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Research Article

Enrichment of pasta by green algae *Enteromorpha intestinalis*: Nutritional, antioxidant, cooking quality, textural, and sensory characteristics

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ABSTRACT- Pasta, made from semolina flour, is widely consumed due to its ease of cooking, consumption, and transportation. This study explores the potential of enriching pasta with varying amounts of green algae (*Enteromorpha intestinalis*). Pasta samples containing 5%, 10%, and 15% algae powder were compared to a control sample in terms of nutritional content, antioxidant properties, cooking quality parameters, textural attributes, and sensory characteristics. The results showed that pasta with 15% algae powder had the highest protein content ($P < 0.05$). However, no significant differences were observed in moisture and ash content among the samples ($P \geq 0.05$). Antioxidant evaluations, including total phenolic content, DPPH radical scavenging activity, and total antioxidant activity, demonstrated that increasing algae concentration enhanced the pasta's antioxidant properties. All samples met standard ranges for cooking loss rate, optimum cooking time, water absorption, and swelling index. While no significant difference in stiffness was found among the raw samples ($P \geq 0.05$), the cooked control pasta exhibited the highest firmness ($P < 0.05$). Sensory analysis of eight factors revealed that pasta with 10% algae powder received the highest overall evaluation. Ultimately, the incorporation of *E. intestinalis* algae powder proved beneficial, enhancing the nutritional value, chemical composition, and sensory properties of the pasta.

INTRODUCTION

Humans have long relied on cereals as a staple food source (Bergman, Gualberto, & Weber, 1994). Among the many products derived from cereals, pasta and its variations hold a significant place in global cuisine. This food group, which dates back centuries, is widely consumed due to its ease of production, diverse forms, affordability, and long shelf life. The chemical composition of pasta includes carbohydrates (70–76%), protein (10–14%), lipids (1.8%), dietary fiber (2.9%), and small amounts of minerals and vitamins (Sissons, 2022). Globally, approximately 16.9 million tons of pasta are produced annually, with Italy, the United States, Brazil, Turkey, and Russia being the leading producers. Italy also has the highest per capita pasta consumption at 23.5 kg per year, followed by Tunisia (17 kg), Venezuela (15 kg), Greece (12.2 kg), and Peru (9.9 kg) (IPO, 2021). In modern times, food consumption serves purposes beyond merely satisfying hunger. The nutritional composition of food plays a crucial role in maintaining health, leading to the emergence of the concept of food as "medicine", now recognized as functional food (Haristy, et al., 2021). Functional foods, while part of the regular diet, contain biologically active compounds that can enhance health and reduce disease risk (Granato et al., 2020). Given pasta's widespread consumption, it presents an excellent vehicle for functional enrichment. In fact, pasta was among the first food products authorized by the FAO in 1940 for enrichment with vitamins and iron (Fradique et al., 2010). Although pasta provides essential nutrients, its proteins have low biological value, necessitating enrichment with proteins of higher biological value (Singh et al., 2021). Most enrichment efforts have focused on vitamins, minerals, and, more recently, bran and various fibers, while relatively little research has been conducted on incorporating high-value protein sources. Addressing dietary deficiencies through the addition of nutrient-rich ingredients can not only enhance pasta's nutritional profile but also improve product quality and consumer appeal. Covering nearly two-thirds of the Earth's surface, the oceans harbor a vast array of marine life, including algae, which offer a renewable resource with significant nutritional potential (Pomponi, 1999). Seaweed, or marine macroalgae, has been a dietary staple in many Asian cultures for centuries. Though relatively new to Western diets, its consumption has been steadily increasing (Murray et al., 2018). Recognized for its bioactive components, seaweed has long been valued for its health benefits, contributing to its growing commercial appeal in recent years (Sobuj et al., 2021; Barbosa, et al., 2019). One notable seaweed species, *Enteromorpha intestinalis*, is found in the Caspian Sea, particularly along the Iranian

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coast. These green algae are globally distributed, thriving in a range of habitats from freshwater to saline environments, including ditches, pools, rock formations, and coastal bedrock (Bäck, et al., 2000; Björk, et at., 2004; J. Blomster et al., 2002; Jaanika Blomster, et al., 1998). Despite their nutritional and ecological benefits, Enteromorpha species also pose challenges. In eutrophic marine environments, they can form "green tides"—massive accumulations of unattached green macroalgae. These macroalgal blooms are primarily caused by green algae and are known to have adverse environmental effects (Ye et al., 2011).

So far, these beneficial algae have remained largely unexploited. Therefore, introducing and investigating their potential applications could not only help mitigate the environmental issues caused by their blooms but also provide a foundation for developing products suitable for various sectors of the food industry. A review of existing literature reveals limited information on the enrichment of wheat flour with *E. intestinalis* algae powder for pasta production. Given the global abundance of this green alga and the growing need to enhance the nutritional quality of pasta to promote human health, conducting this research is both relevant and necessary.

MATERIALS AND METHODS

Materials

Specimens of the green alga *E. intestinalis* were identified and collected from the southern shores of the Caspian Sea in the Noor region (Mazandaran Province, Iran). In this study, null flour (Ard Shad Guilan Company) with 10% protein, 30% wet gluten, and 14% moisture was used to prepare both the control and experimental samples. The chemicals used in this study included ethanol, methanol, ascorbic acid, tannic acid, sodium phosphate, ammonium molybdate, sulfuric acid, Folin-Ciocalteu reagent, and potassium phosphate buffer, all of which were purchased from Merck. Additionally, 2,2-Diphenyl-1-picrylhydrazyl (DPPH) was obtained from Sigma-Aldrich. All solvents and chemicals were of analytical grade.

Methods

Seaweed collection

Algae samples were washed multiple times with seawater to remove epiphytes and sand, followed by rinsing with fresh water to eliminate residual salt. The cleaned samples were then transported to the Seafood Processing Laboratory at the Faculty of Natural Resources, Guilan University. Drying was carried out in an oven (Behdad Medical Co., BM55E, Iran) at 45 °C for four days. Once dried, the samples were finely pulverized using an electric grinder (Hardstone, GCS2700W, England). The resulting powder was then passed through a 60 µm sieve and stored in zippered plastic bags until further analysis.

Proximate composition

The proximate composition of the seaweed was analyzed following the methods outlined by the Association of Official Analytical Chemists (AOAC, 2000). Moisture content (dry matter, DM) was determined using the oven-drying method at 105 °C. Crude fat was extracted from the algal samples using a Soxhlet apparatus with n-hexane as the solvent. Crude protein content was determined by the Kjeldahl method, with a nitrogen-to-protein conversion ratio of 6.25. Total ash content was measured by calcination in an electric muffle furnace at 550 °C until a constant weight was achieved. Total carbohydrate content was calculated by subtracting the sum of the ash, fat, and protein contents from 100 (Onyeike et al., 2000).

Pasta production

Initially, a control sample (Co) was prepared using wheat flour (50%), water (12%), eggs (26.5%), gluten (10%), and salt (1.5%). Subsequently, the wheat flour ratio was reduced, and *E. intestinalis* algae powder was incorporated at weight ratios (w/w) of 5% (T_1), 10% (T_2), and 15% (T_3) as a substitute. After mixing the ingredients, the resulting dough was shaped using a pasta maker (Marcato, Ampia 150 - Deluxe, Italy). The formed pasta underwent a two-step drying process. In the pre-drying stage, it was heated to 30 °C for 30 minutes to prevent rapid surface drying and reduce the risk of cracking. In the final drying stage, the pasta was dried at 45 °C for 17 hours until it reached the desired moisture content of 9.5 ± 0.5% per 100 g.

Proximate analysis methods

Protein

The Kjeldahl method was used to determine crude protein content (AOAC, 2000). Protein evaluation involved three main steps. In the digestion step, 3 g of pasta was weighed and placed in a Kjeldahl flask, then boiled in concentrated sulfuric acid in the presence of two catalysts, sodium sulfate and copper sulfate. Heat was applied to accelerate digestion. In the distillation step, the digested sample was distilled using a Kjeldahl apparatus, with 75 mL of 5% sodium hydroxide slowly added to the flask. On the receiving end, an Erlenmeyer flask containing 2% boric acid and methyl red indicator was used to capture the released ammonia. Distillation continued until the solution volume in the Erlenmeyer flask reached approximately 300 mL, ensuring complete ammonia extraction, which then reacted with boric acid to form ammonium borate. In the titration step, the ammonium borate solution was titrated with 0.1 N hydrochloric acid until a purple endpoint appeared. The volume of acid consumed was recorded and applied in Eq. (1) according to International Organization for Standardization (ISO, 1978).

$$\text{N (\% of nitrogen)} = \frac{\text{volume of sulfuric acid consumed} \times 0.0014}{\text{sample weight}} \times 100 \quad \text{Eq. (1)}$$

$$\text{Protein content (\%)} = \text{N} \times 5.7$$

Moisture

Five grams of the crushed sample were placed on a plate and weighed. The plate containing the sample was then

heated in an oven at 105 °C for 24 hours. After cooling, the sample was reweighed. The weight difference obtained represents the amount of moisture the sample had lost. The moisture content of the pasta was then calculated using the following equation according to the International Organization for Standardization (ISO, 1997):

$$\text{Moisture content}(\%) = \frac{\text{plate and sample weight before oven} - \text{plate and sample weight after oven}}{\text{sample weight}} \times 100 \quad \text{Eq. (2)}$$

Ash

Five grams of the pasta sample were placed in a pre-weighed crucible. The crucibles were then placed in an electric furnace that had been preheated to 600 °C for 4 hours. After the heating period, the samples were removed from the furnace and placed in a desiccator to cool completely. Once cooled, the crucibles containing the ash were weighed. The ash percentage of the pasta sample was calculated using the following equation (ISO, 1998):

$$\text{Ash content}(\%) = \frac{\text{crucible weight containing ash} - \text{crucible weight}}{\text{sample weight based on dry matter}} \times 100 \quad \text{Eq. (3)}$$

Antioxidant analysis methods

Total phenolic content (TPC)

The pasta's TPC was determined using the method outlined by Taga et al. (1984). In this procedure, 200 µL of the sample was mixed with 4 mL of 2% Na_2CO_3 and allowed to stand at room temperature for 2 minutes. Then, 200 µL of 50% Folin-Ciocalteu reagent was added, mixed, and left at room temperature in the dark for 30 minutes. The samples were measured at 720 nm using a spectrophotometer (UNIC, UV/Vis 2100, USA). The measurements were based on a calibration curve prepared with tannic acid, and the results were expressed as mg of tannic acid per gram of raw pasta. The standard curve equation is as follows:

$Y = 0.013x. R^2 = 0.994$ Eq. (4).

DPPH radical scavenging activity

DPPH radical scavenging activity was measured following the method described by Brand-Williams et al. (1995). To do this, 2 mL of pasta extract, which had been placed in methanol for one hour, was mixed with 2 mL of 0.16 mM DPPH free radical methanol solution and well-mixed. The mixture was then kept at room temperature and in the dark for 30 minutes. The absorption of each sample was read at 517 nm using a spectrophotometer. The scavenging effect (percentage) was calculated using Eq. (5) as proposed by Duan et al. (Duan et al., 2006). The results were expressed as radical scavenging activity (RSA, %).

$$\text{RSA}(\%) = [1 - (\text{A sample} - \text{A sample blank}) / \text{A control}] \times 100 \quad \text{Eq. (5)}$$

A sample = Absorbance of the DPPH solution plus test sample.
A control = Absorbance of the DPPH solution without sample.
A sample blank = Absorbance of the sample without DPPH solution.

Total antioxidant activity (TAC)

The TAC was determined following the method outlined by Prieto et al. (1999), with some modifications. Two milliliters of the sample solution were mixed with 2 mL of reagent solution (0.6 M sulfuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate). After preparing the solution, it was placed in a water bath at 95 °C for 90 minutes. The absorption of each sample was then measured at 695 nm using a spectrophotometer. A control sample was prepared using 2 mL of ethanol and 2 mL of reagent solution, and its absorption was recorded at the same wavelength. Measurements were based on a calibration curve using ascorbic acid, and the results were expressed as mg of ascorbic acid per gram of raw pasta. The standard curve equation resulted accordingly.

$Y = 0.003x. R^2 = 0.99$ Eq. (6)

Baking quality indicators methods

Optimum cooking time

To measure the optimum cooking time of the samples, 200 mL of distilled water was added to a beaker, which was then placed on a gas flame to bring the water to a boil. Once the water was boiling, 10 g of pasta, broken into pieces of about 5 cm, was added. During the cooking process, a piece of pasta was removed every 30 seconds and squeezed between two glass plates. The pasta was considered fully cooked when no trace of the white line in the middle remained. The cooking time at which this occurred was recorded as the optimum cooking time (AACC, 2000).

Cooking loss

The cooking loss of pasta was determined in distilled water. First, a beaker was weighed. Then, 10 g of pasta was boiled in 300 mL of water until fully cooked. Afterwards, the pasta was removed from the beaker, and the beaker containing the boiling water was placed in an oven at 105 °C for 6 hours until the water evaporated completely. Finally, the beaker with the remaining dry matter was removed from the oven and weighed. The percentage of material lost (cooking loss) was calculated using the Eq. (7) according to Chillo, et al. (2008).

$$\text{Cooking loss} = \frac{\text{weight of the beaker containing the remaining dry matter} - \text{weight of the beaker}}{10} \times 100 \quad \text{Eq. (7)}$$

Water absorption

To determine water absorption, 10 g of pasta was immersed in 200 mL of boiling distilled water. After cooking, the pasta was removed and left at room temperature for 5 minutes to cool, then weighed. The percentage of water absorption was calculated using the following equation according to Tudorică, et al. (2002):

$$\text{Water absorption} = \frac{\text{weight of cooked pasta} - \text{weight of raw pasta}}{\text{weight of raw pasta}} \times 100 \quad \text{Eq. (8)}$$

Swelling index

To determine the swelling index, 10 g of pasta was immersed in 200 mL of boiling distilled water. After cooking, the pasta samples were weighed and then transferred to an oven at 105 °C for 3 hours to dry. After drying, the pasta samples were weighed again, and finally, the swelling index was calculated according to the following equation (Tudorică et al., 2002):

$$\text{Swelling index} = \frac{\text{weight of cooked pasta} - \text{weight after drying}}{\text{weight after drying}} \quad \text{Eq. (9)}$$

Texture analysis

The Kramer method (Kramer and Szczesniak, 1973) was used for texture analysis in which raw and cooked pasta were examined by a texture measuring device (CT3 Texture, Brookfield, USA). For this purpose, a string of pasta 5 cm long was compressed vertically by a steel probe at a speed of 1 mm s^{-1}. Then, the amount of stiffness and deformation against pressure was calculated.

Sensory evaluation of pasta

The sensory evaluation of pasta samples was conducted using the method described by Larmond and Voisey (Elizabeth & Peter W., 1973). A group of 12 participants was involved in the evaluation. The quality properties assessed included appearance, color, flavor, odor, stickiness, stiffness, elasticity, and the intensity of crushing when chewing. A numerical score ranging from 1 (the worst quality) to 5 (the best quality) was assigned to each of these characteristics.

Statistical analysis

The treatments were conducted in three replications. All statistical analyses were performed using SPSS software, version 27. The quantitative values of the samples were compared using analysis of variance (ANOVA), and differences between the values were assessed using the Duncan test at a significance level of ($P < 0.05$). The shapes were generated using Microsoft Office Excel (Microsoft Office, 2016).

RESULTS AND DISCUSSION

Proximate analysis

According to Table 1, the protein content of the samples increased with the addition of algae. Specifically, the samples with 5%, 10%, and 15% algae had higher protein content than the control sample, and these differences were statistically significant ($P < 0.05$). Moreover, the differences between the samples with varying algae percentages were also significant ($P < 0.05$) (Fig. 1). In all cases, the addition of algae resulted in a decrease in moisture content (Fig. 2) and an increase in ash content in the final product (Fig. 3). However, the differences in moisture and ash content between the samples were not significant ($P < 0.05$).

Table 1. The proximate composition (%) of *Enteromorpha intestinalis*

Lipid (DW)	Ash (DW)	Carbohydrate (DW)	Protein (DW)	Moisture
1.51 ± 0.33	29.42 ± 0.58	51.63 ± 0.39	17.44 ± 0.31	88.75 ± 0.77

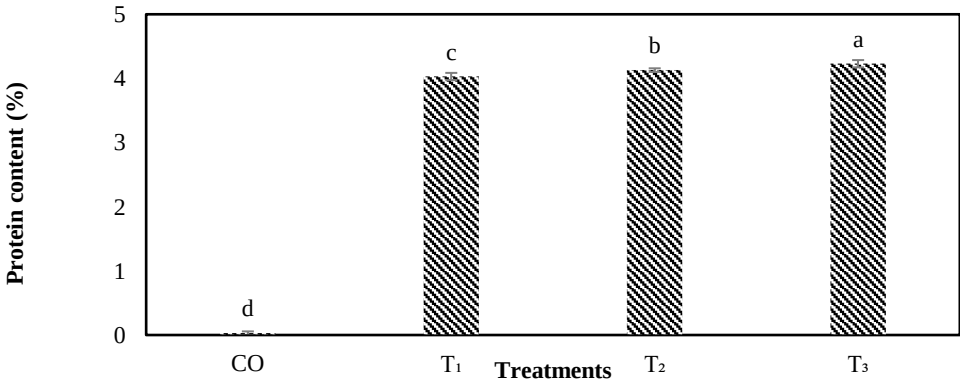

Fig. 1. Protein content in control group pasta (CO) and pasta containing algae with percentages of 5 (T_1), 10 (T_2), and 15 (T_3). * Different superscript letters in a column indicate significant differences ($P < 0.05$).

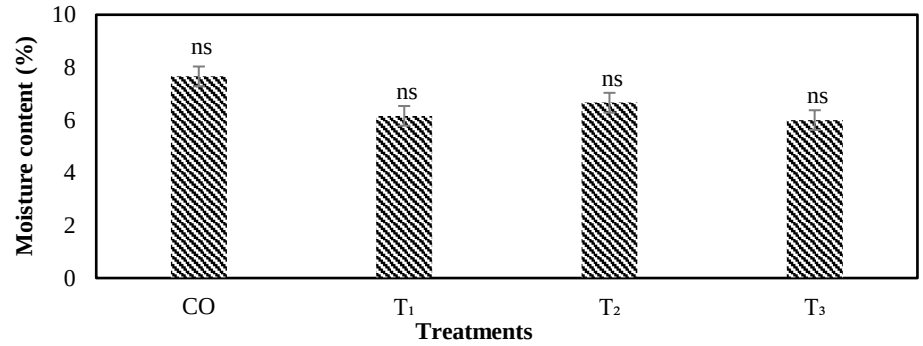

Fig. 2. Moisture content in control group pasta (CO) and pasta containing algae with percentages of 5 (T_1), 10 (T_2), and 15 (T_3). The word ns indicates no significant difference.

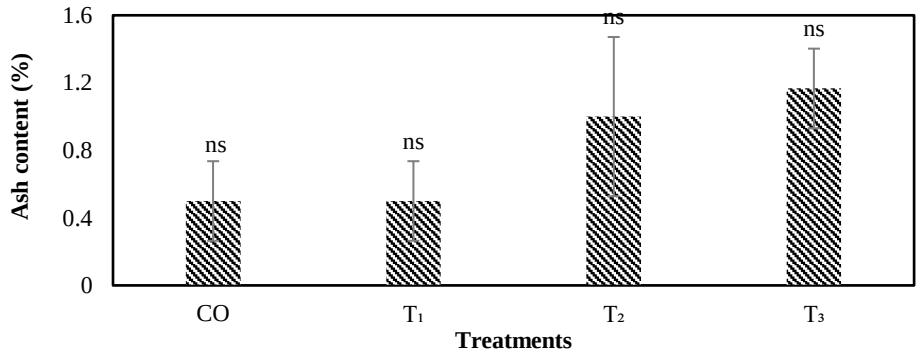

Fig. 3. Ash content in control group pasta (CO) and pasta containing algae with percentages of 5 (T_1), 10 (T_2), and 15 (T_3). * The word ns indicates no significant difference.

The addition of algae significantly increased the protein content, which is a notable advantage for a product like pasta, typically low in protein. Since *E. intestinalis* algae contains substantial amounts of protein, the observed enhancement in pasta protein is entirely justified (Monica Joicy et al., 2021). Furthermore, the low moisture content in the pasta samples indicates that they can be stored safely (Çalışkan Koç, et al., 2020). The increase in ash content in the algae-containing samples is likely due to the presence of minerals in the algae (Hamouda, et al., 2022).

Antioxidant analysis

The results indicated that the TPC in pasta extracts containing 15% algae powder was significantly higher compared to those with 5% algae powder ($P < 0.05$). However, no significant differences were observed between the other samples ($P < 0.05$) (Fig. 4). The highest DPPH radical scavenging activity was observed in the pasta containing 15% algae, which showed a significant difference from the other samples ($P < 0.05$) (Fig. 5). Similar findings were reported by Egodavitharana et al. (2024) when they used Sargassum in wheat noodles. As the algae percentage in the pasta increased, total antioxidant activity (TAC) also increased, with pasta containing 15% algae powder showing the highest TAC ($P < 0.05$). Pasta extracts with 10% and 5% algae powder exhibited the next highest antioxidant activities, while the control pasta extract showed the lowest TAC, which was not significantly different from the pasta containing 5% algae powder ($P < 0.05$) (Fig. 6).

Different plant species contain phenolic compounds, which are important chemical groups that can play a significant role in preventing oxidation (Safari et al., 2015; Liu et al., 2019). Since marine macroalgae are rich in antioxidant sources such as polyphenols (Hodhodi et al., 2022), it can be concluded that the increase in phenolic content in pasta containing algae is justified. DPPH radical scavenging activity is a widely used and reliable method to measure antioxidant potential due to the stable nature of the DPPH radical. The radical's color change upon reaction can easily be measured using a spectrophotometer, making this method both easy and accurate for determining the antioxidant activity of phenolic compounds (Karadag, et al., 2009). Based on the results, it can be concluded that *E. intestinalis* algae, used in pasta enrichment, is an effective inhibitor of DPPH free radicals. Pasta with higher levels of total phenolic compounds also exhibited higher radical scavenging potential. This is likely due to fact that the polyphenols found in seaweed are key contributors to the anti-radical properties of the pasta (Chew et al., 2008; Kuda et al., 2005). Phenolic compounds play a crucial role in inhibiting DPPH free radicals. However, in some species, other compounds such as carotenoids, unsaturated fatty acids, and smaller molecules like polysaccharides, proteins, peptides, and pigments may also contribute to inhibiting these free radicals (Souza et al., 2011). The TAC method relies on the conversion of hexavalent molybdenum to pentavalent molybdenum in acidic conditions at high temperatures. This reaction produces green phosphomolybdenum complexes, which have a maximum absorption at 695 nm (Prieto et al., 1999). Many studies have highlighted the important role of phenolic compounds in preventing oxidative stress (Pradhan et al., 2021; Zhang et al., 2022). Therefore, it is well-supported that a sample with higher total phenolic content will also have higher TAC.

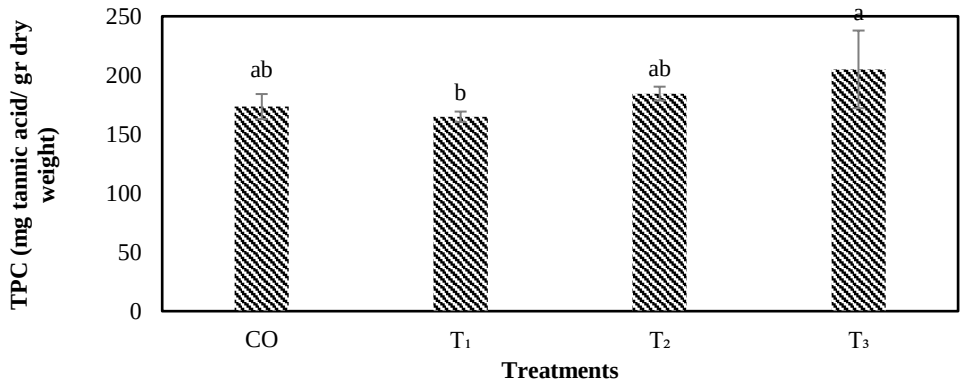

Fig. 4. Total phenolic content (TPC) in control group pasta (CO) and pasta containing algae with percentages of 5 (T_1), 10 (T_2), and 15 (T_3). * Different superscript letters in a column indicate significant differences ($P < 0.05$).

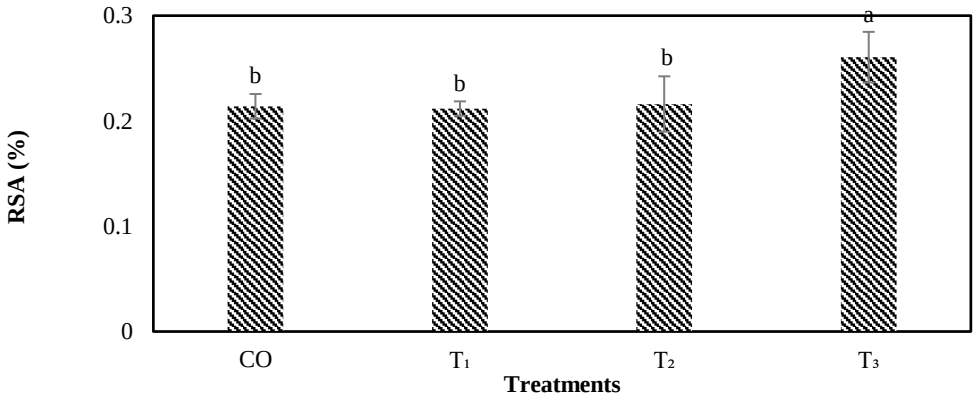

Fig. 5. DPPH free radical scavenging activity (RSA) in control group pasta (CO) and pasta containing algae with percentages of 5 (T_1), 10 (T_2), and 15 (T_3). * Different superscript letters in a column indicate significant differences ($P < 0.05$).

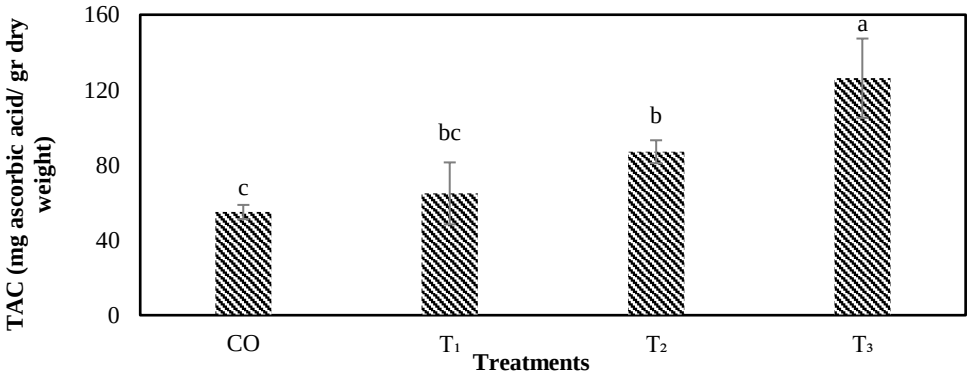

Fig. 6 Total antioxidant activity (TAC) in control group pasta (CO) and pasta containing algae with percentages of 5 (T_1), 10 (T_2), and 15 (T_3). * Different superscript letters in a column indicate significant differences ($P < 0.05$).

Baking quality indicators

The cooking loss provides insight into the surface characteristics of pasta, and an increase in cooking loss typically leads to a stickier surface (Shiau et al., 2001). According to the results presented in Table 2, varying levels of algae powder directly influenced the cooking time of the pasta. As the percentage of algae powder in the pasta composition increased, the cooking time decreased. Specifically, the pasta with 15% algae powder exhibited the shortest cooking time, while the control pasta required the longest cooking time. The lowest cooking loss was observed in the control sample, followed by the pasta containing 5%, 10%, and 15% algae powder, with cooking loss increasing in this order. Notably, the differences between the samples were statistically significant ($P < 0.05$). Additionally, the amounts of water absorption and swelling index of the pasta showed an irregular trend upon the addition of algae powder. The control sample had the highest water absorption and swelling index, while the pasta containing 5% algae had the lowest values for both indices. These differences between the samples were statistically significant ($P < 0.05$).

Table 2. Quality parameters of cooking in pasta fortified with algae (*E. intestinalis*)

Sample	Cooking time (min)	Cooking loss (grams per 100 grams)	Water absorption (grams per 100 grams)	Swelling index (%)
Control	19	$5^{d} \pm 0.10$	$178.30^{a} \pm 2.85$	$225.05^{a} \pm 4.51$
5% algae (*E. intestinalis*) powder	17	$7.36^{c} \pm 0.05$	$124.60^{d} \pm 1.82$	$163.17^{d} \pm 2.07$
10% algae (*E. intestinalis*) powder	15	$7.66^{b} \pm 0.15$	$143.30^{c} \pm 2.43$	$186.82^{c} \pm 4.30$
15% algae (*E. intestinalis*) powder	13	$10.76^{a} \pm 0.11$	$159.06^{b} \pm 0.86$	$206.51^{b} \pm 3.28$

Different superscript letters in a column indicate significant differences ($P < 0.05$).

During the cooking of pasta in water, the starch granules absorb water and undergo gelatinization. The ideal cooking time occurs when the majority of starch granules have fully gelatinized, at which point the gypsum structure between the pasta strands disappears upon compression. According to the results, the addition of algae reduced the cooking time. This can be attributed to the possibility that the algae (*E. intestinalis*) powder dilutes the gluten network in the flour, leading to the decreased water absorption and consequently lowering the moisture content. As a result, the gelatinization temperature of starch is reduced, meaning the starch gelatinizes more quickly, and the gypsum structure of the pasta disappears faster (Nasehi et al., 2009). It is worth noting that, according to both national and international standards, shorter cooking times are generally considered more favorable. As pasta protein content increases due to the enrichment with high-protein ingredients like algae, the solids in the cooking water also increase due to the dilution of gluten and soluble protein parts. The relationship between gluten content and cooking loss is such that higher gluten content leads to lower loss of material in the cooking water. This is because the gluten network helps maintain the physical structure of the pasta. When the gluten structure is weak, more solids are lost in the cooking water, leading to the increased nutrient loss during cooking (Rodríguez De Marco et al., 2014). However, it should be highlighted that the cooking loss rate in this study remained within the standard range (maximum 11%). Furthermore, water absorption is a critical factor in pasta production, influencing both texture and quality.

Increasing the water absorption capacity can cause the dough to loosen, which in turn reduces the pasta's cooking quality. Additionally, higher water absorption leads to longer drying times for the pasta (Miller & Hoseney, 2008). Similarly, Danesi et al. (2012) observed that adding *S. platensis* biomass to pasta resulted in a decrease in water absorption, although the trend was irregular. Water absorption and the swelling index are largely influenced by the gluten content in the flour, with higher gluten levels leading to the greater water absorption and swelling index. Consequently, the weight of the pasta increases after cooking. Since the control pasta contains more gluten, it is understandable that it exhibited the highest water absorption and swelling index (Sung & Stone, 2003). Moreover, since the control pasta had the longest optimal cooking time, it had more time to absorb water compared to the other samples. This likely explains why it showed higher water absorption and swelling index than the samples containing algae. It is worth noting, however, that despite differences in water absorption and swelling index between the algae-enriched samples and the control, the weight of all samples after cooking fell within the standard range (at least 55 g).

Texture analysis

According to Table 3, no significant difference in stiffness was observed between the raw samples ($P < 0.05$). However, in the cooked samples, the control group pasta exhibited the highest stiffness. As the percentage of algae increased, the strength of the pasta's texture decreased. The difference in stiffness between the control sample and those containing 10% and 15% algae powder was significant ($P < 0.05$).

Table 3. Texture Profile Analysis (TPA) of pasta fortified with algae (*E. intestinalis*)

	Sample	Stiffness	Deformation against pressure
Raw	Control	$0.61^{a} \pm 0.22$	$12.56^{a} \pm 0.93$
	5% algae (*E. intestinalis*) powder	$2.05^{a} \pm 0.43$	$3.76^{c} \pm 0.21$
	10% algae (*E. intestinalis*) powder	$2.07^{a} \pm 1.51$	$3.10^{c} \pm 0.23$
	15% algae (*E. intestinalis*) powder	$1.73^{a} \pm 0.88$	$6.56^{b} \pm 0.65$
Cooked	Control	$0.64^{a} \pm 0.11$	$19.40^{a} \pm 0.16$
	5% algae (*E. intestinalis*) powder	$0.49^{ab} \pm 0.10$	$16.50^{b} \pm 0.12$
	10% algae (*E. intestinalis*) powder	$0.45^{b} \pm 0.04$	$15.20^{b} \pm 0.31$
	15% algae (*E. intestinalis*) powder	$0.38^{b} \pm 0.06$	$19.26^{a} \pm 0.31$

Different superscript letters in a column indicate significant differences ($P < 0.05$).

The texture and appearance of pasta during and after cooking are key quality parameters for consumers. The stiffness of the pasta texture after cooking is just as important as the color and chewability (Konik et al., 1993). The texture of the pasta should be strong enough to ensure the strands do not stick to each other. If the pasta becomes too soft, it can be difficult to consume (Edwards, et al., 1993). The components of wheat grain, particularly its protein content, significantly affect the cooking and texture quality of pasta. When algal biomass is added to the flour, it dilutes the gluten, weakening the protein network of the pasta. As a result, amylose is released from the starch granules into the cooking water. Gluten acts as a barrier, preventing the separation of starch, especially amylose, from the pasta tissue, ultimately leading to firmer pasta. The increase in cooking loss in pasta could be attributed to the dilution of gluten. Therefore, the higher the cooking loss, the softer the cooked product becomes (Gallegos-Infante et al., 2010).

Sensory evaluation

As shown in Table 4, the sensory evaluation results indicated that the sample containing 10% algae received the highest score for appearance. This sample showed the least amount of cracks, dark spots, gypsum spots, chopped parts, and crushing, according to the evaluators. In contrast, the control pasta had the lowest score for appearance, with the difference being statistically significant compared to the pasta containing 10% algae ($P < 0.05$). Although the control sample received the highest score for odor, no significant difference was observed between it and the samples containing 5% and 10% algae ($P < 0.05$). However, the difference between the control sample and the 15% algae sample was significant ($P < 0.05$). No significant differences were found between the pasta samples in terms of color, flavor, stickiness, stiffness, elasticity, and chewing intensity ($P < 0.05$).

According to the evidence, the algae powder enhanced the appearance of the pasta. Furthermore, in most cases, the samples containing algae powder did not differ significantly from the control sample in terms of sensory factors. This indicates that there was no notable difference in the overall acceptability of the samples. These results align with the aim of this work to develop a pasta that is not only attractive to consumers but also maintains similar sensory properties to traditional pasta. While algae powder did have a slight negative effect on odor, this issue could be addressed by highlighting the superior nutritional value of the product.

CONCLUSION

In conclusion, it can be stated that enriching pasta with algae enhanced its properties and addressed the nutritional deficiencies commonly found in traditional pasta. This enrichment led to the production of food products with improved nutritional value, cooking characteristics, and sensory appeal. However, additional studies are necessary to assess essential amino acids, vitamin profiles, dietary fiber, pigments, and antimicrobial properties. Moreover, future research should focus on investigating anti-nutritional factors, toxins, and pollutants. Further investigations are essential to evaluate the feasibility of mass-producing this type of pasta and introducing it to the market.

Table 4. Sensory evaluation of pasta fortified with algae (*E. intestinalis*)

Trait	Control	%5 algae powder	10% algae powder	15% algae powder
Appearance	$6.66^{b} \pm 1.55$	$7.66^{ab} \pm 1.15$	$8^{a} \pm 0.85$	$7.16^{ab} \pm 1.33$
Color	$7.33^{a} \pm 1.77$	$6.83^{a} \pm 1.58$	$8^{a} \pm 1.47$	$7.33^{a} \pm 2.30$
Flavor	$6.50^{a} \pm 1.73$	$6.66^{a} \pm 1.96$	$7^{a} \pm 2$	$6.33^{a} \pm 2.05$
Odor	$7.50^{a} \pm 1.50$	$6.50^{ab} \pm 1.24$	$6.83^{ab} \pm 1.58$	$6^{b} \pm 1.70$
Stickiness	$16.25^{a} \pm 4.33$	$17.91^{a} \pm 3.34$	$18.75^{a} \pm 3.76$	$17.50^{a} \pm 3.98$
Stiffness	$13^{a} \pm 3.01$	$14.33^{a} \pm 3.17$	$14.33^{a} \pm 2.05$	$14^{a} \pm 3.19$
Elasticity	$6^{a} \pm 1.90$	$7.16^{a} \pm 1.80$	$6.83^{a} \pm 1.80$	$5.50^{a} \pm 2.43$
Crushing	$3.30^{a} \pm 1.02$	$3.83^{a} \pm 0.83$	$3.58^{a} \pm 0.79$	$3.58^{a} \pm 0.66$
Overall score	$3.32^{a} \pm 0.43$	$3.54^{a} \pm 0.51$	$3.66^{a} \pm 0.44$	$3.37^{a} \pm 0.42$

Different superscript letters in a row indicate significant differences ($P < 0.05$).

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DECLARATION OF COMPETING INTEREST

The authors declare no conflicts of interest.

ETHICAL STATEMENT

This research was conducted without the use of animals or humans, and all procedures adhered to relevant ethical considerations.

DATA AVAILABILITY

Data used and/or analyzed in the current study can be obtained from the corresponding author on reasonable request.

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