Optimization of cooking, textural, and sensorial qualities of macaroni supplemented with tef (Eragrostis tef (Zucc.) Trotter) and chickpea flours

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**ABSTRACT**

Durum wheat semolina is the preferable ingredient for pasta products preparation. However, it has low protein quality, micronutrient and fiber composition. In this study, response surface methodology was applied to optimally formulate a macaroni by supplementing durum wheat semolina with tef (0 to 40)% and chickpea (0 to 15)% flours. The aim was improving the nutritional quality of the product while maintaining the cooking quality. Supplementing the durum wheat semolina (S) with tef (T) and chickpea (C) flours improved the Water Absorption Capacity and Index (WAC and WAI) significantly (p < .05). Among the 11 flour blending ratios of S:T:C, (60: 40: 0)%; (85: 0: 15)%; (60: 25: 15)%; and (68: 28: 4)% improved the WAC and WAI of the semolina flour by (36, 8)%; (25, 7)%; (32, 9)%; and (31, 3)% respectively. With the same blending ratios, the cooking weight and the WAC of the control macaroni increased by (15, 15)%; (10, 19)%; (17, 18)%; and (22, 23)% respectively (p < .05). Interestingly, these blending ratios significantly reduced the wet gluten content of the semolina by 58%, 28%, 53%, and 42% (p < .05). With higher tef and chickpea incorporation, the macaroni had lower and higher firmness. The macaroni prepared with incorporation of chickpea (3.5–15)% appeared to have better color and comparable overall acceptability score with control. The optimum formulation of macaroni for desirable sensorial and cooking quality (better firmness, lower stickiness and cooking loss) was 73.46 g/100 g semolina, 11.55 g/100 g tef flour, and 14.25 g/100 g chickpea flour.

**Introduction**

Pasta is the most widely consumed food across the world due to its versatility, long shelf life, and relatively low cost. It is an unleavened extruded wheat dough, produced by mixing semolina and water. Pasta is processed into different shapes in which macaroni is a type, well liked in many cultures and consumed by all age groups. Durum wheat semolina is a preferable ingredient for making high-quality pasta because of its excellent dough rheological properties, superior color, high gluten content, excellent cooking quality, and better consumer acceptance. Semolina made pasta is a good source of carbohydrates, in contrary being poor in protein quality (lysine and threonine are limiting amino acids), low in micronutrient composition and inadequate in dietary fiber due to the removal of bran and germ during durum wheat milling into semolina. This provides an opportunity for the use of non-traditional raw materials to increase the nutritional quality of pasta. In recent years, fortification of durum wheat semolina with other nutritious cereals and legumes is growing. This is more sustained as the demand for “gluten-free” food increased among...
gluten or wheat-sensitive individuals. However, the elimination of the viscoelastic gluten protein represents a technological challenge. Hence, rather than completely eliminating the wheat supplementing it with other cereals, legumes, and vegetables is preferable. In fact, gluten is not totally absent in the so-called “gluten-free products,”[5,6] instead the cutoff is 20 milligrams of gluten per kilogram of product. [7] Also to obtain nutritional and sensorial quality product as well as to fit to the technology optimizing the proportion of the substituent grains is necessary.

In this study, tef Eragrostis tef (Zucc.) Trotter and chickpea flours were selected to substitute durum wheat semolina partially to prepare macaroni. Tef is an indigenous staple cereal in Ethiopia which is gluten-free. [8] It is used as whole grain with attractive nutritional profiles of micro-minerals (iron, calcium and zinc). Also the protein found in tef is known to be nutritionally superior to that of wheat, due to higher lysine content, a limiting amino acid in cereals. [8–10] Interest in tef-based food products is growing with international consumers with the benefits, thereof. [11] However, industrial application of tef as ingredient in various food products is still limited. [12,13]

Partial or full substitution of durum wheat semolina with other cereals often shows significantly lower protein content compared to wheat-only product. Hence, improving the protein content should be a challenge to address. For this purpose, in this study, chickpea was the other ingredient selected to be partially substituted durum wheat semolina in macaroni preparation. Chickpea is the most widely consumed pulse in the world and a rich source of high-quality protein, vitamins (thiamine and niacin), minerals, essential fatty acid (linoleic), and high dietary fiber. [14,15] The partial substitution of durum wheat semolina will reduce the gluten content of the final macaroni product as both chickpea and tef are gluten free grains. [16] This reduction will contribute in meeting the daily-recommended consumption for gluten or wheat-sensitive individuals. Therefore, the present study aimed to use response surface methodology (mixture design) to be optimally formulated macaroni from durum wheat semolina, tef, and chickpea flours. The resulting products were characterized with cooking, sensorial, and textural quality parameters.

Materials and methods

Materials

Tef and chickpea collection and preparation
Durum wheat (variety: Utuba, high gluten content); chickpea (variety: Habru, Kabuli type with high protein and white seed coat color), and tef (variety: DZ-01-196, very white color) were obtained from Debre Zeit Agricultural Research Center (DZARC), Debre Zeit, Ethiopia. The grains were harvested in 2017/18 main crop production season. The grains were manually cleaned to remove unwanted foreign materials. Then, the durum wheat grains were conditioned and milled into semolina using a Chopin laboratory mill (Moulin CD2 mill, Chopin technology, France) through 80 μm sieve size. The tef grain was milled into whole kernel flour (including bran, germ and endosperm) with a laboratory mill (Perten mill 120, Finland) fitted with a 0.5-mm opening screen size. The chickpea was milled using a Chopin laboratory mill after the seed coat was removed by a disc attrition mill. Then, the flour was sieved through an 80-mesh screen to remove ground hulled pieces.

Experimental design and macaroni formulation
Design expert software (Design-Expert®, version 8.0 software) was used to define the optimum proportions of the enriched macaroni formulation with blends of durum wheat semolina (60–100)%, tef (0–40)%, and chickpea (0–15)%. Eleven runs were obtained from the mixture response surface methodology with D optimal design (Table 3). The upper and lower limits of the flours were selected based on preliminary trial and earlier reports. [17,18] Macaroni made with 100% durum wheat semolina was used as control. Semolina, tef, and chickpea flours were mixed by rotating drum mixer (Chopin MR 10 L, France) for each blending proportion which ensured uniform mixing. Then, the composite flour was kept in polyethylene bag under refrigerated condition until further analysis.

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Macaroni preparation

Prior to extrusion, the dry pre-mix of semolina, tef, and chickpea flours was mixed for 2 min using a low-speed kitchen-aid mixer for further uniform blending. The optimum level of water for proper extrusion varied depending on the incorporation level of composite flour (Table 3). Before extrusion, preliminary trials were conducted for all the composite flours to determine the optimal moisture content by adding water at incremental levels. Then, water was added on the basis of composite flour’s water absorption capacity. The dough was kneaded by extrusion screw for complete water incorporation until it became homogenous. The mixture was designed as rigatoni (short rounded tubes) type and fitted with an adjustable die coated with Teflon. Macaroni was processed using laboratory scale single screw extruder (Lanuova Lampa, Model Minilab 305, Italy). The extruded macaroni cut into pieces of uniform length (2 cm) and dried in oven at 90°C for about 6 hours to obtain a 12% moisture content. Then, the dried macaroni was packed in air-tight plastic bags at room temperature until further use.

Flour functional property analysis

Water Absorption Index (WAI): The WAI of composite flour was determined to Kaushal et al. with some modifications. Two grams of composite flour sample suspended in 25 ml of distilled water in a tarred 50-ml centrifuge tube and shaken for 30 min. Then, it was centrifuged for 10 min at 1736 g (Model Tx425, England, rotor diameter 34.5 cm). The gel remaining in the centrifuge tube was weighed. The WAI was calculated as indicated in equation 1 below.

\[ WAI (g/g) = \frac{W_g}{W} \]

where WAI is Water Absorption Index, \( W_g \) is sediment weight, and \( W \) is sample weight

Water Absorption Capacity (WAC): WAC was determined following the method by Beuchat. Briefly, 2 g of composite flour sample was mixed with 20 ml of distilled water in 25-ml centrifuge tube. The dispersed particles were vortexed for 30 s at room temperature and centrifuged for 30 min at 1736 g (Model Tx425, England, rotor diameter 34.5 cm). The WAC was calculated using equation 2.

\[ \text{WAC}(\%) = \frac{V_2 - V_1}{W} \times 100 \]

where \( V_2 \) is volume of water before centrifuging, \( V_1 \) is volume of water after centrifuging, and \( W \) is sample weight.

Gluten content: Wet and dry gluten contents were determined mechanically with Glutomatic System (Perten Instruments, Sweden) according to International Standardization Organization (ISO 21415–2 and ISO 21415–4).

Proximate composition and mineral analysis

The moisture, ash, crude protein, crude fat, crude fiber, total carbohydrate, and minerals (phosphorus, iron, and zinc) contents in the raw material and composite flour were determined following the standard methods of AOAC. Crude fiber, crude protein, and iron contents determined in both the raw and composite flours.

Cooking quality

Cooking quality indicating parameters including cooking weight, cooking time, and cooking loss were determined by the methods of American Association of Cereal Chemists (AACC) method 66–50.

Cooking weight and Water Absorption Capacity of cooked macaroni: The cooked pasta weight increase was determined by AACC method, protocol 66–50. Briefly, 12 g of the macaroni was cooked, then decanted and weighed. The weight difference before and after cooking was used to calculate the WAC of the product following equation 3.
\[
WAC (%) = \frac{\left( W_c - W_d \right)}{W_d} \times 100
\]

where \( W_c \) is weight of cooked and drained pasta, \( W_d \) is weight of dry pasta.

Cooking time: Macaroni was cooked in distilled water (2 L/100 g) containing 0.7\% (w/v) of sodium chloride. Optimal cooking time was established by boiling the macaroni in distilled water until the time when the white strand core disappeared by squeezing between two glass plates.\(^{[26]}\) Every minute, a macaroni was removed from boiling water and squeezed between two pieces of Plexiglass.

Cooking loss: The cooking loss (%) was determined by AACC method,\(^{[26]}\) method 66–50. Briefly, 10 g of macaroni was cooked in 300 ml of boiling water on water bath for optimal cooking time. Then, the collected cooking water was evaporated to dryness in hot air oven at 105\(^{\circ}\)C to determine the solid loss in the gruel. The residue was weighed and the cooking loss was expressed as a percentage of the original weight of the sample following equation 4 below.

\[
Cooking \ loss \ (DL\%) = \frac{Dm(g)}{Wd(g)} \times 100
\]

where DL is dry matter solid loss (%), DM is dry matter loss after oven drying (g), \( Wd \) is dry weight of uncooked pasta (g).

**Texture of cooked macaroni**

Pasta firmness is the force required to cut a defined amount of pasta while stickiness is the maximum peak force to separate the probe from the sample’s surface upon retraction. The firmness and stickiness of the cooked macaroni were analyzed using TA plus texture analyzer (LLOYD Instruments, UK 2007). The experiment was carried out according to the method by AACC,\(^{[26]}\) method 66–50. The firmness and stickiness were measured with the speed of 2.00 mm/s and strain 50 N. The average value of force (N) required to shear the macaroni was reported after measuring five replicates for each composite sample. Higher shear and force values indicated a firmer and stickier product, respectively.

**Overall acceptability**

The sensory evaluation of the fresh macaroni was carried out by both young-adult female and male 20 semi-trained panelists. The panelists were researchers of food science and nutrition. The panelists sat in a back-to-back position to avoid interaction. Rating acceptance sensory evaluation was conducted using nine-point hedonic rating scale, in which 1 and 9 marking extremely dislike and like, respectively. The sensory attributes tested were color, texture, and overall acceptability. Samples of macaroni coded with three-digit numbers obtained from a Table of random numbers. The samples tested in a randomized order from left to right. The panelists asked to rate the acceptability of each sensory attribute of the macaroni by marking ‘X’ on the line which best-described their sensory perception. Before and after tasting each product, the panelists requested to gargle.

**Statistical analysis**

One-way analysis of variance (ANOVA) was used to check the presence of significant difference between mean values at 95\% confidence interval. The effect of blending proportion of tef and chickpea with semolina was analyzed by Design expert*, version 8.0.1 (Stat-Ease Inc., Minneapolis, MN USA). Duncan’s Multiple Range test (SPSS version 20.0, USA) was carried out to determine level of significant (\( p < .05 \)) differences among samples. All analyses were conducted in triplicate and results were expressed as mean ± standard deviation.
Table 1. Proximate and mineral composition of semolina, tef, and chickpea flours used for macaroni preparation.

| Raw material               | Crude protein (g/100 g) | Crude fat (g/100 g) | Crude fiber (g/100 g) | Ash (g/100 g) | Carbohydrate (g/100 g) | Iron (mg/100 g) | Zinc (mg/100 g) | Phosphorus (mg/100 g) |
|----------------------------|-------------------------|---------------------|-----------------------|--------------|------------------------|-----------------|-----------------|---------------------|
| Durum wheat semolina       | 10.7 ± 0.1<sup>c</sup>  | 0.6 ± 0.0<sup>c</sup> | 1.0 ± 0.0<sup>b</sup> | 0.8 ± 0.0<sup>c</sup> | 77.4 ± 0.2<sup>a</sup> | 0.5 ± 0.1<sup>c</sup> | 1.0 ± 0.0<sup>c</sup> | 163.3 ± 0.0<sup>c</sup> |
| Chickpea flour             | 19.0 ± 0.2<sup>a</sup>  | 7.7 ± 0.0<sup>b</sup> | 3.3 ± 0.1<sup>a</sup> | 2.9 ± 0.0<sup>b</sup> | 61.0 ± 0.3<sup>c</sup> | 1.8 ± 0.0<sup>b</sup> | 2.0 ± 0.0<sup>b</sup> | 192.9 ± 0.9<sup>b</sup> |
| Tef flour                  | 11.6 ± 0.1<sup>b</sup>  | 2.7 ± 0.1<sup>b</sup> | 3.3 ± 0.0<sup>c</sup> | 2.4 ± 0.0<sup>b</sup> | 73.5 ± 0.1<sup>b</sup> | 8.8 ± 0.4<sup>a</sup> | 2.8 ± 0.2<sup>c</sup> | 206.7 ± 1.3<sup>c</sup> |

Data are expressed as mean ± SD (n = 3), on dry basis. Mean values with different superscripts within the same column denote significance difference at p < 0.05 in mean comparisons using Duncan's multiple range test.

Results and discussion

**Proximate composition of semolina, tef, and chickpea flours**

The proximate composition of semolina, tef, and chickpea flours used for the macaroni preparation is reported in Table 1. There was a significant difference (p < .05) in crude protein, ash, crude fat, and total carbohydrate contents between the raw materials. Protein contributes significantly to texture and flavor of food products besides nutrition. Thus, it also gets priority in flour quality determination for pasta product formulation. Among the raw materials, chickpea flour had the highest protein and fat contents followed by tef flour, while semolina flour had the lowest amount. This supports the objective of this study to enrich macaroni with chickpea as a protein source. Similarly, the carbohydrate content of ingredients plays important role in pasta quality (texture) because of the macromolecular structure. Semolina, tef, and chickpea flours had carbohydrate content of 77%, 74%, and 61%, respectively (Table 1). The highest carbohydrate in semolina might have resulted from the common extraction that removed the germ in the durum wheat and lowered the fiber content by removing the bran. Thus, blending semolina flour with tef and chickpea might be beneficial to limit the utilizable carbohydrate content so to decrease glycemic response of the pasta. The crude ash content in tef, chickpea and semolina was 2.94%, 2.36%, and 0.84%, respectively. Similar content of ash in tef was reported by Bultosa. Accordingly, tef is whole milled (contain bran and germ) and retained the lipid in the germ; hence, it has high mineral, fat, and fiber content.

**Mineral composition of semolina, tef, chickpea flours**

The mineral composition of the raw materials used for the macaroni preparation is presented in Table 1. There was a significant difference in the concentrations of zinc, iron, and phosphorus between the three flour samples (p < .05). Among which, tef flour had the highest and while semolina had the lowest mineral concentration. In fact, according to USDA National nutrient data semolina had low concentration of important minerals. This supports the idea to supplement semolina partially with tef/chickpea to enrich end products like macaroni with minerals and other nutrients as well.

**Water absorption capacity and index of semolina, tef, chickpea flours**

The WAC and WAI for the three raw materials are reported in Table 2. Accordingly, semolina, chickpea, and tef flours had WAC and WAI values of (108%, 1.9 g/g), (172%, 2.0 g/g), and (172%, 2.4 g/g), respectively. The higher WAC and WAI values of tef and chickpea flours have importance in the industrial preparation and cooking quality of pasta products.
### Table 2. Water Absorption Capacity and Index values of semolina, tef, and chickpea flours used for macaroni preparation.

| Raw material | WAC (%) | WAI     |
|-------------|---------|---------|
| Durum wheat semolina | 108.06 ± 0.02<sup>b</sup> | 1.91 ± 0.01<sup>c</sup> |
| Tef flour | 172.05 ± 0.05<sup>a</sup> | 2.12 ± 0.01<sup>b</sup> |
| Chickpea flour | 171.93 ± 0.24<sup>a</sup> | 2.42 ± 0.04<sup>a</sup> |

Data are expressed as mean ± SD (n = 3), on dry basis. Mean values with different superscripts within the same column denote significance difference at p < 0.05 in mean comparisons using Duncan's multiple range test. WAC: Water absorption capacity; WAI: Water absorption index.

### Functional properties and selected nutrient compositions of composite flours

The functional properties and selected nutrient compositions (protein, fiber, and iron) of the composite flours are presented in Table 3. Supplementing the durum wheat semolina with tef and chickpea flours improved the WAC and WAI. Among the 11 blending ratios of semolina (S): tef (T): chickpea (C) flours, (60: 40: 0)%,(85: 0: 15)%,(60: 25: 15)%,(68: 28: 4)% improved the WAC and WAI of the semolina by (36, 8)%,(25, 7)%,(32, 9)%,(31, 3)% respectively. Increasing the proportion of tef and chickpea flour increased the WAI and WAC of composite flour. This is associated with higher WAC and WAI of tef and chickpea flours (tef > chickpea > semolina) as shown in Table 2. The higher WAI in tef flour could be due to its smaller starch granule size that led to increase in the bulk surface area. Water absorption results in swelling, which is a required factor in determining quality of pasta products. Therefore, in this study, the amount of water added in the processing of macaroni varied with the amount of tef and chickpea flour (Table 3).

The wet gluten content of the composite flours is presented also in Table 3. Semolina flour (100%) had a wet gluten content of 35.70%. The wet gluten content significantly reduced (p < .05) with incorporation of tef and chickpea flours. With the S:T:C blending ratios (60: 40: 0)%,(85: 0: 15)%,(60: 25: 15)%,(68: 28: 4)% the wet gluten content reduced by 58%, 28%, 53%, and 42%, respectively. Similarly, Sabanis et al. reported improved protein and reduced wet gluten contents in composite flours of semolina and chickpea.

Pasta products are not good sources of protein, fiber, and iron. In this study, the crude protein, crude fiber, and iron contents of the composite flours improved with increased incorporation of chickpea and tef flours (Table 3). Semolina flour had protein content of 10.92%. With ratios of S:T:C (60: 40: 0)%,(85: 0: 15)%,(60: 25: 15)%,(68: 28: 4)% the crude protein content increased by (3, 35, 12, 5)% respectively. With the same blending ratios, the crude fiber and iron contents improved, respectively, by (60, 88)%,(35, 44)%,(58, 84)%,(54, 84)% (p < .05). Supplementing semolina flour with chickpea in spaghetti preparation enriched the protein content and overall nutritional value as well.

### Macaroni quality

A quality pasta or al dente is expressed with reduced cooking loss, optimum cooking time, and weight increase after cooking. The macaroni prepared with the composite flours was evaluated for these quality parameters and results are presented in Table 4. Cooking weight and WAC: The macaroni prepared from Semolina flour only had the lowest cooking weight and WAC among all the compositions (Table 4). With blending ratio of S:T:C, (60, 40, 0)%,(85, 0, 15)%,(60, 25, 15)%,(68, 28, 4)% the cooking weight and the WAC of the semolina only macaroni increased by (15, 15)%,(10, 19)%,(17, 18)%,(22, 23)% respectively (p < .05). This is associated with the higher WAC and WAI of tef and...
### Table 3. Functional properties and selected nutrient compositions of composite flour of semolina, tef, and chickpea with different proportions.

| Run | Semolina (%) | Tef (%) | Chickpea (%) | WAC (%) | WAI (%) | Water added (%) | Glutens (%) | Crude protein (%) | Crude fiber (%) | Iron (mg/100 g) |
|-----|---------------|---------|--------------|---------|---------|----------------|-------------|------------------|----------------|----------------|
| 1   | 80.00         | 20.00   | 0.00         | 111.91 ± 0.02c | 2.19 ± 0.02bc | 39.62 ± 0.27bc | 26.30 ± 0.48c | 10.96 ± 0.22d | 1.43 ± 0.03bc | 2.35 ± 0.19c |
| 2   | 100.00        | 0.00    | 0.00         | 88.91 ± 0.02b | 2.06 ± 0.03def | 37.08 ± 0.21c | 35.70 ± 0.51a | 10.65 ± 0.03d | 0.95 ± 0.02e | 0.75 ± 0.06d |
| 3   | 72.76         | 12.76   | 14.48        | 128.05 ± 0.04bde | 2.12 ± 0.03de | 38.36 ± 0.51d | 22.20 ± 0.81d | 12.10 ± 0.11e | 1.61 ± 0.09b | 1.93 ± 0.03d |
| 4   | 60.00         | 32.58   | 7.42         | 122.11 ± 0.04bde | 2.20 ± 0.02b | 39.76 ± 0.27b | 16.20 ± 0.80g | 11.75 ± 0.08b | 1.88 ± 0.10d | 3.50 ± 0.01ab |
| 5   | 60.00         | 40.00   | 0.00         | 138.05 ± 0.02ab | 2.23 ± 0.01ab | 41.25 ± 0.14a | 14.88 ± 0.16h | 11.15 ± 0.08b | 1.93 ± 0.04d | 4.01 ± 0.13a |
| 6   | 60.00         | 25.11   | 14.89        | 130.00 ± 0.01abc | 2.27 ± 0.02a | 39.67 ± 0.24b | 16.71 ± 0.69f | 12.31 ± 0.01b | 1.90 ± 0.02a | 2.98 ± 0.11b |
| 7   | 92.50         | 0.00    | 7.50         | 115.02 ± 0.06d | 2.18 ± 0.10bcd | 38.25 ± 0.64d | 28.75 ± 0.66b | 11.40 ± 0.07bc | 1.13 ± 0.05de | 0.81 ± 0.01fg |
| 8   | 85.00         | 0.00    | 15.00        | 118.65 ± 0.01def | 2.12 ± 0.01bcd | 38.45 ± 0.12d | 25.62 ± 1.21c | 12.08 ± 0.19d | 1.29 ± 0.01cd | 0.89 ± 0.09f |
| 9   | 68.44         | 28.08   | 3.48         | 129.03 ± 0.01abc | 2.13 ± 0.01cde | 39.75 ± 0.04b | 20.89 ± 0.41g | 11.33 ± 0.20c | 1.76 ± 0.03ab | 3.00 ± 0.21b |
| 10  | 82.15         | 9.11    | 8.74         | 125.05 ± 0.03d | 2.11 ± 0.01de | 38.11 ± 0.18d | 21.34 ± 0.2gde | 11.64 ± 0.09b | 1.39 ± 0.11c | 1.55 ± 0.08e |
| 11  | 89.61         | 10.39   | 0.00         | 117.98 ± 0.02cde | 2.11 ± 0.01e | 38.08 ± 0.07d | 30.11 ± 0.42b | 10.70 ± 0.15d | 1.24 ± 0.03d | 1.57 ± 0.12c |

Data are expressed as mean ± SD (n = 3), on dry basis. Values with different superscripts within the same column denote significance difference at p < 0.05 in mean comparisons using Duncan’s multiple range test. WAC: Water Absorption Capacity, WAI: Water Absorption Index.
### Table 4. Cooking, textural and sensorial quality evaluation of macaroni formulated from composite flour of semolina, tef, and chickpea with different proportions.

| Blend proportion (%) | Cooking quality (%) | Texture analysis (N) |
|----------------------|---------------------|---------------------|
|                      | Cooking weight      | WAC                 | Cooking loss | Cooking time (min) | Firmness | Stickiness | Color | Overall acceptability |
| 80.0                 | 299.9 ± 0.9bcd      | 185.6 ± 1.3g        | 2.1 ± 0.1f   | 10.0 ± 0.5ab      | 5.0 ± 0.0g | 42.9 ± 0.3cde | 6.2 ± 0.0h | 60 ± 0.2c |
| 100.0                | 271.6 ± 1.1d        | 166.5 ± 3.1h        | 1.5 ± 0.1g   | 10.5 ± 0.8a       | 6.1 ± 0.1i | 41.7 ± 0.2c  | 10.7 ± 0.1c | 74 ± 0.3a |
| 72.8                 | 314.1 ± 1.5abc      | 212.6 ± 4.7ab       | 2.9 ± 0.0f   | 9.5 ± 0.5b        | 6.0 ± 0.0d | 42.7 ± 0.2cde | 6.2 ± 0.1h | 52 ± 0.4c |
| 60.0                 | 307.8 ± 2.3ab       | 195.7 ± 1.6ef       | 3.7 ± 0.0b   | 9.5 ± 0.5b        | 4.8 ± 0.0e | 44.2 ± 0.2bc  | 5.6 ± 0.0j | 47 ± 0.4f |
| 60.0                 | 321.0 ± 0.8ab       | 196.9 ± 2.6de       | 4.0 ± 0.2a   | 9.5 ± 0.5b        | 4.4 ± 0.1j | 43.7 ± 0.2cde | 4.3 ± 0.1k | 52 ± 0.3de |
| 60.0                 | 327.9 ± 1.4abc      | 203.1 ± 1.5cde      | 2.8 ± 0.1cd  | 9.5 ± 0.8b        | 5.3 ± 0.0fg | 43.6 ± 0.4cd  | 7.6 ± 0.1f | 56 ± 0.4d |
| 92.5                 | 319.4 ± 1.8abc      | 204.2 ± 2.3cd       | 1.6 ± 0.0a   | 10.0 ± 0.5ab      | 6.6 ± 0.1b | 44.2 ± 0.5bc  | 11.0 ± 0.0b | 68 ± 0.4b |
| 85.0                 | 301.5 ± 0.6bcd      | 205.3 ± 1.9bc       | 2.6 ± 0.1c   | 10.0 ± 0.5ab      | 7.0 ± 0.0a | 46.4 ± 0.2a  | 11.3 ± 0.0ab | 72 ± 0.3a |
| 68.4                 | 347.7 ± 1.8b       | 215.1 ± 1.8abc      | 2.5 ± 0.1p   | 9.0 ± 0.5bc       | 4.7 ± 0.1i | 45.4 ± 1.6ab  | 5.1 ± 0.01j | 46 ± 0.3f |
| 82.2                 | 303.6 ± 1.3bcd      | 189.0 ± 1.9fg       | 2.5 ± 0.1p   | 9.0 ± 0.7bc       | 5.4 ± 0.1bi | 42.3 ± 0.2de  | 6.7 ± 0.1g  | 66 ± 0.4bc |
| 89.6                 | 305.8 ± 0.5bc      | 200.4 ± 1.6cde      | 1.7 ± 0.0g   | 10.0 ± 0.5ab      | 5.5 ± 0.1de | 42.0 ± 0.5de  | 8.2 ± 0.1d | 68 ± 0.4b |

Data are expressed as mean ± SD, (n = 3), Values with different superscripts within the same column denote significant difference in mean comparisons based on Duncan multiple range test (p < 0.05).

WAC: Water Absorption Capacity; S: Durum Wheat Semolina; T: Tef; C: Chickpea
Table chickpea 2262 of a stickiness. In Textural and respective small et leaching observed the loss both macaroni respectively. maximum that significant firmness: Cooking Cooking time: The macaroni prepared from semolina flour only was cooked in 10.5 min. With maximum incorporation of tef (40%) and chickpea (15%), the macaroni cooked in 9.5 and 10.0 min, respectively. As shown in Table 4, as the incorporation of tef and chickpea flours increased, the macaroni cooked in lesser time.

Cooking loss: The cooking loss of the formulated macaroni for individual and interaction effects of both flours significantly varied from 1.47 to 4.03% (Table 4). The semolina only macaroni had cooking loss of 1.5%. With blending ratio of S:T:C, (60, 40, 0)%, (85, 0, 15)%, (60, 25, 15)%,( 68, 28, 4)%, the cooking loss was higher by 63%, 42%, 46%, and 40% from control macaroni, respectively. In general, as the amount of tef flour increases in the composite, cooking loss also increased. Similar trend was observed with chickpea incorporation (Table 4, Figure 1). The cooking loss might be due to amylase leaching and solubilization of some salt-soluble proteins. Also it might be related with the dilution of the gluten that forms a matrix and holds the starch in the pasta together. In contrast, El-Shatanovi et al.\textsuperscript{[35]} and Rasmay et al.\textsuperscript{[36]} reported that increasing the level of chickpea (5 to 15)% in macaroni formulation reduced cooking loss.

Textural characteristics

Texture is a prime concern of consumers, with a firm and non-sticky pasta being generally acceptable. In this study, texture of the formulated macaroni was characterized with attributes of firmness and stickiness.

Firmness: As presented in Table 4, the different blending ratio of tef and chickpea flour had a significant impact (p < .05) on firmness of the macaroni. The macaroni prepared from only semolina flour had firmness of 6.13 N. The least firmness value was obtained in the macaroni prepared from 40% tef incorporated composite flour. In contrast, the macaroni from 15% chickpea composite flour had the highest firmness value of 7.03 N (Figure 2). This might be attributed to higher protein content of the chickpea flour.\textsuperscript{[33]} Hager et al.\textsuperscript{[27]} reported that with increased tef flour in the formulations, the respective macaroni had lower firmness compared with wheat and oat pasta.

Stickiness: The stickiness of all formulated macaroni demonstrated a substantial change with the tef and chickpea flours incorporation (Table 4). Macaroni prepared from semolina flour only had the least stickiness value of 42 N. The highest stickiness value was in the macaroni with 15% chickpea (46.42 N) (Figure 3). With blending ratio of S:T:C, (60, 40, 0)%,( 85, 0, 15)%,( 60, 25, 15)%,(68, 28, 4)%, the

![Figure 1](image_url) Effect of tef and chickpea blending with durum wheat semolina on cooking loss of cooked macaroni (a) Contour graph and (b) Response surface (3D). chickpea flours (Table 2). Abebe et al.\textsuperscript{[29]} reported high water-binding capacity of tef flour due to the small granule size of the starch and high fiber content. On the other hand, Esmat et al.\textsuperscript{[34]} indicated that the inherent proteins in raw chickpea flour may also have vital role in the WAC.

Cooking time: The macaroni prepared from semolina flour only was cooked in 10.5 min. With maximum incorporation of tef (40%) and chickpea (15%), the macaroni cooked in 9.5 and 10.0 min, respectively. As shown in Table 4, as the incorporation of tef and chickpea flours increased, the macaroni cooked in lesser time.

Cooking loss: The cooking loss of the formulated macaroni for individual and interaction effects of both flours significantly varied from 1.47 to 4.03% (Table 4). The semolina only macaroni had cooking loss of 1.5%. With blending ratio of S:T:C, (60, 40, 0)%,( 85, 0, 15)%,( 60, 25, 15)%,(68, 28, 4)%, the cooking loss was higher by 63%, 42%, 46%, and 40% from control macaroni, respectively. In general, as the amount of tef flour increases in the composite, cooking loss also increased. Similar trend was observed with chickpea incorporation (Table 4, Figure 1). The cooking loss might be due to amylase leaching and solubilization of some salt-soluble proteins. Also it might be related with the dilution of the gluten that forms a matrix and holds the starch in the pasta together. In contrast, El-Shatanovi et al.\textsuperscript{[35]} and Rasmay et al.\textsuperscript{[36]} reported that increasing the level of chickpea (5 to 15)% in macaroni formulation reduced cooking loss.

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stickiness value of the semolina only macaroni increased by 5%, 10%, 4%, and 8%, respectively. This might be due to the effect of change in surface structure of macaroni strand and starch quality during cooking. Moreover, the protein matrix gradually disintegrates releasing extrudes during starch gelatinization, which in turn contributes to an increase in stickiness on the cooked pasta surface.\cite{37} Hence, the highest stickiness of the chickpea-fortified macaroni in this study might be related with high protein and amylose contents.\cite{3} In contrast, a significant decrease in stickiness was observed in spaghetti prepared by adding quinoa, broad bean or chickpea flour.\cite{19}

**Overall acceptability**

Most studies on the sensorial evaluation of fortified pasta focused on the overall product acceptability (4). In this study, the blending ratio had a significant (p < .05) effect on the overall acceptability of the macaroni (Table 4). The macaroni prepared from semolina only had overall acceptability score of 7.39 in scale of 9.00. The macaroni prepared with the maximum chickpea (15%, tef 0%) had similar overall acceptability with the semolina only macaroni (p > .05). Similarly, pasta fortified up to a 10–15% substitution with chickpea flour were generally well accepted.\cite{14,17,38,39} With blending ratio of S:T:C, (60, 40, 0)%, (60, 25, 15)%, (68, 28, 4)%, the overall acceptability scores of the macaroni were significantly reduced by 29%, 25%, and 37%, respectively.

![Figure 2. Effect of tef and chickpea blending with durum wheat semolina on firmness of cooked macaroni (a) Contour graph and (b) Response surface (3D).](image1.png)

![Figure 3. Effect of tef and chickpea blending with durum wheat semolina on stickiness of cooked macaroni (a) Contour graph and (b) Response surface (3D).](image2.png)
Optimization

In this study, the best blend ratio was optimized on the basis (response) of cooking, textural, and sensorial properties of macaroni. Accordingly, the optimum formulation for better firmness, lower stickiness, and lower cooking loss was 67.08 g/100 g semolina, 17.93 g/100 g tef flour, and 15 g/100 g chickpea flour (Supplementary Table 1, Figure 4).

Conclusion

Response surface methodology was applied to optimally formulate macaroni by supplementing durum wheat semolina with tef and chickpea flours. Apparently, the blend composite flour had improved crude protein, crude fiber, iron, WAC, and WAI values than the durum wheat semolina. The macaroni prepared from the composite with higher tef and chickpea flours had better cooking qualities of increased cooking weight, WAC, and lesser cooking time. Also, with more incorporation of chickpea the macaroni had comparable overall acceptability, and firmness with the control. In conclusion, the results clearly showed that semolina, tef, and chickpea flours with blending ratio of 67%, 17%, and 15%, respectively, can be used to produce macaroni with acceptable cooking and textural quality.

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Disclosure statement

No potential conflict of interest was reported by the author(s).
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