molecules during cooling, reflecting shelf stability. For the control sample, C5 was 3.08 Nm, while for 25% SLF it was 3.12Nm.

Table 3. Rheological characteristics of control wheat flour and 25% sweet lupine flour (25% SLF-WF) samples measured by Mixolab

Samples[1]	Water Absorption (%)	Torque (Nm)							
		DDT	C_1[2] min	C_2[3] (Nm)	C_3[4] (Nm)	C_4[5] (Nm)	C_5[6] (Nm)	Amplitude (Nm)	Stability time (min)
Control Flour 72% extraction (Sakha 8)	52.3	1.48	1.10	0.56	1.92	1.85	3.08	0. 05	9.12
L25%	53. 1	1.52	1.10	0.53	1.86	1.78	3.12	0.09	8.43

L25:25% SLF.
1= treatment, 2= Time to reach dough development, 3= Torque at the end of stage 2 in Mixolab curve, 4= Torque at the end of stage 3 in Mixolab Curve, 5= Torque at the end of stage 4 in Mixolab Curve, 6= Torque at the end of stage 5 in Mixolab Curve, 7= control.



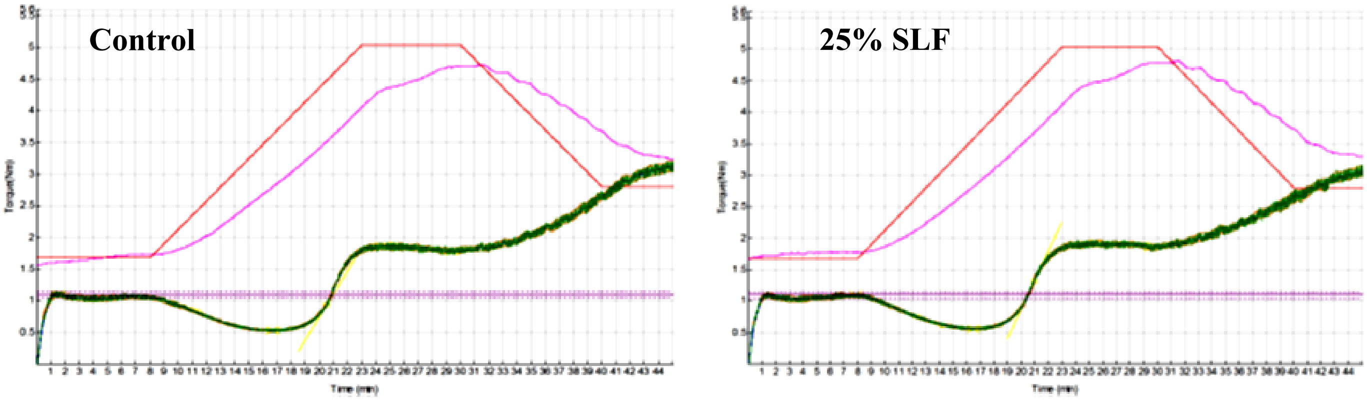


Figure 1. Mixolab profile for control wheat flour and 25% SLF

Chemical Analysis

The chemical composition of the raw materials and Makhrouta samples is presented in Table 4. Lupin flour exhibited higher levels of protein, fat, fiber, and ash content (39.14%, 2.69%, 8.00%, and 1.20%, respectively) compared to wheat flour (10.35%, 1.15%, 0.50%, and 0.40%, respectively). These results align with the findings of Algarni et al. (2019) and Hussien et al. (2023). However, wheat flour was notably higher in carbohydrates (87.60%) than lupin flour (48.97%). In terms of carotene content, lupin flour had a higher concentration (2.58 mg/kg), though these values were lower than those reported by Czubinski et al. (2021).

Table 4. Chemical composition of raw materials and produced Makhrouta

Sample	Protein (%)	Fat (%)	Crude Fiber (%)	Ash (%)	Total Carbohydrate (%)	Energy (Kcal)	Carotenoids (mg/kg)
				Raw Material			
Wheat Flour (72% ext.)	10.35±0.03	1.15 ±0.05	0.50 ±0.07	0.40 ±0.02	87.60 ±0.13	402.15±1.19	ND
Lupine Flour	39.14±0.05	2.69±0.03	8.00 ±0.09	1.20 ±0.04	48.97 ±0.17	376.65±1.23	2.58 ±0.05
				Makhrouta			
Control	10.56^{f}±0.06	0.27^{d}±0.02	0.18^{d}±0.08	1.70^{f}±0.05	87.29^{a}±0.28	393.83^{c}±0.21	ND
5% Lupine Flour	10.91^{e}±0.01	0.44^{c}±0.07	0.33^{c}±0.07	1.79^{e}±0.01	86.53^{b}±0.33	393.72^{c}±0.22	0.13^{e} ±0.02
10% Lupine Flour	11.79^{d}±0.01	0.89^{c}±0.09	0.47^{b}±0.06	1.94^{d}±0.05	84.91^{c}±0.22	394.81^{c}±0.20	0.27^{d} ±0.07
15% Lupine Flour	12.89^{c}±0.02	1.25^{b}±0.10	0.51^{b}±0.05	2.07^{c}±0.07	83.28^{d}±0.25	395.93^{b}±0.23	0.40^{c} ±0.05
20% Lupine Flour	13.61^{b}±0.01	1.98^{a}±0.05	0.82^{a}±0.07	2.19^{b}±0.03	81.40^{e}±0.21	397.86^{a}±0.28	0.53^{b} ±0.11
25% Lupine Flour	14.82^{a}±0.03	2.11^{a}±0.06	0.88^{a}±0.08	2.28^{a}±0.01	79.91^{f}±0.26	397.91^{a}±0.25	0.66^{a} ±0.08

Values are means of three replicates ±SD, on dry weight basis. ** Total carbohydrates were calculated by difference. Data are presented as means ± SD (n=3). Numbers in the same column followed by the same letter are not significantly different at 0.05 level

The addition of lupin flour led to a significant increase in protein content, rising from 10.56% to 14.82%. This increase is due to the higher protein content in lupin flour (39.14%) compared to wheat flour (10.35%), making it a valuable ingredient for enhancing the protein content and nutritional value of Makhrouta. These findings align with those of Jayasena et al. (2010). In this study, as the amount of lupin flour increased, there was a proportional rise in ash and fat content, along with a significant increase in crude fiber content (from 0.18% to 0.88%). These results are consistent with the findings of Jayasena et al. (2010) and Krawęcka et al. (2022). Lupin flour has higher fat, fiber, and ash content (2.69%, 8.00%, and 1.2%, respectively) than wheat flour (1.15%, 0.5%, and 0.4%, respectively). The carotene content also increased with higher lupin flour levels, reaching 0.66mg/kg in Makhrouta containing 25% lupin flour. Additionally, the energy value rose with increased lupin flour substitution, reaching 397.91Kcal.

Mineral content with lupin flour substitution

The mineral content of the raw materials and Makhrouta samples is shown in Table 5. Lupin flour was found to contain higher levels of calcium, magnesium, iron, zinc, copper, sodium, and potassium, consistent with the findings of Algarni et al. (2019) and Hussien et al. (2023).

Table 5. Mineral content (mg/100g) of raw materials and produced Makhrouta

Sample	Calcium	Magnesium	Iron	Zinc	Copper	Sodium	Potassium
			Raw Material				
Wheat Flour (72% ext.)	15.00±0.06	22.00±0.05	1.15 ±0.07	0.40 ±0.05	0.14 ±0.01	200.00±0.04	107.00 ±0.06
Lupine Flour	20.15±0.03	122.00±0.02	2.47 ±0.04	3.89 ±0.01	13.32 ±0.07	587.00±0.15	990.05 ±0.17
			Makhrouta				
Control	16.99^{f}±0.05	23.56^{f}±0.10	1.22^{f} ±0.05	0.75^{f}±0.10	0.20^{f}±0.05	406.89^{f}±0.05	111.43^{f}±0.05
5% Lupine Flour	17.27^{e}±0.02	28.70^{e}±0.06	1.28^{e}±0.05	0.91^{e}±0.05	0.84^{e}±0.05	435.33^{e}±0.05	161.80^{e}±0.05
10% Lupine Flour	17.61^{d}±0.09	34.11^{d}±0.04	1.33^{d}±0.10	1.06^{d}±0.07	1.53^{d}±0.02	464.15^{d}±0.05	211.87^{d}±0.10
15% Lupine Flour	17.80^{c}±0.05	39.27^{c}±0.07	1.39^{c}±0.04	1.23^{c}±0.05	2.23^{c}±0.05	492.69^{c}±0.06	261.93^{c}±0.05
20% Lupine Flour	18.02^{b}±0.04	44.51^{b}±0.02	1.44^{b}±0.04	1.40^{b}±0.01	2.80^{b}±0.05	520.43^{b}±0.08	310.98^{b}±0.01
25% Lupine Flour	18.22^{a}±0.08	48.55±0.08^{a}	49.45^{a}±0.08	1.50^{a}±0.15	1.54^{a}±0.09	3.58^{a}±0.08	546.75^{a}±0.09

Values are means of three replicates ±SD, on dry weight basis. Numbers in the same column followed by the same letter are not significantly different at 0.05 level.

Increasing the substitution of lupin flour from 5% to 25% in Makhrouta samples led to a gradual increase in the mineral content of all measured elements (Table 5). This increase is due to the higher mineral content in lupin flour compared to wheat flour. Similar results have been observed in other studies, where the addition of lupin flour significantly boosted mineral content in spaghetti and other pasta products (Jayasena et al., 2010; Krawęcka et al., 2022). Erbas et al. (2005) noted that pasta products typically have low mineral content, and the addition of lupin flour can enhance their nutritional value, offering health benefits.

Phenolic Content and Antioxidant Activity (DPPH)

The total phenolic content and radical scavenging activity of wheat flour (72%), sweet lupin flour, and Makhrouta samples are shown in Table 6. The data indicate that lupin flour contains more than double the total phenolic content (120.65mg GAE/100g) compared to wheat flour (72% extraction), which has only 59.72mg GAE/100g. These findings align with the work of Vollmannova et al. (2021). Similarly, the antioxidant activity results confirm that lupin flour has significantly higher antioxidant activity than wheat flour, consistent with findings by Ahmed (2012).

Table 6. Phenolic content and DPPH of raw materials and produced Makhrota

Sample	Total Phenolic Content (mg GAE/100gm)	Radical Scavenging Activity DPPH (%)
	Raw Materials	
Wheat Flour (72% ext.)	59.72±0.30	2.95±0.9
Lupine Flour	120.65±0.90	26.0±0.32
	Makhrouta	
Control	53.10 f ±0.50	64.33 f ±0.39
5% Lupine Flour	118.33 e ±0.35	85.42 e ±0.30
10% Lupine Flour	134.33 d ±0.63	87.90 d ±0.60
15% Lupine Flour	145.00 c ±0.29	97.11 c ±0.43
20% Lupine Flour	193.67 b ±0.42	121.45 b ±0.79
25% Lupine Flour	238.00 a ±0.75	154.83 a ±0.34

Values are means of three replicates ±SD, on dry weight basis. Numbers in the same column followed by the same letter are not significantly different at 0.05 level.

The results show that total phenolic content increased with higher levels of lupin flour in the substituted samples. The phenolic content of control Makhrouta was 53.10 mg GAE/100g, significantly rising to 238 mg GAE/100g with 25% lupin flour. This increase is attributed to the high phenolic content in lupin flour (120.65 mg GAE/100g). Antioxidant activity followed a similar trend, increasing significantly to 154.83% with 25% lupin flour compared to 64.33% for the control. These findings are consistent with Plustea et al. (2022) and confirm that lupin flour is a valuable antioxidant source.

Table 7 presents the color measurements. Replacing wheat flour with lupin flour resulted in a darker color (lower L* values) and a redder hue (higher a* values), while yellowness (b* values) remained nearly constant. Yellowness and brightness are influenced by pigment concentration and enzymatic reactions, whereas redness is typically associated with non-enzymatic browning (Doxastakis et al., 2007).

Table 7. Color attributes of raw materials and produced Makhrota

Sample	L*	a*	b*	ΔE
		Raw Materials		
Wheat Flour (72% ext.)	93.82±0.03	-0.81±0.11	8.88±0.07	-
Lupine Flour	82.00 ±0.01	4.26±0.05	21.58±0.02	-
		Dry Makhrota		
Control	77.27^{a}±0.05	0.42^{e}±0.02	11.89^{e}±0.09	-
5% Lupine Flour	76.19^{b}±0.09	0.73^{d}±0.03	13.78^{d}±0.08	2.20±1.25
10% Lupine Flour	75.50^{c}±0.02	1.34^{c}±0.04	15.15^{c}±0.05	3.82±1.46
15% Lupine Flour	74.86^{d}±0.06	1.37^{bc}±0.07	15.42^{b}±0.07	4.38±1.20
20% Lupine Flour	73.37^{e}±0.05	1.43^{b}±0.03	15.51^{b}±0.03	5.42±1.41
25% Lupine Flour	72.56^{f}±0.06	1.56^{a}±0.06	16.44^{a}±0.04	6.65±1.05
		Steamed Makhrota		
Control	64.17^{a}±0.03	0.27^{f}±0.04	17.04^{f}±0.06	-
5% Lupine Flour	63.90^{b}±0.04	0.39^{e}±0.06	19.86^{e}±0.09	2.84±0.06
10% Lupine Flour	62.10^{c}±0.05	1.59^{d}±0.08	22.37^{d}±0.06	5.87±0.03
15% Lupine Flour	61.43^{d}±0.03	1.60^{c}±0.04	24.69^{c}±0.05	8.23±0.07
20% Lupine Flour	60.15^{e}±0.02	2.05^{b}±0.07	25.39^{b}±0.03	9.44±0.04
25% Lupine Flour	56.16 ^{f}±0.06	3.18^{a}±0.05	27.06^{a}±0.07	13.15±0.09

*L (lightness with L = 100 for lightness, and L = zero for darkness), a [(chromaticity on a green (-) to red (+)], b [(chromaticity on a blue (-) to yellow (+)]. Data are presented as means ± SDM (n=3). Numbers in the same column followed by the same letter are not significantly different at 0.05 level.

Color attributes of Makhrouta samples

The addition of lupin flour significantly affected the color of both dry and steamed Makhrouta samples. The *L** value, representing lightness, showed a marked decrease in both dry and fresh steamed samples as the level of lupin flour increased. Doxastakis et al. (2007) similarly observed that spaghetti samples with added lupin protein isolate were darker (lower *L** values) than control samples. Likewise, the inclusion of 25% lupin in pasta resulted in a darker color, as indicated by a significant decrease in *L** value (ŠVec et al., 2008). Demir et al. (2010) reported that an increased Maillard reaction due to higher protein content may contribute to these color changes. Both *a** and *b** values, representing red and yellow hues, respectively, increased in both dry and steamed samples as the concentration of lupin flour rose (Table 7). Statistical analysis revealed significant differences in *a** and *b** color coordinates across the samples. The control sample had the lowest mean b* value, which increased with higher lupin concentrations. Similar results were reported by Jayasena et al. (2010).

This may be attributed to the naturally occurring yellow pigments in lupin flour, which impart yellowness when combined with milled wheat flour (72% extraction), an off-white control sample (Jayasena et al., 2010). The increase in the b* value in lupin-enriched Makhrouta compared to 100% wheat flour samples may also be linked to the higher yellow pigment content in lupin flour compared to semolina (Yaver and Bilgicli 2021).

Texture profile analysis of Makhrouta samples

Table 8 presents the Texture Profile Analysis (TPA) results for dry and steamed Makhrouta, including measurements of hardness, gumminess, chewiness, springiness, and adhesiveness. A significant increase in several TPA parameters was observed when comparing the control Makhrouta to both fortified dry and steamed samples.

Table 8. Texture profile analysis of produced makhrouta

Parameters Samples	Hardness (N)	Gumminess (N)	Chewiness (mJ)	Springiness (mm)	Adhesiveness (mJ)
Dry Makhrouta					
Control	5.12^{f}±0.05	1.59^{f}±0.03	1.00^{f}±0.05	0.10^{a}±0.05	0.20^{a}±0.07
5% Lupine Flour	7.69^{e}±0.09	4.16^{e}±0.07	2.73^{e}±0.04	0.12^{a}±0.10	0.19^{a}±0.05
10% Lupine Flour	10.64^{d}±0.06	5.20^{d}±0.05	3.91^{d}±0.09	0.12^{a}±0.03	0.19^{a}±0.09
15% Lupine Flour	14.66^{c}±0.03	6.17^{c}±0.08	5.11^{c}±0.06	0.12^{a}±0.09	0.19^{a}±0.06
20% Lupine Flour	16.77^{b}±0.08	8.19^{b}±0.09	7.25^{b}±0.11	0.13^{a}±0.06	0.18^{a}±0.05
25% Lupine Flour	19.05^{a}±0.11	9.24^{a}±0.10	9.13^{a}±0.15	0.13^{a}±0.04	0.18^{a}±0.07
Steamed Makhrouta					
Control	4.19^{f}±0.07	2.53^{f}±0.03	1.10^{f}±0.05	0.70^{a}±0.05	0.20^{a}±0.07
5% Lupine Flour	6.22^{e}±0.04	6.86^{e}±0.07	4.70^{e}±0.04	0.69^{a}±0.10	0.19^{a}±0.05
10% Lupine Flour	10.00^{d}±0.09	10.10^{d}±0.05	6.90^{d}±0.09	0.69^{a}±0.03	0.19^{a}±0.09
15% Lupine Flour	12.54^{c}±0.06	16.07^{c}±0.08	10.10^{c}±0.06	0.69^{a}±0.09	0.19^{a}±0.06
20% Lupine Flour	13.57^{b}±0.11	20.79^{b}±0.09	13.20^{b}±0.11	0.69^{a}±0.06	0.18^{a}±0.05
25% Lupine Flour	15.83^{a}±0.10	25.44^{a}±0.10	19.10^{a}±0.15	0.69^{a}±0.04	0.18^{a}±0.07

Values are means of three replicates ±SD. Data are presented as means ± SDM (n=3). Numbers in the same column followed by the same letter are not significantly different at 0.05 level.

The inclusion of lupine flour in both dry and steamed Makhrouta led to increased hardness, as shown by the rise from 5.12 N in control dry Makhrouta to 19.05 N in dry Makhrouta with 25% lupine flour. Similarly, in steamed Makhrouta, hardness increased from 4.19 N in the control to 15.83 N in steamed Makhrouta with 25% lupine flour (Table 8). These findings align with research by Doxastakis et al. (2007), who observed that spaghetti firmness increased with higher concentrations of lupine protein isolate (5–20%). Similarly, El-Sohaimy et al. (2020) reported a significant increase in firmness in pasta fortified with chickpea flour compared to control pasta. Petitot et al. (2010) attributed this effect to the higher protein content in fortified Makhrouta compared to the control. Gumminess and chewiness followed a similar pattern to hardness, increasing with lupine flour substitution. Flores-Silva et al. (2015) explained this trend as being associated with higher cooking loss values. All fortified Makhrouta variants exhibited significantly more chewiness than the control Makhrouta, consistent with Slinkard's (2014) findings. Springiness, however, was not significantly affected by the addition of lupine flour, and no consistent pattern was observed among samples. Additionally, although not significantly different, control Makhrouta showed greater adhesiveness than the lupine flour-containing samples, with no observed pattern in adhesiveness across samples, in line with Slinkard's (2014) results.

The addition of lupine flour to fortified Makhrouta enhances cohesiveness by strengthening the gluten network and improves springiness by modifying the dough's viscoelastic properties. These effects contribute positively to the overall texture and quality of fortified Makhrouta. In summary, the impact of any additional ingredient on Makhrouta texture largely depends on that ingredient's specific physical characteristics.

Cooking quality and water activity

Cooking loss is one of the most important quality indicators for pasta and noodles. Table 9 presents the cooking loss results for Makhrouta prepared with blends of wheat and lupine flours. Cooking loss ranged from 4.49% to 6.00% in samples with varying levels of lupine flour. As the proportion of lupine flour increased, cooking loss also increased. This trend aligns with findings by Jayasena et al. (2010), who reported similar effects when substituting lupine flour in spaghetti and noodles. Wheat flour and semolina can form a gluten matrix when mixed with water, holding the pasta structure together. However, adding non-gluten flours, like lupine flour, reduces gluten strength and weakens the overall structure, leading to more solids leaching into the cooking water. Torres et al. (2021) noted that substituting wheat flour partially or fully affects disintegration during cooking. Nevertheless, according to Foschia et al. (2015), pasta with cooking losses below 8 g/100 g is considered acceptable quality.

Steaming fresh Makhrouta significantly reduced cooking losses in both control and lupine-fortified Makhrouta compared to dry Makhrouta. Cooking losses ranged from 1.10% to 1.20% in samples with 25% lupine flour. In dry Makhrouta, lupine flour addition led to increased cooking losses, a trend also observed by Luo et al. (2015). Nouviaire et al. (2008) explained that heat treatment denatures proteins, stiffening the pasta structure, preventing starch leaching, and thereby reducing cooking loss. Table 9 also illustrates that the volume of dry, cooked Makhrouta increased from 141.66% to 206.25% (for control and Makhrouta with 25% lupine flour, respectively) after 2 minutes of cooking. This observation aligns with findings by Surasani et al. (2019). Kaur et al. (2013) explained that high-protein pasta expands more during cooking, as proteins can absorb more water than starch. The volume of steamed Makhrouta increased significantly, from 112.11% to 165.50% (for control and fresh Makhrouta with 25% lupine flour, respectively), after 2 minutes of steaming. These results are consistent with those reported by Luo et al. (2015).

Lupine flour supplementation led to an increase in the cooked weight of both dry and steamed Makhrouta. For dry Makhrouta, the weight rose from 141.74 g in the control sample to 169.69 g with 25% lupine flour, consistent with findings by Benayad et al. (2021), who attributed this weight gain to increased water absorption. Steamed Makhrouta followed a similar trend, with weight increasing from 100.21 g in the control to 152.25 g with 25% lupine flour. These results align with those of Luo et al. (2015). Garcia-Valle (2021) explained that this weight increase is due to higher water absorption in pastas containing chickpea flour, suggesting that starch granules were highly gelatinized after cooking. This effect could be linked to a weak protein network that facilitated water transport to the starch granule regions, resulting in a weight increase. Water absorption is an indicator of how much water the pasta absorbs under cooking conditions. Results in Table 9 show that lupine flour addition increased water absorption, from 177.39% in the control to 207.87% in Makhrouta with 25% lupine flour. Garcia-Valle et al. (2021) reported that water absorption in pasta formulations is related to the degree of starch gelatinization. Our results reflect a similar trend. The increased water absorption in Makhrouta with lupine flour suggests that starch granules were highly gelatinized after cooking, as noted by Garcia-Valle et al. (2021), which may have formed a weak protein network that promoted water transport to starch granule regions. Additionally, research by Gallegos-Infante et al. (2010) indicated that water absorption depends on the amylose-to-amylopectin ratio and the distribution of amylopectin chain length within the food matrix.

The water absorption values for all steamed Makhrouta samples remained lower than those of dry samples, likely due to the inhibition of water uptake caused by a denser structure, as reported by Luo et al. (2015). Del Nobile and Massera (2000) explained that gelatinized starch on the noodle surface requires more water than ungelatinized starch within, which restricts water movement from the exterior to the interior. However, if the main flour components (protein and starch) show minimal changes at macroscopic and molecular levels during steaming, the water absorption increase might result from the water content gradient acting as a driving force for water migration. Although the steamed Makhrouta had higher water content, the water activity of fortified Makhrouta was significantly higher than that of the control sample (Table 9). This may be due to “stronger” interactions between water and proteins, which could be detected by water activity measurements, consistent with findings by Carini et al. (2012).

Table 9. Cooking Quality and water activity of Dry and Steamed makhrouta

Sample	Cooking Loss (%)	Volume increase (%)	Weight increase (%)	Water Absorption Capacity (%)	Water Activity
Dry Makhrouta					
Control	4.49^{c}±0.03	141.66^{e}±0.05	141.74^{b}±0.06	177.39 ^{d} ±0.12	0.562^{c} ±0.07
5% Lupine Flour	4.81^{bc}±0.11	150.16 ^{de}±0.12	142.17^{b}±0.44	179.70 ^{d} ±0.59	0.566^{c} ±0.04
10% Lupine Flour	5.03^{bc}±0.01	162.50^{cd}±0.05	147.08^{ab}±0.09	186.05 ^{c} ±0.34	0.578^{bc}±0.08
15% Lupine Flour	5.53^{ab}±1.23	173.00^{bc}±0.08	155.90^{ab}±0.07	190.23^{b}±0.56	0.583^{b}±0.06
20% Lupine Flour	5.92^{a}±0.11	182.64^{b}±0.16	160.59^{a}±0.17	201.17^{a}±0.22	0.588^{ab}±0.02
25% Lupine Flour	6.00^{a}±0.45	206.25^{a}±0.15	169.69^{a}±0.03	207.87^{a}±0.54	0.591^{a}±0.05
Steamed Makhrouta					
Control	1.10^{e}±0.05	112.11^{f}±0.07	100.21^{f}±0.17	145.51^{f}±0.17	0.894^{c}±0.04
5% Lupine Flour	1.12^{d}±0.09	119.25^{e}±0.02	113.15^{e}±0.05	152.39^{e}±0.22	0.899^{c}±0.07
10% Lupine Flour	1.13^{c}±0.04	125.17^{d}±0.04	120.70^{d}±0.19	160.39^{d}±0.12	0.902^{bc}±0.06
15% Lupine Flour	1.14^{bc}±0.08	139.34^{c}±0.06	133.00^{c}±0.08	169.17^{c}±0.44	0.904^{b}±0.02
20% Lupine Flour	1.14^{b}±0.06	150.20^{b}±0.03	147.17^{b}±0.64	178.64^{b}±0.16	0.905^{ab}±0.05
25% Lupine Flour	1.20^{a}±0.03	165.50^{a}±0.05	152.25^{a}±0.15	185.23^{a}±0.03	0.910^{a}±0.04

Values are means of three replicates ±SD. Data are presented as means ± SDM (n=3). Numbers in the same column followed by the same letter are not significantly different at 0.05 level.

Sensory evaluation

Sensory evaluation results show that the addition of lupine flour enhanced the color score of Makhrouta, with consumers expressing a preference for the color of lupine-containing samples over the control. Samples with lupine flour exhibited a more appealing color, significantly increasing their sensory score. These findings are consistent with Jayasena et al. (2010), who reported that panelists preferred the yellowish hue imparted by lupine flour over the whitish color of control noodle samples. Incorporating lupine flour into Makhrouta at levels up to 20% did not affect flavor acceptability. However, when the lupine flour content reached 25%, there was a significant decline in average flavor scores. Hall and Johnson (2004) similarly found that flavor differences were noticeable between control pasta samples and those with 28% lupine flour. This flavor variation is likely due to the natural "beany" taste characteristic of lupine flour.

The addition of lupine flour had a noticeable impact on the texture of Makhrouta samples. The average texture score decreased as lupine content exceeded 20%. However, samples with 5%, 10%, 15%, and 20% lupine flour maintained a similar texture to the control (Table 10). These results are in line with those reported by Jayasena et al. (2010) and Hall and Johnson (2004), who noted that lupine flour's inability to form a gluten matrix affects the structural characteristics of noodles (Hall and Johnson, 2004). Regarding taste, lupine flour addition up to 20% did not significantly impact taste scores. However, incorporating lupine flour above this threshold led to a significant decrease in taste scores. This reduction could be due to the "beany" flavor of lupine flour, which negatively affected the overall taste of the product. The inclusion of lupine flour in Makhrouta up to a concentration of 20% did not significantly alter overall acceptability scores, as shown in Table 10. However, when lupine flour exceeded 20%, overall acceptability decreased significantly. These findings align with Jayasena et al. (2010) and Hall and Johnson (2004), who also reported lower acceptability scores for lupine-containing pasta compared to control samples. The reduced overall acceptability may stem from lupine flour's limited capacity to form a strong protein matrix, resulting in a texture perceived as poorer by consumers. Additionally, the beany flavor of lupine flour influenced the taste and flavor of the final products, further contributing to the lower acceptability scores.

Table 10. Sensory evaluation of produced makhrouta

Sample	Color (9)	Flavor (9)	Texture (9)	Taste (9)	Overall Acceptability (9)
			Dry Makhrouta		
Control	$8.50^{d}\pm1.30$	$8.70^{a}\pm1.46$	$8.75^{a}\pm1.17$	$8.70^{a}\pm1.20$	$8.75^{a}\pm1.05$
5% Lupine Flour	$8.50^{d}\pm1.41$	$8.68^{a}\pm1.20$	$8.75^{a}\pm1.12$	$8.70^{a}\pm1.15$	$8.75^{a}\pm1.41$
10% Lupine Flour	$8.55^{cd}\pm1.12$	$8.65^{b}\pm1.05$	$8.75^{a}\pm1.30$	$8.69^{a}\pm1.17$	$8.73^{a}\pm1.12$
15% Lupine Flour	$8.65^{ab}\pm1.20$	$8.70^{a}\pm1.41$	$8.74^{a}\pm1.25$	$8.68^{a}\pm1.46$	$8.73^{a}\pm1.30$
20% Lupine Flour	$8.67^{a}\pm1.46$	$8.70^{a}\pm1.25$	$8.74^{a}\pm1.41$	$8.68^{a}\pm1.12$	$8.73^{a}\pm1.20$
25% Lupine Flour	$8.60^{bc}\pm1.05$	$8.50^{c}\pm1.30$	$8.40^{b}\pm1.20$	$8.30^{b}\pm1.25$	$8.60^{b}\pm1.46$
			Steamed Makhrouta		
Control	$8.69^{a}\pm1.46$	$8.71^{a}\pm1.16$	$8.75^{a}\pm1.17$	$8.73^{a}\pm1.10$	$8.77^{a}\pm1.05$
5% Lupine Flour	$8.68^{a}\pm1.36$	$8.71^{a}\pm1.10$	$8.75^{a}\pm1.12$	$8.73^{a}\pm1.11$	$8.77^{a}\pm1.41$
10% Lupine Flour	$8.65^{ab}\pm1.20$	$8.70^{a}\pm1.05$	$8.75^{a}\pm1.10$	$8.71^{a}\pm1.13$	$8.76^{a}\pm1.12$
15% Lupine Flour	$8.60^{bc}\pm1.05$	$8.70^{a}\pm1.11$	$8.74^{a}\pm1.15$	$8.71^{a}\pm1.16$	$8.76^{a}\pm1.30$
20% Lupine Flour	$8.55^{c}\pm1.12$	$8.63^{b}\pm1.15$	$8.54^{a}\pm1.11$	$8.70^{a}\pm1.14$	$8.75^{a}\pm1.20$
25% Lupine Flour	$8.52^{c}\pm1.41$	$8.60^{b}\pm1.30$	$8.50^{b}\pm1.10$	$8.50^{b}\pm1.15$	$8.50^{b}\pm1.46$

Mean of ten determinations ± standard deviation.
Means with the same letters in the same column are not significant different ($p<0.05$).

Figure 2. Steamed Makhrouta Samples Produced Using Different Concentrations of SLF

T0: 100% Wheat Flour; T1: 5% SLF; T2: 10%SLF; T3: 15% SLF; T4: 20%SLF; T5: 25% SLF

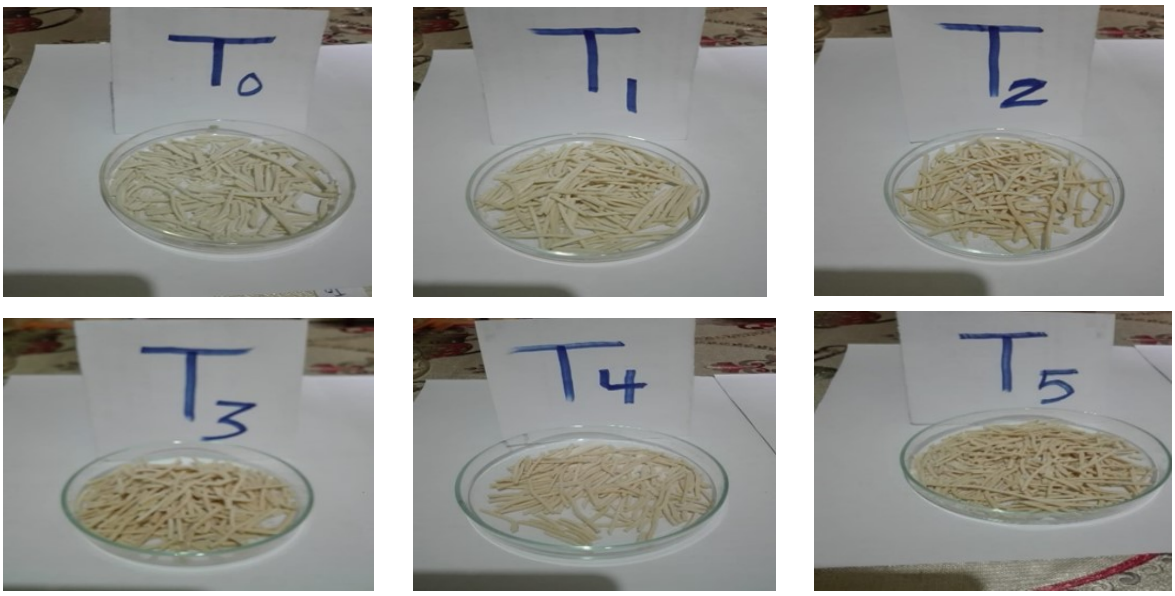


Figure 3. Dry Makhrouta Samples Produced Using Different Concentrations of SLF

T0: 100% Wheat Flour; T1: 5% SLF; T2: 10%SLF; T3: 15% SLF; T4: 20%SLF; T5: 25% SLF

Nutritional Evaluation of Makhrouta

The percentages of the recommended daily allowances (% RDA) provided by 100g of Makhrouta for adults aged 31–50 is presented in Figure 5. The percentage of daily protein requirements increased with the addition of lupine flour, rising from 18.86% to 24.60% for males and from 22.96% to 29.59% for females. For minerals, calcium content in Makhrouta increased slightly from 1.7% to 1.8% for both genders. Iron content also improved, with values rising from 16% to 18% for males and from 7.11% to 8% for females. The zinc content doubled, increasing from 6.82% to 12.73% for males and from 9.38% to 17.5% for females. These results highlight lupine as a valuable source of essential minerals for health.

Karoui et al. (2023) reported that lupine can be considered a functional food, providing not only dietary proteins and fibers but also contributing to essential mineral intake.

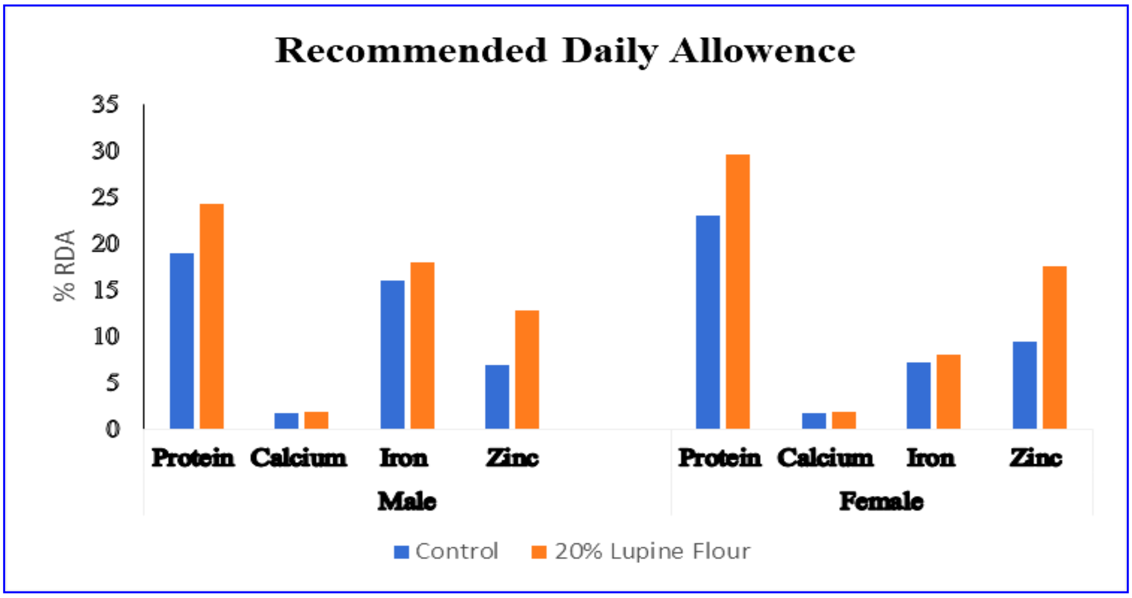


Figure 4. Percent Contribution to RDA for Protein and some Minerals for Adults 31-50 Years

Nutritional Quality of Protein

Figure 5 presents an estimate of essential and non-essential amino acids in Makhrouta prepared with 20% lupine flour compared to the control Makhrouta, alongside the amino acid score based on FAO/WHO/UNU (2007) standards. The amino acid score is essential for evaluating a food's essential amino acid content to ensure it meets protein nutritional requirements. Results indicated that samples with lupine flour had higher levels of key essential amino acids—threonine, valine, methionine, isoleucine, leucine, histidine, and lysine—compared to the control. This increase may be attributed to the high amino acid content in lupine flour, which enriched the amino acid profile of the Makhrouta. These amino acid levels are comparable to those reported by Mahmoud et al. (2012).

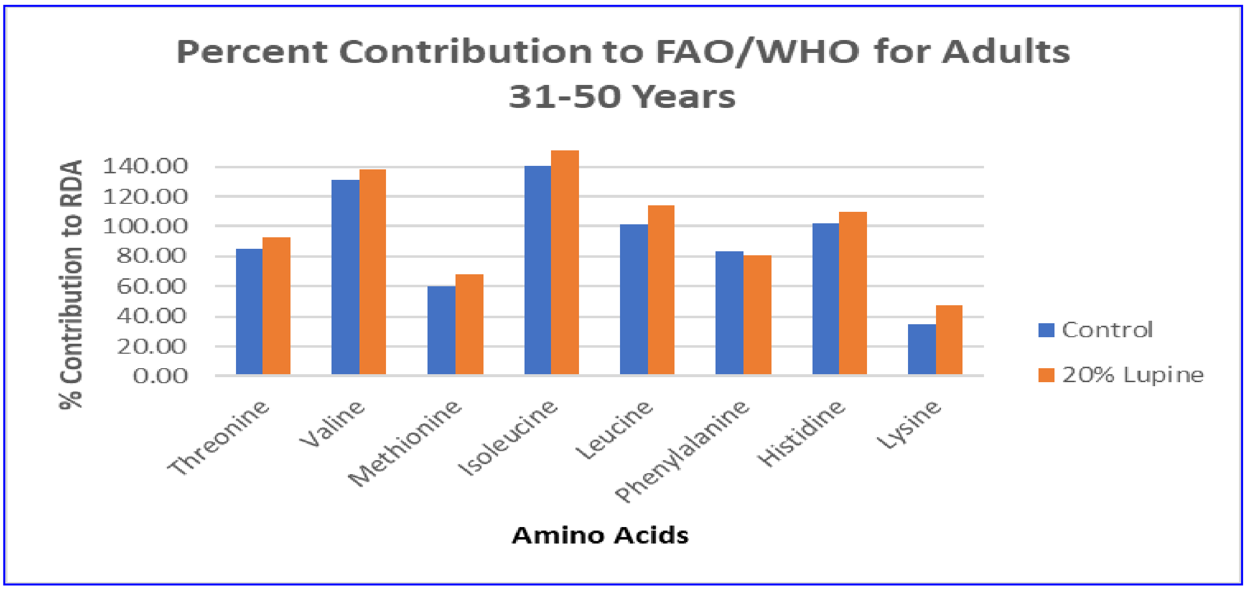


Figure 5. Percent Contribution to FAO/WHO for Amino Acids for Adults 31-50 Years

Economic Evaluation of Produced Makhrouta with 20% SLF

Table 11 provides a financial analysis of Makhrouta production costs, expressed in Egyptian Pounds (LE) per ton, highlighting key economic indicators for assessing profitability. The table outlines the economic metrics for producing one ton of Makhrouta with 20% lupine flour at an industrial scale. This analysis enables a comprehensive evaluation of the cost-effectiveness and potential profitability of incorporating lupine flour into the Makhrouta production process.

Table 11. Economic Indices of Produced Makhrouta (LE/Ton)

Items	Makhrouta with 20% Lupine
Fixed Costs	6,750
Variable Costs (VC)*	21,200
Total Costs	27,950
Total Return (T)	47,785
Net Return	19,835
Return over variable cost	2.25
Added Value (VA)	26,585
Ratio of value add	0.55
Total costs over Total Return	0.59
Return on invested pound	0.71
Profit margin ratio %	41.50

* Including Temporary labor wages, electrical energy consumption and other expenses related to production

The production of Makhrouta with 20% lupine demonstrates strong economic viability. With a total production cost of 27,950 Egyptian Pounds (EGP) per ton and variable costs of 21,200 EGP per ton, the total return of 47,785 EGP per ton yields a significant added value of 26,585 EGP per ton. This indicates efficient transformation of inputs into a higher-value product, with a value-add ratio of 0.55. The positive net return of 19,835 EGP per ton and a profit margin of 41.50% suggest profitability. The return over variable cost of 2.25 indicates reasonable efficiency in utilizing variable inputs.

4. Conclusion

SLF is a rich source of protein and minerals and contains phenolic compounds, which may give it stronger antioxidant properties than wheat flour. The study concluded that enriching wheat flour with SLF increased water absorption and weakened the dough's rheological properties due to the dilution and disturbance of the gluten network. Additionally, it led to increased hardness, cohesiveness, and springiness of Makhrouta as the SLF level increased. The Makhrouta sample enhanced with 5% SLF received the highest consumer acceptance scores for most sensory attributes, even when compared to the control sample. All Makhrouta samples with added SLF at various levels were accepted by the panelists. In conclusion, substituting 15–20% of wheat flour with SLF could be used to produce Makhrouta with higher protein content and antioxidant activity, while maintaining good quality characteristics and consumer acceptability. The Makhrouta enhanced with SLF demonstrated higher antioxidant activity and mineral content than the control. Since the prepared Makhrouta samples are free from artificial colors and preservatives, they are safe, healthy, and nutritious for people of all ages, especially beneficial for those recovering from malnutrition. This study suggests that the product can be manufactured at both a home and commercial scale, providing a cost-effective and nutritious option.

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