Italian Journal of Food Science, 2023; 35 (4): 136–146

Technological, quality and nutritional characteristics of Ramen noodles with wheat flour partially substituted by water chestnut flour

Mehak Ahsan[1], Abeera Moin[2], Humaira Ashraf[1], Maliha Kamran[1], Iqra Manzoor[1], Angelo Maria Giuffrè[3]*

[1]Department of Food Science and Technology, Jinnah University for Women, Nazimabad Karachi 74600, Pakistan; [2]Department of Food Science and Technology, University of Karachi 75270, Pakistan; [3]Department AGRARIA, University of Studies "Mediterranea" of Reggio Calabria, Via dell'Università, 25, 89124 Reggio Calabria, Italy

***Corresponding Author**: Angelo Maria Giuffrè, Department AGRARIA, University of Studies "*Mediterranea*" of Reggio Calabria, Via dell'Università, 25, 89124 Reggio Calabria, Italy, Email: amgiuffre@unirc.it

Received: 23 August 2023; Accepted: 24 November 2023; Published: 27 December 2023

PAPER

Abstract

Ramen noodles were prepared by partially supplementing traditional wheat flour with water chestnut flour (WCF) at 30, 40 and 50% levels w/w. The composition, pasting and farinograph indices of flour blends were studied. Noodles were analysed for colour, radical scavenging and functional characteristics. Time for dough development, stability and farinograph quality number declined significantly from 5.250±0.07 to 1.20±0.01 min, 6.45±0.07 to 1.31±0.01 min and 81.50±0.71 to 18.50±0.71, respectively, after replacement. Statistically significant increment in pasting temperature (60.91±0.01 to 72.05±0.07°C), peak viscosity (1094.05±0.07 to 1099.25±0.35 Brabender Unit, BU), breakdown (310.05±0.07 to 376.05±0.07 BU), hot paste (782.05±0.07 to 996.10±0.14 BU) and cold paste viscosities (1548.10±0.14 to 1701.25±0.35 BU) were found with the addition of WCF. Non-traditional ramen exhibited significantly improved fibre, antioxidant potential and mineral content with significant reduction in % fat and caloric count. The colour variation data in ramen noodles were: L* (66.35–57.86); a* (0.24–2.08); and b* (4.03–4.47). Texture hedonic scores varied between 8.38 and 7.57 with chestnut flour level increment. Hardness of Ramen noodles samples ranged between 13.9 and 19.8 N.

Keywords: Correlation; Composite flour; Farinography; Ramen noodles; Water chestnut

Introduction

Nowadays, consumers look for quick and wholesome meals. In particular, there is great interest in wheat-based products (Saeed *et al.*, 2023; Giuffrè *et al.*, 2023; Giuffrè *et al.*, 2022). Alkaline noodles, also known as Ramen noodles, offer the advantage of a shorter preparation time, a distinct flavour and colour and a chewy and springy texture (Wang, 2014). In Southeast Asia, there are three main types of alkaline noodles: fresh Cantonese noodles, partly cooked Hokkien noodles and fresh or steamed wonton noodles (Hou, 2010; Zi *et al.*, 2022; Du *et al.*, 2023). Widespread alkaline salts used in the preparation of ramen noodles are sodium carbonate and potassium carbonate, or a combination of the two (Li *et al.*, 2018). Traditionally, Kansui (aqueous solution of lye stone or plant ash) was used in the formulation of alkaline noodles.

The primary ingredient of noodles is wheat (*Triticum aestivum* L.*)* flour (Marconi and Carcea, 2001). In Asia, noodles are a dietary staple that account for 20–50% of all wheat flour (WF) consumed (Hou*et al.*,2015; Tong, 2020; Yuliantini *et al.*, 2020). Water chestnut (*Trapa natans*), also known as *Singhara*, is an aquatic angiosperm with floating leaves present in freshwater wetlands, ponds, lakes, slow-moving rivers and fresh water or slightly salty estuaries. It has a tough thick skin with a delicious tuber (Alam, *et al.,* 2021). It is mostly farmed for human consumption, either as a vegetable or dried and ground into flour (Rajkumar and Rajithasri, 2022). The fruits of *Trapa natans* are delicious, diuretic, cooling, astringent and a tonic (Jana, 2019). There is growing interest in the consumption of water chestnut due to its nutritional elements, such as omega-3 fatty acids, vitamins, minerals and antioxidant agents like phenolics and tannins (Ahmed *et al.,* 2016; Mer *et al*., 2022; Kaur *et al*., 2023). However, the rheology of water chestnut flour (WCF) in composite dough is critical due to the lack of gluten.

The present study developed Ramen noodles enriched with WCF, aiming to elevate the nutritional profile of Ramen and contribute to sustainability in the food industry. The novel approach was to study the effect of up to 50% substitution of WF with WCF in terms of the rheological, functional, nutritional and sensory characteristics of Ramen noodles. This combination of water chestnut and WF is not reported for alkaline noodles formulation.

Materials and Methods

The chemicals used in this study were of analytical grade, sourced from Dae-Jung Chemicals in South Korea and Sigma-Aldrich in Germany. The flour samples were purchased from a local supermarket in Karachi who procured flour from Sukkur Grains (Pvt.) Ltd. having an extraction rate of 50% and kept in airtight plastic containers at refrigeration temperature until used.

Preparation of Ramen noodles

The methodology of Hou *et al.* (2015) was followed with minor modifications for the preparation of Ramen noodles. The supplemented dough was prepared by replacing WF with (30, 40 and 50%) WCF while a control dough sample was made with WF (100%). These percentages were chosen to test a significant quantity of chestnut flour. Then, NaCl (1%) and Sodium Carbonate (1%) based on flour weight (db) was dissolved in water to make kansui water. The kansui temperature was maintained to 26°C and it was gradually added to the flour. Manual kneading was performed until formation of a perfect dough ball. Afterwards, the dough was kept covered with cling wrap for 15 min. The rested dough ball was then sheeted to 3 mm thickness and left again for 30 min at room temperature. Subsequently, it was further sheeted to a thickness of 1mm. The sheets were then cut and shaped into ramen noodles. Subsequently, the noodles were air dried for an hour and stored in zip lock bags for further analysis.

Proximate analysis

The standard methodologies of AACC international (2000) for protein (Method 46–13), moisture (Method 44–40), ash (Method 8–01), fat (Method 30–25) and crude fibre (Method 32–10) were followed to evaluate the composition of flour blends and ramen noodles. Total carbohydrates in flour composites and noodles were calculated by employing the following equation;

$$\begin{aligned}\text{\% carbohydrates} = 100 - (&\text{\% protein} + \text{\% fat} + \text{\%ash} \\ &+ \text{\% fibre} + \text{\% moisture}) \qquad (1)\end{aligned}$$

The caloric values of noodles were computed by the Atwater general factor system, i.e., 4 kcal/g for carbohydrates and proteins and 9 kcal/g for fats.

Dough rheology

The Brabender® Farinograph (GmbH & Co.KG, Germany) was used to study the effect of multiple levels of WCF addition to WF on rheology of ramen noodles dough by employing the recognized AACC international Method 54–21 (2000). Consistency and degree of softening (DoS) expressed as BU, (WA, dough development time (DDT), dough stability (DS) and farinograph quality number (FQN) were observed.

Pasting profile of wheat and WCF composites

The Brabender® Micro-Visco-Amylograph (GmbH & Co.KG, Germany) was used to explore viscosity profile of flour composites. The methodology outlined by Moin *et al*. (2016) was followed. Briefly, flour suspension of 10% (w/w, db) was prepared with distilled water and was heated from 40°C to 95°C at a heating rate of 3°C/min. Afterwards, it was held at 95°C for 10min. The slurry was then cooled back to 50°C at a cooling rate of 3°C/min and kept at 50°C for 10 min. Pasting temperature (PT was expressed as °C), peak viscosity (PV), hot paste viscosity (HPV), breakdown viscosity, cold paste viscosity (CPV) and setback viscosities were expressed as (BU).

DPPH assay

The radical-scavenging activity (%RSA) of ramen noodle samples was determined by means of the DPPH assay. The protocol of Littardi *et al.,* (2020) was followed, with some modifications. Ramen noodles (1 g) were mixed with 10 mL of methanol–water solution (70:30) for an hour at room temperature. Afterwards, the extract was filtered through a pleated filter and then dried at 40°C in a Rotavapor (Eyela, Japan). The residues were re-dissolved in 1 mL methanol–water solution (70:30) and filtered. Then, 100 µL filtrate was mixed with methanol (1.3 mL) and 0.2 mmol/L DPPH methanolic solution (1 mL). Afterwards, the sample was kept in the dark for 30 min. Then, at 517 nm, absorbance was noted by using a UV-visible spectrophotometer (CECIL, CE7200). The percentage of radical scavenging activity was calculated using the equation below:

$$\mathrm{RSA}(\%) = \frac{\mathrm{A}_0 \times \mathrm{A}_1}{\mathrm{A}_0} \times 100$$

where

A0 is the absorbance of blank.

A1 is the absorbance of noodles samples.

A calibration curve was created using known concentrations of Trolox (µmol Trolox/g) to quantify the per cent antioxidant capacity.

Colour analysis of ramen noodles

The colorimetric analysis of the ramen noodle samples was conducted by employing the CIE-Lab Colour meter (Colour Tech-PCM, USA). The colour parameters L*, a* and b* (lightness, redness and yellowness, respectively) were noted. L* equal to100 indicated white while zero L* was for black colour. High positive a* indicated red, high negative a* depicted green colour, whereas high positive b* was regarded as yellow and high negative b* indicated blue.

Cooking characteristics

Ramen cooking duration (CT) in minutes was computed by following Yadav *et al.* (2014). Cooking losses (CL) for each noodle sample was estimated by using the AACC (2000) Method 66–50. Water uptake (WU) by noodles upon cooking was measured using Agama *et al.* (2009).

Texture analysis of noodles

The texture of cooked noodles was evaluated by using a texture analyser (Model CT3 1000, Brookfield, USA). The freshly cooked noodles were cooled in distilled water and then strained for 5 min. A cross head speed of 10 mm/min with a load cell of 5 kg was used. Force required to break the noodles was noted and average hardness (N) of three noodles was recorded (Tan *et al.*, 2018).

Sensory analysis

Ramen noodles prepared from composite flours were organoleptically evaluated by using a 9-point Hedonic scale (ranges from 9–like extremely to 1–dislike extremely) by a panel of 10 semi-trained panelists. The protocol of Tomar *et al.* (2021) was followed. The assessors were female graduate students of Jinnah University for Women, Pakistan. They evaluated three digit randomly coded noodle samples in terms of aroma, colour, taste and texture in a bright and well-ventilated laboratory. Drinking water was served along with ramen samples.

Statistical analysis

All analyses were performed in triplicates (n = 3), except for sensory analysis, which was performed in 10 replicates. Three specimens were analysed. The experimental results were subjected to analysis of variance (ANOVA) and Pearson's correlation using the IBM Statistical Package for the Social Sciences (SPSS) software (version 17.0; IBM Corp., Chicago, IL, USA). Duncan's multiple range test was used to identify significant differences between different levels of WCF supplementation with a 95% confidence level ($p<0.05$). Pearson's correlation between the amount of water chestnut and rheological, compositional, colour and cooking characteristics of ramen noodles was evaluated.

Results and Discussion

Compositional analysis of flour blends

The moisture, protein and fat percentages were found significantly higher in WF when compared with composite flours having (30, 40 and 50%) WCF (Table 1). The lower moisture measurement of WCF blends is attributable to their higher WA (Table 2). Kosović *et al.* (2016) interpreted that the lower moisture measurement of WCF blends is attributable to their higher WA which may occur as a result of reduced gluten content and a lack of continuity in the gluten network, causing a more rapid moisture permeation into samples with lower protein content.

With regard to our data, it can be observed that the moisture content decreased with the increase of wheat–water chestnut composite from 11.27 to 7.86% for 0% WCF and 50% WCF, respectively. Similar behaviour was found in Ramen noodles with a decreasing trend ranging between 32.39 and 28.70% for 0% WCF and 50% WCF, respectively (Table 1). The ash content increased by 268% in flour composites and by 185% in Ramen noodles when the percentage of WCF was implemented in the recipe (Table 1). The protein percentage was similar both in chestnut flour composite and in Ramen noodles, also in this case the quantity of protein decreased with the increase of WCF. Similar protein behaviour was found by Michalak-Majewska *et al.* (2020) in both uncooked and cooked pasta prepared with an increasing onion skin powder content.

The fat quantity of our samples decreased by 3.09 times in flour blends and by 4.3 times in Ramen noodles, with the increase of WCF (Table 1). This decrease may be considered positively by consumers requiring a low fat product. The substitution of WF with WCF provided a significant improvement in crude fibres, which is very important for the modern human diet (Giuffrè and Giuffrè, 2023, de Carvalho Correa *et al.*, 2024).

Effects of WCF on compositional analysis of ramen noodles

The compositional analysis findings of ramen noodles are presented in Table 1. The addition of salts (NaCl and $NaHCO_3$) in the formulation of ramen noodles is the reason for higher percentage of ash (5–10%) in all ramen noodle samples. However, mineral content of noodles significantly increased with the rise in the substitution level of WCF. The percentage of proteins in noodles significantly reduced with the increase of WCF. This was due to the dilution of gluten present in WF. Moisture content (%) decreased with the increase in the quantity of WCF in the noodle formulation. Noodles prepared with wheat-banana flour blend and wheat-chestnut blend also exhibited a similar percentage moisture trend (Ritthiruangdej *et al.,* 2011; Altiner and Merve, 2020). A statistically significant reduction in the fat percentage of noodles could be observed after the addition of WCF in the noodles. Noodles prepared with WCF substitution were found to have improved crude fibre content. Moreover, a 50% WCF substitution had a significantly pronounced impact. The caloric value for WCF substituted noodles significantly reduced when compared to control (WF) noodles. The enhanced percentage of crude fibre and reduced calories per 100 g suggest the appropriateness of WCF noodles for gut health and a calorie conscious population.

Farinograph of ramen noodle dough substituted with WCF

The Farinograph® indices of WF and WF–WCF blends are summarized in Table 2. A statistically significant decline in WA was observed with the incorporation of (30 and 40%) WCF. A similar decline in WA of wheat–water chestnut and wheat–amaranth blends was also reported by Krishnaiya *et al.,* (2016) and Sindhuja *et al.* (2005), respectively. The level of starch crosslinks within noodles has a direct influence on their cooking characteristics. In cases where the gluten network within the noodles is weak and the starch crosslinking is not well-established, it can result in disintegration or even breakage of the noodles during the cooking process (Tian *et al.*, 2022). Interestingly, at 50% WCF level, the dough

Table 1. Effect of water chestnut flour addition on compositional analysis of flour blends and Ramen noodles.

Wheat–water chestnut flour composites

Water chestnut flour (%)	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Crude fibres (%)
0	11.27 ± 0.16^{d}	0.95 ± 0.72^{a}	10.51 ± 0.49^{d}	2.26 ± 0.12^{c}	0.54 ± 0.07^{a}
30	9.08 ± 0.24^{b}	1.64 ± 0.11^{b}	8.61 ± 0.66^{c}	1.31 ± 0.21^{b}	0.99 ± 0.16^{b}
40	8.37 ± 0.38^{a}	2.08 ± 0.11^{c}	7.45 ± 0.31^{b}	1.15 ± 0.07^{b}	1.19 ± 0.11^{b}
50	7.86 ± 0.41^{a}	2.55 ± 0.12^{d}	6.31 ± 0.20^{a}	0.73 ± 0.03^{a}	1.19 ± 0.16^{b}

Wheat–water chestnut noodles

Water chestnut flour (%)	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Crude fibre (%)	Energy value (kcal/100g)
0	32.39 ± 0.45^{c}	5.30 ± 0.62^{a}	10.27 ± 0.11^{c}	1.29 ± 0.19^{a}	0.51 ± 0.13^{a}	251.58 ± 1.55^{c}
30	30.20 ± 0.34^{b}	7.83 ± 0.21^{b}	8.22 ± 0.38^{b}	0.48 ± 0.02^{b}	0.57 ± 0.02^{ab}	247.99 ± 2.08^{b}
40	29.31 ± 0.15^{a}	8.78 ± 0.40^{c}	7.40 ± 0.55^{b}	0.38 ± 0.02^{b}	0.61 ± 0.03^{ab}	247.07 ± 1.76^{ab}
50	28.70 ± 0.45^{a}	9.83 ± 0.29^{d}	6.04 ± 0.83^{a}	0.35 ± 0.04^{b}	0.65 ± 0.02^{c}	244.17 ± 0.38^{a}

Note: Values ± standard deviation within the same column having different lowercase superscripts are statistically significantly different at $p<0.05$.

Table 2. Farinograph characteristics of ramen noodle dough substituted with water chestnut flour.

Water chestnut flour (%)	Consistency (BU)	Water absorption (%)	Dough development time (Min)	Stability (Min)	Degree of softening (BU)	Farinograph quality number
0	455.50±0.71^{d}	58.95±0.07^{c}	5.250±0.07^{d}	6.45±0.07^{d}	48.25±0.35^{a}	81.50±0.71^{d}
30	430.50±0.71^{c}	57.15±0.21^{b}	1.20±0.01^{a}	1.71±0.01^{b}	117.50±0.07^{d}	18.50±0.71^{a}
40	421.50±0.71^{b}	55.20±0.28^{a}	1.75±0.07^{b}	1.31±0.01^{a}	102.50±0.07^{b}	42.50±0.71^{b}
50	410.50±0.71^{a}	60.10±0.01^{d}	4.25±0.07^{c}	3.63±0.04^{c}	113.50±0.07^{c}	76.50±0.71^{c}

Note: Findings ± standard deviation within the same column having different lowercase superscripts are statistically significantly different ($p<0.05$).

exhibited significantly higher WA. The significantly highest ash and crude fibre content of 50% WCF–WF flour blend (Table 1) could be the reason for its higher WA, as these components in flour exhibit higher water affinity (Mansoor *et al.,* 2019). The WF substitution with (30, 40, 50%) WCF significantly minimized the time to achieve optimum consistency (500 BU) of dough (DDT), stability and Farinograph® quality number (FQN) when compared to control (0% WCF). However, the DDT of 50% WCF (4.25 min) dough was significantly prolonged when compared to DDT of 30% and 40% (1.20 and 1.75, respectively) WCF substituted dough. The struggle between WF and WCF for water of hydration for proteins and dough development could be the cause of this 3.54 and 2.42 times significant deceleration in DDT at 50% WCF level (1:1 WF and WCF ratio) in comparison to DDT of 30% and 40%. The consistency value of dough (FU) significantly decreased with an increased WCF level. The significant fall in DS and significant increase in DoS after WCF incorporation when compared to control (100% WF) suggested a decline in dough strength. The dilution of gluten protein caused the formulation of weaker WCF dough. A similar trend of DoS was reported in the study by Švec *et al.* (2018) on WF-WCF composites. The drop in FQN with the increasing quantity of WCF could be due to the inclusion of non-glutinous proteins in the flour blend.

Viscoamylograph

Pasting properties are an essential index in the determination of the baking and cooking traits of flours. When the flour and water slurries are subjected to heat and agitation, the starch granules are enlarged and completely dislocated. Gelatinization temperature, breakdown, hot paste and cold paste viscosities significantly increased with the increment in the level of WCF substitution in WF-WCF composites (Table 3). The maximum viscosity attained by gels also increased significantly after addition of WCF. However, 50% substitution with WCF caused a reduction in PV. This is in accordance with the observations of 55% WCF–WF blend by Krishnaiya *et al.* (2016). A similar trend was observed by Biao *et al.* (2020) by incorporating more than 15% mushroom flour, which led to a notable increase in the WA capacity and PV of the mixed flours. As the proportion of mushroom flour increased, the DS time decreased. In addition, the inclusion of mushroom flour resulted in a reduction of both gelatinization temperature and shear modulus values.

The highest setback (720.5 BU) was observed in 50% WCF substituted sample. In the study by Singh and Singh (2010), it was reported that breakdown viscosity of flour is inversely proportional to the amount of protein in regular wheat and durum wheat cultivars. A parallel trend was also observed in the present study (Table 1 and 4). The setback viscosity corresponds to the retrogradation tendency of a gel, suggesting significantly higher staling propensity of noodles prepared with 40% and 50% WCF flour. On the contrary, substitution with WCF to a lower level (30%) caused significant reduction in setback when compared to un-substituted WF noodles.

Effect of water chestnut addition on DPPH (2,2-diphenyl-1-picrylhydrazyl)

The DPPH assay is widely applied to many wheat-based products to evaluate their radical scavenging activity (Masutti *et al.*, 2020; Sidari *et al.*, 2020; Ghardaloo *et al.*, 2023). The effect of WF replacement with WCF (30, 40 and 50%) on antioxidant activity of Ramen noodles was studied in terms of DPPH per cent inhibition (Table 4). With increased WCF quantity in the formulation of Ramen noodles, statistically a significant increase in DPPH free radical scavenging was observed. This could be attributed to the polyphenolic compounds present in WCF. Similar % inhibition results are reported for the cookies and flat bread prepared with WF–WCF blends (Shafi, *et al.,* 2016; Shafi *et al.*, 2017). The lower % inhibition of WF was due to the fact that wheat polyphenols are mostly found in the bran fraction and during the flour refining process, these polyphenols are lost. On the contrary, WCF contains higher total phenolic content in bound form and antioxidant activities than soft WF

Table 3. Effect of water chestnut flour addition on pasting characteristics of composite flour.

Water chestnut flour (%)	Pasting temperature (BU)	Peak viscosity (BU)	Breakdown (BU)	Hot paste viscosity (BU)	Cold paste viscosity (BU)	Setback (BU)
0	60.91±0.01^{a}	1094.05±0.07^{b}	310.05±0.07^{a}	782.05±0.07^{a}	1548.10±0.14^{a}	630.00±0.00^{b}
30	61.11±0.01^{b}	1098.05±0.07^{c}	312.05±0.07^{b}	882.05±0.07^{b}	1654.05±0.07^{b}	620.50±0.71^{a}
40	69.05±0.07^{c}	1099.25±0.35^{d}	328.05±0.07^{c}	892.05±0.07^{c}	1698.05±0.07^{c}	632.50±0.71^{c}
50	72.05±0.07^{d}	1088.50±0.70^{a}	376.05±0.07^{d}	996.10±0.14^{d}	1701.25±0.35^{d}	720.50±0.71^{d}

Note: Pasting profile findings ± standard deviation within the same column having different lowercase superscripts are statistically significantly different.

Table 4. Effect of water chestnut flour incorporation on antioxidant and cooking indices of Ramen noodles.

Water Chestnut flour (%)	Radical scavenging activity DPPH assay (%)	Cooking time (min)	Cooking loss (%)	Water uptake (%)
0	31.15±0.62^{a}	6.78±0.19^{c}	3.99±0.04^{a}	1.79±0.04^{c}
30	43.22±1.35^{b}	5.68±0.17^{b}	4.85±0.07^{b}	1.65±0.03^{b}
40	62.45±0.38^{c}	5.23±0.26^{a}	4.94±0.05^{b}	1.62±0.03^{ab}
50	78.49±0.55^{d}	5.21±0.25^{a}	5.07±0.07^{c}	1.58±0.03^{a}

Note: Findings± standard deviation within the same column having different lowercase superscripts is statistically significantly different.

(Zhu, 2017). Michalak-Majewska *et al.* (2020) studied the effect of onion skin powder on the radical scavenging activity in uncooked pasta. They added (0, 2.5, 5 and 7.5%) onion skin powder to the pasta recipe and found the following DPPH values – 1.6, 2.5, 6.2 and 7.8 mmol TE/g d.m. They also found that the cooking procedure did not reduce the radical scavenging activity.

Cooking properties of ramen noodles

The effect of WF substitution with WCF on the cooking properties, including time for cooking, WU and CL are summarized in Table 3. A statistically significant ($p<0.05$) increase in CL was observed with an increased amount of WCF in ramen noodles. Elevated CL showed poor protein starch matrix and dilution of gluten in WCF containing noodles. A pronounced increase in losses during cooking of noodles is also reported for noodles supplemented with soy-sorghum flour (Rani *et. al.,* 2019). In accordance with our findings, Saman *et al.* (2006) correlated higher protein pastas with lower solid leaching to cooking water and improved tolerance to overcooking. Moreover, decreasing gluten content also reduced the adhesive forces between protein and starch, leading to the development of less dense structures in the noodles. This makes it more conducive for water to permeate into the molecular interior during cooking, ultimately decreasing the ideal CT for the noodles (Mu *et al*., 2022).

The cooking process significantly accelerated for WF–WCF noodles. The presence of WCF in the noodle composite flour may cause discontinuity in the gluten network, causing quicker moisture penetration, consequently accelerating optimum cooking time (Manthey *et al.,* 2004; Deng *et al.,* 2023). Noodles prepared from WF blends with colocasia, water chestnut and sweet potato flours also exhibited significantly shorter CT (Yadav *et al.,* 2014). WU upon cooking is the ability of noodles to retain water and consequently gain weight. A significant drop in WU was observed in WCF noodles when compared to WF. Lesser WU upon cooking leads to harder noodle texture, whereas softer and stickier noodle texture is the outcome of excessive WU. It was observed that incorporation of WCF facilitated the penetration of water, leading to shorter cooking time but retention of water was poor which led to harder texture of WCF containing noodles (Figure 1).

Texture evaluation of Ramen noodles

The texture of cooked noodles was studied in terms hardness (N), which is the force required to rupture the noodle. The hardness depicts the force needed to chew a noodle. The control sample exhibited significantly the lowest hardness value when compared to WCF substituted noodles (Figure 1). The strength of Ramen noodle samples ranged between 13.9 and 19.8 N. It could be observed that with the increase in the level of WCF in noodles, the force of compression increased significantly. This was possibly due to a reduction in the amount of starch and increased fibre content (Table 1) in composite flour noodles. The starch in flour contributed to a

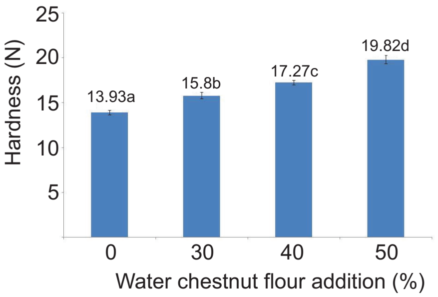

Figure 1. Hardness of Ramen noodles with different levels of water chestnut flour.

network-forming structure and enhanced absorption of water into the Ramen noodle as evidenced by per cent WU upon cooking (Table 4). Moreover, increased hardness led to significantly lower texture scores of highly substituted WCF samples (40 and 50%) than the control sample (Table 5).

Colour and sensory analysis of Ramen noodles

The colour analysis illustrated that as the amount of WCF in the ramen noodles increased (30%, 40% and 50%), there was a significant and gradual decrease in lightness (L*) (Table 5). A similar decline in L* value was observed when Chinese chestnut was incorporated into bread at increasing levels (Wang *et al.,* 2023). The redness (a*) and yellowness (b*) increased significantly after WCF incorporation. However, the increase in (b*) was not pronounced but yet significant. Ramen noodles made with WCF turned out darker (L* ranges between 57 and 59) than WF and had a reddish/yellow hue.

All the studied sensory attributes scored between 7 and 8 hedonic points, suggesting the acceptability of all combinations of ramen noodles (Table 5). The sensory evaluation showed that semi-trained assessors could not find any significant change in the taste and aroma of WCF supplemented Ramen when compared to WF. Nevertheless, WF and 30% WCF–WF noodles scored significantly higher for colour than 40 and 50% WCF–WF noodles. Moreover, the texture of 40 and 50% WCF–WF noodles scored significantly fewer hedonic points than WF and 30% WCF-WF noodles. This could be due to significantly increased losses upon cooking at higher WCF level (Table 4). The losses during cooking made the noodles stickier, consequently, negatively affecting the sensory acceptability of the ramen containing WCF (Shiau and Yeh, 2001). This trend is in accordance with the organoleptic evaluation data of instant noodles prepared with black carrot powder (Singh *et al.*, 2018).

Correlation of the amount of water chestnut with rheological, compositional, colour and cooking characteristics of ramen noodles

Pearson's correlations of the substitution percentage of WF with WCF with compositional constituents, rheological parameters, colorimetric and cooking indices of ramen noodles were observed (Table 6). The dough softening degree, gelatinization temperature and breakdown viscosity are significant and positively correlated rheological properties to WCF supplementation. However, negative correlation of stability was observed with the amount of WCF and DoS at a significant level of $p < 0.05$ and $p < 0.01$, respectively. The antioxidant activity (%RSA) was found strongly correlated (0.930) with WCF supplementation ($p < 0.01$). Colorimetric Pearson's correlations were strong and significantly positive for a* and b* values. However, a stronger negative (−0.98) correlation coefficient was observed for L* (whiteness) at $p < 0.01$ significance. The moisture and protein contents of flour blends exhibited strong positive correlation coefficients with lightness of noodle colour. The correlation of WU by noodles upon cooking, and CT was significantly inverse and strong (−0.952 and −0.957, respectively) with WCF addition. Moreover, statistically significant, strong and positive correlation existed between CL and amount of WCF. The mineral and fibre content are positively correlated compositional constituents of WCF ramen, whereas moisture and protein contents exhibited strong

Table 5. Effect of water chestnut flour supplementation on colorimetric and organoleptic properties of Ramen noodles.

Water chestnut flour (%)	Colour values			Hedonic scores			
	L*	a*	b*	Aroma	Colour	Taste	Texture
0	66.35±0.47^{d}	0.24±0.02^{a}	4.03±0.09^{a}	8.38±0.52^{a}	8.43±0.53^{a}	7.80±0.63^{a}	8.38±0.52^{b}
30	59.81±0.16^{c}	1.37±0.08^{b}	4.21±0.02^{b}	7.80±0.79^{a}	8.29±0.49^{a}	7.80±0.79^{a}	8.43±0.53^{b}
40	58.57±0.42^{b}	1.64±0.09^{c}	4.27±0.02^{c}	7.70±0.67^{a}	7.63±0.53^{b}	7.80±0.79^{a}	7.57±0.55^{a}
50	57.86±0.10^{a}	2.08±0.16^{d}	4.47±0.05^{d}	7.90±0.87^{a}	7.57±0.52^{b}	7.50±0.71^{a}	7.57±0.53^{a}

Note: Values ± standard deviation within the same column having different lowercase superscripts are significantly different. L* value depicts the lightness (100: perfect white/0: perfect black), a* value illustrates (+) redness/(−) greenness, and b* value highlights (+) yellowness/(−) blueness of ramen noodles.

Table 6. Correlation of water chestnut flour addition with rheological, colour values and cooking characteristics.

	DDT	Stability	DoS	FQN	PT	PV	SB	BD	%RSA	L*	a*	b*	CT	CL	WU	MC	Ash	Protein	CF
WCF level	–.436	–.709*	.888**	–.254	.832*	–.187	.606	.753*	.930**	–.980**	.992**	.924**	–.957**	.974**	–.952**	–.977**	.979**	–.950**	.683*
DDT		.937**	–.704	.967**	.036	–.741*	.431	.260	–.110	.599	–.410	–.171	.575	–.619	.422	.380	–.427	.342	–.341
Stability			–.849**	.828*	–.311	–.540	.128	-.070	–.443	.828*	–.676	–.469	.805*	–.832*	.685	.658	–.693	.627	–.564
DoS				-.613	.484	.054	.321	.461	.678	–.939**	.897**	.762*	–.934**	.957**	–.835**	–.830*	.859**	–.792*	.750*
FQN					.269	–.759*	.548	.417	.098	.434	–.244	–.016	.408	–.465	.245	.193	–.243	.141	–.192
PT						–.444	.784*	.890**	.965**	–.723*	.807*	.830*	–.737*	.689	–.801*	–.844**	.824*	–.879**	.702
PV							–.886**	–.766*	–.435	.011	–.246	–.432	.043	–.007	.169	.198	–.169	.239	–.208
SB								.976**	.799*	–.444	.636	.766*	–.474	.432	–.558	–.616	.589	–.636	.550
BD									.910**	–.610	.770*	.858**	–.635	.593	–.706	–.757*	.735*	–.779*	.663
%RSA										–.848**	.919**	.943**	–.851**	.835**	–.859**	–.908**	.926**	–.929**	.680*
L*											–.973**	–.869**	.956**	–.987**	.953**	.948**	–.941**	.905**	–.639*
a*												.915**	–.947**	.965**	–.950**	–.960**	.964**	–.932**	.683*
b*													–.833**	.856**	–.888**	–.879**	.894**	–.903**	.549
CT														–.952**	.908**	.946**	–.937**	.861**	–.635*
CL															–.944**	–.953**	.950**	–.912**	.652*
WU																.917**	–.905**	.918**	–.504
MC																	–.978**	.905**	–.717**
Ash																		–.945**	.711**
Protein																			–.655*

Where, WCF; Water chestnut flour, DDT; Dough development time, DoS; Degree of softening, FQN, Farinograph quality number, PT; Pasting temperature, PV; Peak viscosities, SB setback, BD; breakdown viscosity, %RSA; Per cent radical scavenging activity, L* value; lightness (100: perfect white /0: perfect black), a* value; (+) redness/(-) greenness, b* value; (+) yellowness/(-) blueness, CT; Cooking time, CL; Cooking loss, WU; Water uptake by noodles, MC, Moisture content of ramen noodles.

negative correlation with partial substitution with WCF. Furthermore, statistically significant and positive correlation of fibre content existed between DoS of WCF and CL of ramen noodles.

Conclusion

The study highlights the utilization of a nonconventional resource to develop healthier food options and contribute to sustainability in the food industry. The findings suggested that there is an opportunity to develop nutraceutical noodles with supplementation by non-traditional sources such as WCF, owing to the pronounced improvement in antioxidant potential, mineral and fibre contents, and with lower calorie and fat content. However, regarding various treatments carried out in this study (substitution with chestnut flour at 30, 40, and 50%) only substitutions up to 40% give acceptable outcomes. As the percentage of WCF increases, the gluten content reduces, thus hardness of noodles and CL increase. Therefore, fortification from 50% or onwards will negatively affect the physical properties of noodles. The sensory analysis showed that the incorporation of WCF in the ramen noodle recipe influenced the response of panelists and characterized the food product. Further research is needed to optimize the formulations with additives and different processing conditions for WCF-based Ramen noodles to enhance their commercial viability.

Author Contributions

Mehak Ahsan, Abeera Moin and Angelo Maria Giuffrè conceptualized the study; the methodology was formulated by Mehak Ahsan; Abeera Moin and Angelo Maria Giuffrè were in charge of software; validation was done by Abeera Moin, Humaira Ashraf and Angelo Maria Giuffrè; formal analysis was performed by Abeera Moin, Iqra Manzoor and Maliha Kamran; Iqra Manzoor and Maliha Kamran initiated the study; Mehak Ahsan did the data curation; Abeera Moin was in charge of resources; original draft preparation was done by Abeera Moin; review and editing was done by Mehak Ahsan, Abeera Moin and Angelo Maria Giuffrè; visualization was done by Mehak Ahsan, Abeera Moin and Angelo Maria Giuffrè; Humaira Ashraf, Abeera Moin and Angelo Maria Giuffrè supervised the study; project administration was done by Mehak Ahsan and funding acquisition was done by Angelo Maria Giuffrè.

Acknowledgments

This research was supported by PON03PE_00090_1 fund: "Process and product innovations in baked products and confectionary food chain". All authors are grateful to Mr. Munawar Hussain, English Biscuits Pvt. Ltd., for facilitating the study.

References

Agama-Acevedo E., Islas-Hernandez J.J., Osorio-Díaz, P., Rendón-Villalobos, R., Utrilla-Coello R.G., Angulo O., et al. 2009. Pasta with unripe banana flour: physical, texture, and preference study. J. Food Sci. 74(6):S263–S7. https://doi.org/10.1111/j.1750-3841.2009.01215.x

Ahmed J., Al-Attar H.and Arfat Y.A. 2016. Effect of particle size on compositional, functional, pasting and rheological properties of commercial water chestnut flour. Food Hydrocol. 52:888. https://doi.org/10.1016/j.foodhyd.2015.08.028

Alam H.M., Naeem R., Rubab G., Bilal H., Arooj H., Ashraf I., et al. 2021. Physicochemical Properties of Water Chestnut. Pak. J. Health Sci .2(1):08–13. https://doi.org/10.54393/pjhs.v2i01.36

Altiner D.D. and Merve M. 2020. An investigation of the effect of chestnut flour additive on the nutritional and quality properties of noodle. J. Food 45(6):1061–1072. https://doi.org/10.15237/gida.GD20083

Badaruddin M. 2004. Extrusion properties and cooking quality of spaghetti containing buckwheat bran flour. Cereal Chem. 81(2):232. https://doi.org/10.1094/CCHEM.2004.81.2.232

Biao Y., Chen X., Wang S., Chen, G., Mcclements, D.J. and Zhao, L. 2020. Impact of mushroom (pleurotuseryngii) flour upon quality attributes of wheat dough and functional cookies-baked products. Food Sci. Nutr. 8(1): 361. https://doi.org/10.1002/fsn3.1315

Committee AAOCCAM. 2000. Approved methods of the American association of cereal chemists. AACC.

de Carvalho Correa A., Savioli Lopes M., Firmani Perna R. and Keven Silva E. 2024. Fructan-type prebiotic dietary fibers: Clinical studies reporting health impacts and recent advances in their technological application in bakery, dairy, meat products and beverages. Carbohydrate Polymers 323: 121396. https://doi.org/10.1016/j.carbpol.2023.121396

Deng C., Melnyk O. and Luo Y. 2023. Substitution of wheat flour with modified potato starch affects texture properties of dough and the quality of fresh noodles. Food Sci. Technol. 43: e128222. https://doi.org/10.1590/fst.128222

Du J., Li Q., Obadi M., Qi Y, Liu S., Di an, et al. 2021. Quality Evaluation Systems and Methods of the Whole Making Process of Asian Noodles: A Review. Food Rev. Int. 39(677): 1–28. https://doi.org/10.1080/87559129.2021.2013871

Ghadarloo S., Mansouripour S. and Saremnezhad S. 2023. Effect of the mixture of oleaster (*E. angustifolia* L.) and black cumin (*Nigella sativa*) flours as functional compounds on the quality characteristics of toast bread. Food Sci. Nutr. 15,11(8): 4678–4687. https://doi.org/10.1002/fsn3.3430

Gen Y., Lv W. and Brennan C.S. 2022. Influence of substituting wheat flour with quinoa flour on quality characteristics and in vitro starch and protein digestibility of fried-free instant noodles. LWT. 165: 113686. https://doi.org/10.1016/j.lwt.2022.113686.

Giuffrè A.M., Caracciolo M., Capocasale M., Zappia C. and Poiana M. 2022. Effects of shortening replacement with extra virgin olive oil on the physical–chemical–sensory properties of Italian Cantuccini biscuits. Foods 11: 299. https://doi.org/10.3390/foods11030299

Giuffrè A.M., Caracciolo M., Zappia C., Capocasale M. and Poiana M. 2023. Breadsticks Flavoured with Olives and Onions: One-Year Shelf Life. Foods 12: 1798. https://doi.org/10.3390/foods12091798

Giuffrè D. and Giuffrè A.M. 2023. Mediterranean diet and health in the elderly. AIMS Public Health 10(3): 568–576. https://doi.org/10.3934/publichealth.2023040

Hou G., Center W.M. and Cato L. 2015. AACCI Approved Methods Technical Committee Report on the Guidelines for Laboratory Preparation of Japanese Udon Noodles. Cereal Food World 60(3):140.

Hou G.G. 2010. Asian noodles: Science, technology, and processing: John Wiley & Sons.

Jana B. 2019. Exploring aquatic horticultural crops for higher income of farmers living in water surplus ecology. ICAR Research Complex for Eastern Region, Patna, India, (19–26 December), 61.

Kaur K., Kaur G. and Singh A. 2023. Water chestnut starch: extraction, chemical composition, properties, modifications, and application concerns. Sust. Food Technol. 1: 228. https://doi.org/10.1039/d2fb00041e

KosovIć I., Jukić M., Jozinović, A., Ačkar Đ. and Komlenić D.K. 2016. Influence of chestnut flour addition on quality characteristics of pasta made on extruder and minipress. Czech J. Food Sci. 34(2): 166. https://doi.org/10.17221/451/2015-CJFS

Krishnaiya R., Kasar C. and Gupta S. 2016. Influence of water chestnut (*Trapa natans*) on chemical, rheological, sensory and nutritional characteristics of muffins. J. Food Meas. Charact. 10: 210–219. https://doi.org/10.1007/s11694-015-9295-7

Li M, Sun Q-J, Han C-W, Chen H-H. and Tang W-T. 2018. Comparative study of the quality characteristics of fresh noodles with regular salt and alkali and the underlying mechanisms. Food Chem. 25(246):335–342. https://doi.org/10.1016/j.foodchem.2017.11.020

Littardi P., Paciulli M., Carini E., Rinaldi M., Rodolfi M. and Chiavaro E. 2020. Quality evaluation of chestnut flour addition on fresh pasta. LWT 126:109303.

Mansoor R., Ali T.M., Arif S., Moin A. and Hasnain A. 2019. Effects of barley flour on dough rheology, texture, sensory and glycemic index of traditional unleavened flat bread (Roti). Cereal Chem. 96(6):1170. https://doi.org/10.1002/cche

Manthey F.A., Yalla S.R. and Dick T.J., Marconi E., Carcea M. 2001. Pasta from nontraditional raw materials. Cereal Foods World 46(11):522.

Masutti M.F., Patrignani M. and Conforti P.A. 2020. Development and characterization of cracker fillings with natural antioxidants. J. Food Meas. Charact. 14: 446–454. https://doi.org/10.1007/s11694-019-00306-1

Mer P., Awasthi P. and Shahi, N.C. 2022. Development, quality evaluation, and numerical optimization of process parameters of water chestnut (*Trapa natans*) flour incorporated rusk. J. Food Process. Pres. 46, e16981. https://doi.org/10.1111/jfpp.16981

Michalak-Majewska M., Teterycz D., Muszyński S., Radzki W. and Sykut-Domańska E. 2020. Influence of onion skin powder on nutritional and quality attributes of wheat pasta. PLoS ONE 15(1): e0227942. https://doi.org/10.1371/journal.pone.0227942

Moin A., Ali T.M. and Hasnain A. 2016. Effect of succinylation on functional and morphological properties of starches from broken kernels of Pakistani Basmati and Irri rice cultivars. Food Chem. 15(191):52–58. https://doi.org/10.1016/j.foodchem.2015.03.119

Mu J., Qi Y., Gong K., Chen Z., Brennan M.A., Ma Q. and Brennan C.S. 2022. Influence of substituting wheat flour with quinoa flour on quality characteristics and in vitro starch and protein digestibility of fried-free instant noodles. L.W.T. 165(3): 113686.

Rajkumar P. and Rajithasri M. 2022. Water chestnut: Growing conditions, nutritional and phytochemical composition, novel extraction methods and health properties. Pharma Innov. Inl. J. 11(7):599.

Rani S., Singh R., Kamble D.B., Upadhyay A. and Kaur B.P. 2019. Structural and quality evaluation of soy enriched functional noodles. Food Biosci. 32:100465. https://doi.org/10.1016/j.fbio.2019.100465

Ritthiruangdej P., Parnbankled S., Donchedee S. and Wongsagonsup R. 2011. Physical, chemical, textural and sensory properties of dried wheat noodles supplemented with unripe banana flour. Agric. Nat. Res. 45(3):500.

Saeed S.M.G., Ali S.A., Faheem K., Ali R. and Giuffrè A.M. 2022. The Impact of Innovative Plant Sources (*Cordia myxa* L. Fruit (Assyrian Plum) and *Phoenix dactylifera* L. Biowaste (Date Pit)) on the Physicochemical, Microstructural, Nutritional, and Sensorial Properties of Gluten-Free Biscuits. Foods 11(15): 2346. https://doi.org/10.3390/foods11152346

Samaan J., El-Khayat G.H., Manthey F.A., Fuller M.P. and Brennan C.S. 2006. Durum wheat quality: II. The relationship of kernel physicochemical composition to semolina quality and end product utilisation. Int. J. Food Sci. Technol. 41:47. https://doi.org/10.1111/j.1365-2621.2006.01313.x

Shafi M., Baba W.N. and Masoodi F. 2017. Composite flour blends: Influence of particle size of water chestnut flour on nutraceutical potential and quality of Indian flat breads. J. Food Measur. Character. 11:1094–1105. https://doi.org/10.1007/s11694-017-9486-5

Shafi M., Baba W.N., Masoodi F.A. and Bazaz R. 2016. Wheat-water chestnut flour blends: effect of baking on antioxidant properties of cookies. J. Food Sci. Technol. 53:4278. https://doi.org/10.1007/s13197-016-2423-5

Shiau S-Y, Yeh A-I. 2001. Effects of alkali and acid on dough rheological properties and characteristics of extruded noodles. J.Cereal Sci. 33(1):27–37. https://doi.org/10.1006/jcrs.2000.0344

Sidari R., Martorana A., Zappia C., Mincione A. and Giuffrè A.M. 2020. Persistence and effect of a multi-strain starter culture on antioxidant and rheological properties of novel wheat sourdoughs and breads. Foods 9 (9): 1258. https://doi.org/10.3390/foods9091258

Sindhuja A., Sudha M.L. and Rahim A. 2005. Effect of incorporation of amaranth flour on the quality of cookies. Eur.

Food Res. Technol. 221:597–601. https://doi.org/10.1007/s00217-005-0039-5

Singh J., Kaur S. and Rasane P. 2018. Evaluation of the nutritional and quality characteristics of black carrot fortified instant noodles. Curr. Nutr. Food Sci. 14(5):442–449. https://doi.org/10.2174/1573401313666170724115548

Singh S. and Singh N. 2010. Effect of debranning on the physico-chemical, cooking, pasting and textural properties of common and durum wheat varieties. Food Res. Int. 43(9):2277. https://doi.org/10.1016/j.foodres.2010.07.016

Švec I., Hrušková M. and Kadlčíková I. 2018. Features of flour composites based on the wheat or wheat-barley flour combined with acorn and chestnut. Croatian J. Food Sci. Technol. 10(1):89. https://doi.org/10.17508/CJFST.2018.10.1.16

Tan H.L., Tan T. C. and Easa A. M. 2018. The use of selected hydrocolloids to enhance cooking quality and hardness of zero-salt noodles. Int. J. Food Sci. Technol. 53(7): 160. https://doi.org/10.1111/ijfs.13742

Tian S., Gao P., Xue X. and Yang Y. 2022. Effect of malate starch on cooking, texture and digestion characteristics in vitro of medium glycemic noodles. Int. J. Gastro. Food Sci. 29: 100558. http://doi.org/10.1016/j.ijgfs.2022.100558

Tomar A., Suryawanshi L. and Thakur R. 2022 Utilization of water chestnut in noodles and extruded food development. Pharma Innov. 11(7): 2894.

Tong L-T. Gluten-free noodles. Chapter of a Book. *Asian Noodle Manufacturing: Ingredients, Technology, and Quality*. 125–1491. https://doi.org/10.1016/B978-0-12-812873-2.00007-8

Wang L., Shi D., Chen J., Dong H. and Chen L. 2023. Effects of Chinese chestnut powder on starch digestion, texture properties, and staling characteristics of bread. Grain Oil Sci. Technol. 6(2):82. https://doi.org/10.1016/j.gaost.2023.01.001

Wang W. 2014. Quality Improvement of Whole Wheat Precooked Alkaline Noodles. Thesis, University of Minnesota.

Yadav B.S., Yadav R.B., Kumari M. and Khatkar B.S. 2014. Studies on suitability of wheat flour blends with sweet potato, colocasia and water chestnut flours for noodle making. LWT-Food Sci. Technol. 57(1):352. https://doi.org/10.1016/j.lwt.2013.12.042

Yuliantini E., Kamsiah and Yunianto A.E. 2020. Sensory Acceptance and influence of pumpkins (*Cucurbita moschata*) flour in making crispy noodles toward primary school children of Bengkulu. *Syst. Rev. Pharm.* 11 (10): 612–616. https://doi.org/10.31838/srp.2020.10.91

Zhu F. 2017. Properties and food uses of chestnut flour and starch. Food Bioprocess Technol. 10:1173. https://doi.org/10.1007/s11947-017-1909-0

Zi Y., Cheng D., Li H., Guo J., Ju W., Wang C., et al. 2022. Effects of the different waxy proteins on starch biosynthesis, starch physicochemical properties and Chinese noodle quality in wheat. Mol. Breeding 42: 23. https://doi.org/10.1007/s11032-022-01292-x