International Journal of Food Science + Technology

International Journal of Food Science and Technology 2023

Original article

Utilisation of aquatic fern (*Azolla* sp.) powder for supplementing semolina pasta: quality characteristics of produced pasta

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(Received 8 April 2023; Accepted in revised form 27 June 2023)

Summary Aquatic fern (*Azolla* sp.) powder was used as a non-conventional protein source to supplement semolina pasta. The pre-blanched and dried powder of *Azolla* was used to supplement the pasta at 0, 5, 10, 15 and 20 per 100 g^{-1} level followed by its quality evaluation. Increasing *Azolla* powder content in pasta, the minimum cooking time increased from 5.15 min to 6.00 min ($P < 0.05$). Similarly cooking loss increased from 3.69% to 5.34%, while swelling index showed a decreasing trend ($P < 0.05$). *In vitro* protein digestibility values of produced pasta ranged between 75.32 ± 0.95 and 82.85% ± 1.42%. Increasing *Azolla* powder content in pasta significantly increased its firmness from 2843.8 to 4197.5 g. Lightness (L^*) as well as overall whiteness values were significantly reduced with increasing levels of Azolla powder in pasta ($P < 0.05$). Sensory acceptability was reduced with the increasing *Azolla* powder content, being highest for pasta supplemented with 5% and 10% *Azolla* powder.

Keywords Antioxidants, *Azolla*, bioactive compounds, cooking quality, minerals, pasta.

Introduction

Aquatic weeds are fast-growing aquatic plants that belong to the family Salviniaceae and Lamnaceae consists of several species, including seven species of *Azolla*. In India, among these, *Azolla* (Water fern), is one of the fast growing plants with a bloom rate of 93.4–100 t dw/ha-year (Costa *et al.*, 1999).

Azolla has wide range of applications and is gaining attention in the form of non-conventional food ingredients due to the high nutritional value and low cost of production. It is an excellent source of protein (25%–30%), essential fatty acids and natural antioxidants along with minerals, vitamins, carotenoids and chlorophyll (Dohaei *et al.*, 2020; Tran *et al.*, 2020). Aquatic plants like *Azolla* and duckweed have a high potential for utilisation in the human diet. However, utilisation is not picking up owing to the presence of -anti-nutritional factors. Hydrothermal treatments such as blanching result in higher reduction of anti-nutrients owing to the water-soluble nature of the minerals as they leached to the cooking medium and heat liable nature of these anti-nutrients (Kataria *et al.*, 2022). Besides reducing the anti-nutrients, these methods can influence the product properties depending on the method of processing (Lopez-Sanchez *et al.*, 2015). Such processed products can contribute to various functional properties in the foods thus by increasing the scope to develop wide variety of food products.

Bioactive or nutrient content in foods can be improved through enrichment process. In many countries, a major part of the total population consumes cereals or cereal-based foods, which is an appropriate vehicle for enrichment (Sharma *et al.*, 2021). The Food Drug Administration and the World Health Organization have considered pasta as one of the suitable vectors for incorporating the nutrients (Chillo *et al.*, 2008). Many researchers have shown the possibility of enrichment of pasta with functional ingredients to enhance its nutritional value (Singh *et al.*, 2021; Ainsa *et al.* 2022; Bawa *et al.*, 2022; Raina *et al.*, 2023). Enrichment of pasta with *Azolla* can be an essential strategy for addressing nutritional status in developing nations. The current study was aimed to utilise treated aquatic fern (*Azolla* sp.) powder to supplement semolina pasta and to study the quality characteristics of developed pasta.

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doi:10.1111/ijfs.16582

Materials and methods

Raw material

Azolla was collected from the farm of the College of Fisheries, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab, India. *Azolla* was washed thoroughly (10 times), cleaned, drained and blanched (3 min at 100 °C). The blanched *Azolla* was dried to moisture content of 8 ± 2 at 45 °C for 10 h in tray drier (Narang Scientific works, New Delhi, India), followed by grinding (Kent 16 011 3000 W) and sieving through 90–125 mesh sieve to obtain fine powder. Semolina was bought from the local market for pasta preparation.

Pasta preparation

Azolla powder was weighed accurately to replace semolina in the pasta at 0%, 5%, 10%, 15% and 20% (w/w) to prepare the blends. The blends (500 g) were then added into mixing chamber and optimum amount of water (30%–33%) and uniformly mixed (10 min) in the extruder (Dolly La Monferrina, Italy) proper hydration of each particle. The water requirement of pasta extrusion increased as the level of *Azolla* powder in pasta increased, due to the waster absorption of the *Azolla* powder (Data not shown). Pasta was extruded through an adjustable die (No. 98) of single screw extruder to obtain Rigatoni shaped pasta. The resultant pasta was subjected for drying for 4–5 h at 40 °C–50 °C until constant moisture weight (6%–8%) was obtained.

Physico-chemical composition and mineral analysis

The raw material used the current study and the pasta samples prepared were analysed for their moisture, crude protein, crude fat, crude fibre and ash content as per the standard protocols described in AACC (2000). Total carbohydrates were calculated by difference method. Calorific value was calculated as per the standard equation. Minerals (Zinc, Iron, Manganese and Copper) was determined with the help of thermos inductively coupled plasma atomic emission spectrometry (ICP-AES), model leap 630.

Cooking characteristics

Employing the standard methods of (AACC, 2000) the cooking quality of pasta was determined in terms of the minimum cooking time (MCT), cooked weight (CW), water absorption (WA), swelling index (SI) and gruel solid loss (GSL) as per methodology previously described in detail by Surasani *et al.* (2019). The time needed for the white core to completely disappear while squeezing the sample between a pair of glass plates, which signified that the starch had fully gelatinized was found to be the ideal cooking time. After draining the extra cooking water, the cooked pasta was weighed to determine its cooked weight. Swelling index was determined by calculating the difference in weight of sample after cooking. Water absorption was estimated by noting the increase in weight after cooking. By calculating the difference between expansion of water volume before and after pasta cooking, the volume expansion was determined. Gruel solid loss is the amount of gruel solids in the cooked water, which is determined by drying the water to obtain solid residue, and is expressed as a percentage of the weight of the pasta sample before cooking.

In vitro protein digestibility (IVPD) and protein availability

The methodology as described by Rodríguez De Marco *et al.* (2014) was followed with slight modification to calculate the IVPD of the pasta samples. Two stage protein digestion was carried out using Pepsin and Pancreatin hydrolysis of the sample. The digestibility was expressed as: [(total protein content − protein content after digestion) × 100 per total protein content]. Protein availability calculated over the protein content in cooked pasta and the protein digestibility as: [(protein digestibility × protein content in cooked pasta)/100].

Pasta firmness

The firmness of the cooked pasta was determined using Texture Analyser (TA-XT plus, Stable Micros Systems, UK) (Raina *et al.*, 2023). The pasta was sheared at a 90° angle using a probe of 75 mm diameter with a pre-test and post-test speed of 2.0 mm s^{-1} and 10.0 mm s^{-1}, respectively, and a load cell of 50 N and 10 g trigger force. The maximum force required to shear the pasta was noted as firmness and expressed in g.

Colour characteristics

Colour measurements of uncooked and cooked pasta were measured in terms of L^* (Lightness or darkness), a^* (red or green) and b^* (yellow or blue) value using CR-400 Chromameter (Konica Minolta, Ramsey, USA) as described by Singh *et al.* (2021). The other parameters like Chroma, Hue and ΔE^* were calculated using the following formula:

$$\text{Hue angle } (^\circ) = \tan^{-1}\left(\frac{b^*}{a^*}\right)$$

$$\text{Chroma} = \sqrt{\left(a^{*2} + b^{*2}\right)}$$

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Antioxidant activity & bioactive composition

Antioxidant activity of uncooked and cooked pasta was determined using DPPH (2,2-diphenyl-1-picrylhydrazyl) and expressed as inhibition of DPPH % radical scavenging activity (Sharma *et al.*, 2021). Total Phenolic Content (TPC) and Total flavonoid content of the samples was estimated using the Folin-Ciocalteau method (TPC) and Aluminium Chloride method (TFC) as per methodology described by Singh *et al.* (2019). Chlorophyll content (mg g^{-1}) (Chlorophyll a, Chlorophyll b and total chlorophyll) was determined by the methodology given by Thimmaiah (1999). The carotenoid content (μg g^{-1}) was estimated as per methodology given by Kirk & Allen (1965).

Exploratory sensory test

A panel of 30 people from the Department of Food Science and Technology, Department of Food and Nutrition, Punjab Agricultural University, Ludhiana, India, ages ranging from 20 to 55 evaluated the sensory characteristics of cooked pasta samples (Peryam & Pilgrim, 1957). After their consent, the panellists were informed in advance about the product and asked to rate the pasta samples. Cooked Samples (warm 40 °C) were rated on a 9-point hedonic scale from extremely liked (9) to extremely disliked (1) for appearance, mouthfeel, flavour and overall acceptability.

Statistical analysis

The information presented in each table is an average of three independent observations. One-way analysis of variance (ANOVA) was used to examine the data and Tukey's *post hoc* test was used to compare means at ($P < 0.05$). Statistical analysis of the data was performed using SPSS Statistical Software version 18.0. (SPSS Inc., USA).

Results and discussion

Proximate composition and mineral content

The results presented in Table 1 indicated that, increasing *Azolla* powder level in semolina pasta (5%–20%) significantly increased protein, fat, ash and crude fibre contents in comparison to control pasta. *Azolla* powder is a good source of protein, fat fibre and ash (Table 1) in comparison to semolina, as a result of which the pasta with *Azolla* powder exhibits higher levels of protein, fat fibre and ash content. The results of the nutrient content of *Azolla* in the present study are in accordance with the previous studies of Mosha (2018) and Tran *et al.* (2020) in which they documented that *Azolla* powder is a rich source of nutrients and contains fairly high levels of proteins (13%–30%), fat (4%–6%), fibre (8%–14%) and mineral ash (7%–20%) content.

In the previous studies it was also documented that supplementation of pasta with plant sources and aquatic sources such as microalgae and seafern significantly enhanced the nutritional value of pasta (Batista *et al.*, 2017; Lafarga, 2019; Bawa *et al.*, 2022). Ainsa *et al.* (2022) in their study, however, reported that addition of different seaferns (at 3%) in pasta improved its protein and fibre content; however, in present study addition of *Azolla* beyond 5% level improved the nutritional quality of pasta. quality. Addition of *Azolla* powder also significantly ($P < 0.05$) enhanced the mineral content of pasta, with increasing level of *Azolla* (Fig. 1). The Zinc, Iron, Manganese and Copper content in *Azolla* powder-added paste was higher than the control pasta, due to the reason that *Azolla* contains substantial amounts these minerals (Dohaei *et al.*, 2020).

Cooking characteristicss

Supplementation of semolina pasta with *Azolla* powder significantly ($P < 0.05$) influence the cooking

Table 1 Effect of *Azolla* powder on physico-chemical composition of pasta

	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	CHO (%)
Azolla powder	8.80 ± 0.01^{c}	19.58 ± 0.09^{a}	4.69 ± 0.07^{a}	7.61 ± 0.26^{a}	11.19 ± 0.09^{a}	48.13 ± 0.18^{f}
Semolina	11.58 ± 0.06^{a}	10.03 ± 0.12^{f}	1.04 ± 0.04^{f}	0.92 ± 0.02^{f}	1.89 ± 0.05^{f}	74.54 ± 0.13^{c}
Control (0%)	8.95 ± 0.02^{b}	10.08 ± 0.07^{f}	1.04 ± 0.03^{f}	0.91 ± 0.07^{f}	1.93 ± 0.08^{f}	77.09 ± 0.04^{a}
%	8.01 ± 0.04^{d}	10.69 ± 0.05^{e}	1.19 ± 0.05^{e}	1.30 ± 0.03^{e}	2.36 ± 0.01^{e}	76.55 ± 0.06^{b}
10%	8.00 ± 0.04^{d}	11.23 ± 0.04^{d}	1.38 ± 0.03^{d}	1.63 ± 0.04^{d}	2.84 ± 0.05^{d}	74.92 ± 0.13^{c}
15%	8.04 ± 0.03^{d}	12.68 ± 0.11^{c}	1.55 ± 0.02^{c}	1.96 ± 0.06^{c}	3.29 ± 0.03^{c}	72.48 ± 0.11^{d}
20%	8.04 ± 0.05^{d}	13.51 ± 0.03^{b}	1.71 ± 0.02^{b}	2.32 ± 0.04^{b}	3.75 ± 0.04^{b}	70.87 ± 0.09^{e}

Values are expressed as Mean ± standard deviation ($n = 3$).

Means with different superscripts (a, b, c, d and e) in a column differ significantly ($P < 0.05$) from each other.

[†] Control: Semolina without *Azolla* powder.

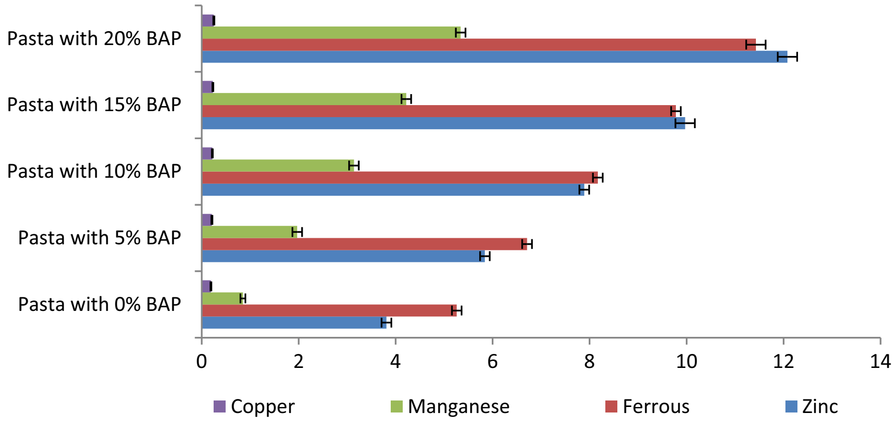

Figure 1 Effect of mixing blanched *Azolla* powder on mineral content (mg 100 g^{-1}) of pasta (dry weight basis).

Table 2 Effect of *Azolla* powder on cooking quality and *in vitro* protein digestibility of pasta

Azolla powder (%)	Minimum cooking time (min)	Cooking weight (g)	Water absorption (%)	Swelling Index	Gruel solid loss (%)	*In Vitro* protein digestibility (%)
Control (0%)	5:15 ± 0.04[e]	18.45 ± 0.09[b]	86.50 ± 1.17[c]	1.01 ± 0.03[b]	3.69 ± 0.12[e]	81.10 ± 0.78[b]
5%	5:25 ± 0.02[d]	18.99 ± 0.08[a]	93.91 ± 0.79[a]	1.12 ± 0.02[a]	4.95 ± 0.09[d]	78.43 ± 1.27[c]
10%	5:40 ± 0.03[c]	17.91 ± 0.23[c]	89.24 ± 0.94[b]	1.01 ± 0.02[b]	5.58 ± 0.11[c]	75.32 ± 0.95[e]
15%	5:50 ± 0.02[b]	17.87 ± 0.31[c]	86.62 ± 1.06[c]	0.95 ± 0.01[c]	6.31 ± 0.26[b]	82.85 ± 1.42[a]
20%	6:00 ± 0.03[a]	17.19 ± 0.07[d]	83.56 ± 1.02[d]	0.89 ± 0.01[d]	7.34 ± 0.27[a]	77.54 ± 1.11[d]

Values are expressed as Mean ± standard deviation ($n = 3$); Means with different superscripts (a, b, c, d and e) in a column differ significantly ($P < 0.05$) from each other.

characteristics of pasta (Table 2). Results showed that MCT and GSL of pasta increased progressively, as level of *Azolla* progressed from 5% to 20%, while CW, WA and SI increased up to 5% supplementation, and further increase in the *Azolla* levels (10%–20%), significantly ($P < 0.05$) decreased them. *Azolla* supplementation in pasta increased the protein content, which interferes with gelatinisation of starch by forming as complex and also due to competitive water absorption potential between *Azolla* proteins and semolina's gluten protein and starch and thus increasing the cooking time (Surasani *et al.*, 2019; Bianchi *et al.*, 2021). Furthermore, increased protein and fibre content in the pasta due to *Azolla* supplementation, disrupt and dilute the gluten protein network, which results in weakening the gluten and starch matrix interaction in pasta and results in higher leaching of the soluble fractions in the cooking water and thus increasing the GSL (Singh *et al.*, 2023; Raina *et al.*, 2023). Furthermore, the GSL in the present study is in the acceptable range (upto 7.4%) for all the supplemented samples, and GSL should not be more than 9.0% (AACC, 2000). (Bawa *et al.*, 2022). Higher levels of *Azolla* supplementation into pasta results in lowering the CW, WA and SI as a result of lower water holding and swelling of *Azolla* powder and higher GSL of pasta with higher levels of *Azolla* supplementation. The proteins and starch present in the pasta mixture competed for the water thus by decreasing the swelling of the starch and water absorption in pasta and furthermore due to the formation of a strong protein network which could decrease the water liberation for gelatinisation and swelling of starch granules (Desai *et al.*, 2018).

In vitro protein digestibility (IVPD)

Addition of *Azolla* powder, however, increased the protein content of pasta, but the IVPD of pasta decreased significantly ($P < 0.05$) as the level of supplementation increased (Table 2). The increase in the *Azolla* level in the pasta significantly increased the bioactive compounds in the pasta, and the presence of bioactive compounds such as phenolic compounds and flavonoids have the potential to bind with proteins making them unavailable for further action and digestion as a result of which IVPD of pasta with *Azolla* powder decreased. Rodríguez de Marco *et al.*, 2014 in their study also reported that supplementation of pasta with spirulina significantly decreased its IVPD, as the level of supplementation increased, as presence of oxidised phenolic compounds in the spirulina react with proteins and form insoluble complexes, thus inhibiting the activity of proteolytic enzymes and interfering with the utilisation of proteins. Furthermore, increased in the fibre content also have negative impact on the IVPD of the pasta, which was also observed in the present study.

Colour characteristics and textural firmness

Addition of *Azolla* powder in pasta significantly affect the colour characteristics of the pasta gives it an attractive green colour. Results showed that as with increasing *Azolla* powder supplementation levels, the lightness (L^*) values of pasta decreased significant ($P < 0.05$). The increased *Azolla* supplementation, increased the greenness value (decreasing a^* value) and decrease the yellowness value of pasta, due to increase in the chlorophyll pigment with the increased concentration of *Azolla* powder. Pasta with higher level of *Azolla* showed lowest a^* value, which specified the domination of green over red colour pasta samples. Bawa *et al.* (2022) and Raina *et al.* (2023) also reported that when level of wheatgrass powder and pumpkin seeds meal in the pasta supplementation increased, the lightness value of pasta decreased and greenness increased as a results of chlorophyll pigment present in wheatgrass powder and after cooking the intensity of green colour increased, which was also observed in present study. The data for ΔE showed that the changes in the colour characteristics of pasta are visible by human eyes (Sharma *et al.*, 2021), and the change in the colour profile was linear with the level of *Azolla* powder supplementation for both for the uncooked and cooked pasta Table 3.

The firmness of cooked pasta is an indication of the extent of protein network. The firmness value of pasta (both cooked and uncooked) increased with an increase in the level of *Azolla* powder (Table 2), which might be due to low swelling index and water absorption. Prabhasankar *et al.* (2009) and Rodríguez De Marco *et al.* (2014) in their study also reported that addition of Edible Japanese seaweed and Spirulina in semolina pasta increased its firmness of the pasta as a result of increase in protein content of the pasta which induces a strong protein network among the pasta samples. Furthermore, increase in the fibre content provide the pasta with the stiff structure as a result of which pasta showed a higher firmness than control (Bianchi *et al.*, 2021). On the contrary, Ainsa *et al.* (2022) reported that addition of different seaweed at 3% level results in decreasing the hardness value of pasta due to weakening of the pasta dough structure by addition of non-gluten protein and fibre rich ingredient.

Antioxidant properties, bioactive compounds and pigments in pasta

Addition of *Azolla* powder in the semolina pasta significantly ($P < 0.05$) enhanced the antioxidant activity and bioactive potential of the pasta. Results showed that as the level of *Azolla* powder in pasta increase from 5%–20%, the DPPH radical scavenging activity, total phenolic and flavonoid content in the pasta increased subsequently Table 4. *Azolla* is a good source of bioactive compounds, and rich in phenolic acids and flavonoids (Dohaei *et al.*, 2020; Tran *et al.*, 2020), as a results of which addition of *Azolla* powder in semolina pasts increased its antioxidant activity, phenolic and flavonoid content. Prabhasankar *et al.* (2009) and Rodríguez De Marco *et al.* (2014) in their

Table 3 Effect of *Azolla* powder on colour characteristics and firmness of pasta

Azolla powder (%)	L^*	a^*	b^*	Chroma	Hue angle	Colour difference (ΔE)	Firmness (*N*)
Uncooked pasta							
Control (0%)	65.28 ± 1.34^a	2.16 ± 0.23^a	15.68 ± 0.39^a	15.69 ± 0.51^a	57.30 ± 0.0	–	2843.83 ± 4.75^e
5%	42.12 ± 0.83^b	0.87 ± 0.03^b	6.20 ± 0.14^b	6.32 ± 0.17^b	57.30 ± 0.0	24.54 ± 1.02^c	2908.51 ± 5.36^d
10%	41.49 ± 0.97^b	0.84 ± 0.07^b	5.92 ± 0.11^{bc}	5.95 ± 0.10^c	57.29 ± 0.0	25.65 ± 0.89^c	2986.46 ± 6.21^c
15%	37.76 ± 0.69^c	0.69 ± 0.03^c	5.64 ± 0.09^c	5.63 ± 0.11^d	57.30 ± 0.0	29.34 ± 0.70^b	3226.3 ± 11.43^b
20%	34.38 ± 0.74^d	0.68 ± 0.05^c	4.55 ± 0.23^d	4.56 ± 0.31^e	57.30 ± 0.0	32.88 ± 0.83^a	4197.53 ± 10.29^a
Cooked pasta							
Control (0%)	74.48 ± 2.07^a	1.40 ± 0.13^a	15.33 ± 0.76^a	15.41 ± 1.01^a	57.30 ± 0.0	–	775.28 ± 5.91^d
5%	34.69 ± 091^b	0.93 ± 0.09^b	11.19 ± 0.63^b	11.22 ± 0.71^b	57.30 ± 0.0	39.89 ± 0.89^d	818.52 ± 6.78^c
10%	30.60 ± 0.89^c	0.93 ± 0.07^b	10.76 ± 0.49^b	10.78 ± 0.63^b	57.30 ± 0.0	44.07 ± 0.83^c	821.67 ± 5.85^b
15%	27.10 ± 0.76^d	0.70 ± 0.05^c	8.56 ± 0.20^c	8.61 ± 0.66^c	57.30 ± 0.0	47.73 ± 0.54^b	843.46 ± 3.84^b
20%	24.23 ± 0.94^e	0.72 ± 0.08^c	6.47 ± 0.22^d	6.78 ± 0.49^d	57.30 ± 0.0	50.79 ± 0.65^a	906.18 ± 7.32^a

Values are expressed as Mean ± standard deviation ($n = 3$); Means with different superscripts (a, b, c, d and e) in a column differ significantly ($P < 0.05$) from each other.

Table 4 Effect of *Azolla* powder on antioxidant activity, bioactive component and pigment content of pasta

Samples	DPPH (% RSA)	TPC (mg GAE g^{-1})	TFC (mg QE g^{-1})	Chlorophyll a (mg 100 g^{-1})	Chlorophyll b (mg 100 g^{-1})	Total Chlorophyll (mg 100 g^{-1})	Carotenoid content (mg 100 g^{-1})
Uncooked pasta							
Control (0%)	21.05 ± 0.32^{e}	0.93 ± 0.01^{e}	0.90 ± 0.01^{e}	–	–	–	0.065 ± 0.002^{e}
5%	23.49 ± 0.19^{d}	1.24 ± 0.02^{d}	1.15 ± 0.01^{d}	0.90 ± 0.03^{d}	1.31 ± 0.01^{d}	2.25 ± 0.02^{d}	7.64 ± 1.31^{d}
10%	25.88 ± 0.25^{c}	1.51 ± 0.04^{c}	1.42 ± 0.08^{c}	1.84 ± 0.01^{c}	2.68 ± 0.02^{c}	4.49 ± 0.02^{c}	14.91 ± 1.05^{c}
15%	28.61 ± 0.27^{b}	1.76 ± 0.03^{b}	1.63 ± 0.07^{b}	2.78 ± 0.04^{b}	4.07 ± 0.01^{b}	6.76 ± 0.03^{b}	23.32 ± 1.42^{b}
20%	30.52 ± 0.34^{a}	1.98 ± 0.02^{a}	1.86 ± 0.11^{a}	3.69 ± 0.03^{a}	5.43 ± 0.04^{a}	8.76 ± 0.03^{a}	30.17 ± 1.13^{a}
Cooked pasta							
Control (0%)	11.76 ± 0.24^{e}	0.59 ± 0.01^{e}	0.54 ± 0.01^{e}	–	–	–	0.026 ± 0.001^{e}
5%	12.92 ± 0.18^{d}	0.71 ± 0.01^{d}	0.65 ± 0.02^{d}	0.49 ± 0.03^{d}	0.73 ± 0.04^{d}	1.21 ± 0.03^{d}	3.09 ± 0.17^{d}
10%	14.69 ± 0.31^{c}	0.83 ± 0.02^{c}	0.79 ± 0.03^{c}	0.99 ± 0.06^{c}	1.78 ± 0.02^{c}	2.79 ± 0.04^{c}	8.18 ± 1.02^{c}
15%	15.97 ± 0.17^{b}	0.92 ± 0.01^{b}	0.86 ± 0.01^{b}	1.48 ± 0.02^{b}	1.97 ± 0.03^{b}	3.43 ± 0.02^{b}	14.40 ± 1.09^{b}
20%	17.15 ± 0.29^{a}	1.09 ± 0.04^{a}	0.98 ± 0.03^{a}	1.82 ± 0.04^{a}	2.68 ± 0.03^{a}	4.46 ± 0.03^{a}	17.92 ± 1.04^{a}

Values are expressed as Mean ± standard deviation ($n = 3$); Means with different superscripts (a, b, c, d and e) in a column differ significantly ($P < 0.05$) from each other.

study also reported that addition of bioactive compounds and antioxidant rich ingredient in the pasta significantly enhanced the antioxidant activity, phenolic and flavonoid content of the pasta. Furthermore, presence of chlorophylls and carotenoids in *Azolla* powder results in increased pigment content in the pasta. Studies of Bawa *et al.* (2022) also reported that addition of wheatgrass powder in pasta progressively enhanced the chlorophyll and carotenoid content in the pasta, due to the presence of these compounds in wheatgrass powder at higher levels. Cooking of pasta results in decreased the antioxidant activity and bioactive compounds in the pasta be due to the loss of biological activity and breakdown of tissue structure due to thermal treatment and also due to associated leaching-out process during cooking (Bawa *et al.*, 2022; Raina *et al.*, 2023).

Sensory characteristics

Addition of *Azolla* powder significantly influenced the sensory characteristics of the pasta. Data presented in Table 5 showed that as the *Azolla* powder incorporation increased, the overall acceptability of pasta was dropped. Pasta enriched by 5% and 10% *Azolla* powder was selected as best with regard to the sensory scores as compared to other enriched samples. It had the highest overall acceptability score of 7.50, whereas the lowest overall acceptability (5.80) was observed in the pasta enriched at a 20% level. It was found that with the inclusion of 15% and 20% *Azolla* powder, a perceived grassy flavour of the *Azolla* powder was easily detectable in pasta, and it was reported that the textural properties of the pasta were maintained. Prabhasankar *et al.* (2009) also reported that pasta samples containing seaweed powder up to 10% had higher acceptance by the panellists. However, the other samples, where seaweed content increased beyond 10%, sensory scores reduced.

Conclusion

The current investigation attempts the utilisation of *Azolla* powder as a protein source and functional ingredient in semolina pasta. Addition of *Azolla* powder at different levels significantly influenced the nutritional quality as well as properties of semolina pasta. Increasing *Azolla* powder content in pasta increased its protein content, mineral content, antioxidant activity, bioactive components as well as pigment content. However, at higher levels of *Azolla* powder (15% and 20%), there was a significant reduction in its cooking yield, whiteness and sensory acceptability. Among various levels tested, *Azolla* powder at 10% level was found to be best considering the nutritional quality, cooking characteristics and sensory properties of end product. Further detailed studies are recommended to check the influence of treated *Azolla* powder with an

Table 5 Effect of *Azolla* powder on sensory characteristics of pasta

Azolla powder (%)	Colour/ Appearance	Mouth feel	Taste/ Flavour	Overall acceptability
Control (0%)	8.0 ± 0.02^{a}	8.0 ± 0.06^{a}	8.0 ± 0.06^{a}	8.0 ± 0.05^{a}
5%	7.8 ± 0.04^{b}	7.5 ± 0.03^{b}	7.0 ± 0.05^{b}	7.4 ± 0.04^{b}
10%	7.9 ± 0.03^{b}	7.5 ± 0.04^{b}	7.0 ± 0.03^{b}	7.5 ± 0.03^{b}
15%	7.0 ± 0.06^{c}	6.0 ± 0.05^{c}	6.0 ± 0.07^{c}	6.3 ± 0.06^{c}
20%	7.0 ± 0.03^{c}	5.5 ± 0.04^{d}	5.0 ± 0.02^{d}	5.8 ± 0.03^{d}

Values are expressed as Mean ± standard deviation ($n = 30$); Means with different superscripts (a, b, c, d and e) in a column differ significantly ($P < 0.05$) from each other.

aim to produce pasta with less objectionable flavour and improved consumer acceptability.

Acknowledgments

Authors are highly indebted to the authorities of Punjab Agricultural University and Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab for providing facilities related to this work.

Author contributions

Amreetpal Kaur: Data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); resources (equal); software (equal); writing – original draft (equal). **Arashdeep Singh:** Conceptualization (equal); data curation (equal); investigation (equal); methodology (equal); resources (equal); software (equal); supervision (equal); validation (equal); writing – original draft (equal); writing – review and editing (equal). **Antima Gupta:** Conceptualization (equal); investigation (equal); methodology (equal); software (equal); supervision (equal); writing – original draft (equal); writing – review and editing (equal). **Vijay Kumar Reddy Surasani:** Conceptualization (equal); investigation (equal); methodology (equal); supervision (equal); writing – original draft (equal); writing – review and editing (equal). **Salwinder Singh Dhaliwal:** Investigation (equal); methodology (equal); resources (equal); supervision (equal); writing – review and editing (equal).

Conflict of interest

The author(s) have declared that they have no potential conflicts of interest in relation to the research, authorship and/or publication of this paper.

Ethical guidelines

Ethics approval was not required for this research.

Peer review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ijfs.16582.

Data availability statement

Data are available from the corresponding author upon reasonable request.

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This work details the utilization of plant biomass as a nutrient source in pasta, which is also the main objective of current study. The methodology used and the research approach is similar to current study. It was one of the basic references, using which we planned our study.

Bawa, K., Brar, J.K., Singh, A., Gupta, A., Kaur, H. & Bains, K. (2022). Wheatgrass powder-enriched functional pasta: techno-functional, phytochemical, textural, sensory, and structural characterization. *Journal of Texture Studies*., **53**, 517–530.

This work details the application of plant based powder in pasta as a source of functional ingredients. In the current study we have used *Azolla* powder, and the discussions used in this study helped us in understanding the concepts and performing the work.

Bianchi, F., Tolve, R., Rainero, G., Bordiga, M., Brennan, C.S. & Simonato, B. (2021). Technological, nutritional and sensory properties of pasta fortified with agro-industrial by-products: a review. *International Journal of Food Science and Technology*, **56**, 4356–4366.

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The study elucidated the application of fish protein powder as a source of protein in semolina pasta. In the current study we have used *Azolla* powder as a source of protein in semolina pasta. This study detailed the interaction of protein with semolina that contributed to end product quality, which was used in explaining the findings of the current study.

Dohaei, M., Karimi, K., Rahimmalek, M. & Satari, B. (2020). Integrated biorefinery of aquatic fern *Azolla* filiculoides for enhanced extraction of phenolics, protein, and lipid and methane production from the residues. *Journal of Cleaner Production*, **276**, 123175.

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