

## Impact of Sesame (*Sesamum indicum* L.) Oil Cake on Pasta Physicochemical Properties

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This study was carried out to evaluate the effects of sesame (*Sesamum indicum* L.) oil cake on pasta processing and the functional characteristics of the end product. The pasta produced from wheat flour fortified with 5, 7.5, 10, 12.5, and 15% (w/w) sesame oil cake showed a significant increase in total protein (i.e., ranging from 12.3 and 16.0 g/100 g), lipid (i.e., 3-fold) and crude fiber (i.e., 0.58 to 0.91 g/100 g) contents with the increasing addition of sesame oil cake. Consistograph tests showed that the pressure maximum decreased significantly from 267.2 kPa for the wheat flour dough (control) to 157.6 kPa upon the addition of 15% (w/w) sesame oil cake to wheat flour. Drop-in pressure after 250 and 450 s was lower for the control sample than for those containing 5, 7.5, 10, 12.5, and 15% (w/w) sesame oil cake. The elasticity value for the control dough was 500.1 Pa, and it was reduced to 392.3 Pa with the addition of 15% (w/w) sesame oil cake to wheat flour resulting also in a significant reduction in the extensibility. The pasta from the flour blend with 7.5% (w/w) sesame oil cake exhibited the highest cooking loss, at 5.40 g/100 g. Sensorial evaluation of the flavor and stickiness of pasta produced from the flour blends containing up to 10% (w/w) of sesame oil cake was satisfactory and recommended to open the door for industrial utilization of such valuable and nutritious by-products. Sesame components and gluten network interactions are believed to play a key role in modifying pasta's functional characteristics and require more investigation.

**Keywords:** pasta, sesame flour, rheological properties, cooking gain, cooking loss

### INTRODUCTION

The widespread acceptance of pasta is attributed to its low cost, ease of preparation, sensory attributes, and long shelf life [Kaur *et al.*, 2013; Oliviero & Fogliano, 2016]. "Pasta" usually refers to various shapes and sizes of products made from a basic mixture of wheat (*Triticum durum* or *Triticum aestivum*) endosperm flour and water, cooked as fresh pasta or dried for consumption later on [Bresciani *et al.*, 2022]. The ideal pasta characteristics include its smooth texture, translucence, hardness, brittleness, elasticity, as well as its rich amber color [Sicignano *et al.*, 2015]. The nutrient composition of pasta is similar to that of the semolina used for its production, owing to which it has become recognized as a healthy food

with low lipid content, no cholesterol, and a low glycemic index [Animashaun *et al.*, 2017]. Moreover, the consumption of cereal products enriched with different plant materials that are rich in bioactive compounds has increased due to their positive influence on human health [Dziki, 2021]. As a result, the nutritional value of pasta has been increased by adding substances of an organic type or minerals [Wang *et al.*, 2022].

Various ingredients such as tomatoes, spinach, basil, garlic, and flours or protein isolates from other grains and legumes have been incorporated into pasta formulations to enhance both its appeal and nutritional value [Kaur *et al.*, 2013; Oliviero & Fogliano, 2016; Schmidt & de Oliveira, 2023]. Recently, the integration

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of plant-based products into pasta has been extensively tested, e.g., Padalino *et al.* [2014] examined the impact of adding up to 15% pea flour to spaghetti, finding a significant reduction in starch digestibility and optimal cooking time. Other studies have aimed to increase dietary fiber levels in pasta by adding high-fiber materials from sources other than durum wheat [Wang *et al.*, 2022]. Pasta formulated with dietary fiber has shown a lower glycemic index than the non-enriched product and low responses in diabetics [Cui *et al.*, 2024]. The addition of endoxylanases to pasta dough has been reported to reduce required extrusion pressure, decrease cooking time, lower dough hydration levels, and increase soluble fibers [Ingelbrecht *et al.*, 2001]. The incorporation of smoked trout fillet powder enhanced the nutritional value of pasta, though it also increased cooking loss and decreased water absorption capacity and swelling index [Ozgoren & Yapar, 2019]. The combined use of propylene glycol alginate (0.1%), monoglycerides of fatty acids (0.5%), and gelatinization of mixed flour (buckwheat, corn, rice) has produced dried pasta with superior cooking characteristics and texture [De Arcangelis *et al.*, 2020]. Bustos *et al.* [2019] investigated the effects of pasta enrichment with freeze-dried and air-dried blackberry, raspberry, and black and red currant powders on its antioxidant, sensory, and cooking quality. While the enriched pasta showed increased antioxidant activity, the enrichment negatively affected cooked pasta functionality, as evidenced by an increased swelling index. Enrichment with 50% of  $\beta$ -glucans and dietary fiber improved pasta cooking qualities, including stickiness, bulkiness, firmness, and the amount of total organic matter released in cooking water [Marconi *et al.*, 2000]. Incorporation of barley  $\beta$ -glucans into pasta products resulted in a higher fiber content and lower glycemic responses [Yokoyama *et al.*, 1997].

There is an increased demand for incorporating an inexpensive source of proteins that would justify the search for the potential utilization of protein-rich by-products as food [Schmidt & de Oliveira, 2023]. One such source may be sesame oil cake, a by-product of pressing oil from seeds, with a protein content of up to 40–50 g/100 g [Mostashari & Khaneghah, 2024]. Sesame protein provides essential amino acids necessary for human nutrition, supporting muscle growth, repair, and overall bodily functions. Moreover, sesame oil cake is abundant in dietary fiber, primarily cellulose and hemicellulose, which aid digestion and promote gastrointestinal health by regulating bowel movements and supporting beneficial gut bacteria [Wei *et al.*, 2022]. Beyond proteins and fibers, sesame oil cake also contains notable levels of phenolic compounds, such as lignans [Mostashari & Khaneghah, 2024]. These compounds may help reduce oxidative stress, inflammation, and the risk of development of chronic diseases, such as cardiovascular ailments and certain cancers [Wei *et al.*, 2022]. The presence of antioxidants, like tocopherols, further enhances the nutritional profile of sesame oil cake, contributing to its potential role in promoting overall health and well-being [Melo *et al.*, 2021; Mostashari & Khaneghah, 2024]. Sesame oil cake further holds a notable economic value within the agricultural sector due to its dual role as a source of nutrients for livestock feed and as a potential ingredient in various industrial applications. These industrial

applications not only contribute to the economic sustainability of sesame oil processing but also support environmental initiatives by promoting waste utilization. Therefore, the objective of this study was to evaluate the effects of using sesame oil cake as an additive ingredient on the pasta dough characteristics, processing ability, and stability of the end product.

## MATERIALS AND METHODS

### ■ Materials

Semolina flour was obtained from a local mill (The Modern Flour Mills and Macaroni Factories Co., Amman, Jordan). Dried sesame (*Sesamum indicum* L.) oil cake, a by-product of pressing sesame oil, was purchased from Al-Nahda Pressing Mills Co., Amman, Jordan. Sesame oil cake was produced from the crop of 2022, a product of Sudan.

### ■ Flour blend preparation

Experimental flour blends were prepared by adding powdered sesame oil cake to durum wheat semolina at levels of 5, 7.5, 10, 12.5, and 15% (w/w) and mixing for 5 min using a medium-speed mixer (Pavan, Padova, Italy). The control flour was durum wheat semolina.

### ■ Proximate composition analysis

Moisture, ash, and protein contents of wheat flour, sesame oil cake and pasta products were determined using approved methods of the American Association of Cereal Chemists (AACC); methods no. 44-15.02, 08-01, and 46-13, respectively [AACC, 2000]. Crude lipid content was determined according to the AOAC International method 922.06 [AOAC, 2005], and crude fiber content was determined according to the International Organization for Standardization (ISO) standard method no. 5498.1981 [ISO, 1981], while nitrogen-free extract (NFE) was determined by difference. Analyses were carried out in duplicates.

### ■ Gluten content and gluten index determination

Gluten content and gluten index of flours were evaluated according to the AACC method 38-12.02 [AACC, 2000]. A 10.0±0.01 g sample was weighed and placed into the Glutomatic wash chamber (Glutomatic® 2200, Perten Instruments, Stockholm, Sweden) equipped with an 88- $\mu$ m polyester sieve. Then, 4.8 mL of a 2% brine solution was added and mixed to form dough within 20 s. After the mixing period, the dough was washed for 5 min with water. To measure the gluten index, the wet gluten piece was centrifuged for 1 min at 2,415 $\times$ g (centrifuge 2015, Perten Instruments). The fraction that passed through the sieve was scraped off and weighed, while the fraction remaining on the inside of the sieve was collected and added to the balance to obtain the total wet gluten content (g/100 g). For estimating dry gluten content (g/100 g), the total wet gluten piece was dried for 4 min at 150°C using a Glutork 2020 dryer (Perten Instruments). The gluten index (GI) was calculated using formula (1):

$$GI (\%) = \frac{\text{Wet gluten remained on sieve (g)}}{\text{Total wet gluten (g)}} \times 100 \quad (1)$$

Results of five replicates were recorded for statistical analyses and means were calculated.

#### ■ **Falling number test**

Flours were analyzed for falling numbers using the AACC method 56-81B [AACC, 2000]. A 7-g sample was combined with 25 mL of distilled water in a glass tube with a stirrer and shaken to form a slurry using Falling Number 1400 apparatus (Perten Instruments). The time (s) it took for the stirrer to fall through the paste was recorded as the falling number value. The measurement for each flour was performed in five repetitions.

#### ■ **Consistograph test**

The consistograph test was conducted following the AACC method no. 54-50 [AACC, 2000]. The test was performed using the Chopin Consistograph (Tripette et Renaud, Asnières-sur-Seine, France) at both constant hydration (CH) and adapted hydration (AH) settings. The parameters determined were flour water absorption capacity (WA, %), hydration at 15% water (%), maximum pressure exerted by the dough against the mixer bowl lining (kPa), time needed to reach pressure maximum (s), tolerance time (s), and drop-in pressure at 250 s (D250, kPa) and 450 s (D450, kPa). The test was performed in five replicates.

#### ■ **Alveograph test**

The alveograph test was conducted in accordance with the AACC-approved method no. 54-30A [AACC, 2000]. In brief, 250 g of wheat flour or flour blends were weighed, and then water (*i.e.*, 60% of the flour weight) was added. After mixing the flour and water to form dough in a mechanical mixer for 8 min, the dough was allowed to rest for 20 min. After resting, the dough was divided into 150-g portions and was then shaped into smooth balls, and then flattened into a circular disc with a uniform thickness using a rolling pin. The shaped dough discs were then placed into a temperature-controlled chamber at 25°C, for an additional resting period of 30 min. After conditioning, the dough discs were placed onto the alveograph NG-97 (Tripette et Renaud) to run the test according to the manufacturer's instructions. The alveograph test involved inflating the dough discs into bubbles, measuring and recording several parameters including dough strength (P; Pa), extensibility (L, mm), work (W, J), swelling index (G, the square root of the volume of air required to rupture the dough), configuration ratio (P/L), and elasticity index (Ie, %). The results of five tests were recorded for statistical analysis.

#### ■ **Pasta production**

Pasta production was carried out in The Modern Flour Mills and Macaroni Factories Co., Amman, Jordan, using a pilot processing line for pasta (Pavan). Flours were mixed in the mixer of the pasta machine, and the water was added through an automatic sprayer to reach a final moisture content of  $31 \pm 0.5$  g/100 g. The mixing time varied from 10 to 12 min. The premix was then subjected to an extruder pressure of 11 MPa under a temperature of 45–50°C, and the dough sheet was formed with a moisture

content of 29.5–30 g/100 g. Then it was passed through parallel sheeting rolls to obtain a stable thickness of 1.5 mm. The sheeted dough formed was cut by rotary cutting disks to reach a final length of 16 to 17 cm and a width of 6 to 7 cm. As a result, rectangular-shaped pasta dough was obtained.

The rectangular-shaped pasta dough was arranged on a mesh mounted on wooden frames, and the frame stacks were then pushed into a two-stage pre-drier. In the first stage of pre-drying, the air temperature at the entrance of the pre-drier was 50°C and increased gradually until it reached 56–59°C at the exit side. The relative humidity inside the pre-drier was in the range of 55–60%. The pasta's moisture after the first stage was lowered from 29.5 to 22.0 g/100 g in 50 min drying time. During the second stage, the air temperature was increased to reach 70°C, while the relative humidity reached 75%. The moisture content of the pasta after the second stage of drying decreased from 22.0 to 18 g/100 g in 10 min time.

During the final drying stage, pasta sheets were exposed to three drying stages, which resulted in the production of pasta with a final moisture content below 12.5 g/100 g. After drying, the pasta product was cooled prior to the packaging process. The temperature of the cooling cabinet was around 30°C, the relative humidity was about 50%, and the total resting time was around 360 min. Identical pasta production protocol was replicated four times for each flour blend.

#### ■ **Pasta cooking gain, cooking loss, and cooking time evaluation**

To evaluate cooking gain, 300 mL of distilled water were poured into and heated in a stainless-steel container covered with a cap circulated by cold water, and when the water started to boil, a 10-g sample of pasta was dropped in the boiling water to be cooked for different periods (10, 13 and 20 min). Cooking gain was evaluated by weighing pasta before and after cooking and expressed as an increase in cooked pasta weight (g/100 g) [Hummel, 1966].

To determine the amounts of solid substances lost in water after cooking (cooking loss), 30 mL of cooking water was placed in a small dry-weighed beaker and completely evaporated. After complete evaporation, the beaker was cooled in a desiccator and weighed to calculate the percentage of solid substances lost after cooking and expressed as g of matter loss *per* 100 g of dry pasta [Hummel, 1966].

Cooking time was measured by taking a small piece of pasta after being cooked in distilled water and crushed between two glass plates until the center white core could no longer be seen, and that indicated the optimum cooking time [Bergman *et al.*, 1994]. Samples were taken after cooking for 10, 13, and 20 minutes and tested for their doneness states.

#### ■ **Pasta storage and acidity measurement**

After processing, pasta samples (100 g) were packed in plastic bags, and stored inside an incubator (Memmert, Model No. INB, E212.0367, Rittersbacher, Schwabach, Germany) set at 25°C and 50% relative humidity. Samples were analyzed for acidity

after zero, three, and six months. Acidity was measured according to the procedure described in Duszkiwicz-Reinhard *et al.* [1988] in which 10 g of ground pasta were weighed into a 250-mL beaker and mixed with 100 mL of 67% (v/v) aqueous ethanol. The extracts were titrated after filtration with 0.1 M NaOH, with phenolphthalein as an indicator.

### ■ Sensory evaluation

Five sensory experts of pasta quality from the Modern Flour Mills and Macaroni Factories Company in Jordan evaluated the quality of pasta products. Samples for sensory evaluation (pasta immediately after production and after 3 and 6 months of storage) were cooked to optimum cooking time in distilled water, drained, and served warm to sensory panelists. A score sheet was developed for judging the pasta samples according to their color, flavor, stickiness, and overall acceptability by using a hedonic scale test from 1 to 7, with 7 being liked very much and 1 being disliked very much [Duszkiwicz-Reinhard *et al.*, 1988].

### ■ Statistical analysis

Data were analyzed using a SAS Institute [2003] software at the University of Jordan / Computer Center. Analysis of variance (ANOVA) of the different flours/doughs/pasta was performed using complete randomized design (CRD) using a *t*-test in which the rheological properties and chemical characteristics were used as a source of variation. The means of replicates from each variable were compared at a significance level of 5% using the least significant difference (LSD) test.

## RESULTS AND DISCUSSION

### ■ Proximate composition of raw materials and end products

The proximate composition of semolina, sesame oil cake, and pasta produced from different formulations of these components is presented in **Table 1**. The ash content of semolina and sesame oil cake was 0.85 and 5.54 g/100 g, respectively. The pasta produced from flour blends containing different levels of sesame oil cake flour showed a significantly ( $p < 0.05$ ) higher ash content compared to the control pasta, with a linear increase

as the rate of sesame oil cake addition increased. Pasta from the flour blends with 5, 7.5, and 10% (w/w) of sesame oil cake met the standard (no. 67) of the Jordanian Institute for Standards and Metrology [1996] for ash content in dry pasta (*i.e.*, less than 1.20%), whereas those with 12.5% and 15% (w/w) of sesame oil cake addition had the ash content greater than 1.20%.

Sesame oil cake addition to wheat flour resulted in an insignificant ( $p \geq 0.05$ ) effect on pasta moisture content (**Table 1**). Moisture contents of semolina and sesame oil cake were 13.5 and 7.5 g/100 g, respectively. **Table 1** also presents the protein content of durum wheat semolina, sesame oil cake, and pasta samples. Upon the addition of sesame oil cake flour to semolina, the protein content of the pasta products increased significantly ( $p < 0.05$ ) from 11.8 g/100 g for the control sample to 16.0 g/100 g for the pasta from the flour blend with 15% (w/w) of sesame oil cake, which corresponded to a 36% increase in protein content. A 17% increase in the protein content of pasta samples was accomplished with the addition of 10% (w/w) sesame oil cake flour. This was expected since sesame oil cake contained over 4.5 times more protein than semolina (54.2 and 11.9 g/100 g, respectively), which was reflected in the final product composition. A similar trend was obtained by Padalino *et al.* [2014], who reported that the fortification of wheat flour with pea flour considerably increased the protein, ash, and dietary fiber contents of the spaghetti samples when compared to the control sample.

In evaluating the nutritional benefits, one should consider the improvement in protein quantity as well as quality. Although it is no longer believed that plant proteins must be complemented at every meal, it is important to consume a wide variety of plant proteins to provide the body with an adequate supply of the limiting amino acids. Traditional protein combinations from various sources, such as sesame, soybeans, and wheat, can complement requirements for essential amino acids [Animashaun *et al.*, 2017; El-Adawy, 1997].

The lipid contents of semolina and sesame oil cake were 1.19 and 18.31 g/100 g, respectively (**Table 1**). The addition of sesame oil cake to semolina showed a significant ( $p < 0.05$ ) increase in the lipid content of pasta samples from 1.13 g/100 g for the control to 3.21 g/100 g for the pasta produced from

**Table 1.** Proximate composition of semolina wheat flour (S), sesame oil cake (SOC), and pasta from S (control) and blends of S with SOC.

Raw material/product	Moisture (g/100 g)	Protein (g/100 g)	Ash (g/100 g)	Lipid (g/100 g)	Crude fiber (g/100 g)	NFE (g/100 g)
Semolina	13.5±0.4	11.9±0.2	0.85±0.05	1.19±0.07	0.50±0.02	72.1±0.4
Sesame oil cake	7.5±0.1	54.2±0.3	5.54±0.14	18.31±0.44	2.00±0.04	12.4±0.1
Control (100% S)	8.9±0.1 <sup>a</sup>	11.8±0.1 <sup>f</sup>	0.83±0.06 <sup>f</sup>	1.13±0.05 <sup>f</sup>	0.46±0.06 <sup>f</sup>	76.9±0.5 <sup>a</sup>
95% S + 5% SOC	8.9±0.2 <sup>a</sup>	12.3±0.1 <sup>e</sup>	1.04±0.06 <sup>e</sup>	1.36±0.04 <sup>e</sup>	0.58±0.04 <sup>e</sup>	75.8±0.4 <sup>b</sup>
92.5% S + 7.5% SOC	8.9±0.0 <sup>a</sup>	13.1±0.2 <sup>d</sup>	1.15±0.06 <sup>d</sup>	1.70±0.06 <sup>d</sup>	0.65±0.02 <sup>d</sup>	74.5±0.1 <sup>c</sup>
90% S + 10% SOC	8.9±0.2 <sup>a</sup>	13.8±0.1 <sup>c</sup>	1.21±0.05 <sup>c</sup>	2.13±0.06 <sup>c</sup>	0.73±0.02 <sup>c</sup>	73.3±0.4 <sup>d</sup>
87.5% S + 12.5% SOC	8.9±0.1 <sup>a</sup>	14.6±0.4 <sup>b</sup>	1.30±0.04 <sup>b</sup>	2.63±0.04 <sup>b</sup>	0.80±0.04 <sup>b</sup>	71.8±0.1 <sup>e</sup>
85% S + 15% SOC	8.9±0.1 <sup>a</sup>	16.0±0.2 <sup>a</sup>	1.39±0.02 <sup>a</sup>	3.21±0.06 <sup>a</sup>	0.91±0.02 <sup>a</sup>	69.6±0.2 <sup>f</sup>

All results are shown as mean ± standard deviation. Means in the same column (for pasta) with different letters are significantly different ( $p < 0.05$ ). NFE, nitrogen-free extract.

the flour blend with 15% (*w/w*) of sesame oil cake. This result was expected since the pasta has been enriched with lipids due to their high content in sesame oil cake, and this enrichment increased the lipid content as well as the nutritional value of the product.

The crude fiber content of semolina was 0.50 g/100 g and that of sesame oil cake was 2.00 g/100 g (Table 1). The increasing addition of sesame oil cake to semolina resulted in a gradual, significant increase ( $p < 0.05$ ) in the crude fiber content of the pasta samples, from 0.46 g/100 g for the control to 0.91 g/100 g for the pasta produced from the flour blend with 15% (*w/w*) of sesame oil cake. Yaseen *et al.* [2021] reported that the dietary fiber content of sesame seed is about four folds of its crude fiber. Therefore, the dietary fiber contents of the pasta from the flour blends with 10 and 15% (*w/w*) sesame oil cake are expected to be about 2.3 and 7 g/100 g, respectively, which represents an increase of 53% and 80% compared to that of the basic durum pasta products.

The nitrogen-free extract was 12.4 g/100 g for sesame oil cake and 72.0 g/100 g for durum wheat semolina (Table 1). As a result, adding sesame oil cake flour with its low nitrogen-free extract to semolina reduced the total nitrogen-free extract of the resulting pasta products from 76.9 g/100 g in the control to 69.6 g/100 g for the pasta samples from the blend with 15% (*w/w*) of sesame oil cake flour.

#### ■ Quality parameters of wheat flour and flour blends

The wet gluten and dry gluten contents of flours used in pasta production are presented in Table 2. The increasing addition of sesame oil cake to semolina resulted in a significant decrease ( $p < 0.05$ ) in the wet gluten content of the blends that ranged from 28.8 g/100 g (semolina flour) to 22.7 g/100 g (flour with 15% (*w/w*) of sesame oil cake). These results were directly related to the dilution effect of gluten content due to the fact that sesame oil cake does not contain gluten. This observation agrees with that of El-Adawy [1997], who added different sesame products (*i.e.*, sesame meal and sesame protein isolates) to the pan bread formulation. In fact, pasta made with a high legume flour content (>30%) is often characterized by poor cooking properties, such as high cooking loss, low swelling index, and cooking time, due to the dilution and weakening of the gluten matrix [Romano *et al.*, 2021].

The dry gluten content of semolina was 9.5 g/100 g, and the significantly ( $p < 0.05$ ) lower values were found for the flour blends with an increasing proportion of sesame oil cake (Table 2). This reduction was parallel to the level of wet gluten content and indicates that the reduction of wet gluten is a true result of gluten drop rather than retardation of water absorption during gluten development.

Semolina had a gluten index of 89.9% (Table 2). The addition of 5% (*w/w*) of sesame oil cake to semolina significantly increased ( $p < 0.05$ ) the gluten index of the flour. However, this high value decreased significantly ( $p < 0.05$ ) for the flour blend containing 7.5% (*w/w*) of sesame oil cake and continued to decrease ( $p < 0.05$ ) for the flour with an increasing proportion of sesame oil cake. As a result, the gluten index of only the blend with 15% (*w/w*) of sesame oil cake was lower ( $p < 0.05$ ) than that of the control. This behavior may be due to a concentration-dependent interaction between sesame oil cake compounds and the gluten network. Gluten strength is widely recognized as an important factor for superior pasta cooking quality, though the relationship between gluten strength and pasta cooking quality remains complex [Matsuo, 1993]. Moayedi *et al.* [2021] found that the quantity of proteins, including gliadins, albumins, and globulins, as well as complex proteins, significantly influenced the variation in cooked firmness of fresh pasta.

The falling number values for semolina and semolina with 5, 7.5, 10, 12.5, and 15% (*w/w*) of sesame oil cake flour were above 400 s (Table 2), indicating that the addition of sesame oil cake to semolina samples at any level tested did not cause any significant difference ( $p \geq 0.05$ ) in the falling number values. This result was expected since the sesame oil cake was processed from highly roasted sesame seeds in which all enzymes had been inactivated.

#### ■ Rheological properties of pasta doughs

##### ■ Consistograph test parameters

Data in Table 3 indicates that the maximum pressure decreased significantly ( $p < 0.05$ ) from 267.2 kPa for the control sample to 157.6 kPa for dough prepared from the flour blend with 15% (*w/w*) of sesame oil cake. No significant difference ( $p \geq 0.05$ ) was observed only between dough from the flours containing 12.5% and 15% (*w/w*) of sesame oil cake. The maximum pressure decrease was attributed to the dilution effect of gluten through

**Table 2.** Wet gluten and dry gluten contents, gluten index (GI), and falling number (FN) of semolina wheat flour (S) and its blends with sesame oil cake (SOC).

Flour	Wet gluten (g/100 g)	Dry gluten (g/100 g)	GI (%)	FN (s)
Semolina	28.9±0.21 <sup>a</sup>	9.5±0.0 <sup>a</sup>	89.9±0.1 <sup>e</sup>	>400±12.5 <sup>a</sup>
95% S + 5% SOC	25.6±0.1 <sup>b</sup>	8.8±0.0 <sup>b</sup>	95.8±0.2 <sup>a</sup>	>400±8.5 <sup>a</sup>
92.5% S + 7.5% SOC	25.0±0.1 <sup>c</sup>	8.4±0.0 <sup>c</sup>	94.4±0.1 <sup>b</sup>	>400±6.6 <sup>a</sup>
90% S + 10% SOC	23.8±0.2 <sup>d</sup>	8.1±0.0 <sup>d</sup>	93.5±0.2 <sup>c</sup>	>400±6.5 <sup>a</sup>
87.5% S + 12.5% SOC	23.0±0.1 <sup>e</sup>	7.9±0.0 <sup>e</sup>	91.1±0.1 <sup>d</sup>	>400±6.6 <sup>a</sup>
85% S + 15% SOC	22.7±0.2 <sup>f</sup>	7.8±0.1 <sup>f</sup>	87.8±0.2 <sup>f</sup>	>400±9.8 <sup>a</sup>

All results are shown as mean ± standard deviation. Means in the same column with different letters are significantly different ( $p < 0.05$ ).



**Table 3.** Consistograph test characteristics of doughs made from semolina wheat flour (S) and its blends with sesame oil cake (SOC).

Dough	Constant hydration			Adapted hydration			
	PrMax (kPa)	WA (%)	HYDHA (%)	TPrMax (s)	Tol (s)	D250 (kPa)	D450 (kPa)
Semolina	267.2±0.8 <sup>a</sup>	55.8±2.4 <sup>a</sup>	53.3±2.3 <sup>a</sup>	94.0±1.0 <sup>a</sup>	122±2 <sup>a</sup>	78.7±0.6 <sup>d</sup>	87.5±0.8 <sup>d</sup>
95% S + 5% SOC	219.7±0.6 <sup>b</sup>	52.7±2.2 <sup>b</sup>	51.2±1.4 <sup>b</sup>	92.0±1.1 <sup>a</sup>	120±2 <sup>ab</sup>	82.5±0.6 <sup>c</sup>	104.5±0.5 <sup>c</sup>
92.5% S + 7.5% SOC	169.8±0.9 <sup>c</sup>	51.4±1.2 <sup>b</sup>	49.4±0.5 <sup>c</sup>	90.0±2.2 <sup>a</sup>	114±2 <sup>ab</sup>	88.2±0.6 <sup>b</sup>	109.8±0.9 <sup>b</sup>
90% S + 10% SOC	165.9±0.7 <sup>d</sup>	51.3±0.9 <sup>b</sup>	49.3±1.5 <sup>c</sup>	92.0±1.4 <sup>a</sup>	113±2 <sup>ab</sup>	89.1±0.6 <sup>b</sup>	110.4±0.9 <sup>b</sup>
87.5% S + 12.5% SOC	159.6±0.9 <sup>e</sup>	51.0±1.2 <sup>b</sup>	48.5±2.2 <sup>c</sup>	90.0±2.3 <sup>a</sup>	112±1 <sup>ab</sup>	93.0±0.6 <sup>a</sup>	119.6±0.6 <sup>a</sup>
85% S + 15% SOC	157.6±0.8 <sup>e</sup>	50.9±2.1 <sup>b</sup>	48.4±1.2 <sup>c</sup>	88.0±1.0 <sup>a</sup>	106±2 <sup>b</sup>	88.6±0.6 <sup>b</sup>	115.4±0.5 <sup>a</sup>

All results are shown as mean ± standard deviation. Means in the same column with different letters are significantly different ( $p < 0.05$ ). PrMax, pressure maximum; WA, water absorption; HYDHA, hydration at 15% water; TPrMax, time needed to reach pressure maximum; Tol, tolerance time; D250 and D450, drop-in pressure at 250 and 450 s, respectively.

sesame oil cake, which causes weakening of the dough. Furthermore, it was expected that the increase in lipid content due to the addition of sesame oil cake may have caused dough softening through the lubrication and shortening action of sesame oil. Similar results were reported by El-Adawy [1997], who studied the farinograph characteristics of wheat flour bread supplemented with sesame proteins.

Generally, the addition of sesame oil cake flour resulted in a reduction in the water absorption values (Table 3). The water absorption decreased from 55.8% for the control dough to 50.9–52.7% for the samples from the flour blends. This reduction in water absorption was attributed to the high lipid content of the sesame oil cake flour. The higher lipid content made that less moisture was required than in semolina to achieve a similar dough consistency. Despite the different proportions of sesame oil cake in the flour blends the differences in water absorption between doughs were not significant ( $p \geq 0.05$ ). This demonstrates that the addition of up to 5% ( $w/w$ ) of sesame oil cake flour resulted in a weakening of the dough gluten matrix, whereas further additions were of minor effect. Padalino *et al.* [2014] concluded that the addition of pea flour considerably increased the cooking loss of spaghetti samples and caused a significant decrease in the swelling index and water absorption when compared to the control. On the other hand, Raungrusmee *et al.* [2022] reported that water absorption was considered an indicator of gluten network extension and gluten matrix maturation during dough formation.

The hydration at 15% water decreased from 53.3% for the control to 48.4% for the dough from the flour blend with 15% ( $w/w$ ) of sesame oil cake, but no significant differences ( $p \geq 0.05$ ) were detected between doughs with sesame oil cake flour content above 7.5% ( $w/w$ ) (Table 3).

The time needed to reach maximal pressure ranged from 88.0 to 94.0 s and did not differ significantly ( $p \geq 0.05$ ) among samples (Table 3).

Tolerance is the time during which the dough consistency stands within the pressure maximum and pressure maximum 20% range [Zheng *et al.*, 2000]. Data in Table 3 indicates that the tolerance time value for the control dough was 122 s and that

no significant differences ( $p > 0.05$ ) were found through the increasing addition of sesame oil cake except for the dough from the blend with 15% ( $w/w$ ) of sesame oil cake, in which a significant decrease ( $p < 0.05$ ) in the tolerance time was observed when compared to the control. Table 3 also presents the drop-in pressure from pressure maximum after both 250 and 450 s for the control sample of 78.7 and 87.5 kPa, respectively. A significant ( $p < 0.05$ ) decrease of drop-in pressure was presented with the addition of 5, 7.5, 10, 12.5, and 15% of sesame oil cake. The results agree with a study by El-Adawy [1997], who reported lower stability time with the addition of sesame products to wheat flour.

Sabanis *et al.* [2009] demonstrated that substituting wheat flour with gluten-free flours adversely affected the protein matrix during pasta processing, resulting in an unacceptable product quality. The texture of pasta made from wheat flours is directly related to the protein structure, particularly gluten proteins, due to their unique viscoelastic properties [Larrosa *et al.*, 2016]. Additionally, the protein in sesame oil cake, which mainly consists of globulins [Kinsella & Mohite, 1985], is believed to weakly contribute to the texture of the wheat gluten network. The presence of fiber particles in sesame oil cake flour may also disrupt the protein-starch network stability, leading to lower firmness. Protein-starch interactions significantly impact the formation and strength of the protein gel matrix during dough network formation [Saleh, 2017]. Moreover, sesame seed proteins contain a high percentage of sulfhydryl groups that soften the dough structure [El-Adawy, 1997]. Taking the above into account, the results of the consistograph test in our study were attributed to the weakening effect resulting from higher levels of sesame oil cake addition. The results were in line with Filipović *et al.* [2017] who concluded that the incorporation of sesame in the flour formulation of pasta resulted in a reduction of the speed of starch gelation, which led to a reduction in starch network stability.

#### ■ Alveograph test parameters

The elasticity values (P) determined for the doughs made from wheat flour and flour blends with sesame oil cake ranged from 392.3 to 500.1 Pa (Table 4). A significant ( $p < 0.05$ ) difference was only found between the control sample and dough from

**Table 4.** Alveograph test characteristics of doughs made from semolina wheat flour (S) and its blends with sesame oil cake (SOC).

Dough	P (Pa)	L (mm)	G	W (10 <sup>-4</sup> J)	P/L	le (%)
Semolina	500.1±19.6 <sup>a</sup>	81±2 <sup>a</sup>	20.0±1.1 <sup>a</sup>	102.0±1.8 <sup>a</sup>	0.63±0.2 <sup>b</sup>	32.9±1.1 <sup>a</sup>
95% S + 5% SOC	490.3±9.8 <sup>a</sup>	64±1 <sup>b</sup>	17.8±1.5 <sup>ab</sup>	83.0±1.6 <sup>b</sup>	0.78±0.0 <sup>a</sup>	30.0±1.2 <sup>b</sup>
92.5% S + 7.5% SOC	460.9±19.6 <sup>ab</sup>	60±2 <sup>b</sup>	17.3±1.2 <sup>ab</sup>	73.0±1.4 <sup>bc</sup>	0.78±0.1 <sup>a</sup>	27.4±1.7 <sup>bc</sup>
90% S + 10% SOC	441.3±19.6 <sup>ab</sup>	57±2 <sup>b</sup>	16.9±1.1 <sup>b</sup>	72.0±1.4 <sup>c</sup>	0.79±0.1 <sup>a</sup>	26.7±1.1 <sup>c</sup>
87.5% S + 12.5% SOC	421.7±9.8 <sup>ab</sup>	55±1 <sup>b</sup>	16.0±1.5 <sup>b</sup>	70.0±1.8 <sup>c</sup>	0.78±0.0 <sup>a</sup>	26.0±1.2 <sup>c</sup>
85% S + 15% SOC	392.3±19.6 <sup>b</sup>	53±1 <sup>b</sup>	16.1±1.5 <sup>b</sup>	68.6±1.1 <sup>c</sup>	0.75±0.0 <sup>ab</sup>	25.6±1.1 <sup>c</sup>

All results are shown as mean ± standard deviation. Means in the same column with different letters are significantly different ( $p < 0.05$ ). P, elasticity; L, extensibility; G, swelling index; W, work; P/L, configuration ratio; le, elasticity index.

the blend with the highest proportion of sesame oil cake. This addition of sesame oil cake resulted in a decrease in the elasticity value. This may reflect an interaction process between the sesame components and the gluten network that also resulted in the dilution effect of gluten. In this regard, Barak *et al.* [2013] reported a positive correlation between P values obtained in the alveograph test and the glutenin content of the dough.

The extensibility (L) of all doughs containing sesame oil cake was significantly lower ( $p < 0.05$ ) when compared to the control dough (Table 4). The L values obtained after adding sesame oil cake flour up to 15% ( $w/w$ ) were in the range of 53–64 mm, which is considered acceptable according to the CHOPIN protocol for durum wheat alveograph [Chopin Protocol, 2000].

The work (W) values, which represent the force necessary for the deformation of the dough, showed that the strength of the dough decreased significantly ( $p < 0.05$ ) with the increasing addition of sesame oil cake to the blend (Table 4). These results confirm the weakening effect due to the addition of sesame oil cake flour to durum semolina, and agree with a study by El-Adawy [1997], who reported that the addition of sesame cake weakened the bread formulation.

The configuration ratio represents the ratio of elasticity (P) of the dough to its extensibility (L). It was 0.63 for the control dough and increased significantly ( $p < 0.05$ ) in doughs with sesame oil cake (Table 4). The configuration ratio summarizes

the viscoelastic behavior of the dough, and the results also confirm the weakening effect due to sesame oil cake addition to wheat flour. A configuration ratio between 0.5 and 1.0 was reported to provide an acceptable balance of extensibility [Tribune, 1999].

#### ■ The effect of sesame oil cake on pasta cooking quality

At the optimum cooking time (10 min), the control sample showed a cooking loss value of 4.5 g/100 g dry pasta, which was significantly ( $p < 0.05$ ) lower than that of pasta from the blend with 7.5% ( $w/w$ ) of sesame oil cake, but not significantly ( $p \geq 0.05$ ) different than those of the other samples containing sesame oil cake flour (Table 5). However, the highest cooking loss, recorded for the pasta made from 7.5% ( $w/w$ ) sesame oil cake blend (5.40 g/100 g dry pasta), did not exceed 0.9% of the result obtained for the control sample, which indicates that the pasta samples were in their acceptable cooking loss quality range. A cooking loss of 12 g/100 g or less was considered acceptable and indicative of good quality pasta [Fu, 2008]. Almost similar cooking loss trend was obtained for the pasta samples cooked for 13 and 20 min (Table 5). Again, the highest cooking loss values were determined for the pasta samples made with 7.5% ( $w/w$ ) of sesame oil cake. The increase in cooking loss values of spaghetti fortified with edible legumes compared to spaghetti made from 100% semolina has also been reported by Filipović *et al.* [2017].

**Table 5.** Cooking gain and cooking loss of pasta made from semolina wheat flour (control) and blends of semolina (S) with sesame oil cake (SOC) and cooked for different times.

Pasta	Cooking gain (g/100 g)			Cooking loss (g/100 g dry pasta)		
	10 min	13 min	20 min	10 min	13 min	20 min
Control (100% S)	198.0±0.1 <sup>d</sup>	208.3±1.4 <sup>c</sup>	250.0±1.1 <sup>c</sup>	4.50±0.1 <sup>b</sup>	5.0±0.3 <sup>c</sup>	8.50±0.2 <sup>c</sup>
95% S + 5% SOC	214.6±0.2 <sup>a</sup>	221.0±0.4 <sup>a</sup>	263.4±1.4 <sup>b</sup>	4.80±0.6 <sup>b</sup>	5.8±0.1 <sup>ab</sup>	9.50±0.2 <sup>b</sup>
92.5% S + 7.5% SOC	212.7±0.4 <sup>a</sup>	224.3±1.1 <sup>a</sup>	271.2±1.7 <sup>a</sup>	5.40±0.4 <sup>a</sup>	5.9±0.1 <sup>a</sup>	9.60±0.7 <sup>a</sup>
90% S + 10% SOC	202.1±0.3 <sup>b</sup>	215.6±0.9 <sup>b</sup>	262.3±1.1 <sup>b</sup>	4.90±1.1 <sup>b</sup>	5.5±0.2 <sup>bc</sup>	9.00±0.1 <sup>bc</sup>
87.5% S + 12.5% SOC	200.9±0.1 <sup>c</sup>	215.0±0.3 <sup>b</sup>	252.2±0.6 <sup>c</sup>	4.80±0.8 <sup>b</sup>	5.4±0.0 <sup>c</sup>	8.80±0.6 <sup>bc</sup>
85% S + 15% SOC	200.0±0.8 <sup>cd</sup>	211.6±1.1 <sup>c</sup>	251.5±1.0 <sup>c</sup>	4.70±0.1 <sup>b</sup>	5.3±0.3 <sup>c</sup>	8.60±0.2 <sup>bc</sup>

All results are shown as mean ± standard deviation. Means in the same column with different letters are significantly different ( $p < 0.05$ ). Means in the same row (separately for cooking gain and cooking loss) were significantly different ( $p < 0.05$ ), and respective letters indicating significant differences were not shown.

The pasta cooking gain data is presented in **Table 5**. The cooking gain of pasta samples with sesame oil cake levels of 5, 7.5, and 10% (w/w) was significantly higher ( $p < 0.05$ ) compared to that of the control. The pasta produced from the flour blend with 7.5% (w/w) of sesame oil cake showed the greatest cooking gain when cooked for 10, 13, and 20 min. The control sample had a cooking gain of 198.0 g/100 g while the pasta made from semolina and 15% (w/w) of sesame oil cake blends had a cooking gain of 200.0 g/100 g at optimal cooking time (10 min). However, increasing the cooking duration for 3 or 10 min over the optimum (13 or 20 min) resulted in significant increases in the cooking gain values ( $p < 0.05$ ) for all pasta samples, which was attributed to giving starch granules an extra time to absorb more water. Results in **Table 5** also show a significant decrease ( $p < 0.05$ ) in the cooking gain when the sesame oil cake proportion in flour blend was increased from 7.5% to 10% (w/w), indicating the optimal level of sesame oil cake affects the starch swelling process and the cooking gain. A significant increase in pasta cooking gain was also reported by Bergman *et al.* [1994] when they supplemented pasta with cowpea meal. In turn, Garcia-Valle *et al.* [2021] reported that the water adsorption capacity was higher in chickpea flour pasta (100.54%) than in durum wheat (59.32%) due to the higher content of dietary fiber in chickpea flour (15.88 g/100 g) as compared to durum wheat semolina (15.88 g/100 g), which might be behind the increased water adsorption capacity of the chickpea flour pasta.

#### ■ Acidity of pasta during storage

The acidity of pasta produced from wheat flour and fortified with sesame oil cake flour during storage for up to six months is shown in **Table 6**. The volume of 0.1 M NaOH used to neutralize

**Table 6.** Acidity (mL of 0.1 M NaOH) of pasta samples made from semolina wheat flour (control) and blends of semolina (S) with sesame oil cake (SOC) during storage.

Pasta	Storage period (month)		
	0	3	6
Control (100% S)	1.64±0.11 <sup>cC</sup>	2.20±0.01 <sup>eB</sup>	2.38±0.10 <sup>eA</sup>
95% S + 5% SOC	1.71±0.07 <sup>cdeC</sup>	2.66±0.00 <sup>dB</sup>	2.86±0.15 <sup>dA</sup>
92.5% S + 7.5% SOC	1.77±0.11 <sup>cdC</sup>	2.92±0.05 <sup>cB</sup>	3.12±0.13 <sup>cA</sup>
90% S + 10% SOC	1.84±0.08 <sup>bcC</sup>	3.11±0.11 <sup>abcB</sup>	3.25±0.20 <sup>bcA</sup>
87.5% S + 12.5% SOC	1.91±0.10 <sup>abC</sup>	3.21±0.05 <sup>abB</sup>	3.37±0.11 <sup>abA</sup>
85% S + 15% SOC	2.00±0.17 <sup>aC</sup>	3.25±0.06 <sup>abB</sup>	3.51±0.20 <sup>aA</sup>

All results are shown as mean ± standard deviation. Means in the same column with different lowercase letters are significantly different ( $p < 0.05$ ). Means in the same row with different uppercase letters are significantly different ( $p < 0.05$ ).

the control pasta at zero time was 1.64 mL. The acidity of pasta made using flour blends with 7.5, 10, 12.5, and 15% (w/w) of sesame oil cake recorded a significant increase ( $p < 0.05$ ) compared to the control, while the use of the blends with 12.5 and 15% (w/w) of sesame oil cake resulted in the highest acidity value of pasta.

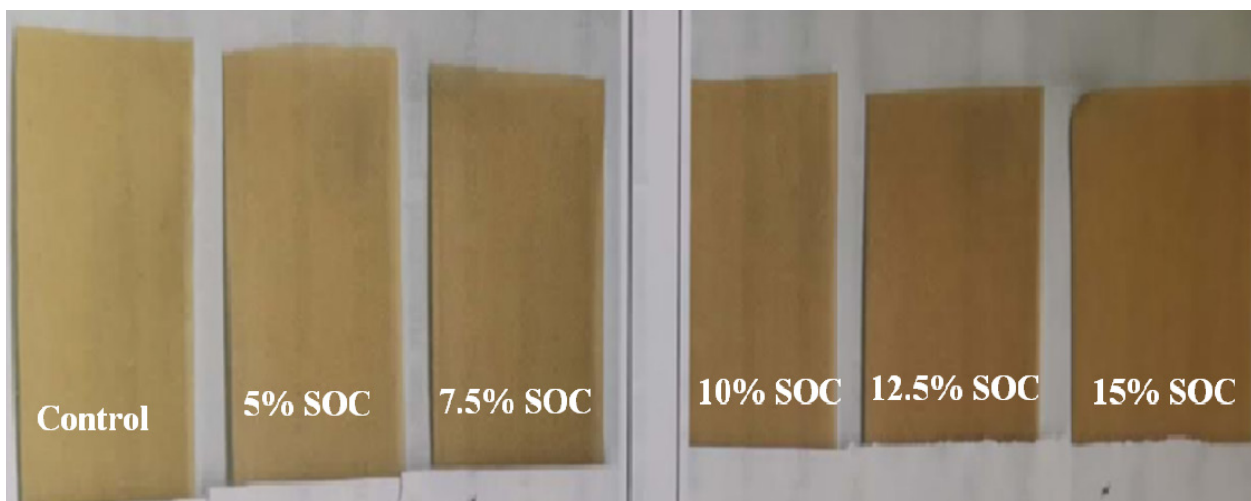
During storage, the acidity of each pasta increased significantly ( $p < 0.05$ ) (**Table 6**). The significantly ( $p < 0.05$ ) higher acidity was also found for the pasta samples made from flours containing sesame oil cake and stored for 3 and 6 months compared to the control sample. This increase can be attributed to the low-molecular-weight volatile fatty acids (secondary products of lipid autoxidation), which are extractable by the ethanol solution. However, the compact dry structure of pasta and the natural

**Table 7.** Results of sensory evaluation using a seven-point hedonic scale of cooked pasta made from semolina wheat flour (control) and blends of semolina (S) with sesame oil cake (SOC).

Storage period (month)	Control (100% S)	95% S + 5% SOC	92.5% S + 7.5% SOC	90% S + 10% SOC	87.5% S + 12.5% SOC	85% S + 15% SOC
<b>Color</b>						
0	6.2±0.3 <sup>a</sup>	4.5±0.1 <sup>b</sup>	4.1±0.1 <sup>d</sup>	4.6±0.3 <sup>b</sup>	4.0±0.5 <sup>d</sup>	3.5±0.3 <sup>e</sup>
3	6.3±0.1 <sup>a</sup>	4.3±0.3 <sup>b</sup>	3.9±0.4 <sup>c</sup>	4.4±0.8 <sup>b</sup>	3.8±0.4 <sup>cd</sup>	3.6±0.2 <sup>d</sup>
6	6.1±0.1 <sup>a</sup>	4.2±0.8 <sup>bc</sup>	4.1±0.0 <sup>bc</sup>	4.4±0.7 <sup>b</sup>	3.9±0.5 <sup>cd</sup>	3.5±0.8 <sup>d</sup>
<b>Flavor</b>						
0	6.3±0.1 <sup>a</sup>	4.4±0.8 <sup>b</sup>	4.1±0.1 <sup>bc</sup>	4.0±0.4 <sup>cd</sup>	3.6±0.4 <sup>d</sup>	3.0±0.1 <sup>e</sup>
3	6.3±0.4 <sup>a</sup>	4.2±0.4 <sup>b</sup>	4.2±0.4 <sup>b</sup>	4.1±0.1 <sup>bc</sup>	3.9±0.3 <sup>c</sup>	3.1±0.2 <sup>d</sup>
6	6.3±0.5 <sup>a</sup>	4.2±0.9 <sup>b</sup>	4.1±0.4 <sup>bc</sup>	3.9±0.7 <sup>cd</sup>	3.8±0.1 <sup>d</sup>	2.8±0.4 <sup>e</sup>
<b>Stickiness</b>						
0	6.3±0.4 <sup>a</sup>	4.3±0.2 <sup>b</sup>	4.3±0.2 <sup>b</sup>	4.2±0.4 <sup>b</sup>	3.8±0.4 <sup>c</sup>	3.1±0.6 <sup>d</sup>
3	6.5±0.1 <sup>a</sup>	4.2±0.2 <sup>b</sup>	4.2±0.1 <sup>b</sup>	4.1±0.1 <sup>bc</sup>	3.9±0.3 <sup>cd</sup>	3.2±0.6 <sup>d</sup>
6	6.4±0.9 <sup>a</sup>	4.3±0.4 <sup>b</sup>	4.2±0.0 <sup>b</sup>	4.2±0.7 <sup>b</sup>	3.7±0.1 <sup>c</sup>	3.1±0.7 <sup>d</sup>
<b>Overall acceptability</b>						
0	6.3±0.2 <sup>a</sup>	4.4±0.8 <sup>b</sup>	4.2±0.5 <sup>bc</sup>	4.2±0.1 <sup>bc</sup>	3.9±0.4 <sup>c</sup>	3.2±0.5 <sup>d</sup>
3	6.3±0.2 <sup>a</sup>	4.2±0.4 <sup>b</sup>	4.1±0.2 <sup>b</sup>	4.2±0.2 <sup>b</sup>	3.9±0.3 <sup>c</sup>	3.3±0.0 <sup>d</sup>
6	6.3±0.4 <sup>a</sup>	4.2±0.2 <sup>b</sup>	4.1±0.8 <sup>b</sup>	4.2±0.2 <sup>b</sup>	3.8±0.1 <sup>c</sup>	3.1±0.1 <sup>d</sup>

All results are shown as mean ± standard deviation. Means for individual characteristics with different letters are significantly different ( $p < 0.05$ ).





**Figure 1.** Appearance of dry pasta produced from semolina wheat flour (control) and its blends with 5, 7.5, 10, 12.5, and 15% (*w/w*) of sesame oil cake (SOC).

antioxidants of sesame oil may suggest limited oxidative rancidity. The presence of endogenous antioxidants in sesame oil cake may play a role in the stability of oxidation and contribute to maintaining nutritional quality and extending the shelf life [Melo *et al.*, 2021]. Sesame seed oil is used in food industries as it has a longer shelf life and tremendous antioxidant properties [Yaseen *et al.*, 2021], and sesame oil cake still contains a proportion of oil (32%) with a fatty acid pattern characterized by the abundance of unsaturated fatty acids [Melo *et al.*, 2021]. Kinsella & Mohite [1985] concluded that sesame oil had excellent stability due to the presence of natural antioxidants such as sesamol, sesamin, and sesamol. Our results agreed with those reported by Duzskiewicz-Reinhard *et al.* [1988], who fortified spaghetti with edible legumes.

#### ■ Pasta sensory acceptability

Overall, pasta produced from wheat flour with 5, 7.5, and 10% (*w/w*) of sesame oil cake showed higher acceptability to the panelists than the pasta samples made from blends fortified with the higher contents of sesame oil cake, while pasta made from pure semolina recorded the highest acceptability (Table 7). Additionally, storage did not affect the panelists' acceptability of pasta samples containing sesame oil cake or those produced only from wheat flour. There was a significant decrease ( $p < 0.05$ ) in the color-liking scores of pasta samples produced from flour blends. As the level of sesame oil cake in blended flour increased, the color of the pasta turned darker (Figure 1) and became less acceptable to the panelists (Table 7). No significant differences ( $p \geq 0.05$ ) in the color scores were recorded between all pasta samples at zero time when compared to those stored for three and six months, which indicates color stability throughout the storage period.

The panelists showed a preference for the flavors of pasta produced from the flour blends containing 5, 7.5, and 10% (*w/w*) of sesame oil cake over pasta from the blends containing 12.5 and 15% (*w/w*) of sesame oil cake (Table 7). However, the control pasta received the highest flavor score. A similar observation

was made by Bergman *et al.* [1994], who supplemented pasta with cowpea meal.

No significant difference ( $p \geq 0.05$ ) was observed in the stickiness of cooked pasta from the flour blends containing 5, 7.5, and 10% (*w/w*) of sesame oil cake, while the pasta samples containing 12.5 and 15% (*w/w*) of sesame oil cake were significantly ( $p < 0.05$ ) stickier than the control sample (Table 7).

#### CONCLUSIONS

Results suggest the possible utilization of sesame oil cake in bakery products. The addition of sesame oil cake flour to semolina showed significant improvement in the pasta's functional characteristics and nutritional value. The blend flours provided higher protein and lipid contents in the pasta; however, the sesame oil cake addition reduced the percentage of gluten content in the flour, thereby weakening the dough formulation and lowering water absorption capacity, which affected the final product's quality characteristics. Moreover, the increase in cooking loss did not exceed 0.9% in any of the pasta samples containing sesame oil cake, which indicates that the pasta samples were in their acceptable cooking loss quality ranges. Sensorial evaluation of the flavor and stickiness of pasta produced from the flour blends containing up to 10% (*w/w*) of sesame oil cake was satisfactory and recommended to open the door for industrial utilization of such valuable and nutritious by-products. The storage period did not affect the panelists' acceptability of pasta samples containing sesame oil cake.

Sesame compounds and gluten network interactions are believed to have a key role in modifying pasta's functional characteristics. However, further investigation of sesame compounds and the gluten network interactions, including their effects on dough rheological characteristics and studying the protein quality of pasta fortified with sesame oil cake, is required to obtain higher quality pasta products.

#### ADDITIONAL INFORMATION

The study was approved by the Ethical Committee of the University of Jordan. Sensory evaluation involving human testing

was conducted after oral consent was permitted from each panel. Written informed consent was obtained from all study participants. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## CONFLICT OF INTERESTS

The authors declare that they do not have any conflict of interest.

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## REFERENCES

- AACC, American Association of Cereal Chemists. (2000). *Approved Methods of Analysis*, (11<sup>th</sup> ed.). Cereals and Grains Association, St. Paul, MN, U.S.A.
- Animashaun, O., Olorode, O., Sofunde, K., Idowu, M. (2017). Quality evaluation of pasta fortified with roasted sesame flour. *Journal of Environmental Science, Toxicology and Food Technology*, 11(7), 29-34. <https://doi.org/10.9790/2402-1107012934>
- AOAC, Association of Official Analytical Chemists International. (2005). *Official Methods of Analysis* (17th ed.). Association of Official Analytical Chemists, Washington, DC, USA.
- Barak, S., Mudgil, D., Khatkar, B.S. (2013). Relationship of gliadin and glutenin proteins with dough rheology, flour pasting and bread making performance of wheat varieties. *LWT – Food Science and Technology*, 51(1), 211-217. <https://doi.org/10.1016/j.lwt.2012.09.011>
- Bergman, C., Gualberto, D., Weber, C. (1994). Development of high-temperature dried soft wheat pasta supplemented with cowpea (*Vigna unguiculata* (L.) Walp). Cooking quality, color, and sensory evaluation. *Cereal Chemistry*, 71(6), 523-727.
- Bresciani, A., Pagani, M.A., Marti, A. (2022). Pasta-making process: A narrative review on the relation between process variables and pasta quality. *Foods*, 11(3), art. no. 256. <https://doi.org/10.3390/foods11030256>
- Bustos, M.C., Paesani, C., Quiroga, F., Leon, A.E. (2019). Technological and sensorial quality of berry-enriched pasta. *Cereal Chemistry*, 96(5), 967-976. <https://doi.org/10.1002/cche.10201>
- Chopin Protocol 2000. Durum wheat Alveograph/Consistograph Study, pp. 1-8.
- Cui, C., Wang, Y., Ying, J., Zhou, W., Li, D., Wang, L.J. (2024). Low glycemic index noodle and pasta: Cereal type, ingredient, and processing. *Food Chemistry*, 431, art. no. 137188. <https://doi.org/10.1016/j.foodchem.2023.137188>
- De Arcangelis, E., Cuomo, F., Trivisonno, M.C., Marconi, E., Messia, M.C. (2020). Gelatinization and pasta making conditions for buckwheat gluten-free pasta. *Journal of Cereal Science*, 95, art. no. 103073. <https://doi.org/10.1016/j.jcs.2020.103073>
- Duszkiewicz-Reinhard, W., Khan, K., Dick, J.W., Holm, Y. (1988). Shelf-life stability of spaghetti fortified with legume flours and protein concentrates. *Cereal Chemistry*, 65(4), 278-281.
- Dziki, D. (2021). Current trends in enrichment of wheat pasta: Quality, nutritional value and antioxidant properties. *Processes*, 9(8), art. no. 1280. <https://doi.org/10.3390/pr9081280>
- El-Adawy, T. (1997). Effect of sesame seeds protein supplementation on the nutritional, physical, chemical, and sensory properties of wheat flour bread. *Food Chemistry*, 59(1), 7-14. [https://doi.org/10.1016/0308-8146\(95\)00197-2](https://doi.org/10.1016/0308-8146(95)00197-2)
- Filipović, V., Filipović, J., Simonovska, J., Rafajlovska, J. (2017). Effect of sesame flour and eggs on technology and nutritive quality of spelt pasta. *Journal of the Serbian Chemical Society*, 82(10), 1097-1109. <https://doi.org/10.2298/JSC170405060F>
- Fu, B.X. (2008). Asian noodles: History, classification, raw materials, and processing. *Food Research International*, 41(9), 888-902. <https://doi.org/10.1016/j.foodres.2007.11.007>
- Garcia-Valle, D.E., Bello-Pérez, L.A., Agama-Acevedo, E., Alvarez-Ramirez, J. (2021). Effects of mixing, sheeting, and cooking on the starch, protein, and water structures of durum wheat semolina and chickpea flour pasta. *Food Chemistry*, 360, art. no. 129993. <https://doi.org/10.1016/j.foodchem.2021.129993>
- Hummel, C. (1966). *Macaroni Products: Manufacture, Processing and Packing*. Food Trade Press: London, UK.
- Ingelbrecht, J.A., Moers, K., Abécassis, J., Rouau, X., Delcour, J.A. (2001). Influence of arabinoxylans and endoxylanases on pasta processing and quality. *Cereal Chemistry*, 78(6), 721-729. <https://doi.org/10.1094/CCHEM.2001.78.6.721>
- ISO, International Organization for Standardization, (1981). *Agricultural food products – Determination of crude fibre content - General Method*. <https://www.iso.org/standard/11544.html>.
- Jordanian Institute for Standards and Metrology, Hashemite Kingdom of Jordan. Standard No.67. (1996). *Cereal and Cereal Products: Dried Pasta*. Amman, Jordan.
- Kaur, G., Sharma, S., Nagi, H.P.S., Ranote, P.S. (2013). Enrichment of pasta with different plant proteins. *Journal of Food Science and Technology*, 50(5), 1000-1005. <https://doi.org/10.1007/s13197-011-0404-2>
- Kinsella, J.E., Mohite, R.R. (1985). Chapter 13: The physicochemical characteristics and functional properties of sesame proteins. In A.A. Altschul, H.L. Wilcke (Eds.), *New Protein Foods. Volume 5: Seed Storage Proteins*, Academic Press, London, pp. 435-456. <https://doi.org/10.1016/B978-0-12-054805-7.50020-8>
- Larrosa, V., Lorenzo, G., Zaritzky, N., Califano, A. (2016). Improvement of the texture and quality of cooked gluten-free pasta. *LWT – Food Science and Technology*, 70, 96-103. <https://doi.org/10.1016/j.lwt.2016.02.039>
- Marconi, E., Graziano, M., Cubadda, R. (2000). Composition and utilization of barley pearling by-products for making functional pasta rich in dietary fiber and beta-glucan. *Cereal Chemistry*, 77(2), 133-139. <https://doi.org/10.1094/CCHEM.2000.77.2.133>
- Matsuo, R.R. (1993). Durum wheat: Production and processing. In E. Bass (Ed.), *Grains and Oilseeds: Handling, Marketing, Processing*, 4th Edition, Canadian International Grains Institute, Winnipeg, Canada, pp. 779-807.
- Melo, D., Álvarez-Ortí, M., Nunes, M.A., Costa, A.S.G., Machado, S., Alves, R.C., Pardo, J.E., Oliveira, M. (2021). Whole or defatted sesame seeds (*Sesamum indicum* L.)? The effect of cold pressing on oil and cake quality. *Foods*, 10(9), art. no. 2108. <https://doi.org/10.3390/foods10092108>
- Moayed, S., Ohm, J.-B., Manthey, F.A. (2021). Relationship between cooking quality of fresh pasta made from durum wheat and protein content and molecular weight distribution parameters. *Cereal Chemistry*, 98(4), 891-902. <https://doi.org/10.1002/cche.10431>
- Mostashari, P., Khaneghah, M.A. (2024). Sesame seeds: A nutrient-rich superfood. *Foods*, 13(8), art. no. 1153. <https://doi.org/10.3390/foods13081153>
- Oliviero, T., Fogliano, V. (2016). Food design strategies to increase vegetable intake: The case of vegetable enriched pasta. *Trends in Food Science and Technology*, 51, 58-64. <https://doi.org/10.1016/j.tifs.2016.03.008>
- Ozgoren, E., Yapar, A. (2019). Effect of the addition of smoked trout fillet powder to the quality properties of pasta. *Italian Journal of Food Science*, 31(1), 110-124. <https://doi.org/10.14674/IJFS-1263>
- Padalino, L., Mastromatteo, M., Lecce, L., Spinelli, S., Contò, F., Del Nobile, M.A. (2014). Chemical composition, sensory and cooking quality evaluation of durum wheat spaghetti enriched with pea flour. *International Journal of Food Science and Technology*, 49(6), 1544-1556. <https://doi.org/10.1111/ijfs.12453>
- Raungrusmee, S., Koirala, S., Anal, A.K. (2022). Effect of physicochemical modification on granule morphology, pasting behavior, and functional properties of riceberry rice (*Oryza Sativa* L.) starch. *Food Chemistry Advances*, 1, art. no. 100116. <https://doi.org/10.1016/j.focha.2022.100116>
- Romano, A., Ferrani, P., Gallo, V., Masi, O. (2021). New ingredients and alternatives to durum wheat semolina for a high quality dried pasta. *Current Opinion in Food Science*, 41, 249-259. <https://doi.org/10.1016/j.cofs.2021.07.005>
- Sabanis, D., Lebesi, D., Tzia, C. (2009). Effect of dietary fibre enrichment on selected properties of gluten-free bread. *LWT – Food Science and Technology*, 42(8), 1380-1389. <https://doi.org/10.1016/j.lwt.2009.03.010>
- Saleh, M.I. (2017). Protein-starch matrix microstructure during rice flour pastes formation. *Journal of Cereal Science*, 74, 183-186. <https://doi.org/10.1016/j.jcs.2017.02.005>
- SAS Institute. (2003). *SAS User's Guide in Statistics*, 10th International Symposium, Cary, NC, USA: SAS Institutes, Inc.

37. Schmidt, H.O., de Oliveira, V.R. (2023). Overview of the incorporation of legumes into new food options: An approach on versatility, nutritional, technological, and sensory quality. *Foods*, 12(13), art. no. 2586. <https://doi.org/10.3390/foods12132586>
38. Sicignano, A., di Monaco, R., Masi, P., Cavella, S. (2015). From raw material to dish: Pasta quality step by step. *Journal of the Science of Food and Agriculture*, 95(13), 2579–2587. <https://doi.org/10.1002/jsfa.7176>
39. Tribune. (1999). Chopin SA. Newsletter for Flour Producers and Users. June No.7 Imprimerie Lni SA, France. <https://www.scribd.com/document/78846090/Chopin-TRibune-No-05-ENGLISH>
40. Wang, J., Brennan, M.A., Serventi, L., Brennan, C.S. (2022). Impact of functional vegetable ingredients on the technical and nutritional quality of pasta. *Critical Reviews in Food Science and Nutrition*, 62(22), 6069–6080. <https://doi.org/10.1080/10408398.2021.1895712>
41. Wei, P., Zhao, F., Wang, Z., Wang, Q., Chai, X., Hou, G., Meng, Q. (2022). Sesame (*Sesamum indicum* L.): A comprehensive review of nutritional value, phyto-chemical composition, health benefits, development of food, and industrial applications. *Nutrients*, 14(19), art. no. 4079. <https://doi.org/10.3390/nu14194079>
42. Yaseen, G., Ahmad, M., Zafar, M., Akram, A., Sultana, S., Ahmed, S.N., Kilic, O. (2021). Chapter 15: Sesame (*Sesamum indicum* L.). In Inamudin, R. Boddula, A.M. Asiri (Eds.), *Green Sustainable Process for Chemical and Environmental Engineering and Science*, Elsevier, pp. 253–269. <https://doi.org/10.1016/B978-0-12-821886-0.00005-1>
43. Yokoyama, W.H., Hudson, C.A., Kunkles, B.E., Chiu, M.M.-Ch., Sayre, R.N., Turnlund, J.R., Schneeman, B.A. (1997). Effect of barley  $\beta$ -glucan in durum wheat pasta on human glycemic response. *Cereal Chemistry*, 74(3), 293–296. <https://doi.org/10.1094/CCHEM.1997.74.3.293>
44. Zheng, H., Morgenstern, M.P., Campanella, O.H., Larsen, O.G. (2000). Rheological properties of dough during mechanical dough development. *Journal of Cereal Science*, 32, 293–306. <https://doi.org/10.1006/jcrs.2000.0339>