Physical Education, Health and Social Sciences

https://journal-of-social-education.org

E-ISSN: 2958-5996

P-ISSN: 2958-5988

Influence of Sorghum Flour Substitution on Cooking, Textural, and Sensory Properties of Pasta

Faisal Fayyaz[1], Arawat Fatima[2], Noor Bakht[3], Moazama Anwer[3], Amara Khan[4], Mohsin Hussain[5], Kaifa Saddique[6], Muhammad Asif[7*]

[1] Department of Food Science and Technology, Faculty of Agriculture and Environment, The Islamia University of Bahawalpur, Pakistan.
[2] Department of Food Science and Technology, Government College University of Faisalabad, Pakistan.
[3] Department of Human Nutrition and Dietetics, Faculty of Allied Health Sciences, University of Okara, Pakistan.
[4] Institute of Food Science & Nutrition, Gomal University, D.I. Khan, Pakistan.
[5] Department of Food Engineering, University of Agriculture, Faisalabad, Pakistan.
[6] Oilseeds Research Institute, Faisalabad, Pakistan.
[7] Department of Food Science and Technology, UAF-Constituent College, Burewala, Pakistan.
*Corresponding author: asifrajab3251@gmail.com

DOI: https://doi.org/10.63163/jpehss.v4i1.1258

Abstract
This study aimed to evaluate the effect of partial substitution of wheat flour with sorghum flour (0–40%) on the quality characteristics of pasta. Composite flours were prepared by replacing wheat flour with sorghum flour at levels of 10, 20, 30, and 40%, while 100% wheat flour served as the control. The prepared pasta samples were analyzed for cooking properties and sensory attributes. Results indicated that increasing sorghum flour significantly ($p < 0.05$) increased the swelling index, reflecting higher water absorption capacity, while firmness decreased due to the weakening of the gluten network. Sensory evaluation revealed a gradual decline in color, texture, taste, and overall acceptability with increasing sorghum levels, with the control sample receiving the highest scores and 40% substitution the lowest. However, samples containing 10–20% sorghum flour showed acceptable sensory quality. The findings suggest that sorghum flour can be successfully incorporated into wheat pasta to enhance its nutritional profile, particularly dietary fiber content, without significantly compromising quality at lower substitution levels. Therefore, a substitution level of up to 20% is recommended.

Keywords: Sorghum flour; Composite flour; Pasta; Swelling index; Cooking properties; Sensory evaluation; Gluten-free incorporation

Introduction
Food provides the basic nutrients required for the normal physiological functioning of the human body (Peressini *et al.*, 2015). Functional foods are those food products that are enriched with potential and functional ingredients with an active role in health promotion and disease prevention (Kaur and Singh, 2017). Consumer behavior and consciousness towards quality food and a healthy lifestyle are important driving agents of functional foods consumption (Pappalardo and Lusk, 2016; Walsh *et al.*, 2017). Pasta is basically a cereal-based Italian cuisine that is getting more fame due to its convenience and palatability (Gull *et al.*, 2015; Foschia *et al.*, 2015). The cost effectiveness, versatility, production ease, long shelf life, and sensory characteristics make the pasta popular and well accepted in the world. Traditional pasta is prepared from durum wheat flour (Bruneel *et al.*, 2016) but pasta preparation from

non-durum wheat ingredients is also possible. Different active and functional ingredients (like dietary fiber etc.) are making their way in the production of functional pasta products (Kaur and Singh, 2017). Pasta products are attracting and appealing the society due to their unique flavor, health benefits and ease of transportation and processing operations (Oliviero and Fogliano, 2016). Due to high global consumption and ease of production, pasta is considered a suitable product for the incorporation of functional and active food ingredients. The basic target is to produce nutritious and novel food products using different nutritional raw materials. These raw materials include different cereals, pseudo-cereals, legumes etc. containing a variety of vitamins, protein, fiber and minerals (Bouasla *et al.*, 2017; Islas-Rubio *et al.*, 2014).

Sorghum (*Sorghum bicolor* L.) is the fifth largest cereal crop worldwide after wheat, rice, maize and barley. It is mostly used for animal feeding and less utilized for human food. It is an important crop in sustainability and food security due to its adaptation to high temperatures and drought resistance (Khan *et al.*, 2013; Espinosa-Ramírez and Serna-Saldívar, 2016). It is being popularized due to its gluten-free properties and functional compounds (Kayitesi *et al.*, 2012). Different bioactive compounds such as flavonoids, phenolic acids and compressed tannins are present in sorghum. The phenolic acids of sorghum are found in endosperm, pericarp, testa, and aleurone layer. The phenolic acids in sorghum (such as vanillic acid, ferulic acid, and p-coumaric acid) are mostly found in the bran layer of the sorghum seed (Afify *et al.*, 2012; Dykes *et al.*, 2009). However, tannins are usually absent in most of the sorghum varieties (Chiremba *et al.*, 2009). Epidemiological studies have revealed that diets rich in phenolic compounds may have protective effects against various chronic diseases associated with oxidative stress, such as diabetes, cancer, and cardiovascular disease (Halliwell, 2008). Sorghum is also rich in various natural antioxidants with higher antioxidant activity. Sorghum phenols are high-quality antioxidants with excellent chelation and radical-scavenging abilities due to their favorable structural configurations (Yang *et al.*, 2009; de Oliveira *et al.*, 2017). Khan *et al.* (2013) found that antioxidant potential and resistant starch contents can be effectively enhanced in the product with the addition of red and white sorghum. This can further help to prevent chronic diseases related to oxidative stress such as type 2 diabetes mellitus, and improve intestinal health. The current research was conducted to develop sorghum based functional pasta. Furthermore, the prepared pasta product was evaluated for its cooking quality parameters, texture and sensory attributes of pasta.

Material and Methods

Procurement of Raw Materials

Wheat and sorghum grains were procured from the local market of Faisalabad, Punjab, Pakistan. Chemicals and Reagents were used of analytical standards (Merck, Germany).

Preparation of raw materials

The wheat and sorghum grains were cleaned to remove all the impurities and foreign matters. These grains were milled using a rotor mill followed by sieving to obtain a uniform particle size. Then, wheat and sorghum flour were packed in air tight bags (Parra *et al.*, 2015).

Preparation of Composite Flours

The composite flour blends were formulated by mixing the wheat flour with sorghum flour according to given treatment plan (Table 1).

Table 1: Preparation of composite flour

Treatments	Wheat flour	Sorghum flour
T_0	100	0
T_1	90	10
T_2	80	20
T_3	70	30
T_4	60	40

Functional Properties of Composite Flours

The water absorption capacity and oil absorption capacity of the composite flour blends were determined according to the protocol of Rana *et al.* (2015). with minor modifications. The water holding capacity of composite flours was measured using the centrifugation method. One gram of the composite flour sample was added to the pre-weighed centrifugation tubes. Then, 10 mL of distilled water was added in the tubes and mixed for 10 minutes using an orbital shaker. The resting time of 1hour was given to the samples at room temperature. The centrifugation tubes were adjusted in the tube holder of the centrifuge machine, and centrifugation was applied for 20 minutes at 5000 rpm. The supernatant was decanted, and excess water was allowed to drain for 15 minutes at 45 $^{\circ}$C. The oil absorption capacity of composite flours was also determined using the centrifugation method. One gram of composite flour sample and 10mL of soybean oil were added to the centrifugation tubes. The tube contents were stirred to mix the oil with sample using wire. The samples were shaken for 5 minutes using an orbital shaker and kept for 30 minutes at room temperature. The samples were put in a centrifugation machine and subjected to centrifugation for 20 minutes at 5000 rpm. The pipette was used to remove the oil and the tubes were inverted for 20 minutes at 45 $^{\circ}$C. The total oil contents were measured, and values were utilized for oil absorption capacity estimation. The water and oil absorption capacities were measured in grams of oil or water absorbed in grams of sample on a dry basis.

Falling Number

The falling number test was performed using Perten's falling number apparatus according to the protocol of AACC Method 56-81B (AACC, 2000). The falling number values provided the estimation of α-amylase activity and overall quality of the composite flours.

Pasta Preparation

The pasta products were prepared following the method of Gull *et al.* (2015). The basic ingredients utilized in pasta manufacturing were composite flour, oil, water and egg white. The pasta dough was prepared by hand mixing of all the ingredients in bowl for 15 minutes. After 30 minutes of dough resting, pasta dough was passed through sheeter and then sheets were passed through the die of Pasta Machine (Pasta drive, Marcato, Italy). The strip pasta was dried in dryer at 60 $^{\circ}$C until 7% moisture level.

Cooking properties of pasta

Cooking properties of pasta samples were evaluated according to the method reported by Gull *et al.* (2015). The different cooking parameters such as optimal cooking time, cooking loss and swelling index were quantified. The optimal cooking time was measured by observing the pasta strip in two glass slides during cooking. It was observed for disappearance of core during squeezing the strip between glass slides after every 30 seconds. Similarly, Pasta samples (10 g) were cooked in boiling water up to their optimum cooking time and then drained. The cooking water was collected in a pre-weighed evaporating dish and dried in a hot air oven at 105°C until constant weight. The residue obtained represented the total solid loss and was expressed as a percentage of the initial pasta weight using the following equation:

$$cooking\ loss = \frac{Weight\ of\ dried\ residue}{Weight\ of\ uncooked\ pasta} \times 100$$

The swelling index of cooked pasta samples was measured according to the protocol of Foschia *et al.* (2015) using following equation:

$$Swelling\ Index\ (SI) = \frac{Cooked\ pasta\ Weight\ (g) - After\ Drying\ Pasta\ Weight\ \ (g)}{After\ Drying\ Pasta\ Weight\ (g)}$$

Color Analysis

The pasta color analysis was performed using Lab Colorimeter (ColorTec-PCM, USA) following the method of (Khan *et al.*, 2022; Urooj *et al.*, 2026; Atique *et al.*, 2026) . The parameters L*, a*, and b* were measured at different points on the pasta in triplicate. The change in color (ΔE), chroma (C*), and whiteness index (WI) were calculated using the following formulas:

$$\Delta E = \sqrt{\left(L^* - L^*_{std}\right)^2 + \left(a^* - a^*_{std}\right)^2 + (b^* - b^*_{std})^2}$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

$$WI = 100 - \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2}$$

Here, std refers to the values of the control sample.

Texture Analysis

The texture of pasta was analyzed through texture analyzer (TA-XT2, Plus, Stable Microsystems, Surrey, UK) following the method of Islas-Rubio *et al.* (2014).

Sensory Evaluation

The sensorial properties of pasta samples were evaluated using a nine-point hedonic scale system where nine scales were arranged from extremely liking (9 points) to extremely disliking (1 point) following the protocol of Sirichokworrakit *et al.* (2015). The different sensory parameters such as appearance, color, taste, aroma, texture, after-taste and overall acceptability were evaluated against each pasta sample. This hedonic evaluation was conducted at National Institute of Food Science and Technology, University of Agriculture, Faisalabad. The sensory panelists were provided with separate cabins with provision of adequate white light. Sensory panelists were also provided with purified water and unsalted snacks to neutralize the mouth feel during evaluation. The samples were presented in secret coding and randomly to the panelists. The panelists assigned the hedonic scores against each parameter of each pasta sample.

Statistical Analysis

All the experiment was performed in triplicates and results are presented as means values along standard deviation. The data was analyzed by using one-way ANOVA through Statistics 8.1 software. The HSD Tukey's test, by keeping 5% level of significance, was used to check the extent of difference among treatments (Fatima *et al.*, 2025; Asif *et al.*, 2025b; Zahid *et al.*, 2025).

Results and Discussion

Functional properties of composite flours

Water absorption capacity (WAC) and oil absorption capacity (OAC) are important functional properties of food, which are associated with food quality. These properties of composite flour were determined, and the results are presented in Figure 1. Results revealed that increasing the concentration of sorghum in wheat flour significantly alters functional properties (oil and water absorption capacity). An increasing concentration of sorghum significantly increased the WAC of composite flour. It may be due to the high fiber and hydrophilic components present in sorghum flour. It also contains non-starch polysaccharides, proteins, and damaged starch granules, all of which enhance water binding. As sorghum concentration increases, more hydroxyl groups become available to interact with water molecules, thereby increasing water retention (Benhur *et al.*, 2015). A similar increasing trend was observed in OAC among the treatments. The enhancement in OAC is mainly due to the protein composition and non-polar side chains present in sorghum flour, which improve oil binding capacity. Proteins with hydrophobic amino acid residues can trap oil molecules, leading to higher OAC values. Moreover, sorghum flour contains lipophilic compounds and structural components that contribute to oil retention. The gradual increase in OAC from T_0 to T_4 suggests improved flavor retention and mouthfeel, which is beneficial for bakery and snack products. Ajanaku et al., (2012) have reported that the addition of sorghum flour to wheat flour confers high water binding capacity to wheat flour, which in turn improves the reconstitution ability and textural properties of the resulting dough.

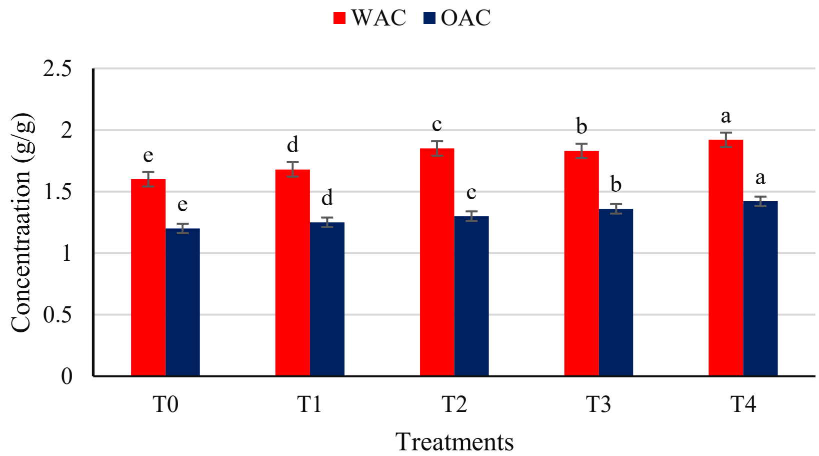

Figure 1. Water absorption and oil absorption capacities of composite flour

Falling Number

The Falling Number (FN) is an important indicator of flour quality, reflecting the level of α-amylase activity and the viscosity of starch paste. In the present study, the FN values of wheat–sorghum composite flours showed a progressive decline with increasing substitution of sorghum flour (T_0–T_4). The control sample (T_0), consisting of 100% wheat flour, exhibited the highest FN value (320 s), whereas the lowest value (250 s) was recorded for T_4 containing 40% sorghum flour. This decreasing trend indicates a significant effect ($p < 0.05$) of sorghum incorporation on the enzymatic and pasting behavior of the flour. The reduction in FN values can be attributed primarily to increased α-amylase activity and greater susceptibility of sorghum starch to enzymatic hydrolysis. Sorghum flour differs from wheat flour in both starch composition and protein structure, which influences its functional properties. The absence of gluten in sorghum leads to dilution of the gluten network in composite flours, resulting in weaker structural integrity and enhanced accessibility of starch granules to enzymatic attack. Consequently, starch degradation occurs more rapidly during the test, leading to lower viscosity and reduced FN values. In addition, sorghum flour contains higher levels of dietary fiber and damaged starch, which further contribute to the reduction in paste viscosity. Fiber interferes with starch gelatinization, while damaged starch increases water absorption and enzyme interaction. These combined effects accelerate the liquefaction of the starch paste, causing a faster descent of the plunger and thus lower FN readings. Gadallah *et al.* (2017) who reported that the falling number values of sorghum flour were significantly lower than that of wheat flour indicating higher damaged starch contents. Similarly, Mancebo *et al.* (2015) also elaborated that wheat flour contains less damaged starch content in comparison with other cereals.

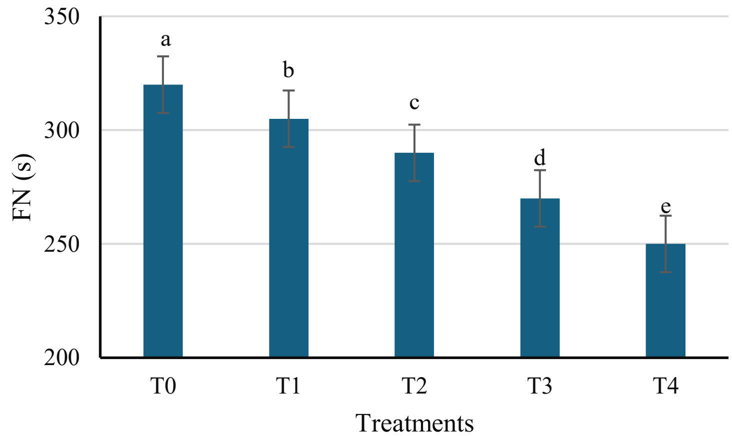

Figure 2. Graphical representation of Falling number of composite flours

Cooking characteristics of pasta

The cooking properties of pasta were determined, and the results are presented in Table 3. Results showed that the addition of sorghum significantly ($p<0.05$) affected the cooking properties of pasta. The optimum cooking time gradually increased from 8.0 min (T_0) to 9.0 min (T_4) as the proportion of sorghum flour increased. The increase in optimal cooking time can be attributed to the lower gluten content in sorghum compared to wheat. Gluten forms a viscoelastic network that allows pasta to soften faster during cooking. As sorghum content rises, the gluten network weakens, water absorption slows, and pasta requires a longer time to reach the desired texture (de Oliveira *et al.*, 2022).

Cooking loss also increased with higher levels of sorghum flour, from 5.2% in T_0 to 6.5% in T_4. Cooking loss refers to the number of solids lost into the cooking water, mainly starch and soluble proteins. The increase is due to the reduced gluten network in composite flour, which cannot hold starch granules as effectively during boiling. This aligns with findings reported in the literature (Khan *et al.*, 2014), who reported that partial substitution of wheat flour with gluten-poor cereals increases cooking loss. Although cooking time and cooking loss increase with sorghum substitution, the values remain within acceptable limits, suggesting that partial replacement (up to 40%) can produce nutritionally enriched pasta without severely compromising cooking quality.

The swelling index (SI) of pasta increased significantly ($p < 0.05$) with increasing levels of sorghum flour incorporation, ranging from 1.57 ± 0.031 in T_0 to 1.76 ± 0.034 in T_4. A gradual and consistent rise in SI was observed across all treatments (T_1–T_4), indicating enhanced water absorption capacity with higher substitution levels. The lowest swelling index in the control sample (T_0) can be attributed to the presence of a strong gluten network formed by wheat proteins, which restricts excessive water penetration and limits starch granule swelling. In contrast, the progressive increase in SI in sorghum-enriched samples is mainly due to the absence of gluten in sorghum flour, resulting in a weakened protein matrix that allows greater water (penetration) during cooking. Additionally, sorghum flour is rich in dietary fiber, which has high water-binding capacity. This contributes to increased hydration and swelling of the pasta matrix (Asif *et al.*, 2023b). The disruption of the continuous protein-starch network further facilitates starch gelatinization and expansion, leading to higher swelling index values. Moreover, the less compact structure formed in composite pasta enables more water uptake, thereby increasing the swelling behavior. These results are in line with the findings of Foschia *et al.* (2015) who reported that the swelling index of pasta increased by increasing the level of dietary fiber where addition of oat bran, psyllium and different types of inulin resulted in higher swelling index values than that of wheat semolina pasta.

Table 3. Effect of vary concentration on cooking quality parameters of pasta

Treatments	Optimal cooking time (min)	Cooking loss (%)	Swelling index (-)
T_0	8.0±0.52^{e}	5.2±0.04^{e}	1.57±0.031^{f}
T_{10}	8.3±0.51^{b}	5.6±0.07^{d}	1.61±0.032^{e}
T_2	8.5±0.47^{bc}	5.9±0.03^{c}	1.66±0.034^{d}
T_3	8.8±0.41^{ab}	6.2±0.01^{b}	1.71±0.035^{c}
T_4	9.0±0.43^{a}	6.5±0.05^{a}	1.76±0.034^{b}

Color Analysis

Color of fortified pasta was determined using a colorimeter in terms of L, a and b values. These values are used to determine the change in color, chroma, and whiteness index and results are depicted in the Figure 3. Results showed that the addition of varying concentrations of sorghum in pasta significantly alters the color. Increasing the sorghum concentration in pasta increased the change in color value by 9.11, 9.53, 10.35, and 11.48 times greater in T_1, T_2, T_3, and T_4, respectively, than the control sample. The addition of sorghum flour in pasta formulation leads to significant changes in color values, generally producing a darker and more reddish-brown product compared to 100% wheat pasta. This change is primarily attributed to the presence of natural pigments such as phenolic compounds, tannins, and flavonoids in sorghum, which reduce lightness (L*) and increase redness (a*). Additionally, the higher fiber content of sorghum contributes to a dull and less bright appearance by affecting light scattering (Asif *et al.*, 2023a). During processing and cooking, enhanced Maillard reactions between amino acids and reducing sugars further intensify browning, while enzymatic browning due to polyphenol oxidase activity may also contribute to color development (Asif *et al.*, 2025a). Moreover, the dilution of the gluten network in composite flour results in a less uniform structure, reducing light reflection and making the pasta appear more opaque (Evangelista *et al.*, 2025).

Similarly, the inclusion of sorghum significantly changes the chroma values of pasta. The increase in chroma value in sorghum-enriched pasta is mainly due to the higher content of natural pigments, enhanced Maillard browning, and fiber-induced optical effects, all of which contribute to a more intense and saturated color (Asif *et al.*, 2023b; Asif *et al.*, 2024). The increase in whiteness index of composite pasta with sorghum incorporation may be attributed to the dilution of wheat carotenoid pigments, finer particle size, and light scattering properties of sorghum flour, particularly when white sorghum varieties are used. The results of the current study are in line with prior findings by Khan et al. (2014).

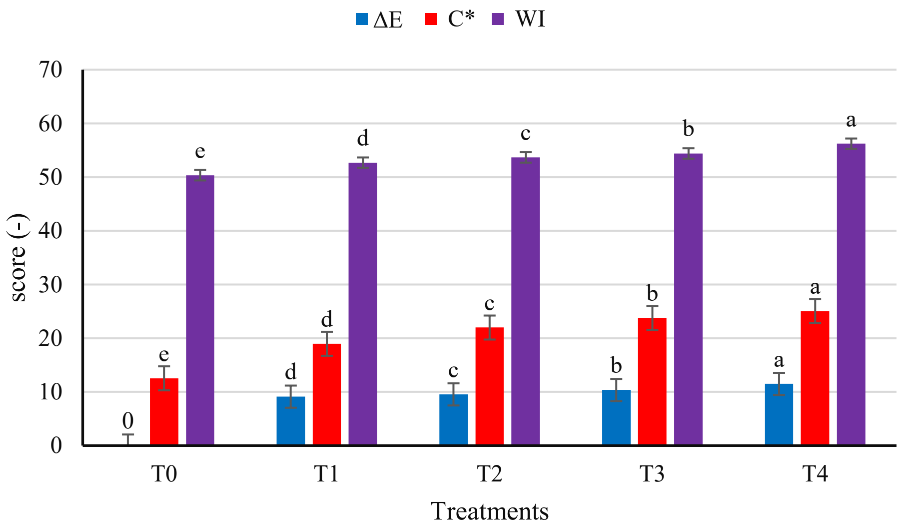

Figure 3. Effect of vary concentration of sorghum flour on change in color, chroma and whiteness index of pasta

Textural Analysis

The firmness of the pasta was determined through texture analyzer and results are depicted in Figure 4. It is evident from the results that the firmness of the pasta decreased with increasing the concentration of sorghum flour. The control sample had maximum firmness. The reduction in firmness of pasta with increasing sorghum flour is primarily due to the dilution of gluten, disruption of the protein-starch matrix, and higher fiber content, which collectively weaken the structural network and result in a softer cooked product. The results of the present study are in line with the findings of Khan et al. (2014) who analyzed textural characteristics of sorghum flour based functional pasta and postulated that the firmness of pasta decreased by increasing the sorghum flour level.

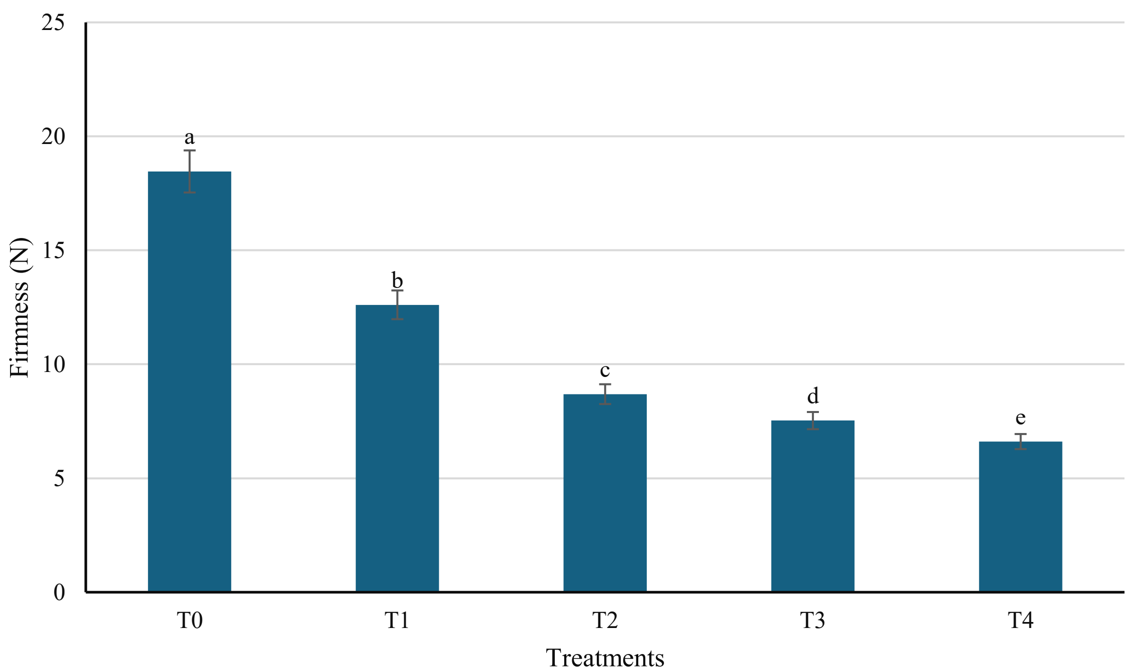

Figure 4. Graphical representation of firmness of fortified pasta

Sensory evaluation

The sensory characteristics of pasta prepared with varying levels of sorghum flour are presented in Figure 5. Incorporation of sorghum flour resulted in a gradual decline in color, texture, taste, and overall acceptability scores. The control sample (T_0; 100% wheat) exhibited the highest scores for color (8.5), texture (8.5), taste (8.4), and overall acceptability (8.5), while the highest sorghum substitution (T_4; 40% sorghum) recorded the lowest scores (6.5–6.4). The decrease in sensory scores with increasing sorghum content can be attributed to several factors. The darker color of sorghum flour reduced the visual appeal of pasta, resulting in lower color scores. Texture scores declined due to the absence of gluten in sorghum, which weakened the protein network and produced a softer, less elastic pasta (Alvarez-Jubete *et al.*, 2009). Taste was also affected by the inherent flavor of sorghum flour and the presence of phenolic compounds, which may impart a slightly different or less familiar taste. Consequently, the overall acceptability decreased with higher levels of sorghum incorporation. The results indicate that while sorghum can be used to enhance the nutritional profile of pasta, its incorporation should be balanced to maintain desirable sensory quality. A decrease in sensory score of sorghum flour added durum wheat for bakery products was also observed by Khan *et al.* (2014). However, Yousif *et al.* (2012) reported that white sorghum flour flat bread scored higher hedonic response than that of the wheat flour flat bread.

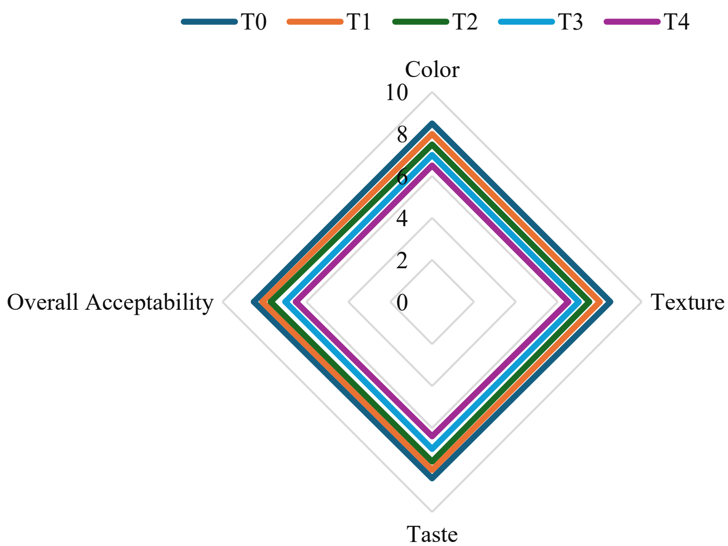

Figure 5. Graphical representation of sensory attributes of pasta

Conclusion

This study demonstrated that partial substitution of wheat flour with sorghum flour (10–40%) affects the cooking, textural, and sensory properties of pasta. Increasing sorghum flour levels resulted in a reduction in firmness and textural quality due to the absence of gluten, while the swelling index increased as a result of higher water absorption and starch gelatinization from fiber-rich sorghum flour. Sensory evaluation showed a decline in color, texture, taste, and overall acceptability, with the highest substitution level (40% sorghum) being the least preferred. Despite these changes, sorghum flour can be incorporated into wheat pasta to improve its nutritional value and dietary fiber content. For acceptable cooking quality and consumer preference, a sorghum substitution level of 10–20% is recommended. These findings suggest that sorghum-enriched pasta can serve as a functional food product with potential health benefits while maintaining desirable sensory and cooking properties.

Conflict of interest

The authors declare no conflict of interest.

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