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Development and quality characterization of Kidney Bean and Hibiscus flower Flour-enriched functional Spaghetti

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Abstract
Spaghetti is among the most widely consumed cereal-based convenience foods in the world, prized for its palatability, affordability and long shelf life, yet its conventional formulation from refined wheat flour alone contributed little in the way of micronutrients or bioactive compounds. The present investigation was carried out to develop a nutritionally improved spaghetti by replacing part of the wheat flour with kidney bean (*Phaseolus vulgaris*) flour and hibiscus (*Hibiscus sabdariffa*) flower powder in equal proportion. Four formulations were prepared: a wheat-based standard S(A) and three composite variants incorporating kidney bean flour and hibiscus flower powder at 5% each [V(B)], 10% each [V(C)] and 15% each [V(D)], with a corresponding reduction in wheat flour. Sensory evaluation on a 9-point hedonic scale showed that S(A) recorded the highest overall acceptability (8.06 ± 0.10), followed by V(B) (7.44 ± 0.12), which retained a “liked moderately” rating and was identified as the most acceptable fortified variant. Proximate analysis of the standard and the most acceptable variant V(D), used to track the trajectory of change across the full substitution range, revealed a decline in moisture (11.0 to 8.8 g/100 g) and carbohydrate (69.5 to 54.5 g/100 g), alongside an increase in ash (1.60 to 2.51 g/100 g) and fat (1.5 to 5.9 g/100 g), while protein content remained largely comparable (11.5 to 11.4 g/100 g). Mineral estimation indicated a marked enrichment in iron (1.20 to 4.91 mg/100 g) and calcium (12.32 to 32.35 mg/100 g) with increasing substitution level. Qualitative phytochemical screening detected flavonoids, phytosterols and phenols in all formulations, while alkaloids were detected exclusively in the fortified variants. These findings indicate that kidney bean flour and hibiscus flower powder can be incorporated into spaghetti at moderate levels to substantially enhance its mineral and phytochemical profile without a disproportionate loss of consumer acceptability, positioning variant V(B) as a practical benchmark for functional pasta development.

Keywords: Kidney bean flour, Hibiscus flower powder, functional spaghetti, proximate composition, mineral fortification, sensory evaluation

Introduction
Pasta occupies a distinctive place among cereal-based staples, having grown from a regional wheat product into a food consumed across nearly every culinary culture. Its widespread adoption is generally attributed to its convenience, neutral flavour, ease of preparation, affordability and comparatively long shelf life (Bustos, Perez, & Leon, 2015) [4]. Spaghetti, one of the most recognisable pasta formats, is manufactured almost exclusively from durum or common wheat semolina, a raw material that supplies energy-dense carbohydrate but relatively little in the way of micronutrients, dietary fibre or bioactive phytoconstituents. As consumer interest in health-oriented convenience foods continues to grow, cereal-based staples such as spaghetti have become an attractive vehicle for nutritional fortification, provided that the sensory identity of the product can be reasonably preserved (Lee & Kim, 2021; Solis, Ferreira, & Costa, 2019) [5, 14].

Kidney bean (*Phaseolus vulgaris*), a widely cultivated grain legume, is well documented as a concentrated source of protein rich in lysine, resistant starch, dietary fibre, and minerals including iron, calcium, magnesium and potassium (Teixeira *et al*., 2023; Silva *et al*., 2023) [13, 16]. Its polyphenolic fraction, concentrated largely in the seed coat, has been associated with antioxidant and anti-inflammatory activity (Sun *et al*., 2019) [15]. *Hibiscus sabdariffa*, valued traditionally for its calyces, contributes a complementary nutrient and phytochemical profile, being comparatively rich in vitamin C, calcium and iron, together with anthocyanins and flavonoids that exhibit free-radical scavenging activity (Nguyen *et al*., 2019; Onyeukwu, Dibie, &Njideaka, 2023) [7, 8]. Combining these two botanicals within a single cereal matrix therefore offers a route to simultaneously address mineral density and bioactive compound content, two dimensions in which conventional wheat-based pasta is comparatively deficient.

Spaghetti is particularly well suited to such fortification strategies because its extrusion-based structure can accommodate non-wheat flour inclusions while its relatively neutral base flavour can mask mild off-notes introduced by legume or floral ingredients (Romano, Ferranti, Gallo, & Masi, 2021 [9]; Schmid, Loschi, Hiltbrunner, & Muller, 2023) [10]. A number of studies have examined legume flour fortification of pasta in isolation, and a smaller body of work has explored hibiscus incorporation into other food matrices, yet the combined effect of kidney bean flour and hibiscus flower powder on the sensory, proximate, mineral and phytochemical characteristics of spaghetti remains largely unexamined. The present study was therefore undertaken to formulate spaghetti fortified with graded levels of kidney bean flour and hibiscus flower powder and to evaluate the resulting product for consumer acceptability, proximate composition, mineral content and qualitative phytochemical profile, with the broader aim of identifying a formulation that balances nutritional enhancement with sensory acceptance.

Methodology

The present study was carried out in the laboratory of the Department of Food Science and Nutrition in Banasthali Vidyapith, Rajasthan.

Procurement of raw materials

Whole red kidney beans, dried hibiscus calyces and refined wheat flour were procured from a local retail market. Kidney beans were cleaned, sun-dried and milled into fine flour using a laboratory grinder, followed by sieving through a 60-mesh screen. Dried hibiscus calyces were similarly ground and sieved to obtain a fine powder. Both flours were stored in airtight containers at ambient temperature until further use.

Formulation and preparation of spaghetti

Four spaghetti formulations were prepared by partially substituting wheat flour with equal proportions of kidney bean flour and hibiscus flower powder, as summarised in Table 1. The standard formulation S(A) consisted of 100% wheat flour, while the three composite variants V(B), V(C) and V(D) contained 5%, 10% and 15% kidney bean flour together with an equal proportion of hibiscus flower powder, with wheat flour making up the balance.

Table 1: Formulation of standard and kidney bean-hibiscus flour enriched spaghetti (%)

Ingredient	S(A)	V(B)	V(C)	V(D)
Wheat flour	100	90	80	70
Kidney bean flour	-	5	10	15
Hibiscus flower powder	-	5	10	15

S(A): standard (100% wheat flour); V(B), V(C), V(D): variants containing kidney bean flour and hibiscus flower powder at 5, 10 and 15% respectively.

For each formulation, the composite flour was combined with a pinch of salt and mixed with water to form a firm, cohesive dough. The dough was kneaded thoroughly to develop the gluten network, rested for 10-15 minutes to allow hydration, sheeted, and cut into spaghetti strands. Strands were cooked in salted boiling water and drained prior to sensory presentation. The overall process flow is summarised in Fig 1.

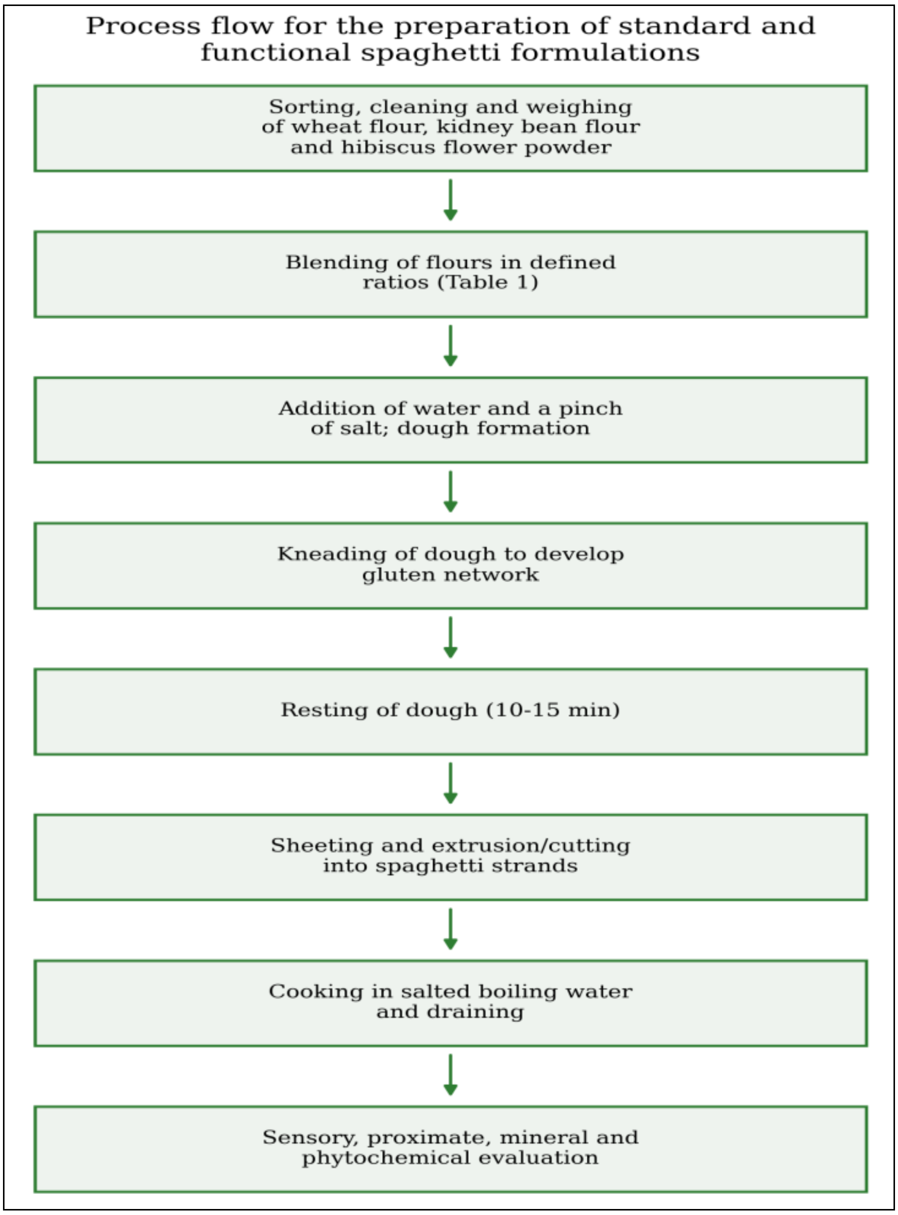

Fig 1: Process flow for the preparation of standard and functional spaghetti formulations

Sensory evaluation

A semi-trained sensory panel was constituted from postgraduate and doctoral students of the Department of Food Science and Nutrition. Panel discrimination ability was first screened using a triangle test, in which panellists were presented with three coded tea samples, two identical and one differing slightly in sugar concentration, and asked to identify the odd sample; individuals who correctly and consistently discriminated the odd sample were retained for the study. The selected panel evaluated the four coded and randomised spaghetti samples for appearance, taste, flavour, texture and overall acceptability using a 9-point hedonic scale ranging from "like extremely" (9) to "dislike extremely" (1). Water was provided between samples to minimise carry-over effects.

Proximate composition analysis

Proximate composition of the standard and fortified spaghetti variants was determined in triplicate following AOAC (2019) protocols. Moisture content was estimated gravimetrically by drying samples to constant weight in a hot-air oven at 100-105 °C. Ash content was determined by incineration of samples in a muffle furnace at 600 °C. Crude protein was estimated by the Kjeldahl method, involving acid digestion, steam distillation into boric acid, and titration with standardised hydrochloric acid, applying a nitrogen-to-protein conversion factor. Crude fat was extracted using the Soxhlet method with petroleum ether as solvent. Crude fibre was determined by sequential acid and alkali digestion followed by ashing of the residue. Carbohydrate content was calculated by difference, subtracting the sum of moisture, ash, protein, fat and fibre from 100.

Mineral analysis

Mineral estimation was carried out on triplicate samples following dry-ashing digestion. Iron content was determined colorimetrically by the thiocyanate method of Sharma (2007), based on the red colour developed between ferric ions and potassium thiocyanate, measured spectrophotometrically at 540 nm against a standard curve. Calcium content was determined by the titrimetric method (AOAC, 2015), in which calcium was precipitated as calcium oxalate and titrated against standardised potassium permanganate solution.

Qualitative phytochemical screening

Standard and fortified spaghetti extracts were qualitatively screened for the presence of phenols, flavonoids, alkaloids and phytosterols following established colour-reaction protocols (Shaikh & Patil, 2020) [12]. Phenolic compounds were detected by the appearance of a deep blue-black colour on treatment with ferric chloride solution. Flavonoids were identified by a green, blue or violet colouration on addition of dilute ferric chloride to the aqueous extract. Alkaloids were screened using Mayer's reagent, with a creamy-white precipitate indicating a positive reaction. Phytosterols were assessed by the Salkowski-type reaction, in which a reddish-brown interfacial ring and a greenish colouration in the chloroform layer indicated a positive result.

Statistical analysis

All analyses were performed in triplicate and data are expressed as mean ± standard deviation. Differences between the standard S(A) and the fortified variants were evaluated using Student's t-test, with $p \leq 0.05$ considered statistically significant. Statistical computations were performed using SPSS software.

Result and Discussion

Sensory evaluation

Sensory scores for appearance, taste, flavour, texture and overall acceptability of the standard and fortified spaghetti formulations are presented in Table 2 and Figs 2 and 3.

Table 2: Sensory evaluation of standard and kidney bean-hibiscus flour enriched spaghetti

Sample	Appearance	Taste	Flavour	Texture	Overall Acceptability
S(A)	7.68 ± 0.11	7.55 ± 0.08	7.72 ± 0.05	7.51 ± 0.09	8.06 ± 0.10
V(B)	6.79 ± 0.13*	6.89 ± 0.06*	6.93 ± 0.08*	6.75 ± 0.13*	7.44 ± 0.12*
V(C)	6.17 ± 0.10	6.13 ± 0.09	5.89 ± 0.12	6.00 ± 0.16	6.41 ± 0.11
V(D)	5.27 ± 0.12	5.65 ± 0.11	5.72 ± 0.18	5.27 ± 0.15	5.72 ± 0.09

Values are mean ± SD (n = 26). *Significantly different from S(A) at $p \leq 0.05$.

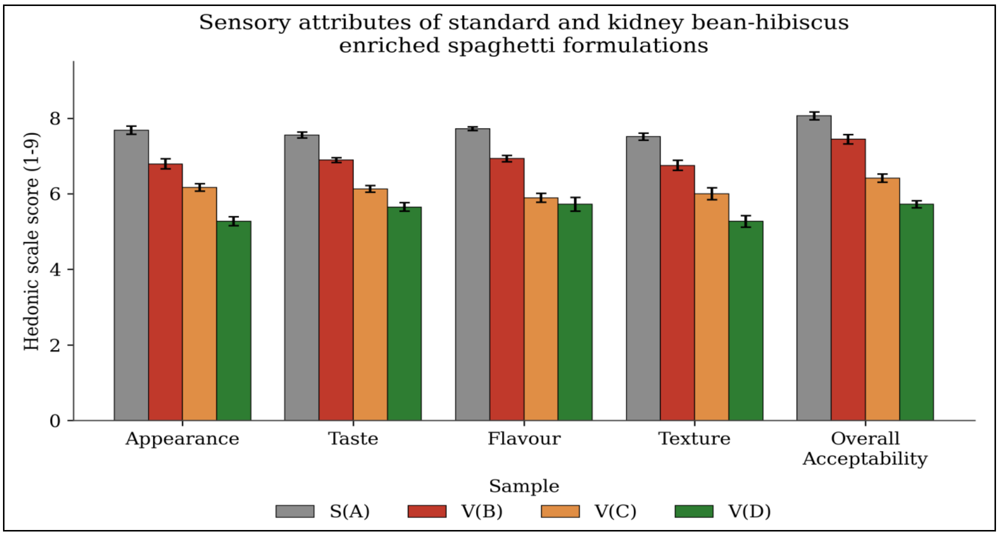

Fig 2: Mean sensory scores of standard and functional spaghetti formulations

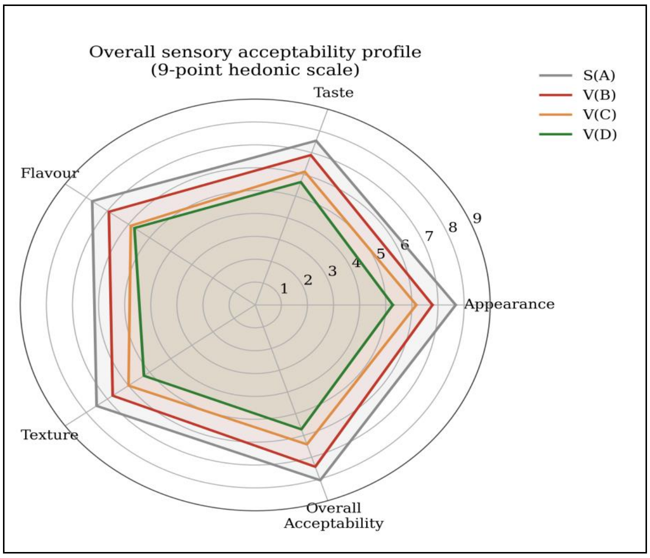

Fig 3: Radar profile of sensory acceptability across formulations

The standard formulation S(A) recorded the highest scores across all sensory attributes, ranging from 7.51 ± 0.09 for texture to 8.06 ± 0.10 for overall acceptability, corresponding to ratings between "like moderately" and "like very much". Among the fortified variants, V(B) consistently received the highest scores, ranging from 6.75 ± 0.13 for texture to 7.44 ± 0.12 for overall acceptability, placing it between "like slightly" and "like moderately". Statistical analysis confirmed a significant difference ($p \leq 0.05$) between S(A) and V(B) across all attributes; nevertheless, the retained hedonic rating indicates that V(B) remained broadly acceptable to the panel.

A clear downward trend in acceptability accompanied the progressive substitution of wheat flour with kidney bean flour and hibiscus flower powder. Overall acceptability declined from 8.06 ± 0.10 in S(A) to 7.44 ± 0.12 in V(B), 6.41 ± 0.11 in V(C) and 5.72 ± 0.09 in V(D). This pattern is consistent with previous reports that legume flour incorporation into pasta and bakery products tends to intensify beany or earthy notes and darken product colour at higher substitution levels, both of which can depress hedonic scores even when nutritional quality improves (Romano *et al*., 2021) [9]. The comparatively modest decline observed at the 5% substitution level suggests that V(B) represents a practical threshold at which fortification does not compromise the essential sensory identity of spaghetti.

Proximate composition analysis

The proximate composition of the standard and fortified spaghetti variants is presented in Table 3 and Fig 4.

Table 3: Proximate composition (g/100 g) of standard and kidney bean-hibiscus flourenriched spaghetti

Parameter	S(A)	V(B)	V(C)	V(D)
Moisture	11.0 ± 0.22	9.4 ± 0.19*	9.1 ± 0.18	8.8 ± 0.19
Ash	1.60 ± 0.03	2.24 ± 0.04*	2.37 ± 0.05	2.51 ± 0.03
Protein	11.5 ± 0.23	11.2 ± 0.22	11.1 ± 0.22	11.4 ± 0.23
Fat	1.5 ± 0.03	5.2 ± 0.11*	5.5 ± 0.11	5.9 ± 0.11
Fibre	4.9 ± 0.10	4.5 ± 0.09	5.1 ± 0.10	5.3 ± 0.11
Carbohydrate	69.5 ± 1.39	57.5 ± 1.15*	55.9 ± 1.12	54.5 ± 1.09

Values are mean ± SD of triplicate determinations. *Significantly different from S(A) at $p \leq 0.05$

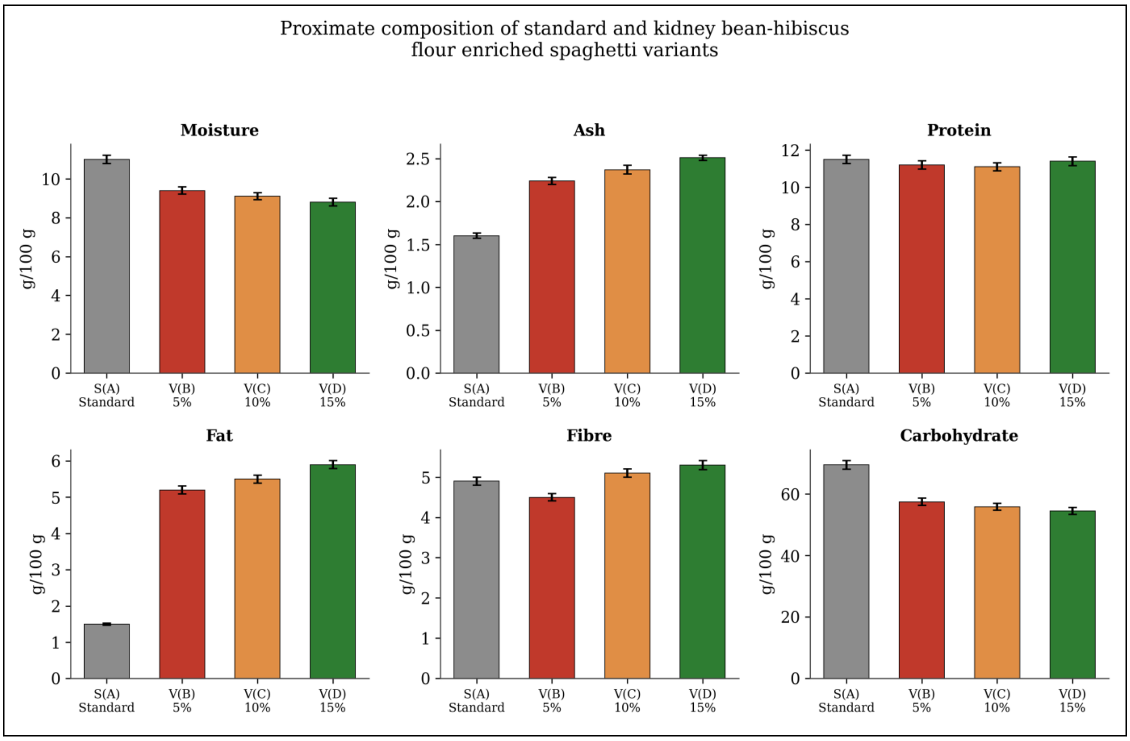

Fig 4: Proximate composition of standard and functional spaghetti variants

Moisture content decreased steadily from 11.0 ± 0.22 g/100 g in S(A) to 8.8 ± 0.19 g/100 g in V(D), a reduction of approximately 20%, attributable to the lower inherent moisture of the dried kidney bean and hibiscus flours relative to wheat flour; this reduction is favourable from a storage-stability standpoint, as lower water activity typically limits microbial proliferation and lipid oxidation (Baigts-Allende, Doost, Ramirez-Rodrigues, & Rodriguez-Rodriguez, 2022) [3].

Ash content, an index of total mineral matter, rose progressively from 1.60 ± 0.03 g/100 g in S(A) to 2.51 ± 0.03 g/100 g in V(D), an increase of roughly 57%, reflecting the comparatively mineral-dense composition of kidney bean flour and hibiscus flower powder relative to refined wheat flour (Audu & Aremu, 2011) [2].

Crude protein remained largely comparable between the standard (11.5 ± 0.23 g/100 g) and the most fortified variant V(D) (11.4 ± 0.23 g/100 g), despite a marginal dip at intermediate substitution levels. This pattern suggests that the moderate protein content of kidney bean flour offset the dilution effect of reduced wheat flour, in agreement with observations that legume-based composite flours can help maintain the protein density of cereal products even as the wheat fraction is reduced (Baigts-Allende *et al*., 2022) [3].

Crude fat increased markedly, from 1.5 ± 0.03 g/100 g in S(A) to 5.9 ± 0.11 g/100 g in V(D), an increase of nearly 295%. Although kidney beans are predominantly a carbohydrate- and fibre-rich legume, their modest native fat fraction, combined with lipid contributed by hibiscus calyx tissue, was sufficient to substantially elevate total fat content at higher substitution levels (Audu & Aremu, 2011) [2].

Crude fibre showed a modest net increase across the substitution series, from 4.9 ± 0.10 g/100 g in S(A) to 5.3 ± 0.11 g/100 g in V(D), despite a slight dip at the 5% level. The overall enrichment in fibre content at higher substitution levels is consistent with the recognised contribution of resistant starch and insoluble fibre fractions present in kidney bean flour (Sun *et al*., 2019) [15].

Carbohydrate content, calculated by difference, declined from 69.5 ± 1.39 g/100 g in S(A) to 54.5 ± 1.09 g/100 g in V(D), a reduction of approximately 22%, mirroring the proportional increase in ash, fat and fibre fractions contributed by the added flours. Despite this numerical reduction, the residual carbohydrate fraction in kidney bean flour is associated with a comparatively low glycaemic response, a property that may be nutritionally advantageous in the fortified variants (Xu, Qin, Mazhar, & Zhu, 2022) [17].

Mineral analysis

Iron and calcium content of the standard and fortified spaghetti variants are presented in Table 4 and Fig 5.

Table 4: Mineral composition (mg/100 g) of standard and kidney bean-hibiscus flour enriched spaghetti

Mineral	S(A)	V(B)	V(C)	V(D)
Iron	1.20 ± 0.02	1.64 ± 0.09*	3.27 ± 0.11	4.91 ± 0.13
Calcium	12.32 ± 0.05	13.45 ± 0.13*	22.90 ± 0.20	32.35 ± 0.22

Values are mean ± SD of triplicate determinations. *Significantly different from S(A) at p ≤ 0.05.

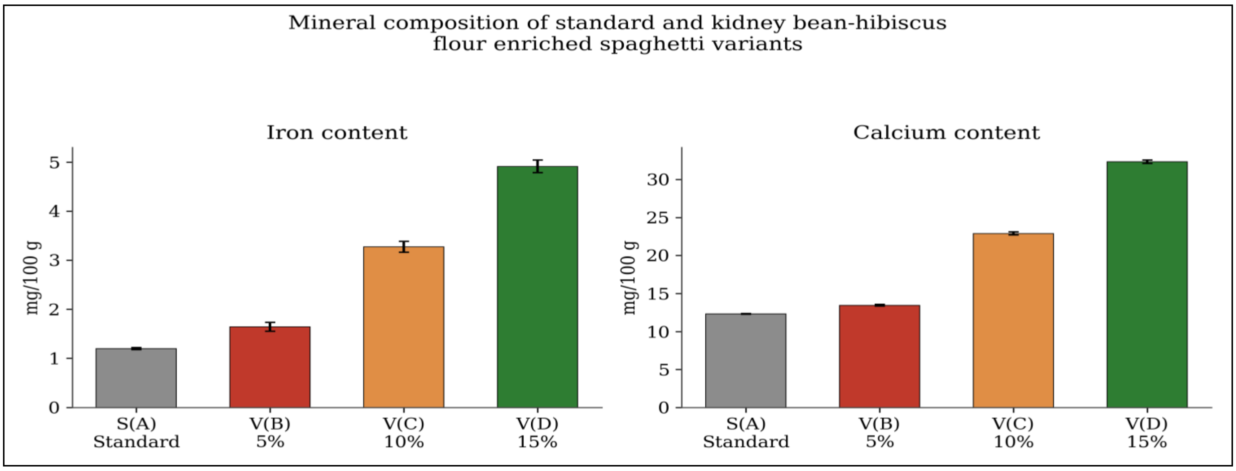

Fig 5: Iron and calcium content of standard and functional spaghetti variants

Iron content increased from 1.20 ± 0.02 mg/100 g in S(A) to 4.91 ± 0.13 mg/100 g in V(D), a more than four-fold enhancement, while calcium content rose from 12.32 ± 0.05 mg/100 g to 32.35 ± 0.22 mg/100 g over the same range, an increase of approximately 163%. Both trends scaled consistently with the proportion of kidney bean flour and hibiscus flower powder incorporated, reflecting the well-documented mineral density of red kidney beans (Audu & Aremu, 2011) [2] and the calcium- and iron-rich composition reported for hibiscus by-products (Baigts-Allende *et al*., 2022) [3]. Given the global prevalence of iron and calcium inadequacy, particularly among adolescent and female populations, fortified spaghetti of this kind could serve as a supplementary dietary source of these micronutrients within an otherwise conventional meal pattern.

Qualitative phytochemical screening

The qualitative phytochemical profile of the standard and fortified spaghetti variants is summarised in Table 5.

Table 5: Qualitative phytochemical screening of standard and kidney bean-hibiscus flour enriched spaghetti

Phytochemical	S(A)	V(B)	V(C)	V(D)
Alkaloids	Absent	Present	Present	Present
Flavonoids	Present	Present	Present	Present
Phytosterols	Present	Present	Present	Present
Phenols	Present	Present	Present	Present

Flavonoids, phytosterols and phenolic compounds were detected in the standard as well as in all fortified variants, indicating that these bioactive classes are inherently present in wheat flour and were retained, or possibly supplemented, following incorporation of kidney bean flour and hibiscus flower powder. Alkaloids, by contrast, were undetectable in the standard but were consistently present in all three fortified variants, indicating that this phytochemical class was contributed specifically by the added legume and floral ingredients. The qualitative retention of these bioactive compounds across all fortification levels supports the potential of kidney bean- and hibiscus-enriched spaghetti to function as a delivery vehicle for dietary antioxidants, consistent with the recognised antioxidant and anti-inflammatory roles attributed to flavonoids and phenolic compounds in plant-based foods (Shaikh & Patil, 2020) [12].

Conclusion

The present study demonstrates that partial substitution of wheat flour with kidney bean flour and hibiscus flower powder can substantially improve the mineral and phytochemical profile of spaghetti while retaining reasonable consumer acceptability at moderate substitution levels. Among the formulations examined, V(B), containing 5% kidney bean flour and 5% hibiscus flower powder, offered the most favourable balance between sensory performance and nutritional enhancement, retaining an overall acceptability rating of 7.44 ± 0.12 on the 9-point hedonic scale. Proximate analysis confirmed a marked increase in ash and fat content, a modest enhancement in fibre, and near-comparable protein levels between the standard and the most fortified variant, alongside a substantial rise in iron and calcium content. Qualitative screening further revealed that alkaloids, absent in the wheat-only standard, were consistently introduced through fortification, alongside retained flavonoid, phytosterol and phenolic content. These findings support the viability of kidney bean flour and hibiscus flower powder as functional ingredients for pasta fortification and suggest a practical formulation window for future product development, though further work on optimising processing conditions, extending shelf-life evaluation, and conducting quantitative phytochemical and glycaemic response assays would strengthen the case for commercial-scale application.

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