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DEVELOPMENT OF SAFFRON ENRICHED DURUM WHEAT SEMOLINA TAGLIATELLE: IMPACT ON NUTRITIONAL, PHYSICOCHEMICAL, AND SENSORY PROPERTIES

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Abstract: Saffron (*Crocus sativus* L.), widely recognized for its strong antioxidant and neuroprotective properties, has recently attracted growing interest as a functional ingredient capable of enhancing both health benefits and sensory quality in food products. This study aimed to formulate a functional food by incorporating saffron (*Crocus sativus*) extracts at concentrations of 0.03% and 0.06% into durum wheat semolina pasta (Tagliatelle). The effects of saffron incorporation on the pasta's nutritional composition, cooking properties, texture, color, and sensory attributes were evaluated using standard analytical methods. The results showed no significant changes in protein, lipid, or moisture levels compared to the control, while a significant increase in ash content was observed. Additionally, saffron addition led to a significant reduction ($P < 0.05$) in optimal cooking time (OCT), water absorption index (WAI), and swelling index (SI). In terms of color, saffron significantly increased yellowness (b*) and redness (a*), while decreasing lightness (L*). Textural analysis revealed no significant changes in cohesiveness, gumminess, adhesiveness, or chewiness. Sensory evaluation showed improved consumer acceptance of color, taste, and odor, with the 0.06% saffron concentration achieving the highest overall preference.

Keywords: Saffron, Enriched Tagliatelle, Durum wheat semolina, Nutritional properties, Sensory evaluation, Textural analysis.

INTRODUCTION

Dry pasta is one of the most popular and essential staple foods, consumed globally by people of all ages and socio-economic backgrounds. Its widespread appeal is due to its culinary versatility and its practical advantages in terms of transport, storage, and long shelf life (Gupta *et al.,* 2021). Traditionally, durum wheat is the preferred cereal for pasta production because of its high protein content and desirable cooking qualities. However, there is growing interest in using alternative ingredients, including food by-products such as soft wheat flour, barley semolina, sorghum, rye, rice, quinoa, corn, and millet flour, to replace or supplement durum wheat (Bustos *et al.,* 2011).

In recent years, there has been a significant shift in human nutrition, with increased awareness of the potential health risks associated with synthetic additives, colorants, and antioxidants. These substances have been linked to toxigenic, mutagenic, and carcinogenic effects, leading to growing consumer demand for healthier, functional foods that offer nutritional benefits (Cutillo *et al.,* 2021). In response to this trend, organizations such as the World Health Organization and the Food and Drug Administration have endorsed fortifying foods with non-conventional products to enhance their nutritional value.

One such non-conventional ingredient that has garnered attention is saffron, derived from the perennial herbaceous plant *Crocus sativus*, which belongs to the Iridaceae family and is extensively cultivated in Iran, India, and Greece (Hosseinzadeh *et al.,* 2008). Saffron is renowned for its medicinal, culinary, and coloring properties, primarily due to its bioactive constituents, including crocetin, crocin (a colorant), safranal (responsible for its spicy aroma), and picrocrocin (which imparts a bitter taste). Additionally, saffron is rich in nutraceuticals such as minerals, sugars, and vitamins B1 and B2 (Garavand *et al.,* 2019).

Saffron is not only used as a spice in main courses but also as a natural food additive to enhance the color and flavor of various foods. Its bioactive and sensory properties are primarily derived from the three key compounds: crocin, picrocrocin, and safranal, which are synthesized during the flowering and processing stages (Armellini *et al.,* 2019). Beyond their technological significance, numerous studies have demonstrated that saffron exhibit potent neuroprotective effects through antioxidant, anti-inflammatory, and anti-apoptotic mechanisms, contributing to improved cognitive function and overall neurological well-being including depression, Alzheimer and Parkinson's disease (Nanda *et al.,* 2021; Lai *et al.,* 2025; Tufail *et al.,* 2025). This emerging evidence highlights saffron as a valuable functional ingredient, suggesting that its incorporation into food products may offer not only sensory benefits but also scientifically supported health-promoting properties, particularly in the context of neuroprotection.

The objective of this study is to comprehensively assess the effects of saffron extract on the properties of

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durum wheat pasta. This research includes an in-depth analysis of culinary quality parameters, such as cooking losses, cooking time, water absorption, and swelling index. By integrating physicochemical analyses, sensory evaluations, and consumer acceptability assessments, the study aims to explore the potential of saffron-enriched durum wheat pasta, thereby opening new avenues for innovation in the pasta industry.

MATERIALS AND METHODS

Raw materials

The ingredients used for pasta preparation were durum wheat semolina and water. The durum wheat semolina, a high-quality fine semolina from the brand "SIM", was purchased from a local market. The mineral water used was from the brand "Sidi Rached", with a pH of 7.39. Saffron was supplied by the saffron producer "Safran Tariki" from the Constantine province of Algeria, as part of the Saffromfood PRIMA research project. The saffron was collected and transported to the Laboratory of Applied Biochemistry in a hermetically sealed glass container covered with steel. It was stored at -20°C until use.

Pasta production

The pasta produced was of the Tagliatelle type, prepared using a PAMA–Roma semi-industrial machine. Three types of pasta were manufactured: a control pasta made from 100% durum wheat semolina and two saffron-enriched pastas containing saffron extract at concentrations of 0.03% and 0.06%.

The saffron extract was prepared by first grinding the saffron stigmas and then mixing them with mineral water. The mixture was stirred using a magnetic stirrer to achieve a homogeneous solution. For the control pasta, the ingredients consisted of semolina and water, while for the saffron-enriched pasta, semolina and saffron extract were used. These ingredients were mixed for 10 minutes to form a smooth and homogeneous dough.

The dough was then extruded through a screw into a bronze die with 3 mm holes to shape the final Tagliatelle. The wet pasta was pre-dried using a ventilation system to prevent sticking and deformation, ensuring that the surface of the product remained intact. The pasta was then transferred to a drying room, where it was dried at a high temperature (80°C) for 12 hours. After drying, the pasta was cooled before being packed and stored.

Determination of nutritional composition of pasta

The moisture content of the pasta was determined according to the AOAC official method 925.09 (AOAC:925.09 1998). Protein content was estimated using the Kjeldahl method, while lipid and ash contents were determined following the official methods outlined by the Srigley *et al.,* (2017) and Marshall (2010), respectively.

Total, insoluble, and soluble fiber were measured using enzymatic and gravimetric methods (Lee *et al.,* 1992). Firstly, starch and proteins in the pasta samples were eliminated by heating them with thermostable α-amylase. The samples were then enzymatically digested with protease and amyloglucosidase. To precipitate soluble fibers, ethanol was added and the residue was subsequently filtered and washed with ethanol and acetone. After drying, the residues were weighed. Half of the samples were analyzed for crude protein content, while the other half were incinerated to determine ash content. All measurements were performed in triplicate. The carbohydrate content was calculated using the following formula:

Carbohydrates (%) = 100 − (Moisture% + Crude Protein% + Crude Fat% + Ash%)

Cooking properties of Tagliatelle

Optimal cooking time

The pasta was cooked following the protocol of Guo *et al.,* (2020). An aliquot of 10g of Tagliatelle was placed into a beaker containing 500 ml of boiling distilled water, and the beaker was then placed on a heating plate set to 100°C. Pieces of pasta were removed every 15 seconds during cooking and squeezed between two transparent plastic plates to check for the disappearance of the white core, indicating the optimal cooking time.

Swelling index

The swelling index provides information on the water absorption capacity of pasta. The procedure for preparing the samples for the determination of the swelling index was the same as that described in the section for determining the optimal cooking time. After draining the cooked pasta at the optimal cooking time, it was directly weighed (W_1). The pasta was then dried in an air oven at 105°C, and the weight after drying was recorded (W_2). The swelling index (SI) was calculated using the following formula:

$$SI(\%) = \frac{W_1}{W_2}$$

Where W_1 is the weight of cooked pasta (g) and W_2 is the weight of cooked pasta after drying (g).

Cooking loss

Total cooking loss (CL) was estimated using the method described by Guo *et al.,* (2020). Briefly, 100 ml of the cooking water was evaporated to dryness in beakers at 105°C in an air oven. The percentage of cooking loss was then calculated using the following formula:

$$CL(\%) = \left(\frac{W_3}{\mathrm{W}\ (1 - \mathrm{M})}\right) \times 100$$

Where W_3 is the weight of dry residue (g), W is the weight of uncooked pasta (g), and M is the moisture of uncooked pasta.

Water absorption

The water absorption (WA) of the pasta sample was evaluated by weighing the sample immediately after cooking and then weighing it again after drying. Water absorption was measured using the following formula:

$$WA(\%) = \frac{(W_1 - \mathrm{W})}{W} \times 100$$

Where W is the weight of uncooked pasta and W_1 is the weight of cooked pasta (g). *Color evaluation*

The color of both cooked and uncooked pasta was measured using a colorimeter (PCE-XXM 30, Germany) on ground and sieved samples. The L*, a*, and b* color coordinates were recorded. The L* scale ranges from 0 (black) to 100 (white), the a* values indicate red hues when positive and green hues when negative, and the b* values indicate yellow hues when positive and blue hues when negative. Each sample was measured in triplicate. The color difference (ΔE) and yellowness index (YI) were calculated using the following formulas:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

$$YI = 142.86\, b^*/L^*$$

Texture of pasta

The texture of the pasta was evaluated using a modified version of the AACC:66-50 (2000). First, 10 g of Tagliatelle was cooked in boiling water to the optimal cooking time. Texture measurements were then carried out using Texture Profile Analysis (TPA) with a texturometer (Lloyd Instruments, USA). The cooked pasta were analyzed by compression, using a cylindrical stainless-steel probe (2 mm in diameter) at a speed of 1 mm/s and a force of 70 N. TPA graphs were used to measure various parameters, including hardness (N), elasticity (mm), adhesiveness (N), mastication, and cohesiveness. All measurements were performed in triplicate.

Sensory evaluation

Sensory evaluation was conducted on both control and saffron-containing Tagliatelle. Pasta samples were cooked to the optimal cooking time, and 10 g portions were presented to panelists on plastic plates. The evaluation took place at the Laboratory of Sensory Analysis at the University of Bejaia, involving 120 participants, including students and university employees aged 19 to 56, along with 8 expert panelists.

The parameters evaluated included color, stickiness, smoothness, flavor, chewability, consistency, odor, taste, and texture. The intensity of each sensory perception was rated on a scale from 1 to 5, with 1 representing very low intensity and 5 representing very high intensity. The overall preference for pasta was examined using a nine-point hedonic scale, where was extremely unpleasant, very unpleasant, moderately unpleasant, slightly unpleasant, neither pleasant nor unpleasant, slightly pleasant, moderately pleasant, very pleasant, and extremely pleasant, according to their preferences.

Statistical analysis

Statistical analysis was conducted using Statistica software (version 7.1). Fisher's Least Significant Difference (LSD) test was applied to compare the means of each parameter, with significance set at $p < 0.05$. Sensory analysis data were analyzed using XLStat software (version 2014.5.03).

RESULTS AND DISCUSSION

Chemical composition

The nutritional composition data and color characteristics of control Tagliatelle and Tagliatelle enriched with saffron at concentrations of 0.03 and 0.06% before and after cooking are presented in Table 1. These low inclusion levels were selected based on previous findings demonstrating that saffron exhibits notable biological and sensory effects even at modest doses. Clinical studies have shown that daily intakes as low as 15 mg are safe and effective for improving mild to moderate depression and anxiety over a six-week period, illustrating the potency of saffron's bioactive compounds even at minimal quantities (Omidkhoda *et al.,* 2022). Although some investigations have incorporated higher concentrations in food matrices, such as 0.2–0.4%, which enhanced antioxidant activity and improved pasta's sensory attributes including color and flavor (Armellini *et al.,* 2018), such levels substantially increase production costs due to the high market value of saffron, one of the most expensive spices worldwide. Therefore, using 0.03 and 0.06% provides a practical balance between maintaining consumer affordability, ensuring cost-effective formulation, and still achieving desirable functional and sensory enhancements. Moreover, evidence shows that saffron and its constituents, particularly safranal, exert dose-dependent neuroprotective and antiepileptic effects in vivo at concentrations ranging from 400 to 800 mg/kg, confirming the broad efficacy of saffron across diverse dose ranges (Hosseinzadeh *et al.,* 2002; Mir *et al.,* 2022). Collectively, these considerations justify the selected doses, ensuring that the pasta benefits from saffron's sensory and potential health-promoting properties while remaining economically viable.

In the uncooked Tagliatelle, the moisture content shows a slight but non-significant decrease with the addition of saffron, ranging from 7.92 g/100 g DM in the control to 7.24 g/100 g DM in the 0.06% saffron formulation. After cooking, the moisture content increases across all samples, as expected, with the control showing the highest moisture content at 13.45%, which is significantly different from the 0.06% saffron formulation (11.88%). This indicates that the addition of saffron slightly reduces moisture absorption during cooking. In a previous study, it was also demonstrated that the addition of saffron did not significantly affect the moisture content of the cookies, with minor variations noted across different concentrations. This suggests that saffron does not heavily impact the moisture retention properties of the product. Conversely, Bhat *et al.,* (2018) revealed that saffron enrichment generally decreases moisture content, as observed in cheese, where moisture levels dropped in saffron-fortified samples compared to the control.

Table 1.
Concentrations of major constituents and color parameters of uncooked and cooked Tagliatelle containing 0.03% and 0.06% saffron compared to the control

Main components	Cooking	% of saffron in pasta formulation		
		0	0.03	0.06
Moisture (%)	Uncooked	7.92±0.69[c]	7.34±0.37[c]	7.24±0.56[c]
	Cooked	13.45±0.76[a]	12.48±0.83[ab]	11.88±0.81[b]
Ash (g/100g DM)	Uncooked	1.73±0.29[b]	1.94±0.21[ab]	2.22±0.26[a]
	Cooked	1.72±0.04[b]	1.84±0.21[b]	2.21±0.06[a]
Proteins (g/100g DM)	Uncooked	12.60±0.13[b]	12.71±0.03[ab]	12.77±0.26 [ab]
	Cooked	13.43±0.87[a]	13.20±0.2[ab]	13.06±0.25[ab]
Lipids (g/100g DM)	Uncooked	0.38±0.02[a]	0.23±0.02[b]	0.29±0.04[ab]
	Cooked	0.22±0.03[b]	0.23±0.02[b]	0.26±0.10[b]
Carbohydrates (g/100g DM)	Uncooked	71.97±3.23[ab]	73.48±2.43[a]	72.38±4.32[ab]
	Cooked	65.48±1.87[c]	65.91±2.54[c]	67.17±3.21[bc]
Total fiber (g/100g DM)	Uncooked	5±0.46[a]	4.3± 0.43[a]	5.6±2.02[a]
	Cooked	5.7±2.99[a]	6.5±0.56[a]	5.5±0.13[a]
Soluble fiber (g/100g DM)	Uncooked	2.2± 0.67[a]	1.7±0.38[a]	1.9±0.86[a]
	Cooked	2.3±1.13[a]	2.50±0.05[a]	3.2±1.16[a]
Insoluble fiber (g/100g DM)	Uncooked	3.1±1.13[b]	2.6±0.05[ab]	3.2±1.16[ab]
	Cooked	3.41±0.45[ab]	3.97±0.23[ab]	4.53±0.1[a]
Color parameters				
L*	Uncooked	85.89±2.91[a]	82.88±1.66[ab]	81.84±2.72[b]
	Cooked	83.79±1.86[ab]	81.9±1.23[ab]	80.33±1.84[b]
a*	Uncooked	0.7±0.24[d]	3.73±0.72[b]	5.97±0.66[a]
	Cooked	1.62±0.15[c]	2.43±0.71[c]	3.94±0.46[b]
b*	Uncooked	25.21±1.22[e]	69.43±4.96[c]	88.61±2.2[a]
	Cooked	22.63±1.4[e]	64.95±1.28[d]	84.55±2.24[b]
YI	Uncooked	41.93	119.68	156.42
	Cooked	38.58	113.29	150.36
∆E	Uncooked	/	44.43	42.37
	Cooked	/	64.74	62.06

Results are expressed as Mean ± SD; DM: dry matter; ΔE: color difference; YI: yellowness index; Color parameters: L (lightness), a* (green to red), and b* (blue to yellow); Values for each parameter in uncooked and cooked states, marked with different letters, are statistically different (ANOVA-LSD test, p<0.05, where a > b > c > d).*

The ash content in the uncooked Tagliatelle increases with the addition of saffron, from 1.73 g/100 g DM in the control to 2.22 g/100 g DM in the 0.06% saffron formulation. After cooking, the ash content remains relatively stable across all samples, with the highest value still observed in the 0.06% saffron formulation (2.21 g/100 g DM). The statistical analysis confirms that the increase in ash content due to saffron is significant. Saffron fortification can increase ash content, reflecting the presence of additional minerals or inorganic matter from saffron, as demonstrated in saffron-supplemented cheese (Bhat *et al.,* 2021). However, in cookies enriched with saffron extract, the ash content did not significantly differ from the control cookies. Ash values ranged from 1.14 to 1.52%, indicating minimal variation between the saffron-treated and control groups. This suggests that saffron addition does not substantially impact the mineral content of cookies (Bhat *et al.,* 2018).

In the uncooked Tagliatelle, the protein content shows a slight increase with the addition of saffron, ranging from 12.60 g/100 g DM in the control to 12.77 g/100 g DM in the 0.06% saffron formulation, although this increase remains statistically insignificant. After cooking, the protein content increases slightly across all samples, with the control sample having the highest value of 13.43 g/100 g DM. However, the protein content of the saffron-containing samples is not statistically different from the control. This suggests that while cooking generally increases protein content, the addition of saffron does not significantly affect protein levels in the pasta, as the differences are not statistically significant. Protein levels may remain stable despite saffron addition, as the protein content of saffron-fortified kradi cheese was not significantly different from the control (Bhat *et al.,* 2021). A similar trend was observed in functional cakes rich in bioactive compounds extracted from saffron, where an increase in protein content was noted after heat treatment (Bhat *et al.,* 2022).

In the uncooked Tagliatelle, the lipid content shows a slight decrease with the addition of saffron, ranging from 0.38 g/100 g DM in the control to 0.23 g/100 g DM in the 0.03% saffron formulation. After cooking, the lipid content decreases slightly across both the control and 0.06% saffron-containing samples, with values ranging from 0.22 g/100 g DM to 0.26 g/100 g DM. These values are statistically similar, indicating that cooking tends to reduce lipid content and that the presence of saffron does not significantly influence this reduction. The fat content may not show significant variation with saffron addition, as seen in some studies where saffron did not significantly affect lipid levels (Bhat *et al.,* 2021).

Carbohydrates are the predominant component in Tagliatelle. They show a slight increase in content with the addition of saffron, particularly in the Tagliatelle enriched with 0.03% saffron. However, statistical analysis reveals that the carbohydrate content significantly decreases after cooking, with an average reduction of 9%.

The total fiber content remains relatively stable across all uncooked samples, with values ranging from 4.3 to 5.6 g/100 g DM. After cooking, there is an insignificant slight increase in total fiber content in the control and 0.03% saffron formulation. This suggests that the addition of saffron has minimal impact on total fiber content in both uncooked and cooked pasta.

The soluble fiber content remains consistent across all uncooked and cooked samples, with no statistically significant differences observed. In uncooked samples, values range from 1.7 to 2.2 g/100 g DM, while in cooked samples, they range from 2.3 to 3.2 g/100 g DM. This indicates that the addition of saffron does not significantly alter the soluble fiber content in Tagliatelle.

The insoluble fiber content varies slightly among the uncooked samples. After cooking, the insoluble fiber content increases slightly in all samples, with the 0.06% saffron formulation showing the highest value (4.53 g/100 g DM). The addition of saffron tends to increase insoluble fiber content depending on the supplemented concentration and cooking, though these increases remain statistically insignificant. This is consistent with the findings of Bhat *et al.,* (2021), who observed that saffron-enriched *kradi* cheese samples exhibited increased firmness, which could be attributed to the higher fiber content in saffron powder, containing about 5% fiber.

The L* value slightly decreases with the addition of saffron in both uncooked and cooked Tagliatelles, indicating that the color tends to become darker as more saffron is added. Alternatively, the a* value increases significantly with the addition of saffron, with the highest value observed in the 0.06% saffron formulation for both cooked and uncooked pasta. Similarly, the b* values of both uncooked and cooked Tagliatelles also increase significantly with saffron addition, with the 0.06% formulation showing the highest values. This suggests that the enhanced redness and yellowness of the enriched product are primarily due to the presence of crocins, the key compounds responsible for saffron's characteristic color. The ΔE and YI values confirm that the addition of saffron leads to significant changes in color, making the pasta more red and yellow.

The lightness and yellowing of pasta are attractive quality attributes that significantly influence consumer perceptions. The L* parameter, directly related to sample clarity, showed a significant decrease ($P < 0.05$) with increasing saffron extract fortification in raw pasta compared to the control, indicating that the samples became darker. The dark color of most enrichment ingredients, along with the oxidation of carotenoid pigments due to the high oxygen permeability of enriched pasta and the non-enzymatic browning of reducing sugars, contributed to the reduced brightness observed with enrichment (Mercier *et al.,* 2016).

A significant increase in redness (a*) and yellowness (b*) was noted in uncooked pasta samples with higher concentrations of saffron extract ($P < 0.05$). The increase in a* and b* parameters was likely due to the high carotenoid content, particularly crocins, a symmetrical apocarotenoid where the two carboxylic groups of the C-20 carotenoid crocetin are esterified with the disaccharide gentiobiose. Crocins and crocetin are the primary carotenoid pigments responsible for the golden yellow color of saffron. Similar results for the a* and b* parameters were obtained by Armellini *et al.,* (2019) in uncooked and cooked fresh pappardelle pasta enriched with saffron.

According to Mokrzycki *et al.,* (2012), if ΔE is greater than 3.5 between two samples, an experienced observer can detect a color deviation. Thus, the results of our study suggest that saffron-enriched pasta samples were distinguishable from the control sample, perceptible to the naked eye. To gain further insight into how saffron affects yellowing, the yellow index (YI) was evaluated. This parameter is particularly important for pasta and should be greater than 30, according to Teterycz *et al.,* (2019). The data showed that YI increased with the proportion of enrichment, and this increase was also observed in cooked pasta.

Optimal cooking time of Tagliatelle

The optimal cooking times of the control and saffron-enriched Tagliatelle are illustrated in Fig. 1. The optimum cooking time is one of the primary technological parameters to be evaluated and is defined as the time required for the center of the pasta to disappear under pressure between two glass plates (Espinosa-Solis *et al.,* 2019). Our data revealed that saffron addition significantly ($P < 0.05$) reduced cooking time, decreasing from 9.9 minutes for the control to 8.90 minutes for pasta with 0.03% saffron and 7.93 minutes for pasta with 0.06% saffron. This aligns with the findings of Covaliov *et al.,* (2022), who reported a decrease in optimal cooking time with the addition of red bell pepper and parsley leaves to pasta. Cooking time is generally associated with the hydration of macromolecules such as wheat gluten and starch granules (Wagner *et al.,* 2009).

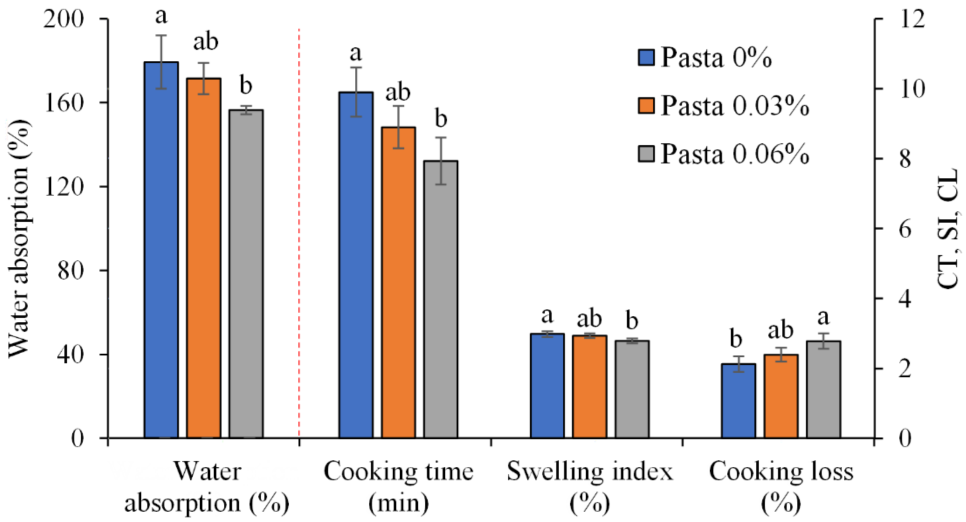

Fig. 1. Cooking properties of Tagliatelle: cooking time, swelling index, water absorption capacity, and cooking loss of control pasta and pasta samples with 0.03% and 0.06% saffron extract. *CT, Cooking time (minutes); SL, Swelling index; CL, Cooking loss; Results for each parameter with different letters are statistically different (ANOVA-LSD test, p < 0.05, where a > b).*

This behavior could be attributed to changes in the chemical composition and microstructure of the pasta due to the addition of saffron extract. The hydrophilic compounds in saffron, particularly crocin and picrocrocin, likely compete for water uptake. This competition may cause physical disturbances in gluten network formation, facilitating water penetration into the starch granules, accelerating gelatinization, and thus reducing the cooking time.

Swelling index

The Swelling Index (SI) of pasta, measured as grams of water absorbed per gram of dry pasta, is influenced by the types of ingredients used and their ability to competitively absorb and retain water during cooking (Krishnan *et al.,* 2012). As shown in Fig. 1, the SI values decreased from 2.98% in the control sample to 2.93 and 2.78% in pasta with 0.03% and 0.06% saffron extract, respectively. The decrease was statistically significant ($P < 0.05$) with increasing saffron concentration.

The reduction in the swelling index in saffron-enriched pasta can be attributed to the hydrophilic nature of saffron. Saffron molecules likely absorb water preferentially, limiting starch expansion and water uptake, which in turn modifies the pasta's texture. This phenomenon is consistent with findings related to water absorption (Ali *et al.,* 2022).

Cooking losses of Tagliatelle

According to Sant'Anna *et al.,* (2014), measuring solid loss (or cooking loss) is an important parameter in assessing the overall quality of pasta. The authors revealed that during pasta cooking, soluble starch components and other elements, such as non-starch polysaccharides, leach into the water, causing the cooking water to turn cloudy and thicken.

Our data, presented in Fig. 1, revealed that the introduction of saffron extract in the production of Tagliatelle resulted in a slight increase ($P > 0.05$) in cooking losses, with values of 2.33 and 2.41% for pasta enriched with 0.03 and 0.06% saffron, respectively, compared to 2.12% for the control. This increase may be attributed to the leaching of saffron molecules, particularly water-soluble carotenoids such as crocin, as evidenced by the yellowish color of the cooking water in both enriched samples (Gaglio *et al.,* 2019).

However, the losses were not statistically significant due to the high-temperature drying process (80°C), which promotes protein coagulation and the formation of a stronger gluten network before cooking (Cimini *et al.,* 2021). All the samples in this study can be considered of high quality, with low cooking losses of less than 8%.

Water absorption capacity of Tagliatelle

Water absorption reflects the ratio of the weight of cooked pasta to its weight before cooking (Reddy Surasani *et al.,* 2019). This is an important quality parameter for assessing the cooking quality of pasta (Gull *et al.,* 2017), as it is primarily linked to starch gelatinization and gluten network swelling during cooking (Guo *et al.,* 2020).

Our results (Fig. 1) showed that increasing the saffron extract concentration in the formulation of Tagliatelle significantly ($P < 0.05$) decreased their water absorption capacity. The values decreased from 179.36% in the control to 171.5 and 156.4% in pasta containing 0.03 and 0.06% saffron extract, respectively. This reduction in water absorption could be explained by the addition of saffron extract. Saffron, being rich in hydrophilic carotenoids, competes with starch and gluten for water absorption, which not only reduces the cooking time but may also lessen post-cooking weight since shorter cooking times decrease water absorption in pasta (Michalak-Majewska *et al.,* 2020).

Texture properties of Tagliatelle

Textural attributes are crucial in determining the cooking quality of pasta and play a significant role in consumer acceptance (Espinosa-Solis *et al.,* 2019). According to ISO:7304-2 (2008), these attributes include the product's response to five primary characteristics: hardness, cohesion, viscosity, elasticity, and adhesiveness. The textural characteristics of pasta are presented in Table 2. The results show that the incorporation of saffron extract at 0.03 and 0.06% in the pasta did not induce any significant (P > 0.05) variation in cohesion, gumminess, chewiness, resilience, or stringiness compared to the control pasta.

Similarly, the sensory analysis of texture attributes, such as stickiness, softness, consistency, and smoothness, showed no significant differences. Consumers perceived only a slight difference between saffron-enriched pasta and the control, concluding that the addition of saffron extract, up to a concentration of 0.06%, does not cause any significant changes in the texture of Tagliatelle.

Table 2.

Textural properties of control pasta and pasta formulations enriched with 0.03% and 0.06% saffron extract

Parameters	% of saffron in pasta formulation		
	0	**0.03**	**0.06**
Hardness[1] (N)	114.04±4.69^a	122.21±12.28^a	110.67±9.99^a
Hardness[2] (N)	78.23±10.14^a	86.50±10.38^a	76.35±13.2^a
Adhesive Force (N)	-7.36±1.51^a	-9.03±3.55^a	-5.25±1.41^a
Cohesiveness (N)	0.31±0.03^a	0.32±0.04^a	0.34±0.08^a
Adhesiveness (N)	6.75±2.66^a	5.11±1.41^a	5.63±3.37^a
Gumminess (N)	35.15±4.58^a	39.63±6.60^a	37.35±11.38^a
Springiness (mm)	-0.70±0.05^a	-0.65±0.06^a	-0.73±0.07^a
Chewiness (N)	19.77±2.60^a	23.17±4.49^a	21.08±8.14^a
Resilience	0.28±0.02^a	0.33±0.04^a	0.30±0.06^a
Fracture (N)	71.90±16.72^a	93.14±36.11^a	93.41±19.45^a

Results are expressed as Mean ± SD; Values for each parameter in uncooked and cooked states, marked with different letters, are statistically different (ANOVA-LSD test, p<0.05, where a > b > c > d).

Sensory quality of Tagliatelle

The biplot (Fig. 2) represents the sensory evaluation of control samples and pasta with different saffron concentrations (0.03 and 0.06%), displayed on a multicolored map to visualize overall consumer acceptance and sensory attributes. The map has two axes, F1 and F2, which together explain 99.63% of the data variability. F1 accounts for 89.43% and is the primary axis for differentiating among the samples, while F2 explains an additional 10.2%.

The plot shows that sample A (Control) is centrally positioned, indicating a balance among various sensory attributes. Sample B (0.03% Saffron), though situated in the red zone, is slightly to the left of the control, suggesting minor variations in the perception of certain sensory attributes compared to the control. Sample C (0.06% Saffron) is located further to the right, which may indicate an increased perception of certain attributes, such as color, due to the higher saffron concentration. The proximity of the distribution points for these attributes to sample C suggests that higher saffron concentrations may significantly enhance these sensory characteristics.

Saffron appears to enhance odor, taste, and color profiles of the pasta, with color being particularly affected due to saffron's strong natural dye properties. This is evident from the plot, where color intensity increases with higher saffron concentrations, especially in sample C, which is further to the right. Crocetin and its glycosidic derivatives (crocins) give saffron its characteristic reddish-yellow and red hues, making saffron a commonly used food colorant (Allahdad *et al.,* 2020).

Similar results were observed by Gaglio *et al.,* (2019) in saffron-enriched yogurt, where the most notable differences between the control and saffron-enriched yogurt were in color, odor intensity, and taste, which are desirable traits for consumer acceptance. Stickiness, chewiness, consistency, and smoothness are texture-related attributes that are crucial in pasta and significantly affect consumer preferences (Hou 2010). These attributes may be slightly altered with increasing saffron concentrations, as suggested by the proximity of the text labels to sample C. This could imply that higher saffron concentrations not only affect flavor and color but also subtly impact texture, possibly making the pasta slightly stickier or modifying its chewiness. The transition of colors from blue to yellow to red across the graph indicates a scale of consumer acceptance from low to high. Notably, all samples fall within the red zone, indicating high acceptance.

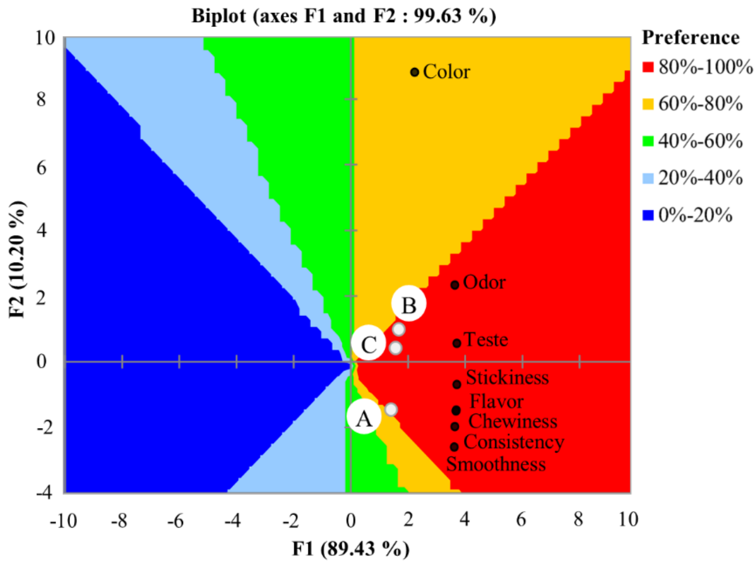

Fig. 1. Preference map (PREFMAP) of sensory profiling data for Tagliatelle. Samples. *A (control without saffron), B (enriched with 0.03% saffron), and C (enriched with 0.06% saffron); the different colors represent the percentages of sensory acceptability: blue (0%-20%), cyan (20%-40%), green (40%-60%), yellow (60%-80%), and red (80%-100%); the evaluated sensory attributes include color, odor, taste, stickiness, flavor, chewiness, consistency, and smoothness.*

CONCLUSION

This study highlights the various effects of adding saffron extract to durum wheat Tagliatelle, focusing on the nutritional, culinary, textural, and sensory qualities of the finished product. The results demonstrated that the moisture content of the products falls within the standard range (7-11%), with saffron addition slightly reducing moisture absorption during cooking. A significant increase in the levels of ash and protein was observed in saffron-enriched pasta, although the impact on protein content was minimal after cooking.

The incorporation of saffron extract enhanced the culinary quality of the pasta by reducing the optimal cooking time, particularly using the higher saffron concentrations. Additionally, saffron-enriched pasta exhibited a significant decrease in swelling index and water absorption capacity, likely due to the hydrophilic properties of saffron competing with starch and gluten for water absorption.

Saffron also significantly impacted the color of the pasta, increasing its yellowness and redness, as indicated by the higher b* and a* values compared to the control. The distinct reddish-yellow color, primarily due to crocins and crocetin in saffron, contributed to the sensory appeal of the enriched pasta. Saffron-enriched pasta, especially at 0.06% concentration, was highly appreciated by consumers for its color, smell, and taste.

Textural properties such as cohesion, gumminess, and chewiness showed no significant changes with saffron addition. Sensory analysis confirmed that the addition of saffron extract, up to 0.06%, does not lead to significant differences in texture-related attributes like stickiness and softness.

Finaly, the incorporation of saffron into pasta formulations offers two major benefits: first, it enhances the overall quality of the pasta, making it a potential functional food rich in bioactive compounds that can contribute to addressing various metabolic pathologies; second, saffron-enriched pasta represents a valuable opportunity to diversify the market and develop high-value-added products.

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AUTHORS CONTRIBUTIONS

Conceptualization: F.T. and D.E.K., Methodology: F.T., M.L.F. and K.T., data collection: F.T. and N.A.M., data validation: M.L.F., D.E.K. and N.A.M., data processing: F.T. and M.B.B., writing—original draft preparation: F.T. and K.T., writing—review and editing D.E.K and M.B.B.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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