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Potential of Food By-Products

Traditional Tunisian Pasta "*Nwasser*" Enriched with Wheat Bran: Impact on Physicochemical Quality, Nutritional Profile, and Acute Postprandial Glycemic Response in Healthy Individuals

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Abstract

Background: Enriching traditional foods with local affordable ingredients allows for the improvement of nutritional status without drastically altering established dietary habits. Wheat bran (WB), the principal by-product of wheat flour processing, represents an inexpensive, nutrient-dense source of dietary fiber, predominantly insoluble fibers.

Aim: This study aimed to formulate and develop traditional Tunisian pasta "*Nwasser*" enriched with wheat bran and to characterize its quality. Specific objectives included the comprehensive assessment of its quality attributes, techno-functional properties, nutritional profile, and consumer acceptance.

Methods: Traditional pasta *Nwasser*s formulations were produced with the incorporation of wheat bran (containing 41% dietary fibers) at concentrations of 0% (control), 3%, and 6%. Proximate composition, CIE Lab color, and techno-functional and cooking quality properties were determined. Acute postprandial blood glucose concentrations were monitored in twelve healthy volunteers at 30-min intervals until 180 min post consumption of pasta. Consumer acceptability of the bran-enriched products was assessed via an online questionnaire administered to 172 respondents (67% women; 83.4% aged under 40 years old; 99% regular pasta consumers).

Results: The consumer survey revealed that 76% of participants were aware of the health benefits associated with wheat bran, and a substantial majority (96% of respondents) expressed willingness to consume WB-enriched pasta. The primary consumption drivers were health benefits (59% of respondents) and taste preferences (30%). Formulation analyses indicated that the 3% and 6% WB indicated increased the water holding capacity and reduced the optimal cooking time of the WB-enriched pasta *Nwasser*s compared to the control, simplifying home preparation. However, no significant differences were observed in oil holding capacity or swelling index. Interestingly, the addition of wheat bran at levels of 3% or 6% in pasta *Nwasser*s resulted in an improvement of nutritional composition with a significant increase in ash content, as well as total fiber levels, but not in total phenolic compounds. Moreover, supplementation of pasta with WB enhanced the *in vitro* pasta antioxidant activity, as well as to a decrease in acute postprandial blood glucose concentrations in healthy volunteers, compared to control pasta. The visual appearance and color of the enriched pasta were affected in comparison to the control samples; specifically, CIE L* and b* values decreased, while the a* value increased, suggesting a shift towards a brownish hue.

Conclusion: This research pointed out that wheat bran-enriched traditional pasta presents a promising opportunity for developing functional foods with enhanced nutritional value and consumer acceptability, contributing to both public health and a circular economy by utilizing a wheat flour processing by-product, while maintaining cultural relevance.

Keywords: Wheat Bran Enrichment; Nutritional Quality; Postprandial Glycemic Response; Circular Economy; Consumers' acceptability.

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1 Introduction

Suboptimal dietary patterns constitute one of the primary factors that leads to a wide range of chronic non-communicable diseases (NCDs), including cardiovascular disorders, various malignancies, diabetes mellitus, and obesity (WHO, 2025). As a leading global cause of mortality, NCDs account for 75% of worldwide deaths in 2021 worldwide (WHO, 2025) and 74 % within the Middle East and North Africa (MENA) region (PRB, 2017). In response to this epidemiological shift, a body of evidence suggests that the consistent consumption of whole-grain products constitutes an efficient preventative strategy against NCDs (Cheng *et al.,* 2022; de Munter *et al.,* 2007; Guo *et al.,* 2022; Patel, 2015). These physiological benefits are primarily attributed to the bioactive compounds of the bran fraction—the outer tegument of the mature wheat kernel (Cheng *et al.,* 2022; Patel 2015).

Wheat bran (WB), the primary by-product of industrial flour milling, possesses a unique blend of bioactive components, notably dietary fibers (42 – 43%) as well as proteins, resistant starch, vitamins, minerals, phytochemicals, and potent antioxidants (Cheng *et al.,* 2022; Stevenson *et al.,* 2012). Empirical studies have demonstrated that regular intake of WB-derived fiber not only improves gastrointestinal function and promotes satiety but also reduces the risk of coronary heart disease, stroke, hypertension, and glycemic instability (Barber *et al.,* 2020; Cheng *et al.,* 2022; European Commission, Regulation EU n°2016/854). Despite FAO/WHO advocating for a daily fiber intake of 25 – 30 g, global consumption remains deficient at approximately 12 grams per day. While intake in North African countries is marginally higher (averaging 16 g per day) due to a traditional reliance on legumes and whole grains, it remains significantly below the recommended threshold (GBD 2017 Diet Collaborators, 2019).

The Mediterranean diet, recognized by its emphasis on nutrient-rich, plant-based foods, healthy fats, and sustainable eating practices, has demonstrated beneficial effects on cardiovascular diseases, specific types of cancer, and conditions related to cognitive decline (Lorca-Camara *et al.,* 2024). In this context, the valorization of traditional dietary staples through nutritional optimization has become a priority (Almpounioti *et al.,* 2025; Fanzo, 2019). Cereal-based products, given their ubiquity, provide an ideal matrix for the incorporation of dietary fibers. Pasta, in particular, enjoys global popularity due to its organoleptic properties, fast and easy cooking method, effortless use and storage properties, as well as its accessibility and affordability. Formally endorsed by Mediterranean dietary guidelines (Sicignano *et al.,* 2015), pasta is considered as a complex carbohydrate source and with a low glycemic index, owing to its slowly digestible starch structure (Seczyk *et al.,* 2016). This gradual glucose liberation reduces postprandial insulin response and is associated with a lower risk of metabolic and esophageal pathologies (Seczyk *et al.,* 2016; Sicignano *et al.,* 2015).

"*Nwasser*" (analogous to *Trida* in Algeria) is a traditional Tunisian pasta characterized by its distinct square geometry and its basis in durum wheat semolina (Boukid, 2025). Current consumer trends indicate a shift away from ultra-processed foods toward authentic, local, and traditional alternatives (Boukid, 2025; Garanti & Berberoglu, 2018). Enhancing the nutritional value of *Nwasser*s would provide an opportunity for value addition and preserving the cultural North African culinary heritage while promoting sustainable dietary shifts (Boukid, 2025; Fanzo, 2019). WB is an attractive functional ingredient due to its cost-effectiveness and health-promoting properties, which makes it interesting as an ingredient in cereal functional food products such pasta (Dziki, 2021; Katileviciute *et al.,* 2019; Pop, 2017; Stevenson *et al.,* 2012; Yan *et al.,* 2022). According to Fortune Business Insights (2025), the global WB market size was USD 18.57 billion in 2020 and is projected to grow up to USD 31.43 billion by 2032. While plain wheat bran's market price is often a fraction of that of semolina, its incorporation into value-added products like functional pasta can increase its market value by 3 to 5 times. Furthermore, the European Food Safety Authority (EFSA, 2010) has approved health claims regarding WB, provided the product meets the threshold of 1.5 g of fiber per 100 kcal (Regulation (EC) No 1924/2006).

Nutritional improvement of food products can help to reduce healthcare burden. In addition, addressing the escalating global issue of food waste requires the employment of by-products such WB, from the food industry in food formulation. Such approaches can significantly enhance resource efficiency and support the tenets of a circular economy, aiming for zero waste. However, the incorporation of WB can impair dough formation, leading to a change of color and texture, which consequently diminishes consumer demand (Li & Wu, 2024; Yan *et al.,* 2022). Previous research indicates that high substitution levels (15 – 20%) negatively impact cooking quality (Chillo *et al.,* 2008; Dziki, 2021). Therefore, the challenge lies in formulating a healthy product that retains consumer acceptability. Thus, developing appealing WB-enriched foods is not solely a nutritional imperative but also an economic opportunity, turning a low-cost by-product into a high-value functional ingredient and contributing to a more sustainable and profitable food system.

This study aimed at incorporating WB—an affordable, nutrient-rich by-product—into traditional *Nwasser* pasta within the framework of circular economy and sustainability. The primary objectives were to evaluate the impact of WB enrichment on physicochemical quality, nutritional profile, and consumer acceptability. Two distinct incorporation levels were investigated to meet complementary experimental goals: a preventative formulation (3% WB) and an optimal functional formulation (6% WB).

2 Material and Methods

2.1 Survey Methodology

To evaluate consumer acceptability of WB-enriched pasta, an online cross-sectional survey was carried out through a selfadministered structured questionnaire, as previously described by Ben Ismail *et al.* (2022). The instrument was developed via the Google Forms platform and administered in French (the primary academic language in Tunisia) from February 27 to March 27, 2021. Respondents were recruited on a voluntary basis through convenience sampling.

The questionnaire consisted of 10 items, including single-option and multiple-choice questions, structured into four thematic sections: (1) Regular pasta consumption patterns; (2) Traditional fresh pasta consumption habits and associated drivers; (3) Nutritional literacy regarding the health benefits of WB and; (4) Acceptability and willingness to consume enriched traditional pasta. The last part final section collected socio-demographic data (sex, age, marital status, employment, and educational attainment). The survey was disseminated through various institutional communication channels, including official website, electronic mailing lists, and social media platforms.

2.2 Raw Materials

Durum wheat (*Triticum durum*) semolina and common wheat (*Triticum aestivum* L.) flour (La Rose Blanche, Tunisia), were utilized as the primary matrices. Wheat bran (WB), characterized by a dietary fiber content of 41% (Celnat, Tunisia), was purchased from a local commercial outlet in Tunis, Tunisia.

2.3 *Nwasser* Pasta Formulation and Processing

The base formulation consisted of durum wheat semolina and common wheat flour in a 2:1 ratio (w/w), supplemented with 0.5 g/100 g of sodium chloride. WB was incorporated at two substitution levels: 3% (PWB1) and 6% (PWB2) of the total flour weight. These concentrations were selected as a low-dose strategy to optimize fiber enrichment while preserving the structural integrity and organoleptic properties of the pasta, thereby mitigating the deleterious effects on color and texture typically associated with higher inclusion rates (Chillo *et al.*, 2008; Dziki, 2021).

The dry ingredients were homogenized and hydrated through manual kneading until a cohesive dough was achieved. The dough was then laminated to a uniform thickness of 0.25 cm, partitioned into 1x1 cm squares, and dehydrated at 44°C for 24 hours. Prior to analysis, the dried pasta was coated with vegetable oil (500:50 w/v), and subjected to traditional steam cooking for 45 minutes.

2.4 Technological Properties

Water holding capacity (WHC) and Oil Holding Capacity (OHC): WHC and OHC were determined according to the protocol established by Jitngarmkusol *et al.* (2008). Briefly, 2 g of the sample was dispersed in 5 mL of distilled water (for WHC) or vegetable oil (for OHC) in a pre-weighed centrifuge tube. The dispersions were agitated, allowed to equilibrate for 30 min before, and subsequently centrifuged at 4000 rpm for 15 min. Following the decantation of the supernatant, the samples were reweighed to determine the mass of the retained liquid.

Swelling index (SI): The SI (expressed as g water/g dry pasta) was evaluated employing the method of Fardet *et al.* (1999) and calculated as follows:

$$SI = \frac{(W1 - W2)}{W2}$$

Where W_1 represents the weight of cooked product and W_2 represents the weight after dehydration.

Optimal Cooking Time (OCT): was determined utilizing the standard method of Quinton and Kennedy (2002). The optimal point was defined as the moment the opaque white core disappeared when the pasta was compressed between two glass plates for 30 s.

All technological analyses were performed in triplicate employing cooked samples.

2.5 Proximate Compositional Analysis

Raw and dried *Nwasser*s samples were characterized for dry extract (AACC method 44 – 15.02), total protein (AACC method 46 – 13.01), crude fat (AACC method 30 – 25.01), ash (AACC method 08 – 01.01) and total dietary fibers (AACC method 32 – 45.01) (Quinton and Kennedy, 2002). Total carbohydrate content was determined by subtracting fat, protein and ash content values from dry extract value.

The total calorie value was calculated by aggregating the energy contribution of proteins (*P*), carbohydrates (*Cb*), and fats (*F*), utilizing specific conversion factors for plant-based products (Southgate & Durnin, 1970).

$$\text{Energy (kcal)} = 3.74P + 4.03Cb + 8.37F$$

Total phenolic content (TPC) was quantified according to the method of Li *et al.* (2024). All analyses were conducted in triplicate on raw pasta.

2.6 *In vitro* Antioxidant Activity

The radical scavenging activity was determined employing the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay (Li *et al.*, (2024). The scavenging capacity was calculated via the following formula:

$$\%\text{DPPH} = \frac{A_{blank} - A_{sample}}{A_{blank}} \times 100$$

Where A_{blank} is the absorbance of the control and A_{sample} is the absorbance of the test sample.

2.7 Colorimetric Assessment (CIE Lab*)

Surface color coordinates were measured using a spectrophotometer (MINOLTA CR6300). The parameters recorded included L^* (lightness, 0 – 100), a^* (redness/greenness), and b^* (yellowness/blueness). The total color difference (ΔE^*) between the control and WB-enriched samples was calculated by applying the following equation:

$$AE^* = [\,(Lc - Lp)^{2} + (a_c^* - a_p^*)^{2} + (b_c^* - b_p^*)^{2}]^{1/2}$$

With Lc, a*c, b*c the values of the control sample and Lp, a*p, b*p the values of the WB enriched fresh pasta samples.

Color score parameter (values from 1 to 10), informing about the level of yellowness or brightness of the pasta, was calculated according to the following equation:

$$\text{Color Score} = \frac{(L^* + (b^* \times 2))}{20}$$

The determinations were performed in triplicate.

2.8 Assessment of *In Vivo* Postprandial Glycemic Responses

A cohort of twelve healthy volunteers (three males and nine females; age range: 22 – 28 years, BMI 18.6 – 23.7 kg/m^2) was recruited from the University of Carthage (Tunis, Tunisia). All participants provided written informed consent prior to enrollment. The study protocol was conducted in accordance with the Declaration of Helsinki and received formal approval from the institutional ethics committee.

The study employed a randomized crossover design, as described by Belkacem *et al.* (2021). Following a 10-h overnight fast, participants reported to the research facility and completed standardized health screening questionnaires. Each subject was served a 50 g portion of one of three pasta formulations: (i) a control (0% WB), (ii) PWB1 (3% WB), or (iii) PWB2 (6% WB).

Capillary blood glucose levels were measured at baseline (t = 0) and at 30-, 60-, 90-, 120-, 150-, and 180-minutes post-ingestion using a calibrated handheld glucometer (Accu-Chek Active system, Roche). The mean fasting blood glucose concentration across the cohort was 93 ± 6 mg/dL. Glycemic responses were expressed as the change in glucose concentration relative to the baseline. The area under the curve ($iAUC_{0\text{-}180min}$) was calculated using the trapezoidal rule.

2.9 Statistical Analysis

Primary survey data were analyzed via descriptive statistics, specifically frequency distributions and percentages, employing Microsoft Excel, following the methodology of Ben Ismail *et al.* (2022). Experimental data were subjected to one-way and two-way Analysis of Variance (ANOVA), to assess the significance of the main effects and interactions. Statistical analyses were performed employing GraphPad Prism (version 8, 2019) Where significant differences were detected, post-hoc mean comparisons were conducted using Tukey's Honestly Significant Difference (HSD) test. The threshold for statistical significance was set at $p < 0.05$.

3 Results

3.1 Consumer Acceptability of Traditional Pasta Enriched with WB

The socio-demographic characteristics of the survey respondents—categorized by sex, age, marital status, educational attainment, and occupation—are summarized in Table 1.

Table 1. Socio-demographic Characteristics of Survey Participants (n=172)

Characteristic	% Respondents
Sex	
Men	33
Women	67
Age (years)	
18-25	42.9
26-40	40.5
41-59	10.1
60 and more	6.5
Marital Status	
Single	52.2
In couple	6.7
Married	42.7
Education Level	
Primary	0
High School	4.5
University	95.5
Occupation	
Farmers	2.4
Craftsmen, traders, entrepreneurs	6.5
Managers and higher intellectual professions	31.0
Intermediate professions	1.2
Employees	11.3
Retired	6.0
Students/ Inactive people	42.9

The demographic profile indicates that 67% of the respondents were female, 51.1 % were professionally active and a substantial majority (95.5%) possessed high levels of education. This specific distribution is attributed to the voluntary nature of recruitment, the dissemination of the survey via social media platforms, and the utilization of the French language for administration. Due to the non-probabilistic sampling design, this cohort is not representative of the general Tunisian adult population; however, it remains representative within the aforementioned groups (Ben Ismail *et al.,* 2022).

Respondents were surveyed regarding their consumption patterns of traditional *Nwasser* pasta, including frequency of intake, as well as their willingness to consume and the primary drivers for accepting WB-enriched traditional pasta (Table 2). Approximately 78% of participants confirmed regular consumption of traditional pasta, with frequencies reported as monthly (41%) and weekly (27%). Interestingly, 96% of respondents expressed a readiness to consume WB-enriched traditional pasta, primarily citing potential health benefits (59%) and a general awareness of the nutritional advantages associated with WB consumption (76%). These findings suggest a promising market potential for the development of WB-enriched food products and provide a robust justification for the present study.

Table 2. Survey Respondents' Acceptability for Traditional *Nwasser* Pasta (n=172)

		% Respondents
Consumption of regular traditional *Nwasser* pasta		
	Yes	78
	No	22
Frequency of consumption		
	More than once a week	11
	Once a week	16
	Once a month	41
	Rarely	12
	Never	20
Awareness of health benefits		
	Yes	76
	No	24
Consumers' Acceptability for traditional *Nwasser* pasta		
	Yes	96
	No	4
Potential Drivers for consumption of traditional *Nwasser* pasta		
	Health benefits	59
	Taste	30
	Texture	2
	Easy to prepare	9

3.2 Effect of Wheat-Bran Incorporation on Techno-Functional and Cooking Quality Attributes

As detailed in Table 3, incorporation of WB in the traditional pasta had a significant effect ($p < 0.05$) on pasta water holding capacity (WHC) and optimal cooking time, in a dose-dependent manner, whereas the swelling index (SI) and the oil capacity (OHC) were not significantly affected by WB addition.

3.3 Effect of Wheat-Bran Incorporation on Composition and *In Vitro* Antioxidant Properties

As indicated in Table 4, the supplementation of WB resulted in significant modifications to the proximate composition of the pasta, specifically regarding dry matter, ash content, and total dietary fibers, thereby enhancing the overall nutritional profile.

The addition of 3% (PWB1) or 6% (PWB2) WB did not significantly alter the total phenolic content (TPC) compared to the control group (Table 4). However, it significantly enhanced the *in vitro* DPPH radical scavenging capacity ($p < 0.05$), thereby improving the antioxidant properties. The utilization of the DPPH assay was justified by its methodological simplicity, rapidity, and sensitivity to the primary TPC present in WB. While alternative assays such as ABTS or FRAP might offer a broader profile, the DPPH approach coupled with TPC determination provided a direct and sufficient correlation to assess the functional impact of the enrichment.

3.4 Effect of Wheat Bran Incorporation on Visual Appearance and Color Attributes

The visual appearance of the pasta samples was characterized as smooth and homogeneous. However, samples exhibited a progressively darker hue with small reddish inclusions increasing with the amount of added WB (data not displayed). This morphological shift is primarily attributed to the bran natural pigments and its higher mineral (ash) content (Alzuwaid *et al.,* 2018).

Table 3. Techno-Functional and Cooking Properties of Control and Traditional Pasta with WB at 3% (PWB1) and 6% (PWB2)

Parameters	Control	PWB1	PWB2
Level of WB-enrichment	**0**	**3%**	**6%**
Water holding capacity (g/g)	1.53 ± 0.026^{a}	2.16 ± 0.15^{b}	2.18 ± 0.061^{c}
Oil holding capacity (g/g)	1.40 ± 0.15^{a}	1.51 ± 0.075^{a}	1.57 ± 0.033^{a}
Swelling index (%)	32.16 ± 9.60^{a}	43.09 ± 7.14^{a}	41.46 ± 0.46^{a}
Optimal cooking time (min)	45.67 ± 1.15^{a}	38.67 ± 1.53^{b}	36.33 ± 2.31^{c}

Results are expressed as mean ± STD; ^{a,b,c}: different letters in the same line indicate $p < 0.05$

Table 4. Biochemical Composition, TPC and DPPH Radical Scavenging Capacity of Control and WB-enriched pasta (n=3)

Parameter (g/100g of product)	Control	PWB1	PWB2
Level of WB-enrichment	**0**	**3%**	**6%**
Dry Extract	46.6 ± 1.0 [a]	48.6 ± 1.0 [a,b]	48.9 ± 0.4 [b]
Proteins	9.6 ± 0.7 [a]	10.2 ± 0.4 [a]	11.3 ± 0.9 [a]
Fat	0.81 ± 0.09 [a]	0.92 ± 0.09 [a]	1.04 ± 0.09 [a]
Carbohydrates	35.51	33.99	33.60
Ashes	0.68 ± 0.12 [a]	3.49 ± 1.30 [b]	2.96 ± 0.13 [c]
Total fibers	1.38 ± 0.59 [a]	2.57 ± 0.67 [b]	3.45 ± 0.73 [b]
Phenolic compounds (g EAG/100g)	6.06 ± 0.94 [a]	6.34 ± 0.95 [a]	6.74 ± 1.06 [a]
Calorie Value (Kcal/100 g)	186.07	182.81	186.37
% DPPH	7.09 ± 0.64 [a]	9.12 ± 0.15 [b]	9.30 ± 0.15 [b]

Results are expressed as mean ± STD; [a,b,c]: different letters in the same line indicate $p < 0.05$

Table 5 presents the instrumental CIE L^* a^* b^* color coordinates for the control and WB-enriched pasta formulations.

Table 5. CIE L^* a^* b^* color parameters of control and enriched traditional pasta with WB at 3% (PWB1) and 6% (PWB2) (n=3)

Parameter	Control	PWB1	PWB2
Level of WB-enrichment	**0**	**3%**	**6%**
L^*	77.45± 0.035[a]	75.16± 0.02[b]	72.38± 0.13[c]
a^*	0.020± 0.001[a]	1.26± 0.03[b]	2.52± 0.02[c]
b^*	18.83± 0.05[a]	17.29± 0.05[b]	16.58± 0.16[c]
Color score	5.76± 0.01	5.49± 0.004	5.28± 0.01
ΔE	-	3.030	6.086

Results are expressed as mean ± STD; [a,b,c]: different letters in the same line indicate $p < 0.05$

Increasing enrichment of pasta with wheat-bran at 3% or 6% led to a significant reduction in lightness (L^*) and significant increase in redness (a^*) and yellowness (b^*) values, consequently increasing the total color difference (ΔE). Conversely, the color scores of PWB1 and PWB2 decreased significantly compared to the control ($p > 0.05$) (Table 5). The color score constitutes a critical parameter determining the degree of brightness or "golden" hue in pasta, often considered a primary quality attribute due to the prevalence of carotenoid pigments in wheat (Bustos *et al.,* 2011). In this study, the characteristic yellowness was significantly diminished in PWB1 and PWB2 with the amount of added WB compared to control, likely due to the masking effect of the reddish-brown bran pigment, as evidenced by the elevated a^* indices.

Following the traditional steaming process (45 min), the colorimetric disparities between the control and enriched samples remained distinctly visible (data not revealed). Qualitative observations indicated no perceptible alteration in the color of the steaming water, suggesting that the carotenoid pigments remained sequestered within the pasta matrix and did not undergo significant leaching. Notably, organoleptic assessment revealed that cooked control samples exhibited higher surface stickiness compared to the PWB1 and PWB2 formulations, suggesting that WB incorporation may influence the protein-starch network and reduce surface adhesiveness.

3.5 Influence of WB-Enrichment on Postprandial Glycemic Response in Healthy Subjects

As illustrated in Figure 1, increasing doses of WB into traditional pasta have modified the acute postprandial glycemic response in healthy volunteers.

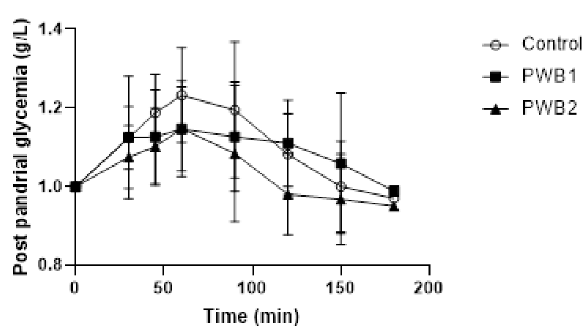

Figure 1. Adjusted blood glucose courses after consumption of the control and enriched traditional pasta with WB at 3% (PWB1) and 6% (PWB2) (n = 12 healthy volunteers). Results are expressed as mean ± STD.

In all experimental groups, incremental blood glucose concentrations peaked at 60 minutes post-ingestion. Subsequent to this peak, glucose levels followed a downward trajectory, returning to baseline values by 120 minutes for the PWB2 group, whereas the control group required 150 minutes to achieve glycemic homeostasis. Physiologically, the consumption of the test meals initiated a transient influx of glucose into the systemic circulation, thereby stimulating insulin secretion by pancreatic β-cells to facilitate glucose uptake.

Comparative analysis revealed that the consumption of control pasta induced a more pronounced and statistically significant elevation in incremental blood glucose concentration compared to the WB-enriched formulations. While the differences in peak glucose concentrations (at t = 60 min) between PWB1 and PWB2 did not reach statistical significance, both enriched samples demonstrated an overall attenuation of the glycemic response relative to the control.

Statistical evaluation via two-ways ANOVA revealed the glycemic response was significantly influenced by the treatment ($p = 0.0047$) and by time ($p < 0.0001$). However, the interaction between treatment and time was found to be non-significant ($p = 0.757$). Moreover, the iAUC was significantly lower after consumption of PWB2 ($iAUC_{0\text{-}180min}$=186.0 ± 5.6), when compared to control ($iAUC_{0\text{-}180min}$ = 198.7 ± 5.6), and PWB1 ($iAUC_{0\text{-}180min}$ = 196.0 ± 6.3) samples ($p < 0.005$).

4 Discussion

The global demand for functional foods that offer health benefits and aid in NCDs prevention is currently undergoing a significant expansion. Within this framework, wheat bran—the primary by-product of wheat milling—presents a strategic opportunity for the development of value-added functional foods. WB is an exceptional source of dietary fibers and bioactive compounds; however, its utilization requires careful consideration. While previous literature has extensively explored enrichment with soluble fiber sources like oat bran or barley flour, the present study focused on WB due to its high proportion of insoluble fiber. This specific fiber profile provides distinct physiological benefits, notably the promotion of intestinal regularity through a mechanical "bulking effect", which contrasts with the lipid-lowering mechanisms of β-glucans (Dziki, 2021; Yan *et al.,* 2022). Furthermore, the enrichment of traditional food products, such as *Nwasser* pasta, facilitates improved nutritional intake without drastically altering established dietary patterns, thereby ensuring cultural continuity. From a sustainability perspective, the valorization of WB aligns with circular economy principles by minimizing industrial waste and maximizing resource efficiency.

Consumer Perception and Acceptability

The initial phase of this study evaluated consumer receptivity toward WB-enriched traditional pasta (Table 2). Although 78% of respondents reported consuming traditional pasta, the frequency was predominantly monthly (41%), a trend likely attributable to the labor-intensive preparation required for the *Nwasser* dish. A high degree of health awareness was observed, with 76% of participants cognizant of the nutritional benefits of WB. This correlates with the respondents' demographic profile—predominantly highly educated individuals (95.5%) —consistent with the findings of Bellisle *et al.* (2014) who identified a positive correlation between educational attainment and the consumption of whole-grain products.

Significantly, 96% of the panelists expressed a willingness to consume WB enriched traditional pasta, driven primarily by perceived health benefits (59%) and sensory appeal (30%). Identical drivers were reported by Laureati *et al.* (2016) and Jaworska *et al.* (2020) for wholegrain pasta consumers and β-glucan enriched fresh pasta, and Foster *et al.* (2020) for wholegrain products consumers. Szakály and Kiss (2023) highlighted that information on health benefits may ameliorate consumer acceptance for cereal-based healthy foods. These data were promising and pointed out a high consumers' acceptability for a more nutritious alternative to regular food products, such pasta. In this context, traditional *Nwasser* pasta were formulated by adding 3% or 6% WB: these levels of incorporation were selected based on previous studies (Dziki, 2021), reporting alterations sensory and cooking quality of pasta enriched with high ratios (15 – 20%) of WB. From a product development perspective, this high acceptability constitutes a critical finding. It suggests that marketing strategies for such enriched traditional products should prominently communicate the health benefits, as this is a primary purchase driver for the target demographic (Table 2). The willingness to accept a product based on a health claim alone—even prior sensory evaluation—de-risks initial product launch and subsequent consumer trials.

Techno-functional and Cooking Quality

Formulation assays revealed that enrichment of traditional pasta with WB at respectively 3% (PWB1) or 6% (PWB2) significantly modified techno-functional characteristics and cooking quality (Table 3). Indeed, it led to an increased pasta WHC, in agreement with studies of Bouacida *et al.* (2017), Gull *et al.* (2018), Islas-Rubio *et al.* (2014), Kaur *et al.* (2012), and Pop (2017). Mechanistically, this can be attributed to the high content of insoluble dietary fibers in WB (Cheng *et al.,* 2022). This type of dietary fiber possesses a high capacity to absorb and hold water. In fact, hydroxyl groups in WB structure react with water through hydrogen bonding, and this in turn enhances water absorption. Moreover, the physical structure of bran, with its porous and fibrous nature, provides a large surface area for water absorption (Cheng *et al.,* 2022). Increased WHC is instrumental in understanding the behavior of dietary fibers during gastrointestinal transit as numerous studies have demonstrated that regular dietary fiber consumption ameliorates gut transit (Patel *et al.,* 2015). Sobota *et al.* (2015) further established that products with elevated WHC are more effective in promoting satiety and reducing hunger and provide. Additionally, WHC significantly influences key technological parameters of pasta (Onipe *et al.* 2015). Specifically, the enrichment of the traditional pasta "*Nwasser*" with WB at 3% (PWB1) or 6% (PWB2) significantly reduced the optimal cooking time of the pasta compared to the control sample.

The underlying mechanism is likely the physical disruption of the continuous gluten-starch matrix by insoluble bran particles. Pasta cooking involves water penetration, followed by the simultaneous processes of starch gelatinization and protein coagulation (Dziki, 2021). Bran, due to its water absorption, alters moisture distribution within the pasta structure during cooking (Makhlouf *et al.,* 2019). This disruption of the gluten network likely facilitates more rapid water penetration, thereby accelerating starch gelatinization and resulting in a reduced OCT (Makhlouf *et al.,* 2019). These results are in agreement with prior research (Bustos *et al.,* 2011; Kaur *et al.,* 2012; Manthey & Schorno 2002).

From a product development and consumer perspective, a shorter OCT constitutes a favorable attribute. This attribute aligns with modern demands for convenience and simpler home preparation, potentially increasing the appeal of this traditional time-intensive dish.

In contrast, the pasta swelling index exhibited no significant variation between the control and WB-enriched samples (Table 3), a result consistent with the findings of Padalino *et al.* (2013). Although bran absorbs water, its contribution to volumetric expansion at the tested incorporation levels (3% and 6%) may be minimal relative to the dominant swelling of the starch matrix itself. Identically, incorporation of 3% and 6% WB into pasta did not significantly affect OHC. The surface area and structural modification introduced by 3% and 6% of bran appear insufficient to produce a measurable alteration in OHC.

Biochemical Composition and Antioxidant Potential

The quality characterization (Table 4) demonstrated that WB enrichment significantly enhanced the nutritional and antioxidant profile of the pasta. The increase in dry extract observed in the PWB2 group (6% WB) is likely due to the hygroscopic nature of dietary fibers, which sequester moisture and improve product stability (Mishra *et al.,* 2024).

The dietary fiber content increased proportionally with WB incorporation ($p < 0.05$). Under Regulation (EC) No 1924/2006, the 6% WB formulation qualifies for the "source of fiber" nutritional claim, meeting the requirement of at least 1.5 g of fiber per 100 kcal. Mineral content—specifically calcium, iron, and potassium—also increased significantly, reflecting the nutrient-dense nature of the grain pericarp Dziki (2021), Espinosa-Solis *et al.* (2019), Laureati *et al.* (2016), Mishra *et al.* (2024), Padalino *et al.* (2015), Pop (2017), and Sobota *et al.* (2015).

While protein and fat contents remained within reference ranges (Filip & Vidrich, 2015) they were not significantly influenced by WB enrichment. This suggests that the nutritional value has been preserved even with the addition of WB. However, our results disagree with those obtained by Laureati *et al.* (2016), Padalino *et al.* (2015), Pop (2017), and Sobota *et al.* (2015) demonstrating that the enrichment of pasta with fibers significantly affected protein, fat and carbohydrate contents. When compared to these studies with high ratios (15 – 30%) (Dziki, 2021), in our work, the level of added wheat-bran was lower and only up to 6%. This stabilization in both components might be attributed to the preparation process of the dough and drying process of the traditional pasta (Bouacida *et al.,* 2017). Consequently, calorie values were comparable in all pasta samples.

Antioxidant Capacity and Phenolic Dynamics

Enrichment with 3% (PWB1) or 6% (PWB2) did not yield a statistically significant increase in TPC relative to the control (Table 4). This may be attributed to the relatively low incorporation dosage, combined with the physical and analytical constraints imposed by the dense pasta matrix. A substantial fraction of phenolic compounds in WB is covalently bound to the insoluble dietary fiber fraction, potentially restricting their extractability during standard assays. Consequently, a "plateau effect" for extractable activity may occur at these ratios (Wahanik *et al.,* 2021). This contrasts with the findings of Dziki (2021) who reported significant TPC increases at higher substitution levels (15 – 20%). Furthermore, thermal processing—specifically the mixing, kneading, and high-temperature drying stages—may trigger the degradation of sensitive bioactive compounds or the activation of polyphenol oxidase, further mitigating measurable phenolic increases (Altunkaya & Gökmen 2012; Biney & Beta, 2014).

However, despite the stability of TPC, the 6% WB formulation (PWB2) exhibited significantly enhanced *in vitro* radical scavenging activity compared to control (Table 4). This discrepancy can be mechanistically explained by considering that the antioxidant potential is not solely mediated by free phenolics. In addition to phenolic compounds, WB contains other antioxidants, such vitamin E, (tocopherols) carotenoids, alkylresorcinols and bound ferulic acid (Cheng *et al.,* 2022; Li *et al.,* 2024; Patel *et al.,* 2015). These components may act synergistically to neutralize free radicals. Furthermore, compounds such as alkylresorcinols and bound ferulic acid, which are released during gastrointestinal digestion, have been associated with systemic anti-inflammatory effects and improved cardiometabolic wellness (Guo *et al.,* 2022, Stevenson *et al.,* 2012). Additionally, Aravind *et al.* (2012), Dziki (2021), and Pasqualone *et al.* (2016) reported that the incorporation of bran in pasta increased the antioxidant activity.

Color Characteristics and Consumer Perception

Color is a primary sensory determinant of consumer acceptance in pasta products (Chillo *et al.,* 2008). The incorporation of WB significantly influenced CIE L^* a^* b^* parameters (p < 0.01; Table 5). Lightness (L^*) decreased proportionally with WB concentration, resulting in a darker appearance, while redness (a^*) increased. This chromatic shift is attributable to the intrinsic pigments of the bran and the potential facilitation of Maillard browning reactions during dehydration.

Yan *et al.* (2022) reported elevated a^* values in WB-enriched pasta, reflecting enhanced red hues. The incorporation of WB also affects the yellowness of pasta. The same authors reported an increase in b^* values, indicating a more yellowish color, when further investigations reported variations depending on the bran content and processing conditions (Yan *et al.,* 2022). A marked rise in the total color difference (ΔE) was observed, signifying a substantial divergence among the samples (Table 3). Comparable results were observed by Aravind *et al.* (2012), and Bouacida *et al.* (2017). These chromatic alterations in pasta color reflected the supplementation with WB, and are unlikely to adversely influence consumer acceptance as darker pigmentation is frequently associated with fiber-fortified pasta products (Chillo *et al.,* 2008; Yan *et al.,* 2022). To explicitly examine this consideration, an online consumer survey was conducted (Table 2). The results confirmed a shift in consumer perception: seventy-six percent of participants were already aware of the health benefits associated with wheat bran. Moreover, consumers increasingly associate darker color with healthier, whole-grain alternatives. This positive association mitigates potential commercial risk arising from the product's altered appearance. Therefore, the visual attribute does not negatively impact the overall acceptability of the final product within the target market.

Postprandial Glycemic Response

Interestingly, postprandial glycemic responses in healthy volunteers were lowered upon acute consumption of WB-enriched pasta formulas, when compared to the control (Figure 1). The current study findings corroborate those of Afaghi *et al.* (2011) and Budhwar *et al.* (2020) supporting the role of WB in the prevention of type 2 diabetes and obesity. (de Munter *et al.,* 2007; Guo *et al.,* 2022; Vega-López *et al.,* 2018). The observed decrease in postprandial glycemic response after enriched pasta consumption may be attributable to the composition of WB in bioactive components, such as dietary fibers, arabinoxylans and phenolic acids antioxidants (Stevenson *et al.,* 2012; Patel, 2015; Călinoiu *et al.,* 2018). WB fibers slow down the digestion and absorption of carbohydrates in the small intestine. In fact, the presence of bran can physically hinder the access of digestive enzymes to starch molecules in the pasta. This results in slower starch digestion and a slower release of glucose. This results in a gradual rise in blood glucose levels, preventing sharp spikes. Intake of food products containing dietary fibers (Kim *et al.,* 2016; Gaesser *et al.,* 2019; Barber *et al.,* 2020), and arabinoxylans (Lu *et al.,* 2000) led to lower incremental glycaemic responses in healthy and diabetic volunteers, when compared to controls. In fact, dietary fiber intake was reported to improve insulin sensitivity (mainly insoluble fibers), as well as to delay gastric emptying, to reduce calorie intake and increase satiety (Barber *et al.,* 2020; Kim *et al.,* 2016; Müller *et al.,* 2018). Yao *et al.* (2014) pointed out in a meta-analysis of 17 prospective cohort studies that increasing intake of cereal dietary fibers by 2 g/day led to reduce the risk of developing a type 2 diabetes by 6% (RR 0.94, 95% CI 0.93 – 0.96). The EFSA (2011) has recognized that arabinoxylans can maintain high viscosity within the gastrointestinal tract, which flattens postprandial glucose curves. Furthermore, because of their anti-inflammatory and antioxidant properties, phenolic components can act beneficially on the gastrointestinal tract and can also contribute to prevent type 2 diabetes, obesity, and some malignancies (Călinoiu *et al.,* 2018).

Limitations, Sustainability, and Economic Implications

It is worth noting that the current study presents several limitations. The online consumer survey, while providing valuable preliminary insights, is subject to self-selection bias and may not fully represent the general population. Additionally, this approach provides only a superficial understanding of consumer preferences, and fails to capture the complexity of sensory analysis. Furthermore, the glycemic response was measured following acute consumption; longitudinal studies are required to elucidate the long-term metabolic impacts of WB enrichment, particularly in populations with compromised glucose tolerance. In addition this study was conducted on healthy volunteers, and should be taken cautiously for people with high risk of life style related diseases or compromised glucose tolerance (Patel, 2015; Belkacem *et al.,* 2021).

Collectively, our findings demonstrate that WB-enriched pasta constitutes an excellent dietary source of dietary fiber and minerals and induces a lower acute postprandial glycemic response. The fortification of staple foods such pasta with WB represents a viable strategy to address widespread nutrient deficiencies, notably inadequate fiber intake (GBD 2017 Diet Collaborators, 2019). This approach holds particular promise for populations whose traditional diets may be deficient in essential micronutrients. The resultant nutritional enhancement can support healthier dietary patterns, potentially contributing to chronic disease prevention and the promotion of health as well as to reduce healthcare expenditures—all while maintaining familiar culinary traditions.

Moreover, the optimized utilization of WB—an affordable, nutrient-dense by product—in the formulation of high-value products such as enriched pasta aligns with circular economy principles by promoting a closed-loop system where resources are reutilized and recycled. From a sustainability perspective, this strategy mitigates agro-industrial waste and enhances resource efficiency. Redirecting bran from low-value applications (e.g., animal feed) toward human consumption reduces the land, water, and energy footprints associated with producing an equivalent amount of dietary fiber from dedicated primary crops.

From an economic perspective, the valorization of WB presents a compelling opportunity. Current global market prices for wheat bran are estimated at USD 200 – 300 per metric ton, significantly lower than the USD 600 – 800 per ton for durum wheat semolina (FAO, 2023; Fortune Business Insights, 2025). Incorporating 6% WB into *Nwasser* effectively upgrades this low-value stream into a product that can command a premium price as a "source of fiber" functional food. A basic cost-structure analysis indicates that this substitution could reduce producers' raw material costs by 2 – 4%, while the enhanced nutritional profile justifies a retail price increase of 10 – 15% or more—consistent with existing market premiums for fiber-enriched products. Thus, a previously undervalued byproduct is transformed into a measurable gain.

The current research provides a practical, culturally-relevant model for enhancing food system sustainability, demonstrating that economic incentives and nutritional goals can be synergistically achieved through the intelligent redesign of traditional foods.

5 Conclusions

The nutritional fortification of traditional foods offers a range of significant advantages for addressing micronutrient deficiencies, promoting overall public health, as well as in maintaining cultural relevance and ensuring acceptance. This study established that for traditional Tunisian pasta (*Nwasser*), the optimization of wheat bran (WB) incorporation is pivotal in balancing enhanced bioactivity with technological and sensory integrity. This research investigated the impact of 3% and 6% WB substitution on the physicochemical, nutritional, glycemic properties of the product, cooking quality, and consumers' acceptability, while simultaneously assessing its alignment with sustainability and circular economy principles.

Market-oriented analysis via our consumer survey has indicated high baseline awareness of the health benefits associated with WB and a willingness to consume WB-enriched pasta, suggesting a robust receptive capacity for nutritionally enhanced traditional staples. The results indicate that the two distinct incorporation levels (3% and 6%) serve complementary strategic roles:

- The 3% WB formulation ("Preventative Formulation"): This level serves as a conservative entry point for health-conscious markets. It successfully augmented dietary fiber content and improved technological performance—specifically by reducing optimal cooking time—without inducing deleterious sensory alteration. This formulation represents a low-risk strategy for introducing healthier alternatives into traditional dietary patterns.
- The 6% WB formulation ("Optimal functionality"): This level represents a transition into the functional food category. By meeting the EU's regulatory requirement to be labeled as a "source of fiber", this dosage provides a tangible nutritional claim. Most notably, the 6% enrichment level achieved a statistically significant reduction in the acute postprandial glycemic response, confirming an interesting physiological benefit beyond basic nutritional improvement for metabolic health management.

The synergy between healthy dietary patterns, tradition cultural authenticity, and artisanal processing encourages a shift from refined, industrial pasta toward nutrient-dense, traditional alternatives. The present study demonstrates the feasibility of incorporating WB, a nutrient-rich by-product of wheat flour processing, into traditional pasta "*Nwasser*" to enhance its nutritional profile. This approach not only enhances product affordability and nutritional density but also advances the circular economy by minimizing resource waste and maximizing the utility of locally available biomass.

While the current results are promising, further studies should prioritize a longitudinal assessment of the sensory stability and shelf-life of WB-enriched pasta. The impact of WB on pasta texture should be scrutinized more closely. Additionally, long-term clinical trials are necessitated to further elucidate the impact of sustained consumption on systemic glycemic control and other cardiometabolic biomarkers. Ultimately, this research provides a scalable model for the sustainable redesign of traditional food systems.

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REFERENCES

Afaghi, A., Ranjbari Omidi, B., Sarreshtehdari, M., Ghanei, L., Alipour, M., Azadmehr, A., & Safari-Varyani, A. (2011). Effect of wheat bran on postprandial glucose response in subjects with impaired fasting glucose. *Current Topics in Nutraceutical Research*, Vol 9, Issue 1/2, 35. [Google Scholar] [Publisher]

Almpounioti, K., Papagianni, O. I., & Koutelidakis, A. E. (2025). Traditional foods, the Mediterranean diet, and health promotion. In *Handbook of Public Health Nutrition: International, National, and Regional Perspectives* (pp. 1-23). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-32047-7_33-1 [Crossref] [Google Scholar] [Publisher]

Altunkaya, A., & Gökmen, V. (2012). Partial purification and characterization of polyphenoloxidase from durum wheat (Triticum durum L.). *Journal of Cereal Science*, 55(3), 300-304. https://doi.org/10.1016/j.jcs.2011.12.013 [Crossref] [Google Scholar] [Publisher]

Alzuwaid, N. T., Fellows, C. M., Laddomada, B., & Sissons, M. (2020). Impact of wheat bran particle size on the technological and phytochemical properties of durum wheat pasta. *Journal of Cereal Science*, 95, 103033. https://doi.org/10.1016/j.jcs.2020.103033 [Crossref] [Google Scholar] [Publisher]

Quinton, L. A., & Kennedy, J. F. (2002). American Association of Cereal Chemists Approved Methods, CD-ROM: American Association of Cereal Chemists, 2000, ISBN: 1-891127-13-6, US $579. https://doi.org/10.1016/S0144-8617(01)00358-7 [Crossref] [Google Scholar] [Publisher]

Aravind, N., Sissons, M., Egan, N., & Fellows, C. (2012). Effect of insoluble dietary fibre addition on technological, sensory, and structural properties of durum wheat spaghetti. *Food Chemistry*, 130(2), 299-309. https://doi.org/10.1016/j.foodchem.2011.07.042 [Crossref] [Google Scholar] [Publisher]

Barber, T. M., Kabisch, S., Pfeiffer, A. F., & Weickert, M. O. (2020). The health benefits of dietary fibre. *Nutrients*, 12(10), 3209. https://doi.org/10.3390/nu12103209 [Crossref] [PubMed] [Google Scholar] [Publisher]

Belkacem, A., Ellouze, I., & Debbabi, H. (2021). Partial substitution of sucrose by non-nutritive sweeteners in sour orange marmalades: effects on quality characteristics and acute postprandial glycemic response in healthy volunteers. *The North African Journal of Food and Nutrition Research*, 5(11), 1-9. https://doi.org/10.51745/najfnr.5.11.1-9 [Crossref] [Google Scholar] [Publisher]

Bellisle, F., Hébel, P., Colin, J., Reyé, B., & Hopkins, S. (2014). Consumption of whole grains in French children, adolescents and adults. *British Journal of Nutrition*, 112(10), 1674-1684. https://doi.org/10.1017/S0007114514002670 [Crossref] [PubMed] [Google Scholar] [Publisher]

Ben Ismail, H., Jribi, S., Doggui, D., & Debbabi, H. (2022). COVID-19 lockdown impact on Tunisian consumer behaviors and awareness related to food consumption and wastage during celebrations: Case of study "Ramadan month". *North African Journal of Food and Nutrition Research*, 6(13), 46-54. https://doi.org/10.51745/najfnr.6.13.46-54 [Crossref] [Google Scholar] [Publisher]

Biney, K., & Beta, T. (2014). Phenolic profile and carbohydrate digestibility of durum spaghetti enriched with buckwheat flour and bran. *LWT – Food Science and Technology*, 57(2), 569–579. https://doi.org/10.1016/j.lwt.2014.02.033 [Crossref] [Google Scholar] [Publisher]

Bouacida, S., Ben Amira, A., Ben Haj Koubaier, H., Blecker, C., & Bouzouita, N. (2017). Chemical composition, cooking quality, texture and consumer acceptance of pasta with Eruca vesicaria leaves. *International Journal of Food Science & Technology*, 52(10), 2248-2255. https://doi.org/10.1111/ijfs.13504 [Crossref] [PubMed] [Google Scholar] [Publisher]

Boukid, F. (2025). Traditional cereals-based foods in North African cuisine: Wheat as the cornerstone. *The North African Journal of Food and Nutrition Research*, 9(19), 41–56. https://doi.org/10.51745/najfnr.9.19.41-56 [Crossref] [Google Scholar] [Publisher]

Budhwar, S., Chakraborty, M., Sethi, K., & Chatterjee, A. (2020). Antidiabetic properties of rice and wheat bran—A review. *Journal of Food Biochemistry*, 44(10), e13424. https://doi.org/10.1111/jfbc.13424 [Crossref] [PubMed] [Google Scholar] [Publisher]

Bustos, M. C., Perez, G. T., & León, A. E. (2011). Sensory and nutritional attributes of fibre-enriched pasta. *LWT-Food Science and Technology*, 44(6), 1429-1434. https://doi.org/10.1016/j.lwt.2011.02.002 [Crossref] [Google Scholar] [Publisher]

Călinoiu LF, Vodnar DC. (2018). Whole Grains and Phenolic Acids: A Review on Bioactivity, Functionality, Health Benefits and Bioavailability. *Nutrients*;10(11):1615. https://doi.org/10.3390/nu10111615 [Crossref] [PubMed] [Google Scholar] [Publisher]

Cheng, W., Sun, Y., Fan, M., Li, Y., Wang, L., & Qian, H. (2022). Wheat bran, as the resource of dietary fiber: A review. *Critical reviews in food science and nutrition*, 62(26), 7269-7281. https://doi.org/10.1080/10408398.2021.1913399 [Crossref] [PubMed] [Google Scholar] [Publisher]

Chillo, S., Laverse, J., Falcone, P. M., Protopapa, A., & Del Nobile, M. A. (2008). Influence of the addition of buckwheat flour and durum wheat bran on spaghetti quality. *Journal of Cereal Science*, 47(2), 144-152. https://doi.org/10.1016/j.jcs.2007.03.004 [Crossref] [Google Scholar] [Publisher]

de Munter, J.S., Hu, F.B., Spiegelman, D., Franz, M., & van Dam, R.M. (2007). Whole grain, bran, and germ intake and risk of type 2 diabetes: a prospective cohort study and systematic review. *PLoS Med.*;4(8):e261. https://doi.org/10.1371/journal.pmed.0040261 [Crossref] [PubMed] [Google Scholar] [Publisher]

Dziki, D. (2021). Current trends in enrichment of wheat pasta: quality, nutritional value and antioxidant properties. *Processes*, 9(8), 1280. https://doi.org/10.3390/pr9081280 [Crossref] [Google Scholar] [Publisher]

EFSA (2010). Scientific Opinion on the substantiation of health claims related to wheat bran fibre and increase in faecal bulk (ID 3066), reduction in intestinal transit time (ID 828, 839, 3067, 4699) and contribution to the maintenance or achievement of a normal body weight (ID 829) pursuant to Article 13(1) of Regulation (EC) No 1924/2006. *EFSA Journal*, 8 (10), 1817. https://doi.org/10.2903/j.efsa.2010.1817 [Crossref] [Google Scholar] [Publisher]

EFSA (2011). Scientific opinion on the substantiation of health claims related to arabinoxylan produced from wheat endosperm and reduction of post-prandial glycaemic responses (ID 830) pursuant to Article 13(1) of Regulation (EC) No 1924/2006. *EFSA Journal*, 9 (6), 1-15. https://doi.org/10.2903/j.efsa.2011.2205 [Crossref] [Google Scholar] [Publisher]

Espinosa-Solis, V., Zamudio-Flores, P. B., Tirado-Gallegos, J. M., Ramírez-Mancinas, S., Olivas-Orozco, G. I., Espino-Díaz, M., & Baeza-Jiménez, R. (2019). Evaluation of cooking quality, nutritional and texture characteristics of pasta added with oat bran and apple flour. *Foods*, 8(8), 299. https://doi.org/10.3390/foods8080299 [Crossref] [PubMed] [Google Scholar] [Publisher]

European Commission, Regulation EU n°2016/854. Règlement d'exécution (UE) 2016/854 de la Commission du 30 mai 2016 autorisant certaines allégations de santé portant sur les denrées alimentaires, autres que celles faisant référence à la réduction du risque de maladie ainsi qu'au développement et à la santé infantiles, et modifiant le règlement (UE) n° 432/2012. https://eur-lex.europa.eu/eli/reg_impl/2016/854/oj [Publisher]

Fanzo, J. (2019). Healthy and Sustainable Diets and Food Systems: the Key to Achieving Sustainable Development Goal 2?. *Food Ethics* 4, 159–174. https://doi.org/10.1007/s41055-019-00052-6 [Crossref] [Google Scholar] [Publisher]

FAO (2023). Food Outlook – Biannual report on global food markets. Food Outlook, November 2023. Rome. https://doi.org/10.4060/cc8589en [Crossref] [Google Scholar] [Publisher]

Fardet, A., Abecassis, J., Hoebler, C., Baldwin, P. M., Buleon, A., Bérot, S., & Barry, J. L. (1999). Influence of technological modifications of the protein network from pasta on in vitro starch degradation. *Journal of Cereal Science*, 30(2), 133-145. https://doi.org/10.1006/jcrs.1999.0266 [Crossref] [Google Scholar] [Publisher]

Filip, S., & Vidrih, R. (2015). Amino Acid Composition of Protein-Enriched Dried Pasta: Is It Suitable for a Low-Carbohydrate Diet? *Food Technology and Biotechnology*, *53*(3), 298–306. https://doi.org/10.17113/ftb.53.03.15.4022 [Crossref] [PubMed] [Google Scholar] [Publisher]

Fortune Business Insights (2025). Wheat Bran Market Size, Share & COVID-19 Impact Analysis, By Type (Organic & Conventional), Application (Bakery Products, Breakfast Cereals, Pasta & Noodles, Other Food and Feed Applications), and Regional Forecast, 2021-2032. Retrieved from: https://www.fortunebusinessinsights.com/wheat-bran-market-103279 [Publisher]

Foster, S., Beck, E., Hughes, J., & Grafenauer, S. (2020) Whole Grains and Consumer Understanding: Investigating Consumers' Identification, Knowledge and Attitudes to Whole Grains. *Nutrients*. 12(8):2170. https://doi.org/10.3390/nu12082170 [Crossref] [PubMed] [Google Scholar] [Publisher]

Gaesser, G. A., Rodriguez, J., Patrie, J. T., Whisner, C. M., & Angadi, S. S. (2019). Effects of glycemic index and cereal fiber on postprandial endothelial function, glycemia, and insulinemia in healthy adults. *Nutrients*, 11(10), 2387. https://doi.org/10.3390/nu11102387 [Crossref] [PubMed] [Google Scholar] [Publisher]

Garanti, Z., & Berberoglu, A. (2018). Cultural Perspective of Traditional Cheese Consumption Practices and Its Sustainability among Post-Millennial Consumers. *Sustainability*,10, 3183. https://doi.org/10.3390/su10093183 [Crossref] [Google Scholar] [Publisher]

GBD 2017 Diet Collaborators (2019). Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*, 393(10184), 1958-1972. https://doi.org/10.1016/S0140-6736(19)30041-8 [Crossref] [PubMed] [Google Scholar] [Publisher]

Gull, A., Prasad, K., & Kumar, P. (2018). Nutritional, antioxidant, microstructural and pasting properties of functional pasta. *Journal of the Saudi Society of Agricultural Sciences*, 17: 147–153. https://doi.org/10.1016/j.jssas.2016.03.002 [Crossref] [Google Scholar] [Publisher]

Guo, H., Wu, H., Sajid, A., & Li, Z. (2022). Whole grain cereals: the potential roles of functional components in human health. *Critical Reviews in Food Science and Nutrition*, 62(30), 8388-8402. https://doi.org/10.1080/10408398.2021.1928596 [Crossref] [PubMed] [Google Scholar] [Publisher]

Islas-Rubio, A. R., De La Barca, A. M. C., Cabrera-Chávez, F., Cota-Gastélum, A. G., & Beta, T. (2014). Effect of semolina replacement with a raw: popped amaranth flour blend on cooking quality and texture of pasta. *LWT-Food Science and Technology*, *57*(1), 217–222. https://doi.org/10.1016/j.lwt.2014.01.014 [Crossref] [Google Scholar] [Publisher]

Jaworska, D., Królak, M., Przybylski, W., & Jezewska-Zychowicz, M. (2020). Acceptance of fresh pasta with β-glucan addition: expected versus perceived liking. *Foods*, 9(7), 869. https://doi.org/10.3390/foods9070869 [Crossref] [PubMed] [Google Scholar] [Publisher]

Jitngarmkusol, S., Hongsuwankul, J., & Tananuwong, K. (2008). Chemical compositions, functional properties, and microstructure of defatted macadamia flours. *Food Chemistry*, 110(1), 23-30. https://doi.org/10.1016/j.foodchem.2008.01.050 [Crossref] [PubMed] [Google Scholar] [Publisher]

Katileviciute A, Plakys G, Budreviciute A, Onder K, Damiati S, Kodzius R. (2019). A Sight to Wheat Bran: High Value-Added Products. *Biomolecules*;9(12):887. https://doi.org/10.3390/biom9120887 [Crossref] [PubMed] [Google Scholar] [Publisher]

Kaur, G., Sharma, S., Nagi, H. P. S., & Dar, B. N. (2012). Functional properties of pasta enriched with variable cereal brans. *Journal of Food Science and Technology*, 49, 467-474. https://doi.org/10.1007/s13197-011-0294-3 [Crossref] [PubMed] [Google Scholar] [Publisher]

Kim, E. K., Oh, T. J., Kim, L. K., & Cho, Y. M. (2016). Improving effect of the acute administration of dietary fiber-enriched cereals on blood glucose levels and gut hormone secretion. *Journal of Korean Medical Science*, 31(2), 222. https://doi.org/10.3346/jkms.2016.31.2.222 [Crossref] [PubMed] [Google Scholar] [Publisher]

Laureati, M., Conte, A., Padalino, L., Del Nobile, M. A., & Pagliarini, E. (2016). Effect of fiber information on consumer's expectation and liking of wheat bran enriched pasta. *Journal of Sensory Studies*, 31(4), 348-359. https://doi.org/10.1111/joss.12218 [Crossref] [Google Scholar] [Publisher]

Li, C., & Wu, W. (2024). Wheat bran: A nutritional treasure or bread-making challenge?—A mini-review. *Food Biomacromolecules*, 1(1), 3-8. https://doi.org/10.1002/fob2.12007 [Crossref] [Google Scholar] [Publisher]

Li, C., Wu, W., Tilley, M., Chen, R., Sun, X. S., Wang, W., & Li, Y. (2024). In vitro antioxidant properties of wheat bran extracts and their inhibitory effects on collagenase, elastase, and hyaluronidase. *ACS Food Science & Technology*, 4(8), 1960-1966. https://doi.org/10.1021/acsfoodscitech.4c00310 [Crossref] [Google Scholar] [Publisher]

Lorca-Camara, V., Bosque-Prous, M., Batlle-Bayer, L., Bes-Rastrollo, M., O'Callaghan-Gordo, C., & Bach-Faig, A. (2024). Environmental and Health Sustainability of the Mediterranean Diet: A Systematic Review. *Advances in Nutrition*, 100322. https://doi.org/10.1016/j.advnut.2024.100322 [Crossref] [PubMed] [Google Scholar] [Publisher]

Lu, Z. X., Walker, K. Z., Muir, J. G., Mascara, T., & O'Dea, K. (2000). Arabinoxylan fiber, a byproduct of wheat flour processing, reduces the postprandial glucose response in normoglycemic subjects. *The American Journal of Clinical Nutrition*, 71(5), 1123-1128. https://doi.org/10.1093/ajcn/71.5.1123 [Crossref] [PubMed] [Google Scholar] [Publisher]

Makhlouf, S., Jones, S., Ye, S. H., Sancho-Madriz, M., Burns-Whitmore, B., & Li, Y. O. (2019). Effect of selected dietary fibre sources and addition levels on physical and cooking quality attributes of fibre-enhanced pasta. *Food Quality and Safety*, 3(2), 117-127. https://doi.org/10.1093/fqsafe/fyz010 [Crossref] [Google Scholar] [Publisher]

Manthey, F. A., & Schorno, A. L. (2002). Physical and cooking quality of spaghetti made from whole wheat durum. *Cereal Chemistry*, 79(4), 504-510. https://doi.org/10.1094/CCHEM.2002.79.4.504 [Crossref] [Google Scholar] [Publisher]

Mishra, S., Sarkar, D., Roy, P., Roy, P., Shriram, N., Tewari, S., & Farhana, K. (2024). Proximate analysis of dietary fibre-enriched pasta. *International Journal of Advanced Biochemistry Research*; SP-8(12): 94-96. https://doi.org/10.33545/26174693.2024.v8.i12Sb.3075 [Crossref] [Google Scholar] [Publisher]

Müller, M., Canfora, E., & Blaak, E. (2018). Gastrointestinal transit time, glucose homeostasis and metabolic health: Modulation by dietary fibers. *Nutrients*, *10*(3), 275. https://doi.org/10.3390/nu10030275 [Crossref] [PubMed] [Google Scholar] [Publisher]

Onipe, O. O., Jideani, A. I., & Beswa, D. (2015). Composition and functionality of wheat bran and its application in some cereal food products. *International Journal of Food Science & Technology*, 50(12), 2509-2518. https://doi.org/10.1111/ijfs.12935 [Crossref] [Google Scholar] [Publisher]

Padalino, L., Mastromatteo, M., Lecce, L., Cozzolino, F., & Del Nobile, M. A. (2013). Manufacture and characterization of gluten-free spaghetti enriched with vegetable flour. *Journal of Cereal Science*, 57(3), 333-342. https://doi.org/10.1016/j.jcs.2012.12.010 [Crossref] [Google Scholar] [Publisher]

Pasqualone, A., Gambacorta, G., Summo, C., Caponio, F., Di Miceli, G., Flagella, Z. & Lenucci, M. S. (2016). Functional, textural and sensory properties of dry pasta supplemented with lyophilized tomato matrix or with durum wheat bran extracts produced by supercritical carbon dioxide or ultrasound. *Food Chemistry*, 213, 545-553. https://doi.org/10.1016/j.foodchem.2016.07.006 [Crossref] [PubMed] [Google Scholar] [Publisher]

Patel, S. (2015). Cereal bran fortified-functional foods for obesity and diabetes management: Triumphs, hurdles and possibilities. *Journal of Functional Foods*, 14, 255-269. https://doi.org/10.1016/j.jff.2015.02.010 [Crossref] [Google Scholar] [Publisher]

Pop, F. (2017). Improvement of the nutritional value of pasta by the addition of wheat bran. *Journal of Agroalimentary Processes and Technologies*, 23(4), 245-249. [Google Scholar] [Publisher]

Population Reference Bureau PRB (2017). Curbing the noncommunicable disease epidemic in the Middle East and North Africa. Retrieved from: https://www.prb.org/resources/curbing-the-noncommunicable-disease-epidemic-in-the-middle-east-and-north-africa/ [Publisher]

Sęczyk, Ł., Świeca, M., & Gawlik-Dziki, U. (2016). Effect of carob (Ceratonia siliqua L.) flour on the antioxidant potential, nutritional quality, and sensory characteristics of fortified durum wheat pasta. *Food Chemistry*, 194, 637-642. https://doi.org/10.1016/j.foodchem.2015.08.086 [Crossref] [PubMed] [Google Scholar] [Publisher]

Sicignano, A., Di Monaco, R., Masi, P., & Cavella, S. (2015). From raw material to dish: Pasta quality step by step. *Journal of the Science of Food and Agriculture*, 95(13), 2579-2587. https://doi.org/10.1002/jsfa.7176 [Crossref] [PubMed] [Google Scholar] [Publisher]

Sobota, A., Rzedzicki, Z., Zarzycki, P., & Kuzawińska, E. (2015). Application of common wheat bran for the industrial production of high-fibre pasta. *International Journal of Food Science & Technology*, 50(1), 111-119. https://doi.org/10.1111/ijfs.12641 [Crossref] [Google Scholar] [Publisher]

Southgate, D. A. T., & Durnin, J. V. G. A. (1970). Calorie conversion factors. An experimental reassessment of the factors used in the calculation of the energy value of human diets. *British Journal of Nutrition*, 24(2), 517-535. https://doi.org/10.1079/BJN19700050 [Crossref] [PubMed] [Google Scholar] [Publisher]

Stevenson, L. E. O., Phillips, F., O'sullivan, K., & Walton, J. (2012). Wheat bran: its composition and benefits to health, a European perspective. *International Journal of Food Sciences and Nutrition*, 63(8), 1001-1013. https://doi.org/10.3109/09637486.2012.687366 [Crossref] [PubMed] [Google Scholar] [Publisher]

Szakály, Z., & Kiss, M. (2023). Consumer acceptance of different cereal-based "healthy foods". In : Developing Sustainable and Health Promoting Cereals and Pseudocereals (pp. 467-488). Academic Press. https://doi.org/10.1016/B978-0-323-90566-4.00002-3 [Crossref] [Google Scholar] [Publisher]

Vega-López, S., Venn, B. J., & Slavin, J. L. (2018). Relevance of the glycemic index and glycemic load for body weight, diabetes, and cardiovascular disease. *Nutrients*, 10(10), 1361. https://doi.org/10.3390/nu10101361 [Crossref] [PubMed] [Google Scholar] [Publisher]

Wahanik, A. L., Neri-Numa, I. A., Pastore, G. M., Felisberto, M. H. F., Campelo, P. H., & Clerici, M. T. P. S. (2021). Technological and antioxidant characteristics of pasta with whole wheat flour and natural colored concentrates. *Research, Society and Development*, 10(3), e7110312072-e7110312072. https://doi.org/10.33448/rsd-v10i3.13072 [Crossref] [Google Scholar] [Publisher]

WHO (2025): Unhealthy diet. Retrieved from: https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases [Publisher]

Yan, J., Lv, Y., & Ma, S. (2022). Wheat bran enrichment for flour products: Challenges and solutions. *Journal of Food Processing and Preservation*, 46(11), e16977. https://doi.org/10.1111/jfpp.16977 [Crossref] [Google Scholar] [Publisher]

Yao, B., Fang, H., Xu, W., Yan, Y., Xu, H., Liu, Y., & Zhao, Y. (2014). Dietary fiber intake and risk of type 2 diabetes: a dose–response analysis of prospective studies. *European Journal of Epidemiology*, 29, 79-88. https://doi.org/10.1007/s10654-013-9876-x [Crossref] [PubMed] [Google Scholar] [Publisher]