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Integrating green banana and cauliflower into whole wheat pasta: Approaches to enhance nutritional benefits while maintaining quality

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A B S T R A C T

This study aimed to formulate whole wheat flour (WWF) pasta fortified by several flour varieties like green banana flour (GBF), cauliflower powder (CF), onion powder (OP) and garlic powder (GP). In comparison to the commercial (control) pasta, WWF pasta and pasta fortified with GBF, CF, OP, and GP were found to have significantly ($p \leq 0.05$) higher levels of soluble and insoluble dietary fiber, micronutrients, total phenolic, flavonoid, and antioxidant content, as well as in-vitro antioxidant activity (DPPH and ABTS). Among different formulation, 33.0 % WWF replacement with different flour showed highest dietary fiber and antioxidant content. The soluble and insoluble dietary fiber was increased 1.03 to 6.81 g/100 g and 4.07 to 14.26 g/100 g respectively whereas optimum cooking time, cooking loss and water uptake increased 6.90 %, 13.63 % and 61.93 % respectively. The effects were also found in changes in color coordinates. In comparison to the control sample, it was demonstrated that all the developed pasta increased the lightness (L*), yellowness (*b**), and lowered the redness (a*), and whiteness (W). Pasta's adhesiveness (0.04 to 0.11 J/m^3), stickiness (0.80 to 1.19 N), cohesiveness (0.31 to 0.43) and gumminess (40 to 51 N) increased while its hardness (124 to 98 N), chewiness (34 to 28 N), and springiness (0.79 to 0.66) decreased when 33.0 % fortified pasta compared with control pasta. The sensory panel ranked the control pasta as the most preferred among all the samples in this study, with the 20 % GBF-enriched pasta receiving the second-highest overall acceptability score. Notably, none of the laboratory-produced pasta samples were found to be unappealing. Even it does not have the same technological and sensory quality as commercial pasta, fortified whole wheat flour pasta has a greater antioxidant and dietary fiber content, which is equal to 46 % and 80 % of the required dietary intake recommendation, respectively for 100 g developed pasta consumption. Therefore, our findings imply that in the future food business, dietary fiber and antioxidant-enhanced pasta may be formulated with whole wheat flour, green banana flour, cauliflower, onion, and garlic powder.

1. Introduction

Numerous studies have thoroughly documented the health benefits of dietary fiber and antioxidants. These are the two most important bioactive substances that can be utilized in the formulation of new food items (Nilusha et al., 2019). A diet low in dietary fiber can lead to a range of diseases such as gallstones, diabetes, obesity, appendicitis, constipation, coronary heart disease, and hiatus hernia. Consuming sufficient amounts of dietary fiber lowers the risk of the diseases listed above (Hayyat et al., 2024). In the human body, free radicals and reactive oxygen species (ROS) generated due to several internal and external factors that can causes several cellular dysfunctions like

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oxidative stress (Zehiroglu & Sarikaya, 2019). It has been demonstrated that oxidative stress is linked to a number of clinical disorders associated with metabolic syndromes such as cancer, hypertension, hyperlipidemia and hyperglycemia (Liaqat et al., 2021). A group of compounds known as antioxidants can neutralize the free radicals and ROS in the cell (Zehiroglu & Sarikaya, 2019). Furthermore, research has indicated that people who consume a sufficient amount of dietary fiber and antioxidant may be less susceptible to cardiovascular disease, stroke, and colorectal cancer (Marrelli et al., 2021; Yang et al., 2021). A higher consumption of antioxidants and dietary fiber also lowers blood pressure, serum cholesterol, and the risk of diabetes. It also helps with weight loss and may boost immunity (Borghi & Pavanelli, 2023). High-fiber diet is linked to lower risk of death and chronic illness, according to a new study published in the journal The Lancet that was based on systematic reviews and meta-analyses conducted by experts in New Zealand (Reynolds et al., 2019).

In accordance with Dietary Guidelines of WHO/FAO, adults are advised to have an adequate intake of fiber: >25.0 g per day for men and women (Crawford et al., 2010). For adults, the majority of dietitians also advise consuming 18.0–38.0 g of fiber per day, or 8.0–20.0 g per 1000 Kcal (O'Keefe, 2019). Based on the vitamin C equivalent, a Recommended Dietary Allowance (RDA) of 90 mg per day for adult men and 75 mg per day for adult women is established to guarantee antioxidant protection (Institute of Medicine, 2001). According to recent estimates, the majority of people worldwide do not consume half of the daily recommended intakes of antioxidants and dietary fiber. Fortifying foods with fiber and antioxidant offer an alternative method to meet the recommended daily intake (RDI) through diverse food options like pasta, cereals, bread and cookies.

Pasta is a traditional wheat-based cuisine that is enjoyed worldwide because it is easy to handle, prepare, transport, and store (Bello-Perez et al., 2022). Also, it is important due to its great market demand as well as its nutritional benefits. But pasta made with refined wheat flour are typically high in starch and low in phenolic compounds, minerals, vitamins, and dietary fiber (Gull et al., 2018). It has been shown that at present, there are more overweight than underweight people across the globe, primarily due to the overconsumption of high-calorie, low-nutrient foods, leading to a surge in chronic diseases related to diet. A commonly recognized and frequently suggested solution is to substantially reduce the consumption of refined grains and regular intake of whole grain and whole wheat foods (Hirawan & Beta, 2014). Incorporating fibers and antioxidants into pasta formulations can also play a significant role in creating a highly consumed functional staple food that is nutritionally beneficial and rich in fiber and antioxidant, helping to bridge the gap between recommended fiber intake and current consumption levels (Gull et al., 2018; Makhlouf et al., 2019).

Many research has looked into the possibilities of incorporating functional substances into pasta to increase its nutritional value (Diantom et al., 2019). Whole wheat dry pasta can be a source of minerals (magnesium, potassium, phosphorus), bioactive compounds and fiber, which can also be a source of pantothenic acid, one of the major vitamins in the B vitamins complex (Vignola et al., 2018). Biernacka et al. (2020) found that substituting varying percentages of dried banana powder for wheat flour increased the antioxidant potential and total phenolics content. Green banana flour also has a number of unique advantages, including a high percentage of dietary fiber (14.5 %), resistant starch (17.5 %), and total starch (73.4 %) (Islam et al., 2024). Incorporate cauliflower powder with other ingredients to make pasta that's suitable for low-carb or gluten-free lifestyles (Sinha & Sharma, 2023). Cauliflower is rich in essential nutrients such as vitamins C and K, folate, vitamin B6, and dietary fiber, all of which are vital for maintaining overall health, supporting immune function, and promoting healthy digestion (Ahmed & Ali, 2013). Fortification by onion powder led to a significant ($P \leq 0.05$) improvement in nutritional characteristics, as seen by increased levels of antioxidant activity, dietary fiber, total minerals, total phenolic components, and flavonoid content (Michalak-Majewska et al., 2020). Depending on the variety of garlic and the degree of enrichment levels, adding garlic powders to pasta enhanced its antioxidant capacity by 185–600 % and its levels of phenolics (26–146 %), flavonoids (40–360 %), and potassium (up to thrice) after cooking (Filipcev et al., 2023). With rising interest from health-conscious individuals, the demand for pasta products that are high in minerals, phenolic compounds, dietary fiber, and have a low glycemic index has become a top priority.

The flexibility of pasta formulation allows for the addition of ingredients that enhance dietary fiber, and antioxidant capacity (Bello-Perez et al., 2022). The research on fiber and antioxidant fortification in pasta products is still underdeveloped, with few studies analyzing how fiber and antioxidant addition influences pasta quality, cooking behavior, color, and sensory appeal. The uncertainty regarding how different types and amounts of fiber and antioxidant source impacts in pasta food products is largely at the research stage. While some successful examples have reached commercialization, they continue to face challenges with limited consumer acceptance.

Considering all this issue, it is time to develop dietary fiber and antioxidant enrich functional pasta with desirable quality attributes. This is the first time in pasta formulation research, we are going to incorporate all of these four viz: green banana flour (GBF), cauliflower (CF), dried onion powder (OP), and garlic powder (GP) as a representative source of dietary fiber and antioxidants in our formulation. Green banana flour was individually incorporated into pasta recipes at four different levels: 10 %, 15 %, 20 %, and 25 % (w/w). Tomato paste (TP) was used as a replacement of water. Therefore, the primary purpose of this research is to investigate the viability of different pasta formulation using WWF and different dietary fiber and antioxidants source containing raw materials. This study will also evaluate the cooking quality, as well as the nutritional, antioxidant and sensory characteristics of the whole wheat flour fortified pasta.

2. Materials and method

2.1. Raw materials

Whole wheat flour (*Triticum aestivum*), tomato (*Solanum lycopersicum*), onion (*Allium cepa*), garlic (*Allium sativum*), soyabean oil, table salt, egg, freshly harvested green banana (*Musa paradisiaca*) and cauliflowers (*Brassica oleracea, variety botrytis*) were purchased from the local market and transported to the laboratory of Institute of Food Science and Technology (IFST), BCSIR, Dhaka, where the edible parts were processed. A commercial pasta manufactured by a renowned manufacturer using refined wheat flour was procured from a local super shop. The processed peeled green banana, cauliflowers, onion and garlic were further cut into small pieces and dried using a lab scale forced air dehydrator (ST-01, Septree, China). The dried raw materials were processed individually into fine powder using a domestic grinder (Philips, Simply Silent, 600 W). The coarse powder was sieved through an 80 mesh, packaged in a plastic bag, and stored at 2–8 °C for subsequent use.

2.2. Reagents and chemicals

Merck (New Jersey, USA) supplied the boric acid, sodium hydroxide, and acetic acid. Sigma-Aldrich supplied the petroleum ether (40:60), methanol (99.9 %), 100 % ethanol and Cholesterol (Certified Reference Material) (St. Louis, MO, USA). 2,2-Diphenyl-1-picrylhydrazyl was procured from Research-Lab Finen Chem Industries, Mumbai, India. Sodium (Na) and Potassium (K) standard for flame photometer were supplied by Fluka Analytical, Sigma-Aldrich, Switzerland. Magnesium (Mg), Phosphorus (P), Calcium (Ca), Iron (Fe), and Copper (Cu) standard for Atomic Absorption Spectroscopy were purchased from Ultra Scientific, USA. Megazyme in Ireland provided the assay kit for total dietary fiber. In addition, deionized water, 98 % sulfuric acid, and 37 % hydrochloric acid were utilized to prepare the solution. The glassware was purchased from Pyrex in the USA and Glassco in the UK.

2.3. Pasta formulation

Whole wheat flour, selected dietary fiber and antioxidant sources, oil, egg mixture, and salt were weighted separately as per the information provided in the supplementary documents (Table S1). The raw materials required for 100.0 g composite flour was calculated in gram and presented in the Table S1. The weighted dry ingredients, along with the tomato paste (moisture content 92.03 %), were transferred to a domestic pasta maker (model SK-1776, Sokany, China), and the dough was kneaded for 5 min at medium speed. Through trial and error, the ideal tomato paste level for each pasta was established without the use of water. Once the optimal tomato paste addition levels were determined, a domestic pasta extruder was used to make fusilli shape pasta. The resulting pasta samples were streamed under water vapor for 5.0 min and then dried in a forced air circulation dehydrator (ST-01, Septree, China) at 45 °C for 12 h to achieve a final moisture content of 3.0–5.0 %. The dried pasta was transferred to Ziploc bags with proper labels for subsequent analysis.

2.4. Assessment on characteristics of pasta samples

2.4.1. Water activity (a_w)

Water activity (a_w) reflects the extent to which water is available for biological activity. To determine the water activity (a_w) of the pasta samples, Makhlouf et al. (2019) method with slight modification was employed. A bench-top a_w meter (RS 200, Novasina AG, Switzerland) was used, ensuring measurements were conducted at a constant room temperature. The mean values were obtained by performing three measurements.

2.4.2. Color characteristics

The lightness (L*), redness (a*), and yellowness (b*) of prepared fresh pasta samples were measured using a handheld portable chromameter (CR-400, Konica Minolta Co., Osaka, Japan). The calibration of the instrument was performed using a standard white tile (L*= 94.12, a*= −0.09 and b*= 3.26). The L* value represents lightness, where 100 corresponds to white and 0 to black. The a* value represents redness when positive and greenness when negative, whereas the b* value signifies yellowness when positive and blueness when negative (Makhlouf et al., 2019). Each sample's chromatic coordinates (L, a, and b) are reported as the mean of three measurements. The W value representing the pasta's whiteness was calculated as follows (equation 1):

$$W = 100 - \left[(100 - L*)^2 + a*^2 + b*^2\right]^{1/2} \quad (1)$$

By calculating the color differential index (ΔE) following Eq. (2), the color shift caused by fortification with fiber and antioxidant source was identified. Each pasta sample was measured in four replicates, and mean values and standard deviations were computed.

$$\Delta E* = \left[(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2\right]^{1/2} \quad (2)$$

2.4.3. Optimal cooking procedure

According to the AACC method 66–50.01 (AACC, 2005) with slight modification, the cooking time for the fresh pasta samples was estimated. Pasta cooking time was optimized by adding 10.0 g of sample into a beaker filled with 100.0 mL boiling water. The cooking time of fusilli-shaped pasta was determined by cutting it in half with a sharp knife until the white core completely vanished and this time was designated as optimum cooking time (OCT). The cooking time was determined in three separate trials, and the average values were reported.

2.4.4. Cooking characteristics assessment

2.4.4.1. Water uptake index. The water absorption index measures the quantity of water absorbed by a specific dry weight during cooking and retained after draining. Filipcev et al. (2023) method was followed to measure the water uptake with few changes. Briefly, 10.0 g of dry pasta (w_1) was cooked at OCT in 100.0 mL of boiling water and drained off the water and immediately measure the cooked pasta weight (w_2). The water uptake was measured using the Eq. (3) provided below. The average means of duplicates were recorded in grams.

$$\text{Water uptake } (\%,\ \text{dry basis}) = \frac{(w_2 - w_1)}{w_1} \times 100 \quad (3)$$

2.4.4.2. Cooking loss. Cooking loss represents the dry matter lost into the water during cooking under ideal conditions (Makhlouf et al., 2019). The post-cooking weight (w_2) of the dry pasta (pre-weight w_1) was noted after it was cooked at the OCT. The pasta was weighed again after being cooked at OCT and then dried in a force dehydrator at 40 °C until its weight remained consistent (w_3). Using a moisture analyzer (Series 335XM, Precisa, Switzerland), the moisture content (MC's) was analyzed and represented as MC_{dry} and MC_{cooked} respectively. The following formula (Eq. (4)) was used to get the cooking loss. The reported values represent the average of the samples measured in replicates.

$$\text{Cooking loss } (\%,\ \text{dry basis}) = 1 - \frac{w_3\ (1 - MC_{cooked})}{w_1\ (1 - MC_{dry})} \times 100 \quad (4)$$

2.4.5. Texture characteristics assessment

A texture analyzer (Model: FRTS-100N-I, Imada, Japan) with the Force Recorder software package was used to measure the texture characteristics of cooked pasta. With a little adjustment, the following characteristics were assessed: hardness, stickiness, chewiness, cohesiveness, springiness, gumminess, and adhesiveness. Two compression cycle mode tests were carried out using a 20 mm diameter flat probe (Islam et al., 2024a). The flat probe underwent a two full cycle of compression and retraction with setting of 5.0 mm/s and 3.0 mm/s pre and post-test speed respectively. To analyze the sample, the cooked pasta was taken in an aluminum dish and placed on the surface. Each pasta sample was measured using a minimum of five replicates.

2.4.6. Proximal composition, mineral and cholesterol analysis

A moisture analyzer (Series 335XM, Precisa, Switzerland) was used to measure the moisture content. Using the AACC method (AACC, 2005), the protein (2001.11), fat (2003.05), and ash (924.05) content were determined. The amount of carbohydrates was computed by following the method of FAO, 2003. The Atwater general factor approach was used to compute the calorific values (Kcal/100 g), with energy values of 4 Kcal/g for carbohydrates, 4 Kcal/g for proteins, and 9 Kcal/g for lipids. The Islam et al. (2024a) method was employed to prepare the mineral solution. The ash dissolved with 40 mL of 10 % HCl and heat over a water bath for 1.0 h to dehydrate silica. Add more water to dissolve soluble salt and filter into a 100.0 mL volumetric flask using Whatmann No. 1 filter paper volume adjusted with deionized water. The sodium (Na) and potassium (K) content of the samples were determined by using a flame photometer (Jenway, PEP7, St Neots Cambridgeshire, UK). Magnesium (Mg), Phosphorus (P), Calcium (Ca), Iron (Fe), and Copper (Cu) content were determined by atomic absorption spectrometer (VARIAN-220, Palo Alto, California, USA). Standard calibration curve method was employed to calculate the actual concentration. The calibration curves of all analyzed minerals provided in the supplementary file S1.4. Duplicate analysis was performed to obtain mean values. Cholesterol was determined by employing a reverse phase high performance liquid chromatography-UV detector (HPLC-UV) method developed by Kolaric and Simko (2020) with slight modification. Cholesterol extraction and chromatographic separation procedure has been provided in details in the supplementary file S1.1 section. Cholesterol content was calculated using the following Eq. (5).

$$\text{Cholesterol (mg / kg)} = \frac{\text{AS} \times \text{Cstd.} \times \text{DF}}{\text{Astd} \times \text{Ws}} \tag{5}$$

Here, A_s stands for area of sample, C_{std} stands for concentration of standard, DF stands for dilution factor, A_{std} stands for area of standard and W_s stands for weight of sample taken for analysis.

2.4.7. Dietary fiber analysis

Soluble, insoluble and total dietary fiber was analyzed employing our previous method with slight modification (Islam et al., 2024a). Using heat-stable α-amylase, protease, and amyloglucosidase, 1.0 g of fat-free pasta was subjected to sequential enzymatic digestion and SDF, IDF and TDF were quantified by employing AOAC 991.43 and AACC 32–07.01 methods. The details of the method have been provided in the supplementary file S1.2 section.

2.4.8. Fatty acid analysis

ISO 12966-2:2017(E) method with minor modification as described by Lisa et al. (2024) was followed to analyze the fatty acid composition. To prepare fatty acid methyl ester (FAME), 50 mg pasta sample oil (Soxhlet extraction) was added to 2.0 mL isooctane in a 10.0 mL screw capped test tube. Subsequently, 0.1 mL, 2.0 M methanolic KOH and 2.0 mL of saturated NaCl solution were added and vigorously shaken for 2 min. After that, the upper isooctane layer was passed through anhydrous Na_2SO_4 and collect the FAME in a 2.0 mL GC vial for analysis.

FAME analysis was carried out by a Thermo Scientific Gas Chromatograph (Trace 1300, USA) equipped with a flame ionization detector, an autosampler, and a highly polar fused silica capillary column (Rt-2560, Restek, Bellefonte, PA, USA) with a film thickness (100 m × 0.25 mm id × 0.25 μm). The ultrapure nitrogen gas was used as carrier with flow rate 1.0 mL/min; split injection system with a splitting ratio 20:1; the temperature of the injection and detector were kept at 250 °C. The initial oven temperature program was 150 °C (hold for 10 min), then increased to 200 °C at 5 °C/min and held for 10 min, increased to 240 at 5 °C/min and held for 20.0 min. The individual fatty acids were identified by comparison of retention time of Supelco 37 Component FAMEMIX (Supelco, Bellefonte, PA, USA), a Linolenic acid methyl ester isomer mix, and a Linoleic acid methyl ester mix (Supelco, Bellefonte, PA, USA). The relative percentage of all identified fatty acids (%) was used to express the composition of every individual fatty acid.

2.5. In vitro antioxidant activity

2.5.1. Extraction of phenolic compounds

Samples were extracted using the method of Gull et al. (2018) with slight modification. Briefly 10.0 g uncooked pasta were extracted for 2 h with 100 mL of 80 % methanol at ambient condition on an orbital shaker set at 200 rpm. The mixture was filtered and supernatant was collected in a beaker. The filter residue was re-extracted under identical conditions and filter supernatant was combined with the previous one. Using a vacuum rotary evaporator (BM510, RE801, Yamato, Chuo-ku, Tokyo, Japan), the supernatant was dried and reconstitute into 25.0 mL of 100 % methanol. This extract solution was stored at 4 °C for future study.

2.5.2. Determination of total phenolic, flavonoid and antioxidant content

The total phenolic, flavonoid and antioxidant contents (TPC, TFC & TAC) were assessed by following the method developed by Islam et al. (2024b) with slight modifications. The Folin-Ciocalteu phenol reagent method was used to determine the total phenolic content (TPC), the aluminium chloride colorimetric assay method was used to detect the total flavonoid content (TFC), and the phosphomolybdenum assay method was employed to determine the total antioxidant activity (TAC). The test methods explained in details in the supporting information documents S1.3 section.

2.5.3. DPPH$^{\bullet}$ scavenging activity

With a few adjustments, the 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical scavenging activity was carried out using the methodology described by Gull et al. (2018). 3.0 mL of 0.1 mM DPPH solution prepared in methanol reacted with 100 μL of 20, 40, 60, 80, 100 and 120 μg/mL sample/Trolox solution and then allowed to stand for 30 min at RT at the dark place. Absorbance was taken against a blank (methanol) at 517 nm, whereas DPPH solution served as a control. Each sample's DPPH radical-scavenging activity was determined using Eq. (6):

$$\text{Inhibition (\%)} = \left[1 - \frac{\text{Absorbane of sample}}{\text{Absorbance of control}}\right] \times 100 \tag{6}$$

2.5.4. ABTS$^{\bullet+}$scavenging activity

Pasta sample phenolics extracts ABTS$^{\bullet+}$ scavenging activities were evaluated following modified approach of Xiao et al. (2020). Briefly, 4.0 mL of ABTS$^{\bullet+}$ working solution in phosphate buffer (pH 7.4) mixed with 100 μL of 20, 40, 60, 80, 100 and 120 μg/mL sample/Trolox solution and then incubated for 30 min in dark at room temperature. Absorbance was measured at 734 nm against phosphate buffer as blank whereas ABTS^{+} working solution served as a control. Using Eq. (5), the ABTS$^{\bullet+}$ radical-scavenging activity was computed.

2.6. Microbial load analysis

The developed pasta underwent six months with three-month interval microbiological testing to determine bacterial, fungal, yeast, and mold counts in a laboratory setting. The American Public Health Association method was used to determine the total counts of *Salmonella* spp. and coliform bacteria in the pasta, as well as the Total Viable Count (TVC), fungal, yeast, and mold counts (Salfinger & Tortorello, 2015). A 25 g sample was subjected to microbial tests. To find out how many viable microbes there were in the pasta, the plate count method was used. The decimal dilution method was used to estimate the TVC, and for yeast and fungus, respectively, the pour plate and spread plate procedures were used. To isolate the particular microorganism, the streak plate method was employed. The most provable number (MPN) method was utilized to isolate and count the total coliform and *E. coli* bacteria.

2.7. Consumer testing

Sensory attributes of cooked samples were conducted by a panel of 10 trained individuals aged between 27 and 45 years. This committee was formed by the Institute of Food Science and Technology (IFST), Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka-1205, Bangladesh. The panelists were skilled at determining and evaluating pasta factors. No ethical permission was required to perform this test. As advised by ISO, a number of screening tests was administered to each panel member to determine their degree of expertise (ISO, 8586:2023). The panelists were asked to evaluate the cooked pasta's color, flavor, texture, taste and overall quality. A 1.0 min break was imposed between each sample. Each parameter was quantified using a 9-point scale, ranging from 1 for extremely unpleasant, 5 for acceptable, and 9 for extremely pleasant.

2.8. Statistical analysis

All determinations were carried out in triplicate, unless otherwise stated and results were expressed as the mean ± standard deviation (SD). Experimental data was analyzed by means of one-way analysis of variance (ANOVA) and a Tukey's test for a statistical significance ($p \leq 0.05$). The analysis was carried out with the package OriginPro 2024 software (Origin Lab Corporation, Northampton, USA).

3. Results and discussion

3.1. Optimum tomato pastes levels

As stated in the material and methods section, a domestic extruder was used to run several extrusion trials on a base of 100 g each batch in order to find the optimal tomato paste addition level for each formulation. The best extrusion runs required some adjustments to the tomato paste addition amounts. The screening method showed that producing pasta enhanced with fiber and antioxidants source is doable; nevertheless, formulation factors have a significant impact on both the process and the final product's quality. The results of the screening tests indicated that the amount of tomato paste needed for the WWF and WWF supplementation with GBF formulations was nearly equal at 34, 36, 37, and 38 percent (dry basis) for the 10, 15, 20, and 25 percent formulations, respectively. Using the domestic pasta extruder, the five pasta formulations were scaled up to a typical batch size of 0.5 kg per formulation, taking into account the optimal levels of tomato paste addition.

3.2. Water activity, proximate composition and cholesterol content

Food safety and quality are significantly influenced by moisture content (MC) and water activity (a_w). It impacts texture, flavor, aroma, safety, and shelf life. For example, most molds stop growing at water activities below a_w 0.80, while bacteria do not thrive at water activities below a_w 0.9. The a_w 0.5 indicate the safety of pasta sample from microorganism's attack (Makhlouf et al., 2019). The commercial product known as the control, had an a_w of 0.50 and an MC of 8.01 percent (Table 1). In comparison to the commercial pasta, different formulation like F-0, F-1, F-2, F-3 and F-4 formulation had MC value 5.34, 5.45, 5.35, 5.43 and 5.39 % respectively and a_w readings 0.44, 0.43, 0.45, 0.47 and 0.47 respectively and they were significantly ($p \leq 0.05$) varied. This can be attributed to the commercial pasta being sourced from a local store, where it may have absorbed moisture during storage and transport due to its extended shelf life. In contrast, the lab-prepared samples were freshly made, and measurements were taken right after they were removed from the dehydrator. Laboratory formulated five sample exhibited similar MC and a_w value and they were not statistically significant ($p > 0.05$) with each other's. The significantly lower ($p \leq 0.05$) MC (5.34 %−5.45 %) and a_w ranging from 0.44 to 0.47 at all laboratory formulation when compare with control sample indicating the better shelf-life stability of the novel fiber and antioxidant source supplemented WWF pasta products.

The chemical compositions of the control and fortified formulations with 10, 15, 20, and 25 % GBF enrichment levels are displayed in Table 1. Pasta made with 100 % WWF (F-0) showed significantly lower ($p \leq 0.05$) ash content (2.27 g/100 g) compared with others four formulations (2.56, 2.60, 2.67 and 2.69 g/100 g respectively for F-1, F-2, F-3 and F-4) and significantly higher ($p \leq 0.05$) than the control sample (0.50 g/100 g). The variation of GBF addition levels also increase the ash content but didn't change significantly ($p > 0$). The higher ash value indicates the presence of more micronutrient in the WWF, GBF, OP and GP than the refined flour (Castelo-Branco et al., 2017; Filipcev et al., 2023; Vignola et al., 2018). Fat content was found significantly higher ($p \leq 0.05$) in our developed pasta and this is because of the addition of oil and egg in our formulation. The more lipid content (10.73 g/100 g) of F-0 supposed the relatively higher fat content in whole grain wheat flour (Vignola et al., 2018). There was no significant ($p > 0$) change was observed in protein results except F-0 and for this formulation protein content was found significantly ($p \leq 0.05$) higher. The protein was found in the range of 12.82 to 14.09 g/100 g. Carbohydrate content of control sample (74.25 g/100 g) significantly ($p \leq 0.05$) varied with the other developed pastas (66.48–70.68 g/100 g) and no significant ($p > 0$) change was found among the laboratory developed pasta products. Similar trends like carbohydrate were also followed when energy was calculated. Cholesterol was not detected in the commercial (control) pasta samples but in the developed pasta cholesterol was found and this might be for the addition of egg in the laboratory developed pasta. The developed products cholesterol was found in the range of 35.76–37.53 mg/100 g and this didn't indicate the risk since according to the Dietary Guidelines one can consume cholesterol 200 mg each day, even one has heart disease risk factors if not then one can consume 300 mg per day (Soliman, 2018). Therefore, developed pasta with high energy value also provide more dietary fiber (Fig. 2) and antioxidant (Table S4 & Fig. 3).

3.3. Color parameter

One of the most important quality characteristics for food appeal is color. since it has an impact on consumer expectations for product freshness and flavor. Pasta has come in a variety of colors in recent years, ranging from classic yellow tones to red, green, and black. The color comes from artificial colorants or, more frequently, from the addition of other components (whole wheat, carrot, onion, garlic, tomato, bran, spinach, etc.) (Michalak-Majewska et al., 2020; Vignola et al., 2018). Table 2 shows the color values for the commercial (control) and laboratory formulated pasta.

Whole wheat pasta enriched with different fiber and antioxidant source exhibited lower L* value than control pasta and the change was statistically significant ($p \leq 0.05$). The control pasta lightness value was found 84.74 whereas laboratory developed pasta products lightness values ranged from 75.93 to 77.85 and no significant difference ($p > 0.05$) were observed among laboratory made pasta. Various studies reported that WWF pasta, GBF, OP and GP supplements significantly alter L* value and values of L* above 60 are preferred (Castelo-Branco et al., 2017; Filipcev et al., 2023; Michalak-Majewska et al., 2020; Vignola et al., 2018). The color shift from green (negative value) to red (positive value) is shown by the a* value. When comparing fortified pasta to control samples, the redness parameter (a*) increased significantly ($p \leq 0.05$). The control pasta exhibited −5.58 a* value whereas fortified pasta a* value lies in between 3.55 to 4.01. The increased a* value of the developed pasta might be due to the presence of pigments aromatic

Table 1
Water activity (a_w), moisture, ash, fat, protein, carbohydrate (g/100 g), energy (Kcal/100 g) and cholesterol (mg/100 g) content of control and developed pasta.

Test parameter	Control	F-0	F-1	F-2	F-3	F-4
Water activity	0.50 ± 0.00^{a}	0.44 ± 0.00^{b}	0.43 ± 0.00^{b}	0.45 ± 0.00^{b}	0.47 ± 0.00^{b}	0.47 ± 0.00^{b}
Moisture	8.01 ± 0.11^{a}	5.34 ± 0.04^{b}	5.45 ± 0.06^{b}	5.35 ± 0.07^{b}	5.43 ± 0.04^{b}	5.39 ± 0.05^{b}
Ash	0.50 ± 0.0^{a}	2.27 ± 0.0^{b}	2.56 ± 0.0^{c}	2.60 ± 0.02^{c}	2.67 ± 0.03^{c}	2.69 ± 0.04^{c}
Fat	2.91 ± 0.04^{a}	10.73 ± 0.1^{b}	9.06 ± 0.08^{c}	8.85 ± 0.17^{c}	8.68 ± 0.11^{c}	8.63 ± 0.12^{c}
Protein	13.15 ± 0.11^{a}	14.09 ± 0.1^{b}	13.25 ± 0.10^{a}	12.99 ± 0.09^{a}	12.86 ± 0.18^{a}	12.82 ± 0.13^{a}
Carbohydrate	74.25 ± 0.51^{a}	66.48 ± 0.33^{b}	69.59 ± 0.21^{b}	70.11 ± 0.39^{b}	70.47 ± 0.48^{b}	70.68 ± 0.57^{b}
Energy	381.88 ± 1.07^{a}	421.53 ± 1.2^{b}	413.25 ± 0.9^{b}	411.89 ± 1.5^{b}	411.01 ± 0.9^{b}	409.18 ± 1.1^{b}
Cholesterol	Nd	36.31 ± 3.4^{a}	36.59 ± 2.1^{a}	37.53 ± 3.8^{a}	36.11 ± 4.8^{a}	35.76 ± 3.1^{a}

Results are expressed as mean ± standard deviation ($n = 3$). Different letters in the same row indicate significant differences determined by Tukey's test ($p \leq 0.05$) in the mean value. F-0: pasta with 100 % whole wheat flour; F-1: pasta with 82.0 % whole wheat flour; F-2: pasta with 77.0 % whole wheat flour; F-2: pasta with 72.0 % whole wheat flour and F-4: pasta with 67.0 % whole wheat flour, Nd: Not detected.

Table 2
Color values (L*, *a**, *b**, W and ΔE) of uncooked pasta products.

Color values	Control	F-0	F-1	F-2	F-3	F-4
Lightness (L*)	84.74 ± 0.94[a]	77.85 ± 0.14[b]	76.54 ± 0.15[b]	76.28 ± 0.13[b]	76.09 ± 0.74[b]	75.93 ± 0.20[b]
Redness (*a**)	−5.58 ± 0.15[a]	3.56 ± 0.05[b]	4.01 ± 0.07[b]	3.82 ± 0.08[b]	3.55 ± 0.18[b]	3.67 ± 0.03[b]
Yellowness (*b**)	39.25 ± 0.37[a]	13.99 ± 0.07[b]	19.68 ± 0.06[c]	18.84 ± 0.16[c]	18.57 ± 0.10[c]	18.16 ± 0.04[c]
Whiteness (W)	57.52 ± 0.48[a]	73.56 ± 0.17[b]	68.81 ± 0.23[c]	68.69 ± 0.27[c]	69.82 ± 0.33[c]	69.92 ± 0.21[c]
ΔE	37.60 ± 0.41[a]	19.83 ± 0.13[b]	24.69 ± 0.17[c]	24.76 ± 0.11[c]	23.64 ± 0.19[c]	24.30 ± 0.09[c]

Values are expressed as mean ± standard deviation ($n = 3$). Different letters in the same row indicate significant differences determined by Tukey's test ($p \leq 0.05$) in the mean value. F-0: pasta with 100 % whole wheat flour; F-1: pasta with 82.0 % whole wheat flour; F-2: pasta with 77.0 % whole wheat flour; F-2: pasta with 72.0 % whole wheat flour and F-4: pasta with 67.0 % whole wheat flour.

structure of wheat bran, GBF, CF, OP and GP that could result in a greater Millard reaction when combined with other food matrix ingredients (Makhlouf et al., 2019). The b* value indicates the color's hue, ranging from blue to yellow (−*b** to +*b**). Based on color parameters, it can be inferred that adding any amount of GBF, CF, OP, and GP to WWF pastas increased the b* value significantly ($p \leq 0.05$), indicating a yellowish color. The b* value of control pasta (39.25) was found significantly higher ($p \leq 0.05$) than all the laboratory formulated (13.99 to 19.68) products. Nevertheless, the amount of addition level of GBF within the same formulations did not appear to significantly ($p > 0$) alter the yellowness (Biernacka et al., 2020). The whiteness (W) values revealed that they were significantly ($p \leq 0.05$) differed among the control (57.52), WWF pasta (73.56) and WWF supplemented pastas (68.81 to 69.92). The color differences between the formulated pasta and control were also assessed using the ΔE values. With an increase in GBF level in WWF pasta, ΔE values also rose. Michalak-Majewska et al. (2020) study on the quality attributes of pasta enhanced with onion powder and various hydrocolloids revealed values of ΔE greater than 40. Customers now select pasta with fascinating colors to make fancier dishes instead of only yellow pasta, as they are used to it. It is true that dark coloring helps consumers associate products with high fiber and antioxidant content. In summary, all of the formulations appeared to have changed the blueness to yellowness (b* value), red to green color coordinate (a* value), and lightness to darkness (L* value).

3.4. Optimum cooking time, water uptake index and cooking loss

Fig. 1A displays the OCTs of the laboratory-prepared and control pasta samples. The data indicated that all developed pasta samples enhanced with fiber and antioxidants had OCTs higher than the control group. The maximum and minimum cooking time were found respectively 535 ± 33 s and 435 ± 21 s ($p \leq 0.05$) for 100.0 % WWF-based pasta and control pasta. This finding might be due to the shape and thickness difference of the laboratory formulated and control pasta products. OCTs scenario of pasta products was found different when WWF was replaced with certain percentage of fiber and antioxidant source raw materials and was found significantly ($p \leq 0.05$) lower. The value was found in the range of 465 ± 27 to 515 ± 19 s. This could be explained by the possibility that the inclusion of fiber and antioxidants in the WWF formulation will physically disrupt the gluten matrix during extrusion, producing a "shortening" effect that will facilitate the starch gelatinization process and shorten the water diffusion and absorption pathway. Overall, these results are consistent with those seen in other work (Bello-Perez et al., 2022).

Water uptake index values were found in the range of 101.09–163.70 %. Fig. 1B shows that, as compared to the control pasta, all of the fiber and antioxidant enriched formulations showed a greater water uptake index during cooking. This is not unexpected, given that dietary fiber has a higher propensity to bind water than does refined wheat flour pasta formulation (Makhlouf et al., 2019). Water uptake level significantly ($p \leq 0.05$) increased with the increase of GBF enrichment levels. 163.70 %, 115.93 % and 101.09 % water uptake were found for F-4, F-0 and control pasta respectively. This finding is consistent with earlier research that found whole wheat pasta enriched with GBF, CF, OP, and GP had increased water absorption (Biernacka et al., 2020; Filipcev et al., 2023; Michalak-Majewska et al., 2020; Vignola et al., 2018). The findings regarding water uptake were in line with the outcomes of formulation screening tests, which showed that formulations containing fiber and antioxidant sources needed more tomato paste to create extrudable mixtures, while formulations containing WWF needed less tomato paste to have the appropriate extrudable qualities. The higher water uptake also corelated with the relatively higher a_w and longer cooking time.

All samples were assessed for the amount of solid matter lost during cooking, including the control sample, which was a commercial product since one of the main factors influencing consumer acceptability of pasta products is cooking loss (Vignola et al., 2018). All of the laboratory formulations had greater cooking loss values than the control, even though the control's cooking loss was 11.11 % (Fig. 1C). The control sample cooking loss was found significantly ($p \leq 0.05$) lower than the developed pastas (13.03–13.75 %) but no significant change ($p > 0$) was found among the formulated samples. This indicates that fiber and antioxidant source addition level in WWF pasta increase the cooking loss value but not significantly ($p > 0$). The increased cooking loss appears to be caused by a breakdown in the protein-starch matrix of WWF,

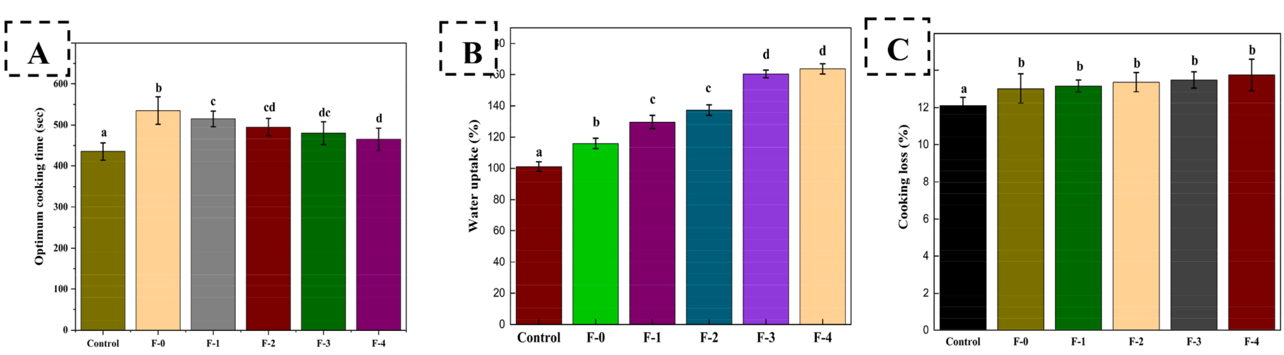

Fig. 1. Optimum cooking time (**A**), Water uptake (**B**) and cooking loss (**C**) of fiber and antioxidant enriched formulated pasta. Values are expressed as mean ± standard deviation ($n = 3$). Different letters indicate significant differences determined by Tukey's test ($p \leq 0.05$) in the mean value. F-0: pasta with 100 % whole wheat flour; F-1: pasta with 82.0 % whole wheat flour; F-2: pasta with 77.0 % whole wheat flour; F-2: pasta with 72.0 % whole wheat flour and F-4: pasta with 67.0 % whole wheat flour.

resulting in a large concentration of solid materials seeping into the cooking water. Pasta of high quality was deemed to have a cooking loss of no >12 % (Makhlouf et al., 2019). It seems that making pasta with 100 % WWF is not a recommended practice, as this could result in considerably lower-quality final products but when this practice provides you certain health beneficial nutrition like dietary fiber (Fig. 2) and antioxidant (Fig. 3& Table S4) then it becomes a practice worth considering.

3.5. Texture properties of cooked pasta

Pasta's texture is a crucial factor in determining a consumer's acceptability. In particular, pasta cooking quality is greatly influenced by hardness. Results of pasta textural characteristics are shown in Fig. S1. Hardness was measured as the highest shear strength needed to cause a sample to rupture (Yahia & Carrillo-Lopez, 2019). When fiber and antioxidant was added to the WWF formulation using different source materials, the cooked pasta's hardness changed significantly ($p \leq 0.05$). Hardness values were found significantly ($p \leq 0.05$) higher in formulations F-0, F-1 and F-2 than the control whereas the F-3 and F-4 sample hardness value was not varied significantly ($p > 0$) with the control. The hardness value was found 124, 196, 155, 156, 111 and 98 N respectively for control, F-0, F-1, F-2, F-3 and F-4. The higher cooking loss values indicated in the previous section are consistent with the pattern of decreased pasta hardness as substitution level increases. Higher hardness value was also found for whole wheat extruded pasta in previous report (Vignola et al., 2018). Additionally, it's possible that whole grain pasta's comparatively high lipid content contributes to its higher hardness when compared to other formulations. The force required to overcome the attraction between the product's surface and the surface of the substance it comes into touch with is referred to as adhesiveness or stickiness (Yahia & Carrillo-Lopez, 2019). With the increase of GBF addition level, both adhesiveness and stickiness decreased except F-1 stickiness and this change was significantly ($p \leq 0.05$) different. Pasta adhesiveness value was observed 0.31, 0.29, 0.22, 0.20, 0.11 and 0.04 J/m^3 and stickiness value was found 2.87, 3.19, 2.60, 1.80, 1.19 and 0.80 respectively for F-0, F-1, F-2, F-3, F-4 and control samples. This is consistent with research findings when different dietary fiber sources are used (Makhlouf et al., 2019). The rate at which a material deforms and then returns to its initial state is known as springiness (Yahia & Carrillo-Lopez, 2019). F-2 formulation exhibited the significantly lower ($p \leq 0.05$) springiness (0.41) value among the studied pasta sample and values were in between 0.41–0.66. The cohesiveness value was also found significantly lower ($p \leq 0.05$) up to 15 % GBF addition and more than that cohesiveness didn't change significantly ($p > 0$) and cohesiveness is the capacity of a sample to tolerate deformation before breaking (Yahia & Carrillo-Lopez, 2019). The observed values fell between 0.31 and 0.43. The gumminess and chewiness value followed similar trends in texture analyzer. According to Yahia & Carrillo-Lopez, 2019, gumminess is the amount of energy required to break down semi-solid food into a form that can be ingested, whereas chewiness is the amount of energy required to chew a product until it is ready to swallow. With the increase of GBF addition in WWF pasta formulation, these test parameters significantly reduced ($p \leq 0.05$) and continued up to 20 % GBF addition. The chewiness values were between 20.48–53.78 N whereas gumminess values were fell between 37.07–78.66 N. Overall, the texture data for pasta suggests that a larger percentage of GBF addition level in WWF pasta may produce products that are more appealing and have texture features similar to the control product.

3.6. Mineral content

The mineral results show that the Mg, P, K, Ca and Fe composition of the formulated pasta samples was significantly ($p \leq 0.05$) higher and Cu was significantly lower ($p \leq 0.05$) after whole wheat flour supplemented by GBF, CF, OP and GP (Table S2). Results also exhibited that all the formulated sample had significantly higher ($p \leq 0.05$) amount of all analyzed minerals than the commercial (control) pasta. The Mg, P, K, Ca and Fe content was found 153.56 %, 8.85 %, 58.43 %, 138.33 % and 37.81 % higher in the F-4 formulation than the F-0 formulation. The scenario was found different for Cu and maximum Cu content was found in 100 % whole wheat flour-based pasta. The Mg, P, K, Ca, Fe and Cu

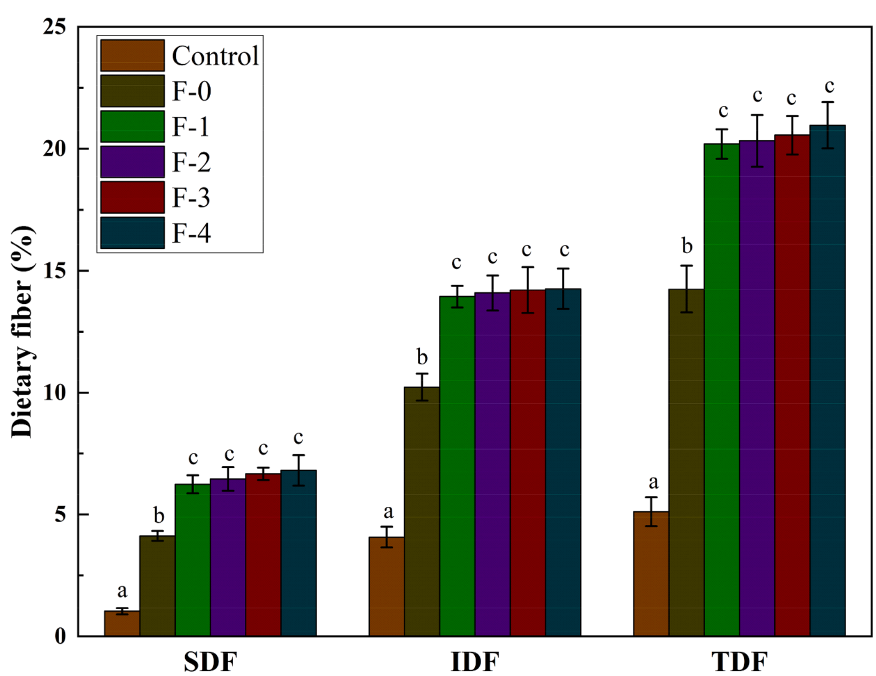

Fig. 2. Soluble, insoluble and total dietary fiber (SDF, IDF and TDF) content of formulated pasta. Values are expressed as mean ± standard deviation ($n = 2$). Different letters within same test parameters indicate significant differences determined by Tukey's test ($p \leq 0.05$) in the mean value. F-0: pasta with 100 % whole wheat flour; F-1: pasta with 82.0 % whole wheat flour; F-2: pasta with 77.0 % whole wheat flour; F-2: pasta with 72.0 % whole wheat flour and F-4: pasta with 67.0 % whole wheat flour.

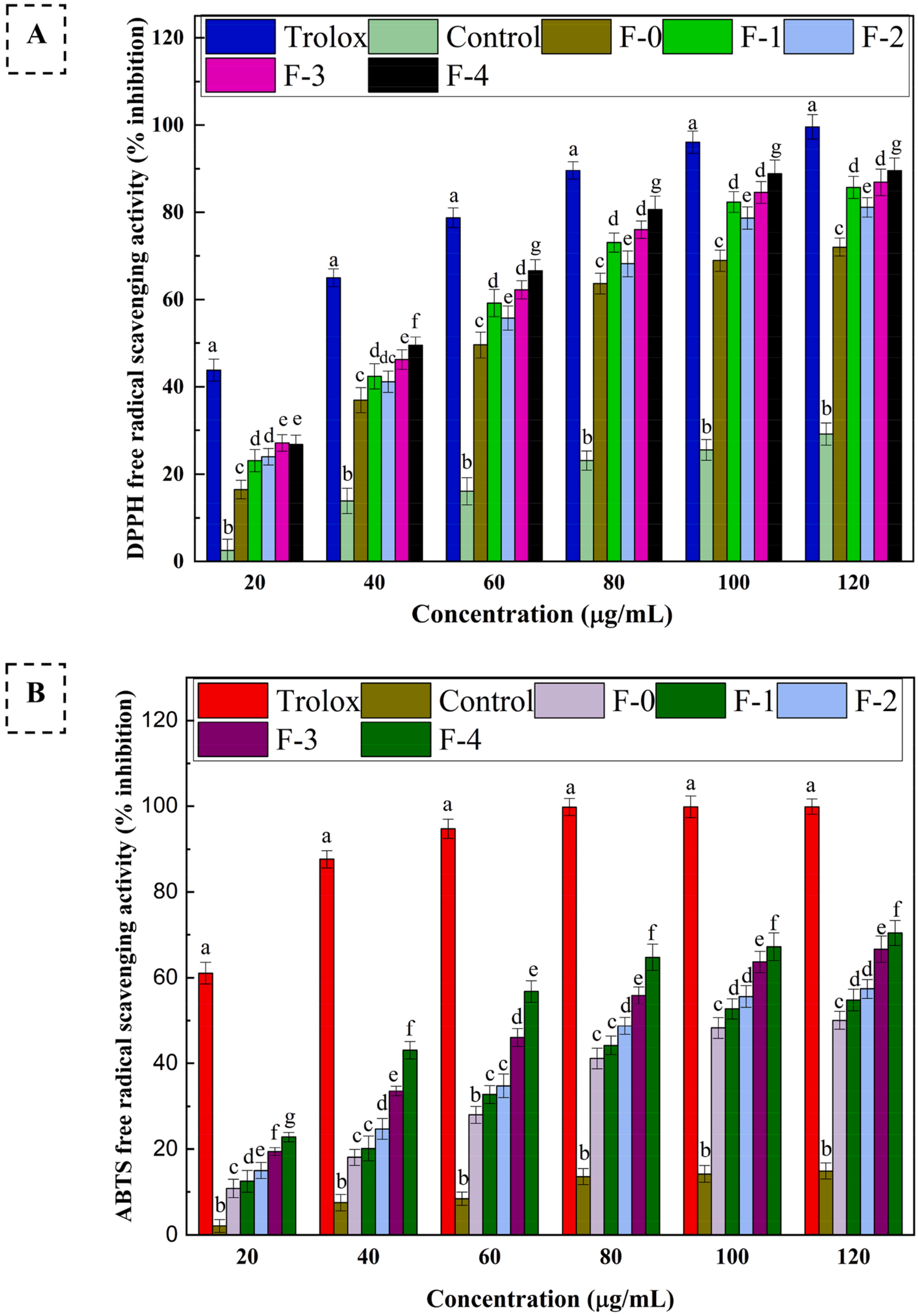

Fig. 3. DPPH (**A**) and ABTS (**B**) free radical scavenging activity of the free phenolic extract of uncooked pasta. Values are expressed as mean ± standard deviation ($n = 2$). Different letters at each concentration indicate significant differences determined by Tukey's test ($p \leq 0.05$) in the mean value. F-0: pasta with 100 % whole wheat flour; F-1: pasta with 82.0 % whole wheat flour; F-2: pasta with 77.0 % whole wheat flour; F-2: pasta with 72.0 % whole wheat flour and F-4: pasta with 67.0 % whole wheat flour.

content was found in the range of 118.91–433.67 mg/100 g, 29.55–153.75 mg/100 g, 218.92–475.66 mg/100 g, 208.11–998.10 mg/100 g, 2.05–6.16 mg/100 g and 5.60–6.75 mg/100 g respectively. This indicates that the increased concentration of micronutrients was for the addition of GBF, CF, OP and GP which have more minerals on dry basis. Choo and Aziz (2010) discovered that adding 30 % green banana flour to instant noodles raised their calcium, potassium, and magnesium contents to 831.0, 3604.8, and 604.1 mg/kg, respectively. One possible explanation for the pasta's high calcium content is the use of powdered cauliflower (Sinha & Sharma, 2023). In a previous study, it was found that pasta formulated with garlic powder related to the higher amount of Mg, K, Ca and Fe (Filipcev et al., 2023). Consequently, the mineral content of whole wheat flour pasta, excluding copper, increased as the proportion of GBF in the formulation rose, due to the higher mineral content present in GBF.

3.7. Fatty acid profile

The fatty acid profiles of the pasta samples supplemented with GBF, CF, OP, and GP powders are detailed in Table S3. The analysis revealed the presence of fourteen fatty acids in the studied pasta samples. Both saturated and unsaturated fatty acids were detected. The amount of individual fatty acids in the various formulations and control samples varied significantly ($p \leq 0.05$). In terms of saturated fatty acids (SFA), palmitic (C16:0) and stearic (C18:0) acids were identified as the major fatty acids (15.21–21.09 % and 0.95–5.01 % fatty acid profile) in control and whole wheat pasta made with different fiber and antioxidant sources. The addition of GBF, CF, OP and GP significantly ($p \leq 0.05$) reduced the palmitic acid contents in the developed products. The control sample's oil had a greater proportion ($p \leq 0.05$) of palmitic acid than the other samples made from other flours. Among whole wheat flour supplemented products, 25 % GBF enriched showed maximum palmitic acid but this level was not significant ($p > 0$). Another predominant saturated fatty acid, stearic acid was found significantly higher ($p \leq 0.05$) in all developed products compared with the control and increased with the increase of GBF content in the formulation. Among all other fatty acids, myristic acid (C14:0) was found gradually increased with the increase of GBF but not significantly ($p > 0$). Pentadecanoic (C15:0) and margaric (C17:0) acids was found absent in control and gradually decreased ($p \leq 0.05$) with GBF addition level. In contrast, behenic (C22:0) acid was found significantly higher ($p \leq 0.05$) in whole wheat flour supplemented pasta samples. Concerning unsaturated fatty acids (UFA), GBF, CF, OP and GP fortification raised ($p \leq 0.05$) the amounts of linoleic (C18:2 n6 *cis*), α-linoleic (C18:3 ALA), eicosenoic (C20:1) and eicosapentaenoic (C20:5) acids, and decreased ($p \leq 0.05$) the amount of palmitoleic (C16:1), oleic (C18:1 9cis), vaccenic (C18:1 11cis) and arachidonic (C20:4) acids. The major two UFAs are oleic and linoleic acids whereas oleic and linoleic acid respectively predominates (32.18 % and 56.53 %) in the control and WWF-based pasta (F-0) samples fatty acid profile. The oleic acid relative percentage was found in the range of 17.22–32.18 % and linoleic acid relative percentage was found within 30.43–56.53 %. The third major UFA was alfa-linoleic acid which was found in between 1.48–3.32 % fat content of the developed products. Palmitoleic, vaccenic, eicosenoic, arachidonic and eicosapentaenoic acids were found absent in the control sample. Eicosapentaenoic acid was also absent in the whole wheat flour formulated pasta sample. From a previous report, it was found that when compared to monounsaturated and saturated fatty acids, whole wheat dry pasta has twice the amount of total polyunsaturated fatty acids (Hirawan & Beta, 2014). From these investigations, the fatty acid composition could be considered as positive output since unsaturated fatty acids predominates.

There are currently very few studies assessing the fatty acid profile of pasta products supplemented with various flours, and no publications exist about the fatty acid composition of dry pasta enriched with GBF, CF, OP, and GP. As a result, it does not permit a comparison of the data with findings from the literature. Pasta enriched with various oleiferous powders, such as hazelnut, peanut, walnut, almond, and pumpkin, exhibited significant differences in their fatty acid composition (Koc et al., 2020). As reported by Anbudhasan et al. (2014) pasta products are primarily composed of carbohydrates and have a low fatty acid content.

3.8. Soluble, insoluble and total dietary fiber

Whole wheat pasta offers substantial dietary fiber, and many important phenolic phytochemicals are found within the fiber components of wheat (Hirawan & Beta, 2014). Predictably, whole grain flour varieties have higher levels of dietary fiber and other bioactive substances compared to refined flour varieties. The soluble, insoluble and total dietary fiber (SDF, IDF and TDF) of the GBF, CF, OP and GP enriched whole wheat flour pasta was analyzed and presented in the following Fig. 2. As expected, pasta samples' SDF, IDF, and TDF content rises dramatically upon the addition of GBF, CF, OP, and GP. For dried pasta, the SDF, IDF and TDF values varied from 1.03 to 5.81, 4.07–17.26 and 5.11–21.97 g/100 g respectively. The laboratory developed pasta showed significantly higher ($p \leq 0.05$) SDF, IDF and TDF values than control products. Significant change ($p \leq 0.05$) was also observed in between the WWF pasta and pasta formulated by the addition of GBF, CF, OP and GP considering the values of SDF, IDF and TDF. But, no significant differences ($p > 0$) were found with the addition level of GBF. Since wheat bran is a primary source of dietary fiber, all whole-grain pasta displayed greater total dietary fiber contents (Vignola et al., 2018). It is also proved that, with a higher soluble: insoluble dietary fiber ratio (SDF:IDF) and a variety of metabolic and physiological effects, onions are a significant source of total dietary fiber (TDF) (Michalak-Majewska et al., 2020). According to the report of a previous study, dietary fiber is made up of a wide range of materials, including as cellulose, pectin's, fructo-oligosaccharides, hydrocolloids, non-starch polysaccharides and resistant starch (Barber et al., 2020). Unripe banana flour is a starchy food that has a high percentage of non-starch polysaccharides such dietary fiber and indigestible substances like resistant starch (Biernacka et al., 2020). It is worth mention that vegetables and whole-grain products are the major sources of soluble and insoluble dietary fiber (Barber et al., 2020). Therefore, addition of GBF, CF, OP and GP in pasta formulation will provide a considerable fraction of soluble and insoluble dietary fiber in whole wheat pasta.

3.9. Total phenolic, total flavonoids, total antioxidant and in vitro antioxidant activity

The levels TPC, TFC and TAC in uncooked pasta extracts are shown in Table S4. According to the findings of the analyses, the WWF pasta and addition of GBF, CF, OP and GP in WWF significantly raised ($p \leq 0.05$) the total phenolic, flavonoid, and antioxidant levels. The change between WWF basta and pasta formulated by addition of fiber and antioxidant source with WWF also significant ($p \leq 0.05$). In contrast, values obtained for the control sample was found significantly lower ($p \leq 0.05$) than the laboratory developed pasta samples. The total phenolic, flavonoid and antioxidant content varied between 4.93 to 59.75 μg GAE, 2.11 to 98.71 μg QE and 54.07 to 461.20 μg GAE per gram dry pasta. The sample with 25 % banana flour had the highest TPC, TFC and TAC values but the banana flour addition level didn't change the value significantly ($p > 0$) except TPC. These results suggested the presence of higher levels of bioactive polyphenolic and flavonoid compounds in wheat bran, banana flour, cauliflower, onion powder and garlic powder than the refined wheat flour. Ovando-Martinez et al. (2009) studied durum spaghetti with banana flour and found that GBF addition to pasta significantly ($p \leq 0.05$) enhanced the TPC values, particularly when it came to condensed tannin concentration. Wheat pasta supplemented with onion peel powder greatly increased the amount of total phenolic and flavonoid content discovered in a different study (Michalak-Majewska et al., 2020).

Radical scavenging activity (DPPH and ABTS) was employed to evaluate the antioxidant power of raw pasta samples (Fig. 3A& B). Antioxidant molecules demonstrated their ability to scavenge both DPPH and ABTS free radicals by exchanging a hydrogen atom (Vignola et al., 2018). The DPPH free radical scavenging activity calculated as percent inhibition of laboratory developed pasta was found significantly higher ($p \leq 0.05$) than the commercial one at each concentration but this value was found significantly lower ($p \leq 0.05$) compared to the Trolox standard. At 60 μg/mL, all laboratory developed pasta samples free phenolic extract showed >50 % inhibition whereas control sample only inhibited 14.6 % free radicals. Similar trend was also found for ABTS free radical scavenging activity. With the increase of extract concentration, the ABTS scavenging activity was found significantly higher ($p \leq 0.05$) compared with the control and significantly lower ($p \leq 0.05$) considering the Trolox ABTS free radical scavenging activity. Data also revealed that to scavenge >50 % ABTS free radical, laboratory developed pasta sample extract concentration required 100 μg/mL whereas control sample extract can only scavenge 16.09 %. These findings support the results from prior research that several substances with antioxidant activity are known to be found in whole grain products at substantial concentrations (Vignola et al., 2018). These data also support previous research that shown that adding whole wheat kernels, banana flour, and onion powder to pasta products raises the values of antioxidants in pasta compared to regular pasta (Biernacka et al., 2020; Michalak-Majewska et al., 2020; Ovando-Martinez et al., 2009). The majority of health-promoting antioxidant chemicals are found in the bran and germ parts of whole grains (Hirawan & Beta, 2014).

3.10. Microbial quality evaluation

All of the pasta formulations were subjected to a microbiological examination for six (06) month period with three (03) month intervals before the sensory assessments and results are presented in supplementary documents Table S5. According to the test results, the microbial test data were found lower than what the Bangladesh Standard and Testing Institute (BSTI) legislation suggested. To guarantee food safety, BSTI complies with International Organization for Standardization (ISO) criteria (BDS ISO, 6887–3:2019).

3.11. Sensory evaluation testing

The sensory qualities of food products are crucial factors in ensuring their acceptance from the perspective of the customer. Color, flavor, taste, texture, and overall acceptability were assessed for cooked pasta samples enriched with varying amounts of fiber and antioxidant source by the sensory panel and data are presented in Fig. 4.

The descriptive data that was acquired show that the sensory panel could distinguish between different pasta samples according to their sensory attributes. Overall, the evaluation of all sensory attributes was not below the scale's middle point (5 = neither like nor dislike), suggesting that laboratory developed pasta samples were not disliked but it is evident from a statistical study that the fortified formulations containing various fiber and antioxidant sources differ significantly ($p \leq 0.05$) from the control. It is not surprising because the gluten network found in refined wheat pasta is the most important factor influencing the quality of pasta cooking (Biernacka et al., 2020; Makhlouf et al., 2019). For this reason, replacing wheat gluten entirely or in part with other ingredients such as the fiber and antioxidant ingredients chosen for this study changed the functions of the dough matrix and ultimately led to a decline in the final product's quality.

Pasta formulated with 100 % WWF scored significantly ($p \leq 0.05$) lower than the control as well as fiber and antioxidant source fortified WWF pasta by the panelist for all sensory characteristics whereas control samples were preferred with scores significantly ($p \leq 0.05$) higher than those of the fortified pasta except flavor attributes. This led to its flavor being well-liked during the sensory evaluation and high flavor content might be due to the incorporation of onion and garlic powder in formulation (Filipcev et al., 2023; Michalak-Majewska et al., 2020). The sensory panel favored the control pasta sample's color above all of the developed formulations for fiber and antioxidant enrichment. This is consistent with the color measurements mentioned before (Table 2), which showed that when WWF and chosen fiber and antioxidant components were added, the color values appeared to change in comparison to the control pasta. Similar trends were also observed for both taste and texture characteristics. The control pasta ranked highest in overall preference among the sensory panel. However, among the five formulations, the panelists favored F-3 the most, followed by F-2 > (F-1 = *F*-4) > *F*-0.

4. Conclusion

This study demonstrated that WWF pasta and incorporating diverse dietary fiber and antioxidant ingredients into a WWF pasta recipe can be successfully done via the extrusion process without visibly compromising the shape, appearance, or texture of the finished product. However, they showed varying degrees of change in cooking quality and sensory properties, depending on the addition levels of GBF. The WWF and fortified WWF pastas showed higher water uptake, optimal cooking time and cooking loss, along with alteration of pasta texture characteristics compared to the control pasta. According to this, the bran in WWF and other non-gluten components addition changes the pasta's structure by interfering with the gluten-starch matrix. The color

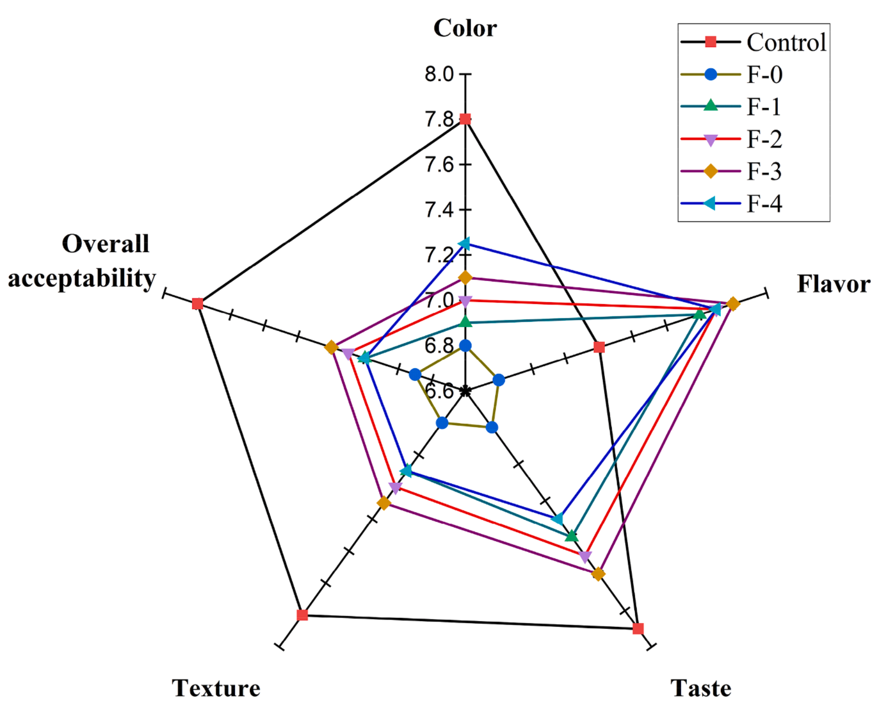

Fig. 4. Radar plot of the sensory attributes of cooked pasta. Values are expressed as mean ± standard deviation ($n = 10$). F-0: pasta with 100 % whole wheat flour; F-1: pasta with 82.0 % whole wheat flour; F-2: pasta with 77.0 % whole wheat flour; F-2: pasta with 72.0 % whole wheat flour and F-4: pasta with 67.0 % whole wheat flour.

coordinates of pastas are also impacted by addition level of GBF in WWF fortification but no negative effects were in shelf life. The highest ratings for WWF pasta's overall acceptability were achieved when GBF was added in amounts of 20 % and this formulation helped the pasta include >20.0 g of fiber per 100 g serving size, which is equal to 80 % of the RDI based on a diet of 2000 calories. Because of its high polyphenol and total dietary fiber content, whole-grain pasta has promise for the manufacture of value-added foods. Importantly, WWF pasta and WWF enrichment with GBF, CF, OP, and GP increased the TPC, TFC, TAC, and antioxidant activity (DPPH and ABTS). Among the bioactive compounds dietary fiber and antioxidants represents notable role and both of them are an influential component in a healthy diet. This study has a few limitations, one of the most significant being the lack of access to a commercial pasta extruder and shaper. This constraint prevented the production of various pasta shapes and the subsequent optimization of shape-related cooking quality. Therefore, future research is recommended to explore these aspects further and enrichment of pasta products with dietary fiber and antioxidants without affecting the functional properties, technical quality and consumer acceptability.

Ethical statement

In the sensory investigation of cooked pasta, only adults took part. The Local Bioethics Committee of Biomedical and Toxicological Research Institute (BTRI), BCSIR, Dhaka, Bangladesh, came to the conclusion that the Commission's approval was not necessary for the aforementioned study since there was no expected danger or discomfort in these studies. Verbal informed consent was provided by each person to take part. They were made aware of the purpose and nature of the study, as well as the anonymity and confidentiality of the participants. Each participant agreed to disclose their evaluation results anonymously and conducted an objective assessment of the tested products.

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CRediT authorship contribution statement

Shariful Islam: Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition. **Md. Faridul Islam:** Funding acquisition, Resources. **Mohammad Nazrul Islam Bhuiyan:** Funding acquisition, Resources. **Khurshida Jahan Tisa:** Methodology, Formal analysis. **Amena Kibria:** Formal analysis. **Md. Habibur Rahman Bhuiyan:** Resources. **Md. Jaynal Abedin:** Methodology, Formal analysis. **Abu Tareq Mohammad Abdullah:** Methodology, Resources. **Md. Alamgir Kabir:** Methodology, Formal analysis, Resources. **Md. Abdus Satter Miah:** Supervision, Writing – review & editing, Funding acquisition, Resources.

Declaration of competing interest

The authors declare no conflict of interest.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.focha.2025.100933.

Data availability

Data will be made available on request.

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