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Evaluation of Physicochemical, Sensory, and Microbial Characteristics of Ginger Fiber-Fortified Pasta

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HIGHLIGHTS

- Ginger root fiber reduced pasta moisture content significantly over storage.
- Elevated ginger root fiber levels increased post-cooking acidity and solid residuals.
- Ginger root fiber fortification markedly suppressed mold and yeast proliferation.
- Lower ginger root fiber (2.5–5%) preserved optimal sensory and colorimetric attributes.
- Higher ginger root fiber concentrations compromised taste and texture acceptability.

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Abbreviations
PCA = Principal Component Analysis

ABSTRACT

Background: Fortifying pasta with dietary fibers enhanced its nutritional value. This study examined the effects of ginger root fiber, a by- product of ginger processing, on pasta quality and shelf life over six months, using varying concentrations (2.5%, 5%, 7.5%, and 10%).

Methods: Pasta was fortified with ginger root fiber at 2.5%, 5%, 7.5%, and 10% and stored for 0, 1, 3, and 6 months. Ginger root fiber was extracted by washing, drying at 60 °C for 24 h, milling, and treating with 1% hydrogen peroxide at pH 11.5, followed by acid desiccation. Pasta, produced at MAK Pasta Company, was extruded and dried to 12% moisture at 77 °C. Quality parameters were analyzed in triplicate using a five-point hedonic scale. Statistical significance ($p<0.05$) was assessed via XLSTAT (2022), with Principal Component Analysis (PCA) based on a standardized Pearson correlation matrix (eigenvalues > 1, loadings > ±0.5). Combination plots were generated in MATLAB (R2024b).

Results: Higher ginger root fiber levels decreased moisture content, with 10% showing the lowest. Ash, acidity, and solid residuals increased with ginger root fiber concentration and storage time. Color analysis revealed reduced brightness and increased yellowness, particularly at 10%. Ginger root fiber-fortified pasta exhibited significantly lower mold and yeast growth, enhancing microbial stability. Sensory analysis showed that 2.5% and 5% ginger root fiber pasta maintained similar appearance, texture, and taste to the control, while 7.5% and 10% samples had lower acceptability due to texture and color changes.

Conclusions: Ginger root fiber fortification boosts pasta's nutritional profile by increasing fiber and mineral content while improving microbial resistance.
5% ginger root fiber level balances health benefits and sensory quality, highlighting its potential as a functional ingredient while emphasizing the need for optimized formulations to ensure consumer satisfaction.

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Introduction

Rising consumer demand for nutritious and health-promoting foods has spurred research into fortifying staple foods with functional ingredients to combat global malnutrition (Latifi *et al.*, 2025). Carbohydrate-based fortification, a key strategy in this effort, enhances the nutritional profile of widely consumed staples such as grains, cereals, and starchy vegetables by incorporating essential nutrients like vitamins (e.g., vitamin A, D, folate), minerals (e.g., iron, zinc), and proteins. This approach not only addresses dietary deficiencies in vulnerable populations but also supports global health initiatives, including the Sustainable Development Goals for Zero Hunger and Good Health and Well-being. Evidence highlights the efficacy of carbohydrate fortification in reducing nutrient deficiencies and improving public health outcomes worldwide (Bhutta *et al.*, 2013). Among staple foods, pasta stands out as an ideal candidate for fortification due to its global consumption, versatility, and ability to integrate diverse nutrients and bioactive compounds (Rodríguez *et al*., 2018). Fortifying pasta with dietary fiber, in particular, offers benefits such as improved digestive health, better glycemic control, and increased satiety (Chillo *et al*., 2008).

Ginger fiber, derived from the rhizome of *Zingiber officinale*, emerges as a promising fortifying agent due to its rich bioactive components, including gingerols, shogaols, and paradols, which confer antioxidant, anti-inflammatory, and antimicrobial properties (Butt and Sultan, 2011). These attributes position ginger fiber as a valuable addition to functional foods, potentially enhancing pasta's nutritional value while providing health benefits such as improved gastrointestinal function and protection against oxidative stress (Semwal *et al.*, 2015; Shaukat, Nazir, and Fallico 2023). However, incorporating high-fiber ingredients like ginger fiber into pasta presents challenges, as it may alter sensory and structural properties, including texture, cooking quality, and consumer acceptability. Additionally, the bioactive compounds in ginger fiber could affect pasta's microbial stability and oxidative spoilage, influencing shelf life (Wu and Gani, 2021). Balancing these health benefits with product quality and palatability is critical for successful fortification.

This study investigated the effects of ginger fiber fortification at concentrations of 2.5%, 5%, 7%, and 10% on pasta's quality and shelf life. By analyzing moisture, protein, and ash content, post-cooking acidity, colorimetric properties (brightness, yellowness, redness, and color variation), and sensory attributes (appearance, color, texture, taste, and acceptability), the research aimed to determine an optimal fortification strategy. Furthermore, the study evaluated the impact of ginger fiber on oxidative stability and shelf life at one-, three-, and six-month intervals, exploring its potential as a natural preservative to enhance product marketability and reduce food waste. The findings advanced the development of fiber-enriched functional pasta, aligning with consumer preferences for healthier dietary options. By addressing the benefits and challenges of ginger fiber fortification, this research aimed to inform broader applications in functional food innovation and promote the development of nutrient-rich products that support global health and sustainability goals.

Materials and methods

Extraction of ginger root fiber

Initially, ginger root underwent a thorough washing procedure employing water, ensuring multiple rinses until the effluent attained complete clarity. Subsequent to this, the cleansed fiber was subjected to complete dehydration in an oven set at 60 °C for a duration of 24 h. The desiccated ginger roots were then milled to attain particle sizes of 4, 75, and 105 µm, respectively. The milled ginger skins were subsequently treated with an alkaline solution in the presence of a 1% hydrogen peroxide solution, maintaining a pH level of 11.5. The specific proportions and durations of this treatment were in accordance with Table 1. Following the completion of the mixing phase utilizing a paddle stirrer, the resultant solution underwent desiccation utilizing 0.1 normal hydrochloric acid to achieve a neutral, homogeneous consistency. This desiccation process took place within an oven at 60 °C over a period of 8 h (Cappelli and Cini, 2021).

Table 1: Composition of each prepared treatment

Treatments / Properties	Wheat flour W/W (12% moisture, 9.8% protein)	Semolina W/W (12% moisture and 13% protein)	Ginger root fiber g/100 grams of flour
Control T	75%	25%	0
T1	75%	22.5%	2.5
T2	75%	20%	5
T3	75%	18%	7
T4	75%	15%	10

T=control treatment; T1=pasta treatment with 2.5%; T2=pasta treatment with 5%; T3=pasta treatment with 7%; T4=pasta treatment with 10% of ginger root fiber

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Flour testing, sample preparation, and pasta production

All samples were produced at MAK Pasta Company (KHOSHNAM Food Products Co., Isfahan, Iran) using a short-line production system from Fava (Ferrara, Italy), with a processing capacity of 1.5 tons per hour.

The production process commenced with the formulation of a control sample comprising null flour combined with water, beta-carotene, and gluten. This blend underwent the procedures outlined in Table 1. Subsequent to the thorough mixing of the components, the resultant dough was extruded through a mold's aperture under applied pressure, yielding the desired pasta configurations. A knife situated at the mold's egress efficiently sliced the dough into the desired dimensions. The subsequent stage involved introducing the formed pasta pieces into a pre-drying unit, subsequently advancing into the primary drying chamber, where the dryer temperature was maintained at 77 °C. The pasta underwent this drying phase for a duration of 2 h and 48 min until achieving the specified humidity level of 12%. Post-drying, the pasta was conveyed from storage silos to the weighing apparatus via a conveyor belt, where it was portioned into 500 g increments and subsequently packaged in propylene bags (Cappelli and Cini, 2021).

Product testing

Each test was carried out in compliance with predetermined standards and performed in triplicate. These evaluations were conducted at four separate time junctures: immediately post-production and subsequently at intervals of 1-, 3-, and 6-months following production. This methodology facilitated a thorough examination of the progression of the evaluated traits and facilitated substantive comparisons across these timeframes. The post-production evaluation of the products was done at the end of each month.

Measurement of moisture

At the outset, a clean glass plate was placed in an oven and left for approximately 30 min to attain thermal equilibrium. Subsequent to this, 4 g of the conditioned sample was carefully deposited onto the plate, and its exact mass was documented. Following this step, a portion of the sample was subjected to autoclaving for 3.5 h at a consistent temperature of 105±5 °C. Once the autoclaving process was completed, the plate was reinstated into the desiccator until its temperature equilibrated with the ambient surroundings, after which its weight was recorded (Abdolmaleki *et al.*, 2025). The moisture content was then calculated using the provided equation.

$$\text{Moisture (\%)} = \frac{M_1 - M_2}{M_2} \times 100$$

Where M_1 is the weight of the plate and sample, and M_2 is the weight of the sample and the plate after 3 h in the oven.

Measurement of ash content

The determination of ash percentage followed a systematic procedure. First, porcelain equipment was cleaned, dried, and heated in an electric oven at 550 °C for 30 min. After cooling in a desiccator, a precise amount (2-5 g) of rice flour was weighed and placed in a porcelain crucible. The crucible was heated at 550 °C for 4 h to combust the organic material. Distilled water was then added to the ash, and the sample was dried at 105 °C for an hour. The final weight of the ash was recorded after cooling, and this value was used to calculate the ash content percentage with the following equation (Latifi *et al.*, 2021).

$$\text{Ash (\%)} = \frac{C_w + A_w}{S_w} \times 100$$

Where C_w is the crucible weight, A_w is the ash weight and S_w is the sample weight.

Measurement of protein content

The protein percentage measurement procedure is predicated on the quantification of total nitrogen content in wheat flour, assuming that all nitrogen constituents are of the protein variety. Conversion factors for nitrogen-to-protein content are utilized according to (Maleki, Daneshniya, and Abdolmaleki, 2025) with modifications. In this procedure, 0.7 g of wheat flour is weighed and transferred into a Kjeldahl flask along with 7 g of sodium sulfate, 1 g of copper sulfate, and 20 ml of sulfuric acid. The mixture is heated until the contents turn green, signaling complete digestion. Next, 75 ml of 5% sodium chloride is added, causing the solution to change from blue to black, while 2% boric acid with methyl red is prepared for distillation. The distilled ammonia reacts with boric acid, forming ammonium borate. Finally, the ammonium borate is titrated with 0.1 N hydrochloric acid until the solution turns purple, and the amount of acid used is recorded to determine protein content according to the following equations.

$$\text{Nitrogen content} = \frac{100 \times 14 \times H_{HCl} \times Acid_N}{S_w \times 1000}$$

$$\text{Protein (\%)} = \text{Nitrogen percentage} \times 5.7$$

Where V_{HCl} is the used volume of hydrochloric acid, $Acid_N$ is the normality of acid and S_w is the sample weight (g).

Measurement of Acidity in cooking water

The determination of cooking water acidity comprises several procedural stages. Following a 30 min interval, precisely 10 cc of pasta sample cooking water was measured and placed in an Erlenmeyer flask. Subsequently, 50 cc of a 67% alcohol solution was introduced into the

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flask, and the amalgam (combination of cooking water and the solids dissolved or suspended within it, formed during the cooking process) was agitated for a duration of 10-15 min to ensure thorough homogenization. Post-mixing, the Erlenmeyer flask was allowed to settle, resulting in the formation of two discernible phases. The upper phase was decanted, and approximately 20-25 cc of the decanted solution was extracted. A small quantity of phenolphthalein reagent was then added, and the solution underwent titration with a 1/10% standard solution until a faint pink hue appeared. The acidity level was subsequently determined in relation to the initial 50 cc volume of the solution (Abdolmaleki *et al.*, 2024).

Measurement of solids content

The quantification of solid percentage in cooking water comprised the following procedures. First, the water-cooking amalgam underwent evaporation utilizing a heat source or steam bath. Subsequently, it underwent drying in an oven set at 105±2 °C until complete desiccation was attained. The specimen was then positioned in a desiccator until it equilibrated to room temperature, whereupon the weight of the remaining solids was ascertained, employing the following formula to compute the percentage in grams (Semwal*et al.*, 2015).

$$\text{Total Solids Residual (\%)} = \frac{D-F}{W} \times 100$$

Where D is the weight of the beaker containing solids after cooking, F is the weight of the empty beaker, and W is the weight of the sample (all based on g).

Mold and yeast count

The mold and yeast assessment was conducted in adherence to the Iranian National Standard (INS No. 997, 2021). A volume of 1 ml from the initial suspension was introduced onto a plate supplemented with 15–20 cc of Dichloran Rose Bengal Chloramphenicol agar (DRBC agar). Upon complete solidification of the medium, the plate underwent incubation at 26 °C for a period spanning 3–5 days. Subsequent to the incubation period, the number of colonies present on the plate was multiplied by the reciprocal of the dilution factor, yielding the mold and yeast count per gram of the sample.

Colorimetric evaluation

The colourimetric assessment involved the examination of color changes in the produced samples and the impact of varying ginger root fiber concentrations on product color. This evaluation was performed using the Hunterlab device (ColorFlex EZ [Hunter Associates Laboratory, Inc., United States]) on raw pasta samples. The colourimeter was initially calibrated using both black and white calibration plates. Subsequently, the samples were individually inserted into the machine, and each pasta was tested in triplicate using different samples from the same treatment to ensure production consistency. Pasta color was determined by measuring parameters $a*$ (redness), $b*$ (yellowness), $L*$ (lightness), and ΔE (total color difference), calculated using the following equation (Latifi et al., 2024).

$$\Delta E = \sqrt{(L - Lstd)^2 + (a - astd)^2 + (b - bstd)^2}$$

Sensory evaluation

The assessment of sensory attributes in the samples followed the five-point hedonic method, encompassing the evaluation of color, taste, texture, and overall acceptance across three distinct storage periods (Iranian National Standard [INS] No. 12042, 2018). A trained panel comprising eight individuals, affiliated with the Research Institute of the National Standard Organization of Iran, participated in each session of this examination. Each panel member received approximately 50 g of individual samples, discreetly packaged in transparent containers with distinct codes. To maintain uniformity, all pasta samples underwent cooking under identical conditions—immersed in boiling water with a specified quantity of salt for a duration of 10 min, ensuring the prevention of flavor interference during evaluation. Prior to each tasting, evaluators rinsed their palates with water.

Participants were instructed to articulate their assessments of each sample's attributes using a questionnaire tailored for this purpose. The rating scale was structured as follows as described by Vu *et al.* (2025), with modifications.

1) Color Assessment: Rated from Colorless (1) to Dark (5), with Normal (3) as the midpoint.
2) Taste Index: Scored from Tasteless (1) to Delicious (5), with Normal (3) as the intermediate value.
3) Texture Index: Measured from Soft (1) to Hard (5), with Normal (3) as the central point.
4) General Evaluation Index: Assessed on a scale from Strongly Disliking (1) to Strongly Liking (5), reflecting the participants' overall preference.

Statistical analysis

This study evaluated the impact of ginger root fiber levels (2.5%, 5%, 7%, and 10%) and storage duration (0, 1, 3, and 6 months) on various quality parameters, including acidity, moisture, protein, ash, color indices, sensory properties, and microbial counts. Data were analyzed using XLSTAT (2022), with measurements performed in triplicate and reported as mean ± Standrad Deviation (SD, $p<0.05$). Combination plots were created in MATLAB (R2024b), and Principal Component Analysis (PCA) was conducted using XLSTAT (2022) for sensory and colorimetric data, based on a standardized Pearson correlation matrix. Factors were

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selected using Kaiser's criterion (eigenvalues > 1), with variable contributions defined by loadings > ±0.5. Statistical significance was set at α=0.05.

Results and discussion

Moisture evaluation

Figure 1 presents moisture content (%) across four treatments (T1, T2, T3, and T4) and the control, measured on the production day and at the 1st, 3rd, and 6th months. A clear decreasing trend in moisture is observed across all treatments over time, likely due to ongoing drying or storage-related processes.

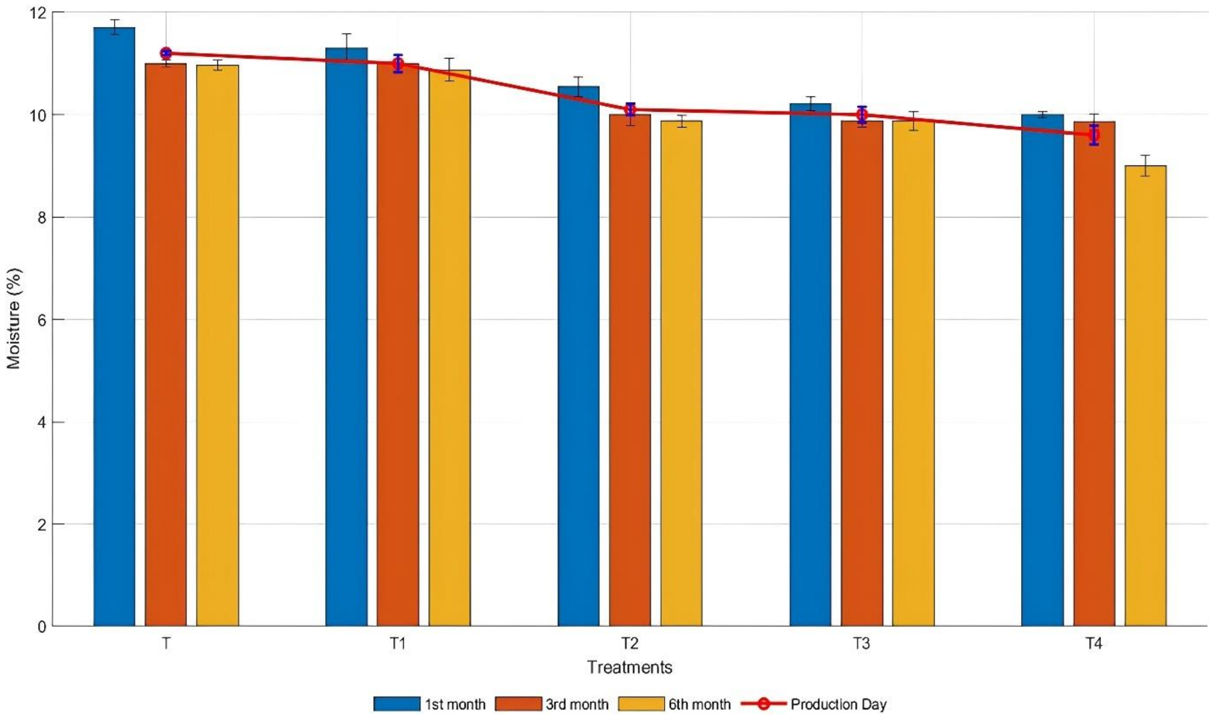

Figure 1: Comparison of the moisture percentage (mean ± Standrad Deviation [SD]) considering the combined influences of treatment and storage duration on pasta
T=control treatment; T1=pasta treatment with 2.5%; T2=pasta treatment with 5%; T3=pasta treatment with 7%; and T4=pasta treatment with 10% of ginger root fiber

Treatment T, the control, consistently exhibited the highest moisture levels throughout the study period, beginning at approximately 11.8% in the first month and decreasing marginally to around 11.2% by the production day. Treatment T1 followed a similar trajectory, with moisture content decreasing from roughly 11.3% to 11.0%. Treatments T2, T3, and T4 demonstrated more substantial reductions in moisture content over the same period. T2 declined from approximately 10.6% to 10.2%, while T3 followed a similar pattern with slightly lower final values. Notably, T4 exhibited the greatest reduction, decreasing from around 10.0% in the first month to approximately 9.0% by the sixth month, and maintaining a final production day value of roughly 9.6%. In conclusion, the data indicate that while all treatments experienced a temporal reduction in moisture content, the magnitude of this reduction varied. Treatment T4 was the most effective in lowering moisture levels, suggesting enhanced efficacy in moisture regulation or preservation. Conversely, the control (T) retained the highest moisture content, indicating limited or no intervention. These findings have implications for optimizing post-treatment storage or processing methods where moisture control is critical.

The results of the present study indicate that different ginger root fiber ratios significantly influenced the moisture content of the pasta samples over time, with a consistent decline observed across all treatments. This contrasts with findings from Simonato *et al*. (2021), where the inclusion of Moringa oleifera leaf powder in fresh pasta formulations did not significantly alter moisture content. Similarly, Bianchi *et al.* (2022) reported that fortification with maqui berry powder had no effect on moisture levels, though it impacted other physicochemical and functional properties. However, the observed reduction in moisture content in the current study aligns with the findings of Lawal *et al*. (2021), who developed functional pasta using yellow cassava and amaranth leaf powder, achieving low moisture levels (<12%) that ensured shelf life and

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compliance with Codex Alimentarius standards. Furthermore, El-Sohaimy *et al*. (2020) reported that chickpea flour and protein isolate significantly increased moisture content in cooked pasta, demonstrating how specific ingredients can influence water retention differently depending on the formulation and processing conditions.

Additionally, the temporal decline in moisture content recorded in this study is supported by storage-based findings from Sharma *et al.* (2021) and Kamble *et al.* (2021), who reported a significant increase in moisture content during storage, particularly under accelerated conditions (≥38–40 °C), emphasizing the role of environmental factors in moisture dynamics. In contrast to those studies, which observed moisture gain over time under certain conditions, the reduction in moisture content observed in the current study may reflect a combination of ingredient composition, ambient storage conditions, and possible dehydration or moisture migration from the matrix over time. Collectively, the variability reported across these studies underscores the complex interplay between ingredient type, environmental factors, and storage duration in determining the moisture behavior of fortified pasta products.

Acidity analysis after cooking pasta

Figure 2 illustrates the changes in acidity (%) over time for four treatments (T1, T2, T3, T4) and the control, measured on the production day and at the 1st, 3rd, and 6th months, . A general increasing trend in acidity was observed across all treatments over time. Initially, at the 1st month, acidity values ranged from approximately 2.1% to 2.5%. By the 6th month, these values had increased to between 2.45% and nearly 2.9%, suggesting progressive acidification during storage.

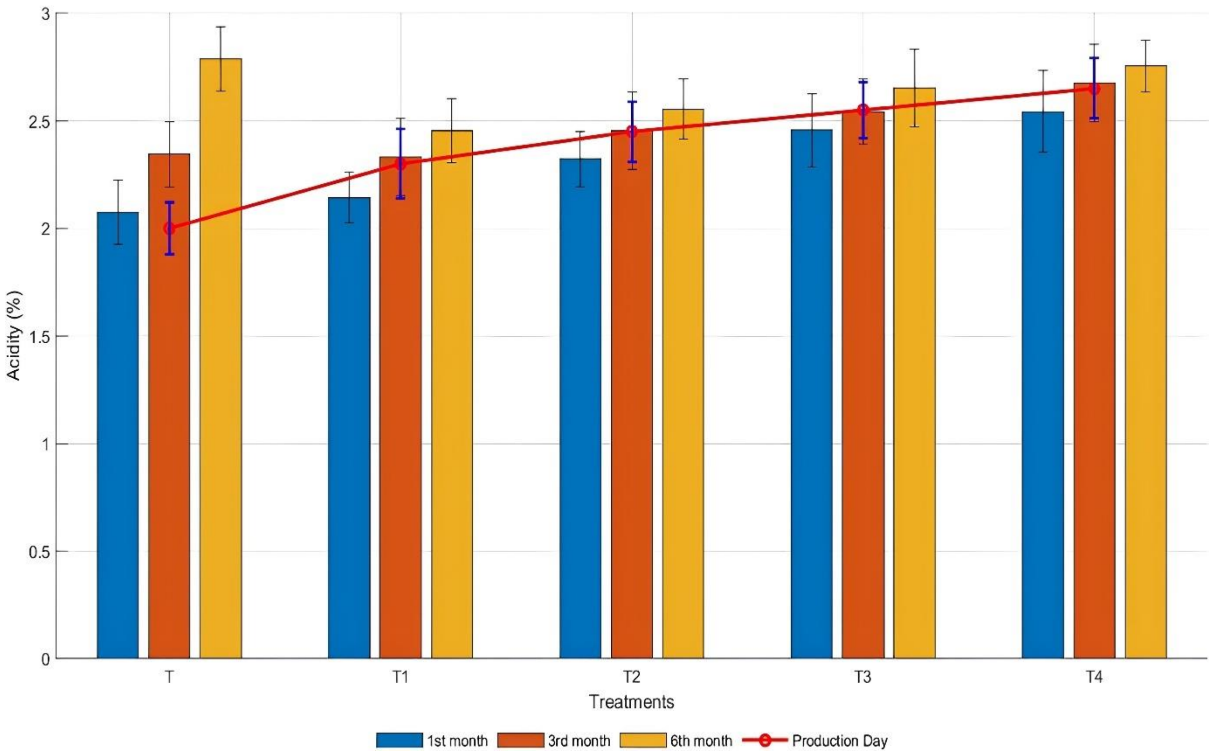

Figure 2: Comparison of the acidity percentage (mean ± Standrad Deviation [SD]) considering the combined influences of treatment and storage duration on pasta
T=control treatment; T1=pasta treatment with 2.5%; T2=pasta treatment with 5%; T3=pasta treatment with 7%; and T4=pasta treatment with 10% of ginger root fiber

Treatment T shows the highest variability and the most significant increase in acidity over time, especially by the 6th month. Treatments T1 through T4 display a more gradual rise, with T4 exhibiting the highest final acidity level (~2.85%). The red line representing acidity on the production day shows a steady upward trend from T to T4, indicating that initial acidity levels varied slightly among treatments, with T4 starting the highest. The error bars indicate Standard Deviation (SD) or confidence intervals, showing moderate variability within each treatment and time point, though they are relatively consistent and overlap modestly among treatments. These findings suggest that all treatments experienced acid development over time, with possible implications for product stability,

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quality, or microbial activity. The consistent increase in acidity may be attributed to ongoing fermentation or biochemical changes. Treatment T appears less stable compared to T4, which maintained more uniform acidity increments and smaller variability, possibly indicating better preservation or formulation.

The observed increase in acidity across all treatments over time aligns with findings from several recent studies on pasta enrichment. Bianchi *et al.* (2022) reported that the inclusion of maqui berry powder significantly increased acidity, especially at higher concentrations, supporting the trend seen in treatments like T4 with elevated final acidity levels. Similarly, Pop, Voşgan, and Finta (2023) found that pasta enriched with vegetable purees exhibited higher acidity, largely influenced by moisture content and drying dynamics, paralleling the progressive acidity rise noted in the present study. Rodrigues *et al.* (2023) also demonstrated that incorporating Opuntia ficus-indica flour raised acidity due to malic acid, reinforcing the impact of specific ingredients on titratable acidity. Additionally, Lupu *et al.* (2023) observed that adding carob powder increased acidity compared to controls. Collectively, these studies justify the results observed in the graph, emphasizing that formulation and bioactive ingredient incorporation can significantly affect acidity levels during storage.

Evaluation of solid residuals

Figure 3 presents the percentage of cooking solids for four treatments (T1, T2, T3, and T4) and the control over storage intervals—1st, 3rd, and 6th months—alongside initial measurements taken on the production day (represented by the red line). A clear increasing trend in cooking solids is observed with higher treatment levels, particularly from T2 onwards.

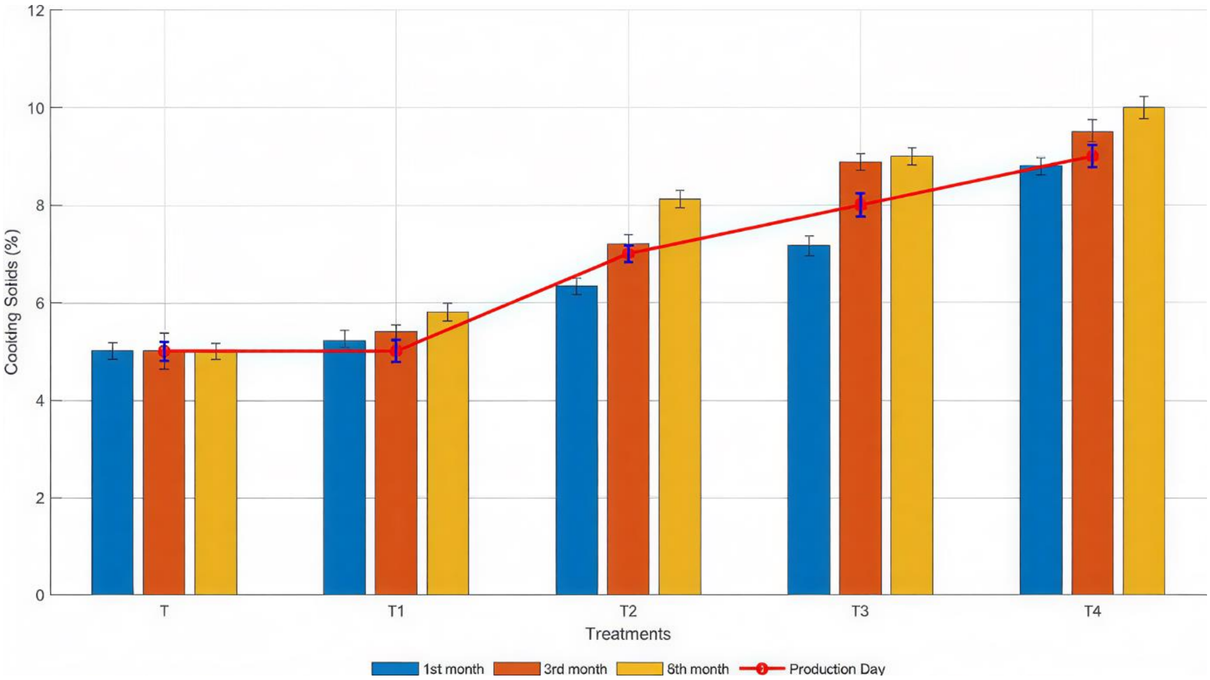

Figure 3: Comparison of the cooking solids (mean ± Standrad Deviation [SD]) considering the combined influences of treatment and storage duration on pasta
T=control treatment; T1=pasta treatment with 2.5%; T2=pasta treatment with 5%; T3=pasta treatment with 7%; and T4=pasta treatment with 10% of ginger root fiber

Treatments T and T1 exhibited relatively stable cooking solid percentages over time (around 5–5.8%), while T2, T3, and T4 showed progressive increases, reaching up to approximately 10.2% by the 6th month in T4. This trend suggests that the incorporation of ginger root fiber, especially at higher concentrations, promotes higher cooking loss, likely due to weakened gluten matrix structure and increased fiber leaching during cooking. The steady rise in solids over storage time may also indicate structural degradation or increased solubility of components. These results highlight the impact of fiber enrichment on cooking quality, with potential implications for texture and nutritional loss during preparation.

The observed increase in cooking solids, particularly in treatments T2 to T4, aligns with existing research on the effects of fortification on pasta structure and nutrient retention. As shown in the study by Cappa *et al.* (2021), fortifying gluten-free gnocchi with red rice or buckwheat flour led to increased solid loss during cooking, with red rice causing the highest leaching due to its impact on matrix

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integrity. This supports the current findings, where higher levels of ginger root fiber appear to compromise structural cohesion, resulting in greater solids release. Additionally, while Dziki (2021) notes that legume-fortified pasta retains more nutrients and limits cooking loss due to a more stable matrix, the present data suggest that the type of fortifying agent plays a critical role . Ginger fiber, unlike legumes, may not integrate as tightly within the protein-starch network, leading to higher solid loss. Therefore, while fiber fortification can enhance nutritional value, it may also lead to increased cooking losses depending on the ingredient's interaction with the pasta matrix.

Mold and yeast evaluation

Figure 4 illustrates the mold and yeast count (Log Colony Forming Unit [CFU]/ml) across four treatments (T1, T2, T3, and T4) and the control over storage periods, 1st, 3rd, and 6th months, along with measurements from the production day. A distinct trend is evident, showing a progressive increase in microbial load with longer storage, particularly in untreated (T) and lower-level treatments (T1 and T2).

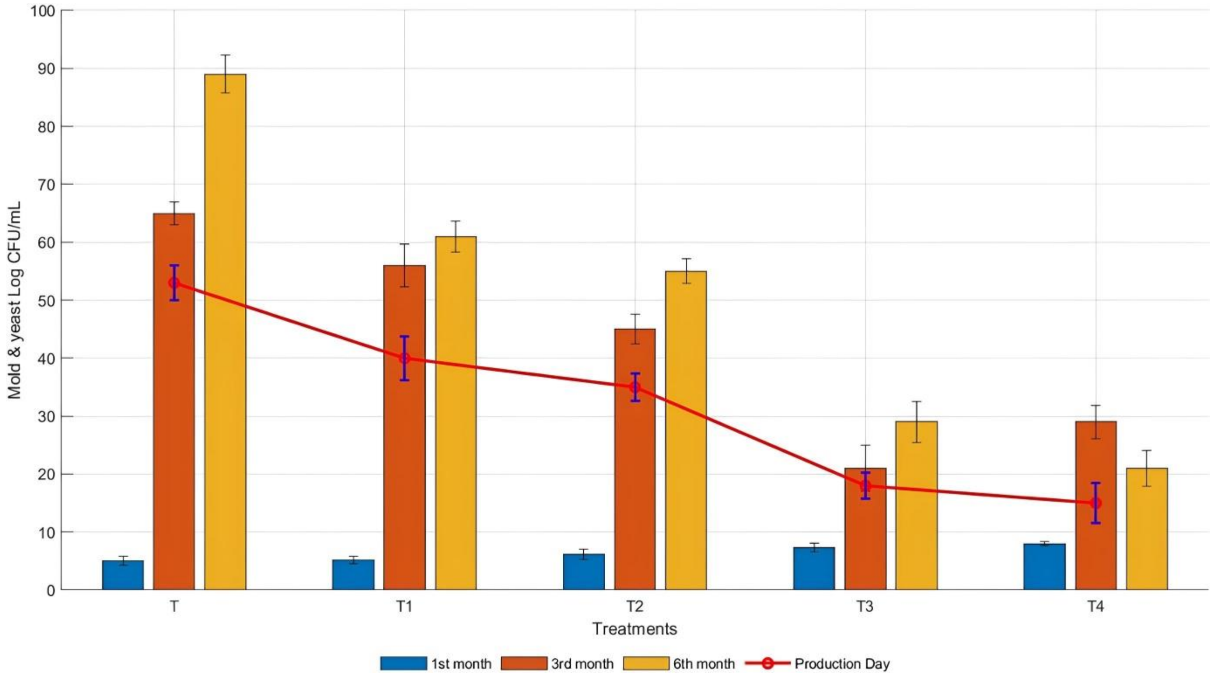

Figure 4: Comparison of the quantity of mold and yeast (mean ± Standrad Deviation[SD]) considering the combined influences of treatment and storage duration on pasta
T=control treatment; T1=pasta treatment with 2.5%; T2=pasta treatment with 5%; T3=pasta treatment with 7%; and T4=pasta treatment with 10% of ginger root fiber

Treatment T exhibited the highest microbial proliferation by the 6th month (~90 Log Colony Forming Unit [CFU]/ml), whereas higher ginger root fiber concentrations (T3 and T4) significantly suppressed microbial growth, with T4 maintaining the lowest levels across all time points. This suggests that ginger root fiber may exert antimicrobial effects, potentially due to its bioactive compounds such as gingerol and shogaol, which are known for their inhibitory activity against fungal growth. The reduction in mold and yeast counts with increasing fiber content underscores the potential of ginger root fiber not only as a functional ingredient but also as a natural preservative, enhancing the microbial stability of pasta during storage.

The observed reduction in mold and yeast counts with increasing levels of ginger root fiber can be scientifically justified by existing literature on the antifungal potential of bioactive plant-based ingredients. Schettino *et al.* (2020) demonstrated that pasta fortified with chickpea flour fermented by Lactic Acid Bacteria (LAB) exhibited strong antifungal properties, significantly inhibiting mold growth over a 40-day period, even outperforming chemical preservatives like calcium propionate. This effect was attributed to the generation of antifungal peptides and an overall improvement in the nutritional profile, including higher fiber and protein content. Similarly, Wang *et al.* (2018) reported that staghorn sumac extract, rich in polyphenols, delayed mold growth in bread in a concentration-dependent manner, achieving up to a 5-log reduction during a 7-day storage period. These findings align with the current results, where the highest concentration of ginger fiber (T4) led to the most

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pronounced inhibition of fungal growth, likely due to the presence of natural antimicrobial compounds such as gingerol. Thus, the inclusion of ginger root fiber appears to act as a functional ingredient, enhancing microbial stability through its inherent antifungal activity, comparable to other bioactive plant additives reported in the literature.

Sensory and colorimetric evaluation

The set of three PCA biplots in Figure 5 illustrates the relationships among sensory attributes (taste, texture, and overall acceptance), colorimetric parameters (appearance color, ΔE), and their evolution across three storage periods, 1st month, 3rd month, and 6th month. The samples include a control (T) and four pasta treatments: T1 (2.5% ginger root fiber), T2 (5% ginger root fiber), T3 (7% ginger root fiber), and T4 (10% ginger root fiber), where ginger root fiber denotes the functional additive used in the formulations.

Table 2 reveals the contribution of variables to each factor. Factor 1 shows a balanced influence with T2 (25.309%) leading, followed by T, T1, and T3, while T4 (6.591%) contributes the least, suggesting a broad effect across variables. Factor 2 is dominated by T4 (63.095%), with T3 and T contributing moderately, indicating T4's strong influence. Factor 3 is heavily driven by T2 (62.673%), with T1 and T3 adding notable contributions, while T and T4 are minimal. Factor 4 highlights T3 (41.825%) as the primary contributor, with T4 and T also contributions, while T1 and T2 contributed to a lesser extent. Factor 5 is led by T (47.576%) and T1 (42.848%), with T2, T3, and T4 playing minor roles.

Table 2: Contribution of the variables (%) to each factor in the principal component analysis model

	F1	F2	F3	F4	F5
T	23.022	12.089	0.106	17.207	47.576
T1	23.066	11.189	18.095	4.802	42.848
T2	25.309	0.785	62.673	7.546	3.688
T3	22.012	12.842	18.349	41.825	4.972
T4	6.591	63.095	0.777	28.620	0.917

F1-5 are the variables considered for this PCA model.
T=control treatment; T1=pasta treatment with 2.5%; T2=pasta treatment with 5%; T3=pasta treatment with 7%; and T4=pasta treatment with 10% of ginger root fiber

The first biplot (F1 vs. F2), which accounts for 96.54% of the total variance (F1: 73.08%, F2: 23.46%), shows that taste, appearance color, and ΔE are positively correlated and strongly associated with F1, indicating their dominant role in product differentiation. In the 1st month, T1 and T2 (2.5% and 5% ginger root fiber) cluster near these vectors, suggesting enhanced sensory and colorimetric profiles during early storage stage. In contrast, texture and overall acceptance load less strongly on F1 and F2, and the 6th-month samples show a notable shift away from this region, indicating sensory decline and increased ΔE values, which signal greater color deviation.

In the second biplot (F2 vs. F3; 25.40% variance), taste continues to load along F2, while texture and overall acceptance become more prominent along F3. This plot reveals broader dispersion of the 6th-month samples, particularly among T3 and T4 (7% and 10% ginger root fiber), suggesting increased variability and possible sensory deterioration at higher ginger root fiber levels. T2, however, maintains relatively stable taste scores, indicating that 5% ginger root fiber may offer a balance between sensory quality and functional enrichment. The ΔE parameter remains near the origin along F3 but retains influence along F2, reinforcing its role in visual quality differentiation over time. The third biplot (F3 vs. F4; 3.21% variance) highlights more subtle changes, with texture contributing significantly along F3. T3 appears aligned with this vector, implying better textural retention in the 7% ginger root fiber treatment; ΔE also separates slightly along F4, indicating progressive color changes in some samples. Overall acceptance and appearance color cluster near the origin, suggesting minimal variation in these dimensions at this level of analysis.

Overall, the PCA reveals that taste, appearance color, and ΔE are key indicators of product quality, especially in early storage. Treatments T1 and T2 (2.5% and 5% ginger root fiber) show the most favorable profiles during the initial period, while T3 (7% ginger root fiber) demonstrates better structural resilience over time. T4 (10% ginger root fiber), although high in ginger root fiber content, appears more variable, particularly in the later storage months. These findings support the use of PCA in integrating sensory and instrumental data to evaluate the effects of ginger root fiber concentration and storage on pasta quality, aiding in the development of formulations with optimal sensory appeal and shelf stability.

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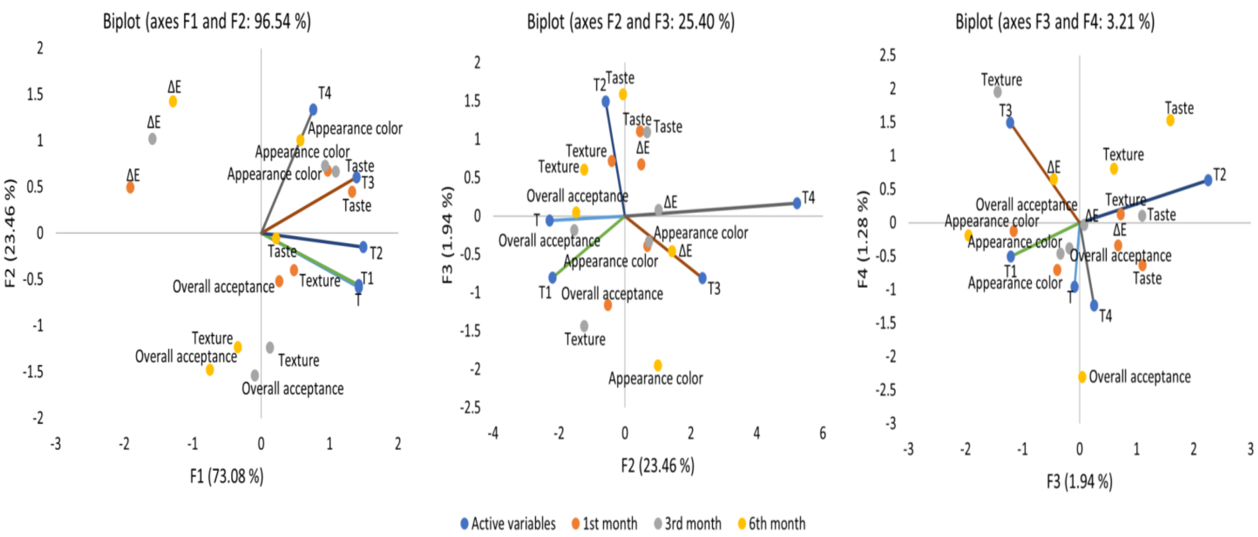

Figure 5: The Principal Component Analysis (PCA) model for sensory attributes (taste, texture,and overall acceptance) and colorimetric parameters (appearance color, ΔE).
A significance level of α=0.05 was applied to ensure the statistical validity of the results.
T=control treatment; T1=pasta treatment with 2.5%; T2=pasta treatment with 5%; T3=pasta treatment with 7%; and T4=pasta treatment with 10% of ginger root fiberfiber

The present study's findings on the sensory and colorimetric behavior of pasta treatments fortified with varying levels of ginger root fiber (2.5–10%) over a 6-month storage period are strongly supported by a wide body of literature on functional ingredient incorporation in pasta products. The observed reduction in lightness (L*) and increased total color difference (ΔE) over time, especially in higher fortification levels (T3 and T4), aligns with previous studies demonstrating that fortification with plant- or protein-based additives significantly alters pasta's visual appearance. For instance, Attanzio *et al.* (2019) reported that the addition of Opuntia ficus-indica cladode extract (10–30%) to durum wheat tagliatelle progressively reduced lightness and shifted the color toward the blue spectrum. Similarly, Desai, Brennan, and Brennan (2019) found that salmon fish powder (SFP) at 5–20% levels significantly decreased lightness in uncooked pasta compared to the control.

These changes are not exclusive to plant or marine-based additions. Krawęcka, Sobota, and Sykut-Domańska (2020) showed that beta-glucan fortification from oats decreased brightness while enhancing yellowness and redness, paralleling the color shift trends noted in the current study. Lawal *et al.* (2022) and Rainero *et al.* (2022) also corroborated that leafy vegetable and grape pomace powder incorporation alters redness and yellowness levels, reinforcing the conclusion that color deviations are an inherent effect of ingredient substitution—especially as ginger root fiber levels increase.

Moreover, the impact of fortification on sensory perception and texture stability during storage is well supported in the literature. In our study, higher ginger root fiber concentrations and prolonged storage periods (particularly at the 6th month) led to noticeable declines in taste, texture, and overall acceptance, especially in T3 and T4. Messia *et al.* (2021) similarly highlighted the slightly bitter aftertaste resulting from protein isolate enrichment in pasta, affecting palatability. Furthermore, Espinosa-Solis *et al.* (2019) observed that oat bran fortification reduced pasta elasticity and increased gumminess, while Teterycz *et al.* (2020) reported a firmer and less cohesive texture with legume flours—both of which mirror the declining textural acceptability seen in the current study with storage.

Lastly, the influence of ingredient addition on consumer perception and marketability is well documented. For instance, while olive pomace pâté fortification in pasta reduced visual appeal, nearly one-third of consumers still preferred the fortified products, suggesting that visual alterations may not completely negate consumer interest if nutritional or functional value is perceived (Cecchi *et al.*, 2019).

The current study's PCA findings are substantiated by a wide spectrum of empirical studies, which collectively affirm that functional ingredient fortification—particularly at higher levels—alters the color, taste, and texture of pasta products. These effects are further compounded by storage time, necessitating careful optimization of fortification levels to maintain product quality and consumer appeal throughout shelf life.

Conclusion

This study demonstrated that incorporating ginger root

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fiber into pasta formulations significantly influences its physicochemical properties, microbial stability, and sensory characteristics, particularly increasing fiber content and storage duration. Higher concentrations of ginger root fiber (7.5% and 10%) resulted in substantial reductions in moisture content, increased ash levels, and elevated acidity post-cooking. Additionally, fortified pasta showed improved microbial stability, with lower mold and yeast counts, indicating that ginger fiber can enhance shelf life. However, sensory evaluations revealed that higher ginger root fiber concentrations adversely affected consumer acceptability, with reductions in taste, texture, and overall appearance.

The findings suggest that while ginger fiber fortification offers nutritional benefits and shelf-life extensions, there is a critical balance between maximizing health advantages and maintaining sensory quality. Pasta fortified with lower levels of ginger root fiber (2.5% and 5%) showed minimal sensory deviations from the control, suggesting these concentrations may provide an optimal compromise. Future research could explore formulation adjustments or combinations with other fortifying agents to further optimize the functional and sensory properties of ginger root fiber -fortified pasta products.

Author contributions

M.H.M. and F.A. designed and performed the experiments; M.D. reviewed the manuscript and handled the editing; Z.L. accomplished the data analysis and contributed to writing the manuscript. All authors read and approved the final manuscript.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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Ethical consideration

The sensory panel was provided with all the necessary information regarding the evaluation process, ensuring that they could make informed decisions in accordance with both ethical standards and legal guidelines.

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