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Pasta Fortified with Wild Garlic (*Allium ursinum* L.) as a Functional Food Rich in Phenolic Compounds

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In this study, fortified pasta was produced using *Allium ursinum* L. in three forms: powder (5%, 10%, and 15% of the wheat flour weight); blanched and chopped leaves, used to replace 30%, 60%, and 90% (*w/w*) of the mixing liquid, while keeping the flour content constant; and water residue after blanching and chopping (replacing 30%, 60%, and 90%, *w/w,* of the mixing liquid). This approach aimed to identify the optimal formulation for a novel functional pasta with improved bioactive properties. Before and after cooking, each pasta variant was evaluated based on the total phenolic and total flavonoid contents, the antioxidant capacity, and colour parameters, while sensory analysis was conducted only after cooking. All the formulations exhibited acceptable cooking characteristics, with variations noted based on the type and quantity of wild garlic leaf formulation included. Optimum cooking time decreased from 320 s (control) to 180 s for pasta enriched with the highest level of wild garlic leaf powder. The cooking loss in pasta enriched with leaf powder and blanched leaves was found to be higher than in the control, ranging from 3.23% to 6.00%. In terms of colour analysis, these formulations significantly reduced *L** parameter, regardless the enrichment level, in both raw and cooked pasta. Enrichment with leaf powder and blanched and chopped leaves resulted in a higher total phenolic content and improved antioxidant capacity of the pasta samples. Pasta enriched with chopped leaves received the highest sensory scores, followed by pasta containing wild garlic powder, both at a medium level. The study reveals that wild garlic leaves can be utilized as a functional ingredient in pasta production, resulting in innovative, high-quality pasta.

Keywords: antioxidant capacity, blanching, chromatic parameters, cooking quality, enriched pasta, wild garlic leaves

ABBREVIATIONS

ANOVA, analysis of variance; CL, cooking loss; DPPH radical, 2,2-diphenyl-1-picrylhydrazyl radical; FRAP, ferric-reducing antioxidant power; GAE, gallic acid equivalents; HT, hydration test; IPO, International Pasta Organisation; OCT, optimum cooking time; QE, quercetin equivalents; Sa, arithmetic mean height; SI, swelling index; TE, Trolox equivalent; TFC, total flavonoid content; TPC, total phenolic content; TPTZ, 2,4,6-tri(2-pyridyl)-1,3,5--triazine; WA, water absorption.

INTRODUCTION

Since pasta can be prepared and cooked in so many different ways, it is a popular and affordable ingredient in kitchens around the world. The pasta is defined as a cooked, extruded, and dried food made primarily of water and durum wheat semolina, being regarded as an essential food in the human diet worldwide, along with bread and cereal-based products [Cappelli & Cini, 2021; Muresan *et al.*, 2017]. Pasta consumption ranks second globally after bread consumption due to its nutritional qualities, ease

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of preparation, affordability, and commercial availability [Dziki, 2021]. In 2022, the International Pasta Organization (IPO) released a report showing that 16.9 million tons of pasta were produced worldwide, with the following percentages: European Union – 32.8%, the rest of Europe – 17.9%, Central and South America – 17.7%, Africa – 13.8%, North America – 12.9%, Middle East – 3.5%, Asia – 1.4%, and Australia – 0.3% [IPO, 2024]. In terms of pasta consumption *per* capita, the top 5 pasta consuming countries are Italy (23.2 kg), Tunisia (17 kg), Venezuela (13.6 kg), Greece (12.2 kg), and Peru (9.9 kg). Pasta is divided into eight families: spaghetti, tubular pasta, shell pasta, ribbon pasta, short pasta, micropasta, ravioli (filled pasta), and dumplings (pseudo-pasta) [Alexander, 2000]. This classification has been further expanded to include whole-wheat, natural, enriched, flavoured, and fortified pasta forms [Hastaoğlu *et al.*, 2023]. Pasta in some countries (Italy, Greece, and France) must be produced exclusively of durum wheat semolina [Dimitrios, 2024], while pasta in other nations is manufactured with common wheat flour.

As a result of growing demand for high-quality foods and functional foods, intense research is conducted on pasta enriched with additional, natural ingredients, in order to increase its nutritional value and bioactive potential [Dziki, 2021; Sissons, 2022]. The focus is on developing fortified products enriched with plants rich in dietary fibre and antioxidants, including fruits and vegetables, or by-products from the processing of plant and animal raw materials. These ingredients may have a positive effect on human health, although, on the other hand, they affect the technological qualities of pasta, not always in a favourable way. Among the plant materials, powdered leaves are often used as a partial substitute for wheat flour in the pasta production, for example, Bouacida *et al*. [2017] used arugula (*Eruca vesicaria* (L.) Cav.) and spinach (*Spinacia oleraceae* L.) leaf flour at three different levels of wheat semolina substitution (5%, 10% and 20%, *w/w*) and found that pasta with leaf flours had a higher dietary fibre content compared to the control formulation, and that 10% (*w/w*) substitution produced good cooking quality pasta with cooking loss ≤ 8% after 14 days of storage and a high overall acceptability score by consumers. The nutritional and nutraceutical potential of wheat pasta supplemented with powdered parsley leaves (replacing 1–4% of wheat flour, *w/w*) was evaluated by Sęczyk *et al.* [2016]. The findings demonstrated that, in comparison to the control sample, pasta produced with 4% parsley leaf in flour had a 146% higher ABTS cation radical scavenging activity and a 67% higher total phenolic content.

Wild garlic (*Allium ursinum* L.) leaves can also be used as an ingredient to enrich pasta due to their nutritional properties and bioactive compound profile. The sulphur compounds (including cysteine-sulfoxides, thiosulphinates and (poly)sulfides [Kovačević *et al.*, 2023; Sobolewska *et al*., 2015; Vidović *et al.*, 2021] as well as phenolic compounds including phenolic acids and flavonoids (mainly kaempferol derivatives) [Oszmiański *et al.*, 2013; Parvu *et al*., 2010; Wu *et al.*, 2009;] were determined in wild garlic. The leaves of *A. ursinum* are also high in pigments, particularly carotenoids and chlorophylls, as well as vitamin C [Bernaś *et al.*, 2024] and iron, the content of which can reach 230.34 mg/kg [Piątkowska *et al*., 2015]. Owing to their phytochemical composition, *A. ursinum* leaves exhibit antioxidant and antimicrobial properties, cytotoxic potential, and cardioprotective effects [Sobolewska *et al*., 2015].

So far, wild garlic leaves in three different forms (powder, extract, and encapsulated extract) have been used in pasta production by Filipčev *et al.* [2023], who assessed how the cooking process affected the pasta's bioactive compound content, antioxidant capacity, colour and texture, as well as cooking and sensory qualities. In our previous study, pasta enriched with a fixed amount of blanched and chopped wild garlic leaves was prepared, and the effect of different content of eggs in the pasta recipe on cooking properties, nutrition composition, phenolic content and antioxidant capacity of products was analysed [Rosan *et al*., 2024]. However, to the best of our knowledge, pasta enriched with different amounts of blanched leaves has not been studied so far, and no comparisons have been made between pasta enriched with different forms of wild garlic leaves. In this study, pasta was doubly fortified with egg and *Allium ursinum* L. to enhance its nutritional and functional properties. Therefore, the aim of this study was to show how incorporation of various forms of wild garlic at different levels affects the quality indicators, bioactive compound content, antioxidant capacity, colour, microstructure and sensory characteristics of egg pasta. To achieve this, we developed three types of pasta: one with wild garlic powder as a partial flour substitute, one fortified with blanched and chopped wild garlic leaves, and one based on the recovery of the water residue after blanching and chopping the wild garlic leaves.

MATERIALS AND METHODS

Preparation of wild garlic leaf formulations

The leaves of wild garlic (*A. ursinum*) were collected in May 2024 at a site located in the forest near Băile Felix, Bihor County, northwest Romania (46°59′04.0″N 21°58′31.5″E). The plant was identified and recognized by experts from the Faculty of Medicine and Pharmacy of the University of Oradea, Romania. A specimen of the plant, bearing the code UOP 05718, is kept in the herbarium registered at the New York Botanical Garden.

The leaves of wild garlic were sorted, washed and drained to remove excess water. A part of the fresh leaves (3.5 kg) was put into the oven (model CLN 53, Nitech Pol Eko, Wodzisław, Poland) and dried at 30°C until their mass remained constant. Then, the leaves were ground into a fine powder and sieved through a sieve with mesh size of 1 mm to form *A. ursinum* powder (AUP). The low drying temperature was selected to maintain both the distinctive flavour of wild garlic and the particular green hue of the leaves. For the blanching treatment, 3 kg of wild garlic leaves were placed in a stainless-steel vessel, and hot water at 80°C was poured over them at a water-to-leaf ratio of approximately 5:1 (*w/w*). The leaves were gently stirred in the hot water for 2 min to ensure even blanching. After treatment, the leaves were transferred to a fine-mesh sieve and allowed to drain for 5 min to remove excess water. The drained and finely chopped *A. ursinum* leaves (AUL) and the resulting water residue (AUW) after blanching and chopping (by-product) were used in the pasta formulations.

Pasta production

White superior wheat flour 000-type, commercially available (M.P. Băneasa-Moară S.A. Buftea, România), was used for the pasta production. The nutritional value of the flour was as follows (*per* 100 g): 10 g of protein, 0.9 g of fat, 76 g of carbohydrates, and 0.10 g of dietary fibre. In addition, the pasta preparation involved the use of different wild garlic formulations, eggs, water, and kitchen salt. By using three different formulations from *A. ursinum* leaves (leaf powder, blanched and chopped leaves, and water by-product of leaf blanching and chopping) at three different substitution levels (low (L), medium (M), and high (H)), ten different types of pasta were finally obtained, including the control pasta (CTRL), in which no kind of *A. ursinum* formulation was employed. *A. ursinum* leaf powder was used to replace 5%, 10% and 15% (*w/w*) of wheat flour in the pasta recipe and the resulting pasta was designated as AUP_L, AUP_M, and AUP_H, respectively. In the AUL_L, AUL_M, and AUL_H pasta recipes, the mixing liquid (water + eggs) was replaced by blanched and chopped wild garlic leaves at low (30%, *w/w*), medium (60%, *w/*w), and high (90%, *w/w*) levels, respectively, while maintaining a constant wheat flour content of 250 g. The levels of substitution by AUL were selected based on preliminary tests aimed at maintaining dough processability and pasta structure while achieving visible differences in composition. Leaf moisture was taken into account in adjusting water to maintain dough consistency. A by-product obtained from *A. ursinum* leaf blanching and chopping was used to replace water in the final pasta formulation; AUW_L, AUW_M, and AUW_H pasta was produced with 30%, 60%, and 90% (*w/w*) substitution of the mixing liquid by AUW, respectively. The ingredients for the control pasta were: wheat flour, egg, salt, and water. The coding of the pasta samples and the ingredients used are summarised in **Table 1**. Each of the ten pasta types was produced in triplicate. In total, 30 batches of pasta were made for this study.

The ingredients for each type of dough were mixed, and dough was kneaded by hand for 10 min, allowed to rest for 1 h, shaped to 3 mm thickness and separated into 7 mm wide strips with a Grünberg GR 155 cutting machine purchased from eMAG, Romania. The resulting raw pasta was dried at 30°C until its weight remained constant and was used for future analyses. A portion of each dried raw pasta was cooked in water for optimum cooking time (determined as described below). The cooked pasta was dried at 30°C for analyses of total phenolic content, total flavonoid content and antioxidant capacity.

Cooking properties determinations

Determination of the optimum cooking time

Determination was performed using AACC International approved method no. 66-50.01 [AACC, 2010]. After adding 25 g of raw dried pasta to 300 mL of boiling water, the mixture was brought to a boiling point. During cooking, pasta samples were taken at 30-s intervals and their texture was assessed by

Table 1. The ingredients of pasta enriched with *Allium ursinum* L. leaf powder (AUP), blanched and chopped leaves (AUL), and water by-product of leaf blanching and chopping (AUW).

Ingredient	Control	AUP_L	AUP_M	AUP_H	AUL_L	AUL_M	AUL_H	AUW_L	AUW_M	AUW_H
Wheat flour (g)	250	237.5	225	212.5	250	250	250	250	250	250
Egg (g)	10	10	10	10	10	10	10	10	10	10
A. ursinum leaf powder (g)	–	12.5	25	37.5	–		–	–	–	–
Blanched and chopped *A. ursinum* leaves (g)	–	–	–	–	30	60	90	–	–	–
Water by-product (g)	–	–	–	–	–	-	–	30	60	90
Water (g)	90	90	90	90	60	30	–	60	30	–
Salt (g)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

squeezing them between two transparent glass slides. The optimum cooking time (OCT) was considered to be the time needed for the white core of the pasta to disappear in this test. The measurements were performed in triplicate.

Determination of cooking loss

Ten g of the dry pasta were cooked in 100 mL of water until the OCT had been reached. After cooking, water was refilled to its initial volume, and 25 mL of cooking water were dried to a constant weight at 105°C [Chetrariu & Dabija, 2021]. From the weighed residue, the solid content of the cooking water was determined and cooking loss (CL, %) was calculated as g of solids lost into the cooking water *per* 100 g of pasta.

Swelling index determination

Pasta cooked as described above for CL determination, was drained for a few minutes, weighed ($w_{cooked\ pasta}$), and then dried in an oven at 105°C until reaching a constant weight ($w_{dry\ pasta}$). The swelling index (SI) was calculated using Equation (1) [Gopalakrishnan *et al.*, 2011]:

$$SI\ (g/g) = \frac{w_{cooked\ pasta} - w_{dry\ pasta}}{w_{dry\ pasta}} \tag{1}$$

Determination of water absorption of pasta

The water absorption (WA) of pasta during cooking was determined by measuring the weight of the pasta before cooking ($w_{before\ cooking}$) and after cooking at the optimum cooking time ($w_{after\ cooking}$). The WA was calculated using Equation (2) [Chetrariu & Dabija, 2021]:

$$WA\ (\%) = \frac{w_{after\ cooking} - w_{before\ cooking}}{w_{after\ cooking}} \times 100 \tag{2}$$

Hydration test

Five g of the pasta ($w_{raw\ pasta}$) were kept at 25°C in a glass vessel with 100 mL of water. After incubation periods of 5, 10, 15, 30, 60, 90, and 180 min, the samples were taken out and drained for 1 min before being weighed ($w_{hydrated\ pasta}$). The hydration of pasta was calculated according Equation (3) [Chetrariu & Dabija, 2021]:

$$Hydration\ (\%) = \frac{w_{hydrated\ pasta} - w_{raw\ pasta}}{w_{raw\ pasta}} \times 100 \tag{3}$$

The samples were analysed in triplicate, and the curves of pasta hydration *vs*. time of hydration were plotted.

Determination of total phenolic content and total flavonoid content

The pasta was extracted using the method suggested by Filipčev *et al.* [2023]. Briefly, 1 g of raw and cooked dried pasta (previously ground) were combined with 2.5 mL of a mixture of ethanol and water (4:1, *v/v*). After 15 min of sonication at 40°C, the suspension was centrifuged for 10 min at 1,000×*g* using an NF 200 centrifuge (Nüve, Ankara, Turkey). The supernatant was used for the analyses outlined below.

The total phenolic content (TPC) was determined using the Folin-Ciocalteu reagent [Singleton *et al.*, 1999]. Briefly, 100 µL of the pasta extract were mixed with 1,700 µL of distilled water and 200 µL of freshly diluted Folin-Ciocalteu reagent (1:10, *v/v*), and shaken vigorously. Thereafter, 1,000 µL of a 7.5% Na_2CO_3 solution were added, and the mixture was kept for 2 h at room temperature in the dark. The absorbance was measured at a wavelength of 765 nm using a Shimadzu 1240 mini-UV-Vis spectrophotometer (Kyoto, Japan). Gallic acid solutions in a concentration range of 0.1–0.5 mg/mL were used for the calibration curve. A regression equation of the resulting curve was y=25.42x+0.010 with a coefficient of determination (R^2) of 0.9933. The results were reported as mg of gallic acid equivalents (GAE) *per* g of pasta dry weight (dw).

The total flavonoid content (TFC) of the pasta was determined using the aluminium chloride colorimetric method according to the procedure described by Marinelli *et al.* [2015] with some modifications. In brief, 1 mL of extract was transferred to a 10 mL volumetric flask, which already contained 4 mL of distilled water. Subsequently, 300 µL of a 5% $NaNO_2$ solution were added. After 5 min, a volume of 300 µL of a 10% $AlCl_3$ solution was introduced. Following additional 6 min, 2 µL of a 1 M NaOH solution were added. The flask volume was adjusted with distilled water, and then it was thoroughly mixed. The absorbance was recorded at a wavelength of 510 nm (Shimadzu 1240 mini-UV-Vis spectrophotometer) in comparison to a blank sample. The total flavonoid content was calculated using quercetin as a standard. The calibration curve was plotted using a concentration range of quercetin solutions (0.1–0.5 mg/mL), resulting in the regression equation: y=1.27x+0.090 (R^2=0.9988). The results were expressed as mg of quercetin equivalents (QE) *per* g of pasta dw.

Antioxidant capacity determination

The 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity of pasta was determined according to the method of Brand-Williams *et al.* [1995]. To this end, 100 µL of the extract were combined with 2,800 µL of a freshly prepared 80 µM DPPH radical solution. The mixture was then incubated in darkness at room temperature for exactly 30 min. The measurement of absorbance was conducted at a wavelength of 517 nm, and the results were quantified as µmol Trolox equivalents (TE) *per* g of pasta dw based on the calibration curve (y=962.19x+1.2931, R^2=0.9977) made with different concentration of Trolox (0.05–1.00 mM).

The ferric-reducing antioxidant power (FRAP) assay was based on the work of Benzie & Strain [1996], with some modifications [Vicas *et al.*, 2009]. The stock solutions were prepared: a 300 mM acetate buffer with a pH of 3.6, a 20 mM solution of $FeCl_3 \times 6\ H_2O$, and a 10 mM solution of 2,4,6-tri(2-pyridyl)-1,3,5--triazine (TPTZ) in 40 mM HCl. The FRAP solution was prepared by combining acetate buffer, $FeCl_3 \times 6\ H_2O$ solution, and a TPTZ solution in a volumetric ratio of 10:1:1. Pasta extract (100 µL) was mixed with 500 µL of the FRAP solution and 2 mL of distilled water. The mixture was left to react for 1 h in a dark environment. The absorbance was recorded at 595 nm, using a Shimadzu 1240 mini-UV-Vis spectrophotometer. The results were quantified as µmol TE *per* g of pasta dw (calibration curve regression equation: y=14.32x+0.019, R^2=0.9978).

Chromatic analysis

Pasta samples (raw and cooked) were scanned at a resolution of 600 dpi with a CanoScan 9000F scanner (Canon Inc., Tokyo, Japan). This optical image resolution generated 0.0423 mm *per* pixel and a two-dimensional definition of 1,791 μ^2. Background noise and additive noise were eliminated from the scanned image prior to processing the data in order to prevent image distortion that could produce inaccurate results. These issues have been resolved by using algorithms for contour reduction and Gaussian noise reduction. The chromatic parameters of the CIELab space, including L^* (lightness), a^* (greenness/redness), and b^* (blueness/yellowness), were examined. Moreover, total colour difference (ΔE) between each wild garlic enriched pasta (with L^*, a^* and b^* values) and the control pasta (with L_0^*, a_0^*, and b_0^* values) was calculated using Equation (4):

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (4)$$

Determination of surface roughness parameter and microstructure characteristics

The surface of raw pasta samples was visualized using a laser scanning confocal microscope (KEYENCE, model XYZ123, Keyence Corporation, Osaka, Japan). The system was operated using KEYENCE VK_X3100 software, while the images were captured at different magnifications: 250×; 1,250×; and 3,750×, and three distinct areas were considered during scanning. Arithmetical mean height (Sa) was employed as a characteristic surface roughness parameter, representing, as an absolute value, the difference in height of each point compared to the arithmetical mean of the surface.

Sensory evaluation of cooked pasta

A preliminary consumer test was carried out to evaluate the acceptability of the cooked pasta samples. The panel consisted of 21 participants (6 males and 15 females), aged between 19 and 55 years, all of whom had prior experience with sensory evaluation techniques.The hedonic test was applied utilizing a linear hedonic scale of nine points, where 1 represents "extremely unpleasant" and 9 denotes "extremely pleasant." This analysis focused on various sensory attributes, including appearance, form, texture, colour, stickiness, aroma, taste, and chewiness. The overall quality score for each sample was determined by calculating the mean of the individual scores given by the participants, divided by the total number of participants.

Dried pasta samples were cooked at OCT and served to the evaluators separately on white plates at ambient temperature. The results provide indicative insights into consumer perception and should be considered preliminary due to the limited and non-representative consumer panel size.

Statistical analysis

Each type of pasta was produced in triplicate, and results were expressed as mean and standard deviation (SD). Data for each parameter included in the study were analysed using one-way analysis of variance (ANOVA) followed by completed post-hoc multiple pairwise comparisons of means *via* Tukey's test. Differences among pasta variants were considered significant at $p<0.05$.

RESULTS AND DISCUSSION

This section discusses the impact of wild garlic fortification on the culinary properties, polyphenol content, colour parameters, antioxidant characteristics, and sensory attributes of pasta. Three formulations from wild garlic leaves as a pasta ingredient were used in the study: dried leaf powder, blanched and chopped leaves, and blanching residue. Enriching pasta by replacing wheat flour with dried plant material in the powder form is a common practice [Bianchi *et al*., 2021]. In turn, the thermal treatment applied to the leaves was performed in order to improve their texture for subsequent processing. The thermal treatment results in cellular turgor loss, leading to cell membrane destruction, while simultaneously inducing alterations in the polymers of the cell wall, particularly the pectic compounds [Einhorn-Stoll *et al*., 2007]. The blanching concurrently releases nutrients (minerals, vitamins, carbohydrates, proteins) from plant tissues into the water [Xiao *et al*., 2017]. To recover some of the nutrients lost during leaf processing, a third set of pasta was prepared using the water by-product remaining after leaf blanching and chopping.

Influence of formulations from wild garlic leaves on the cooking properties of pasta

The cooking properties, including OCT, SI, CL, WA, of pasta enriched at three different levels with wild garlic leaf powder, blanched and chopped leaves, and water by-product of leaf blanching and chopping were examined compared to the control sample (without wild garlic), and the results are shown in **Table 2**. Furthermore, the HT results are presented in **Figure 1**. Since each replicate for OCT determination produced identical values within each paste group (SD=0.00), statistical significance could not be established. However, differences between samples compared to the control were observed. The AUP pasta variants exhibited a visible reduction in OCT compared to the control, which depended on the amount of the powder used in pasta recipe. The increased substitution of wheat flour by wild garlic leaf powder led to a lesser reduction in OCT. In contrast, there was a minor difference among the AUL pasta types, with the observed decrease being lesser when compared to the control. In the third set of pasta samples (these with AUW), the OCT was almost identical to the control. The decrease in OCT of AUP and AUL pasta samples might be due to changes in the wheat protein structure caused by compounds found in wild garlic leaves, like phenolics

Table 2. Cooking properties of pasta enriched with *Allium ursinum* L. leaf powder (AUP), blanched and chopped leaves (AUL), and water by-product of leaf blanching and chopping (AUW).

Pasta	OCT(s)	WA (%)	SI (g/g)	CL (%)
CTRL	320±0.00	182±7^{ab}	3.06±0.03^{a}	3.47±0.42^{cd}
AUP_L	300±0.00	178±8^{ab}	2.35±0.02^{bc}	4.27±0.72^{b}
AUP_M	210±0.00	165±14^{ab}	2.29±0.28^{bc}	5.47±0.31^{a}
AUP_H	180±0.00	148±23^{b}	1.98±0.32^{c}	6.00±0.10^{a}
AUL_L	270±0.00	198±32^{a}	2.56±0.36^{b}	3.23±0.35^{d}
AUL_M	240±0.00	180±18^{ab}	2.27±0.17^{bc}	3.93±0.15^{bc}
AUL_H	240±0.00	194±12^{a}	2.60±0.07^{b}	3.97±0.06^{bc}
AUW_L	330±0.00	189±36^{a}	2.45±0.37^{b}	3.53±0.06^{cd}
AUW_M	330±0.00	174±6^{ab}	2.20±0.04^{bc}	3.23±0.45^{d}
AUW_H	330±0.00	179±1^{ab}	2.22±0.03^{bc}	3.73±0.15^{bcd}

Results are expressed as mean ± standard deviation (n=3). Different letters in the same column correspond to significant differences (p<0.05). OCT, optimum cooking time; WA, water absorption; SI, swelling index; CL, cooking loss. Pasta coding: CTRL, control without wild garlic; AUP_L, AUP_M and AUP_H, pasta produced with 5%, 10% and 15% (*w/w*) substitution of wheat flour by AUP, respectively; AUL_L, AUL_M and AUL_H, pasta produced with 30%, 60% and 90% (*w/w*) substitution of mixing liquid by AUL, respectively; AUW_L, AUW_M and AUW_H, pasta produced with 30%, 70% and 90% (*w/w*) substitution of mixing liquid by AUW, respectively.

and dietary fiber. Bustos *et al.* [2019] achieved similar results when they incorporated dried berry fruits in pasta recipe. This resulted in a decrease in OCT compared to the control sample; however, the level of substitution had no impact on OCT.

As the level of mixing liquid substitution by wild garlic powder increased, the water absorption in the AUP pasta set slightly decreased, but without statistically significant differences (p≥0.05) (**Table 2**). Moreover, the incorporation of different wild garlic formulations into the pasta at low and medium levels had an insignificant (p≥0.05) impact on WA. Significant differences (p<0.05) were found only between pasta with the highest substitution level (AUP_H and AUL_H pasta). In our previous study, the addition of wild garlic leaves into pasta led to a significant increase in WA compared to the control samples with different egg quantities [Rosan *et al.*, 2024]. On the other hand, SI varied significantly between control pasta (3.06 g/g) and all enriched pasta samples for which it ranged from 1.98 to 2.60 g/g (**Table 2**). The SI of the AUP pasta set showed a decreasing trend with increasing the amount of wild garlic leaf powder in pasta recipe, although the differences between the samples were not statistically significant (p≥0.05). The acceptability of pasta quality was determined by its ability to absorb water (150–200 g/100 g of pasta) and achieve an SI of approximately 1.8 [Bustos *et al.*, 2019]. That estimation did not take into account pasta containing additional non-starch ingredients, which could potentially impact both of those parameters, as well as the microstructure of the pasta [Del Nobile *et al.*, 2005].

When wild garlic leaf powder was used in the pasta production, CL increased significantly (p<0.05) compared to the control, and this increase was directly proportional to the increase in the level of substitution by AUP (**Table 2**). When compared to the control, CL did not exhibit statistically significant changes (p≥0.05) in the other two pasta sets (AUL and AUW). The literature indicates that pasta with a cooking loss of up to 8% is considered acceptable [Bianchi *et al.*, 2021]. The pasta produced in our study conformed to this requirement.

The hydration test involves immersing dried pasta in water at a constant temperature of 25°C and recording its weight at various points in time. This test provides significant insights into the quality of the pasta [Chetrariu & Dabija, 2021; Rosan *et al.*, 2024]. In our study, the hydration test revealed that all pasta samples enriched with AUP and AUL exhibited higher hydration compared to the control (**Figure 1**). This effect was influenced by both the form of wild garlic incorporated and the level of substitution. In the case of AUP pasta, a rapid increase in hydration was observed during the first 30 min, followed by a plateau phase, and a slight decrease at 180 min (**Figure 1A**). This result can probably be attributed to the fine particle size and a high surface area of wild garlic powder, which promoted water absorption. For AUL pasta (**Figure 1B**), the plateau occurred later, at around 60 min, possibly due to the physical barrier effect of the wild garlic leaf fragments, which delays water penetration. In contrast, AUW pasta showed a hydration pattern comparable to that of the control (**Figure 1C**). Chetrariu & Dabija [2021] did not explicitly report hydration values of HT; they demonstrated that spelt pasta enriched with spent grain showed altered water absorption behaviour, evidenced by changes in texture and moisture distribution, that aligns with increased hydration rates commonly associated with fiber-rich additive matrices. In another study [Schettino *et al.*, 2021], pasta containing fermented spent grain (fBSG-p) exhibited the fastest water absorption, reaching equilibrium before the other samples (native spent grain pasta and control

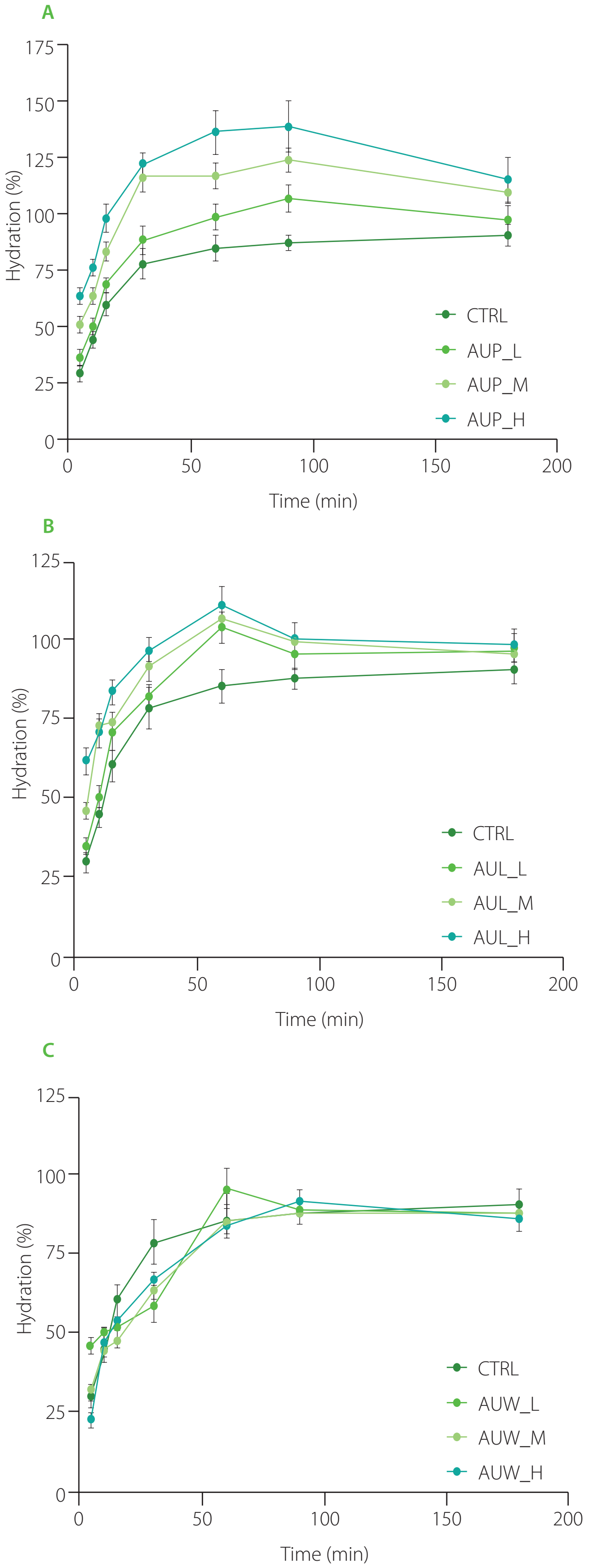

Figure 1. Results of a hydration test of pasta enriched with *Allium ursinum* L. leaf powder (AUP) (**A**), blanched and chopped leaves (AUL) (**B**), and water by-product of leaf blanching and chopping (AUW) (**C**) at 25°C over a period of 180 min. Pasta coding: CTRL, control without wild garlic; AUP_L, AUP_M and AUP_H, pasta produced with 5%, 10% and 15% (*w/w*) substitution of wheat flour by AUP, respectively; AUL_L, AUL_M and AUL_H, pasta produced with 30%, 60% and 90% (*w/w*) substitution of mixing liquid by AUL, respectively; AUW_L, AUW_M and AUW_H, pasta produced with 30%, 70% and 90% (*w/w*) substitution of mixing liquid by AUW, respectively.

pasta). The accelerated hydration observed with fBSG-p is likely due to its more porous microstructure and a higher soluble fiber content resulting from bioprocessing, which facilitates improved water penetration and retention.

■ Total phenolic content, total flavonoid content, and antioxidant capacity of pasta enriched with formulations from wild garlic leaves

TPC and TFC determined in both the raw and cooked forms of the pasta enriched with *A. ursinum* leaf powder, blanched and chopped leaves and by-product of leaf blanching and chopping, as well as the control pasta are presented in **Table 3**. Raw pasta enriched with wild garlic leaf powder showed a significantly higher ($p<0.05$) TPC than the CTRL, and the difference was depended on the amount of AUP used in pasta production. While the differences between AUL samples were statistically insignificant ($p\geq0.05$), in the case of the second set of raw pasta containing blanched and chopped leaves of *A. ursinum*, noticeably increased TPC was observed compared to the CTRL. When considering raw pasta with by-product, regardless of the amount of AUW used in its production, no significant differences ($p\geq0.05$) were found in the total phenolic content of the enriched and control pasta. When compared to the other raw pasta variants, the pasta enriched with AUP had the highest TPC, ranging from 2.48 to 3.72 mg GAE/g dw. The total flavonoid content of raw pasta samples followed the same trends as the total phenolic content. The highest TFC was determined in the AUP_H pastas – 0.31 mg QE/g dw. The increase in TPC and TFC of pasta enriched with AUP and AUL was expected due to the high phenolic content of wild garlic leaves [Cinkmanis *et al.*, 2022; Kovačević *et al.*, 2023; Tóth *et al.*, 2018]. Tóth *et al.* [2018] and Lachowicz *et al.* [2017] reported that the TPC of wild garlic leaves was dependent on the maturity stage of the plant and was the highest in June, *i.e.*, 827 and 470 mg GAE/kg of fresh weight, respectively. In turn, Kovačević *et al.* [2023] reported that TPC of *A. ursinum* leaves collected from different locations in Croatia ranged from 9.96 to 11.2 mg GAE/g dw. According to literature, the phenolic compounds occurring in wild garlic leaves include mainly kaempferol derivatives [Oszmiański *et al.*, 2013] followed by *p*-coumaric and ferulic acids [Parvu *et al.*, 2010]. Another study demonstrated that, gallic acid, ferulic acid, caffeic acid, chlorogenic acid, and synaptic acid were the main phenolic acids in wild garlic leaves, while the main flavonoids identified in bear's garlic leaves were rutin, catechin hydrate, and epicatechin [Cinkmanis *et al.*, 2022].

Two methods were used to evaluate the antioxidant capacity of the pasta, and respective results are shown in **Table 3**. While the FRAP method refers to the reduction of Fe^{+3} ions to Fe^{+2} within the TPTZ complex [Benzie & Strain, 1996], the DPPH assay demonstrates the ability to scavenge the DPPH radical [Brand-Williams *et al.*, 1995]. The highest DPPH radical scavenging capacity and ferric-reducing antioxidant power were demonstrated by the raw AUP_H pasta with values of 19.09 and 6.26 µmol TE/g dw, respectively. Compared to the control,

Tabel 3. Total phenolic content (TPC), total flavonoid content (TFC), and antioxidant capacity of raw and cooked pasta enriched with *Allium ursinum* L. leaf powder (AUP), blanched and chopped leaves (AUL), and water by-product of leaf blanching and chopping (AUW).

Pasta treatment	Pasta	TPC (mg GAE/g dw)	TFC (mg QE/g dw)	DPPH• scavenging capacity (µmol TE/g dw)	FRAP (µmol TE/g dw)
Raw pasta	CTRL	1.25±0.06gh	0.12±0.00e	0.00±0.00e	0.73±0.12jk
	AUP_L	2.48±0.13c	0.17±0.02d	15.58±0.09c	2.23±0.16de
	AUP_M	3.26±0.10b	0.26±0.04b	17.43±0.11b	4.36±0.05b
	AUP_H	3.72±0.05a	0.31±0.04a	19.09±0.13a	6.26±0.07a
	AUL_L	1.52±0.08ef	0.13±0.02e	0.04±0.00 e	1.36±0.01gh
	AUL_M	1.58±0.06e	0.19±0.02cd	0.04±0.01e	1.54±0.07f
	AUL_H	1.63±0.06e	0.21±0.01c	0.05±0.01e	2.12±0.04e
	AUW_L	1.25±0.01h	0.08±0.02f	0.01±0.00e	0.61±0.08klm
	AUW_M	1.39±0.06fgh	0.09±0.01f	0.01±0.00e	0.64±0.05klm
	AUW_H	1.40±0.12fg	0.09±0.00f	0.02±0.00e	0.77±0.14j
Cooked pasta	CTRL	0.43±0.01m	0.04±0.00g	0.01±0.00e	0.39±0.02n
	AUP_L	0.90±0.04i	0.07±0.00f	0.33±0.01d	1.28±0.07h
	AUP_M	1.34±0.15gh	0.12±0.00e	0.35±0.00d	2.32±0.05d
	AUP_H	1.81±0.05d	0.19±0.00cd	0.38±0.01d	3.36±0.10c
	AUL_L	0.63± 0.01kl	0.04±0.00g	0.02±0.00e	0.58±0.02lm
	AUL_M	0.91±0.15i	0.04±0.00g	0.05±0.00e	1.00±0.01i
	AUL_H	0.87±0.12ij	0.07±0.00f	0.07±0.01e	1.47±0.02fg
	AUW_L	0.76±0.05jk	0.01±0.00h	0.01±0.00e	0.52±0.00m
	AUW_M	0.58±0.03l	0.02±0.00gh	0.02±0.00e	0.57±0.00lm
	AUW_H	0.62±0.00kl	0.03±0.00gh	0.02±0.00e	0.68±0.01jkl

Results are expressed as mean ± standard deviation (*n*=3). Different letters in superscript in the same column of both, raw and cooked pasta, correspond to significant differences ($p<0.05$). FRAP, ferric-reducing antioxidant power; GAE, gallic acid equivalent; QE, quercetin equivalent; TE, Trolox equivalent; dw, dry weight. Pasta coding: CTRL, control without wild garlic; AUP_L, AUP_M and AUP_H, pasta produced with 5%, 10% and 15% (*w/w*) substitution of wheat flour by AUP, respectively; AUL_L, AUL_M and AUL_H, pasta produced with 30%, 60% and 90% (*w/w*) substitution of mixing liquid by AUL respectively; AUW_L, AUW_M and AUW_H, pasta produced with 30%, 70% and 90% (*w/w*) substitution of mixing liquid by AUW, respectively.

all raw AUP pasta samples showed significantly ($p<0.05$) higher antioxidant capacity in both assays, and raw AUL pasta was characterised by significantly ($p<0.05$) higher FRAP. Enhancing the antioxidant capacity of pasta is a key objective in the development of functional food products through ingredient supplementation. Filipčev *et al*. [2023] demonstrated that the incorporation of wild garlic leaves, both as powder and extract, resulted in a significant increase in the antioxidant capacity of pasta, as assessed by the DPPH assay. This enhancement was attributed primarily to the presence of phenolic compounds. In turn, fortification of pasta with egg, in combination with chopped wild garlic leaves, led to improved antioxidant capacity measured by the FRAP assay [Rosan *et al*., 2024]. This effect was found to be dose-dependent with respect to the amount of egg incorporated.

Regarding the effect of cooking on the TPC of pasta, all cooked pasta had significantly ($p<0.05$) lower TPC than their raw counterparts (**Table 3**). The degree of reduction depended on the pasta formulation. The sample with the highest content of wild garlic leaf powder (AUP_H) exhibited the lowest reduction (51.28%), followed by AUP_M (58.76%) and AUP_L (63.83%). In the other two pasta variants (pasta with AUL and AUW), reductions in TPC were also depended on the amount of wild garlic formulation used. Among the three pasta variants, the AUL_M pasta showed the minimum loss of TPC of 42.48%. A possible reason may have been the more difficult removal of phenolics from blanched wild garlic leaves during the cooking process. The total flavonoid contents of the pasta, as in the case of TPC, indicated a loss of these compounds during cooking depended on the amount of wild garlic leaf formulation used in the recipe. For the AUP variants, the maximum amount of leaf powder (AUP_H) led to a TFC reduction of 37.97%, while AUP_M and AUP_L showed TFC reduction of 53.68% and 61.39%, respectively. Our findings are consistent with the research conducted by Filipčev *et al.* [2023] who used three different pasta formulations, which included wild garlic (powder, extract, and encapsulated extract) and found that cooked pasta had a lower TPC compared to raw pasta, with differences depending on the matrix. The most notable decrease in TPC was reported in the pasta formulation that included encapsulated wild garlic at moderate and high supplementation levels. Our previous study showed that the loss of phenolic compounds during cooking of pasta enriched with wild garlic leaves was influenced by the content of other dough ingredients, like eggs – wild garlic leaf enriched pasta with the highest egg content had the lowest TPC reduction [Rosan *et al.*, 2024].

Cooking reduced not only the TPC and TFC of pasta, but also the antioxidant capacity of most pasta samples (**Table 3**). This finding did not apply to the antioxidant capacity of pasta of the AUW variants determined in both assays and pasta of the AUL variants in DPPH assay, for which the results before and after cooking did not differ significantly ($p \geq 0.05$). The pasta fortified with powdered *A. ursinum* leaves showed a 98% reduction in DPPH radical scavenging capacity and 42–46% reduction in FRAP. However, greater FRAP reduction (57%) was observed in the samples with a low content of blanched and chopped *A. ursinum* leaves (AUL_L). The changes observed in the antioxidant capacity of pasta enhanced with wild garlic are in line with findings from previous research indicating a reduction in antioxidant capacity after thermal processing. In our previous study [Rosan *et al.*, 2024], we observed a significant reduction in antioxidant capacity (between 20 and 30%), as determined by the FRAP assay, in pasta fortified with wild garlic leaves and egg. This effect was attributed to the loss of phenolics in the cooking water and/or thermal degradation of bioactive compounds. Verardo *et al.* [2011] found that 11.6% of the various phenolic compounds in cooked buckwheat spaghetti were released into the cooking water, while the pasta-making process resulted in a loss of 45.9% of the total phenolic compounds originally present in the raw materials used for the production of buckwheat spaghetti. According to Bustos *et al.* [2019], in berry-enriched pasta, heating partially destroyed the phenolics and reduced antioxidant capacity, while preserving the functional properties of the product. However, some studies indicated that cooking pasta in certain instances resulted in a noticeable increase of antioxidant capacity, attributed to the release of bound antioxidant compounds from the food matrix [Podio *et al.*, 2019]. Such results were also seen in durum wheat pasta that had been enhanced with debran fractions; cooking increased the antioxidant activity *in vitro* [Fares *et al.*, 2010].

The effects of varying drying temperatures (40, 50, and 60°C) on the total phenolic content and antioxidant activity in dried leaves of *Allium ursinum* L. subsp. *ucrainicum* were examined by Lukinac & Jukić [2022]. They demonstrated that higher drying temperatures led to a significant decrease in TPC and antioxidant activity determined in the DPPH assay as temperature increased. In order to maintain the quality and nutritional value of dried *A. ursinum* leaves, our drying temperature of both leaves and fortified pasta was 30°C.

Colour of pasta enriched with formulations from wild garlic leaves

An essential quality for coloured pastas is their colour stability. The results of measurements of the colour parameters made in raw and cooked pasta enriched with wild garlic leaf formulations are displayed in **Table 4**. When *A. ursinum* formulations were used, the colour of pastas changed from the light yellow of the control pasta (CTRL) to a green hue of the wild garlic leaves, and the colour intensity being dependent on the type of wild garlic formulation. The raw pasta fortified with powdered *A. ursinum* leaves (AUP) showed the highest total colour difference compared to CTRL (46.2–52.1), but this difference did not change significantly ($p<0.05$) with the increasing substitution level of what flour by powder in pasta recipe. The ΔE for raw pasta enriched with blanched and chopped wild garlic leaves (AUL) ranged from 13.6 to 26.5, which was significantly ($p<0.05$) lower than the value for AUP pasta. Finally, the raw pasta produced with by-product of leaf blanching and chopping (AUW) showed the smallest difference compared to the control. The colour difference was also calculated between the cooked enriched pasta and the corresponding cooked control. Minor alterations were noted for the AUW pasta, whereas the sample AUP_H showed the highest ΔE (43.1). Moreover, ΔE for cooked AUP and AUL pasta was found to be lower compared to their corresponding raw pasta, indicating a reduced overall colour difference.

In the case of the raw and cooked control pasta, the colour parameter L^* was 89.9 and 74.2, respectively (**Table 4**). Regardless of the level of substitution of wheat flour by wild garlic leaf powder, the L^* values of raw and cooked pasta were lower ($p<0.05$) compared to the respective controls. The pasta with blanched and chopped wild garlic leaves (AUL) also showed low L^* values, but not as significant as AUP. When compared to the raw pasta, the L^* values significantly decreased ($p<0.05$) after cooking. According to Filipčev *et al.* [2023], dark pasta had by L^* values below 55. Regardless of the substitution level and form of enrichment, the parameter a^* had negative values for all pasta samples (**Table 4**). This indicated the green colour of pasta caused by the green hue of the wild garlic leaves. The substitution of wheat flour by AUP lowered the a^* value of raw and cooked pasta much more than AUL. Regarding the b^* value, which indicates blueness/yellowness, the AUP pasta variants had the lowest values, while the AUW pasta variants had the highest values, and an increase compared to the control pasta was observed in the case of raw pasta samples. Filipčev *et al.* [2023] reported L^* values of 72.46 and 72.59, respectively, for raw and cooked pasta produced from durum wheat semolina, which, similarly to our study, decreased significantly compared

Table 4. Parameters of colour of raw and cooked pasta enriched with *Allium ursinum* L. leaf powder (AUP), blanched and chopped leaves (AUL), and water by-product of leaf blanching and chopping (AUW).

Pasta treatment	Pasta	*L**	*a**	*b**	Δ*E*
Raw pasta	CTRL	89.9±7.2^{a}	−8.0±0.8^{ab}	−14.0±6.4^{i}	–
	AUP_L	63.1±4.9^{fg}	−27.4±3.5^{f}	26.3±4.0^{a}	52.0±2.2^{a}
	AUP_M	59.5±3.6^{g}	−23.3±4.8^{ef}	17.2±4.0^{c}	46.2±3.8^{a}
	AUP_H	58.0±2.9^{g}	−23.2±4.3^{ef}	15.9±2.8^{c}	46.3±1.1^{a}
	AUL_L	79.5±3.7^{bcde}	−11.7±4.8^{abc}	−5.9±0.6^{gh}	13.6±4.5^{cd}
	AUL_M	71.8±7.3^{def}	−17.2±7.8^{cde}	3.0±0.4^{d}	26.5±4.1^{b}
	AUL_H	74.3±4.4^{de}	−15.4±5.8^{bcd}	−1.2±0.2^{defg}	21.5±1.0^{b}
	AUW_L	88.7±3.2^{ab}	−7.0±0.5^{a}	−14.0±3.9^{i}	1.6±3.8^{e}
	AUW_M	87.4±2.3^{abc}	−8.5±0.6^{ab}	−6.8±0.5^{gh}	7.7±0.8^{d}
	AUW_H	80.9±2.1^{abcd}	−8.7±0.8^{ab}	2.0±0.3^{de}	18.4±1.3^{cd}
Cooked pasta	CTRL	74.2±3.1^{de}	−8.7±0.6^{ab}	−6.9±0.7^{gh}	–
	AUP_L	57.7±6.8^{g}	−21.4±4.1^{def}	28.9±6.4^{a}	41.4±4.1^{a}
	AUP_M	46.9±7.1^{h}	−22.8±5.3^{def}	23.8±1.6^{ab}	43.5±3.7^{a}
	AUP_H	40.7±4.4^{h}	−16.4±3.4^{cde}	19.1±9.0^{bc}	43.1±4.3^{a}
	AUL_L	69.8±7.3^{ef}	−15.3±2.9^{bcd}	−14.8±2.1^{i}	11.2±2.4^{cd}
	AUL_M	62.3±4.9^{fg}	−16.9±5.4^{cde}	−7.8±0.3^{h}	14.6±1.4^{bc}
	AUL_H	59.2±6.6^{g}	−16.5±7.7^{cde}	−4.2±0.4^{efgh}	17.2±1.0^{b}
	AUW_L	75.6±7.9^{de}	−6.6±0.6^{a}	−4.6±0.7^{fgh}	3.4±1.4^{d}
	AUW_M	74.3±5.7^{de}	−7.9±0.8^{ab}	−2.6±0.6^{defgh}	4.3±0.9^{d}
	AUW_H	77.9±7.7^{cde}	−6.5±0.6^{a}	1.4±0.6^{def}	9.3±2.1^{cd}

Results are expressed as mean ± standard deviation (n=3). Different letters in the same column of both, raw and cooked pasta, correspond to significant differences (p<0.05). *L**, lightness; *a**, greenness/redness; *b**, blueness/yellowness; Δ*E*, total colour difference compared to control. Pasta coding: CTRL, control without wild garlic; AUP_L, AUP_M and AUP_H, pasta produced with 5%, 10% and 15% (*w/w*) substitution of wheat flour by AUP, respectively; AUL_L, AUL_M and AUL_H, pasta produced with 30%, 60% and 90% (*w/w*) substitution of mixing liquid by AUL, respectively; AUW_L, AUW_M and AUW_H, pasta produced with 30%, 70% and 90% (*w/w*) substitution of mixing liquid by AUW, respectively.

to pasta enriched with wild garlic powder, extract, and encapsulated extract. At the same time, *a** values considerably increased in the samples supplemented with extract in both forms, but decreased in the samples supplemented with powder. Considering pasta enriched with other leafy plant materials, Drabińska *et al*. [2022] found lower *L** and *a** values and a higher *b** value of raw (fresh and dried at different temperatures) pasta enriched with broccoli leaf powder compared to control pasta without powder incorporation, which is consistent with our findings regarding pasta samples with AUP and AUL. However, Wang *et al.* [2021] reported a decrease in *L**, *a**, and *b** values when pasta was fortified with spinach juice, puree, and pomace. Additionally, the lightness, greenness, and yellowness of the spinach pasta were much diminished throughout the cooking process. In turn, Teterycz *et al.* [2020] produced pasta with partial replacement of semolina with legume flours of different colours and demonstrated a decrease in the lightness, unchanged redness, and an increase in yellowness of cooked pasta when green pea flour was used.

■ Confocal microscopy images and surface roughness parameter of raw pasta enriched with formulations from wild garlic leaves

The results of laser microscopy analysis of raw pasta fortified with various *A. ursinum* formulations are displayed in **Figure 2**. Using laser confocal microscopy and profile analysis, the arithmetic mean height (Sa), the parameter of surface roughness, was calculated and shown in **Figure 2** along with the corresponding surface image. The surface roughness analysis of pasta showed that the Sa was influenced by the level of substitution of wheat

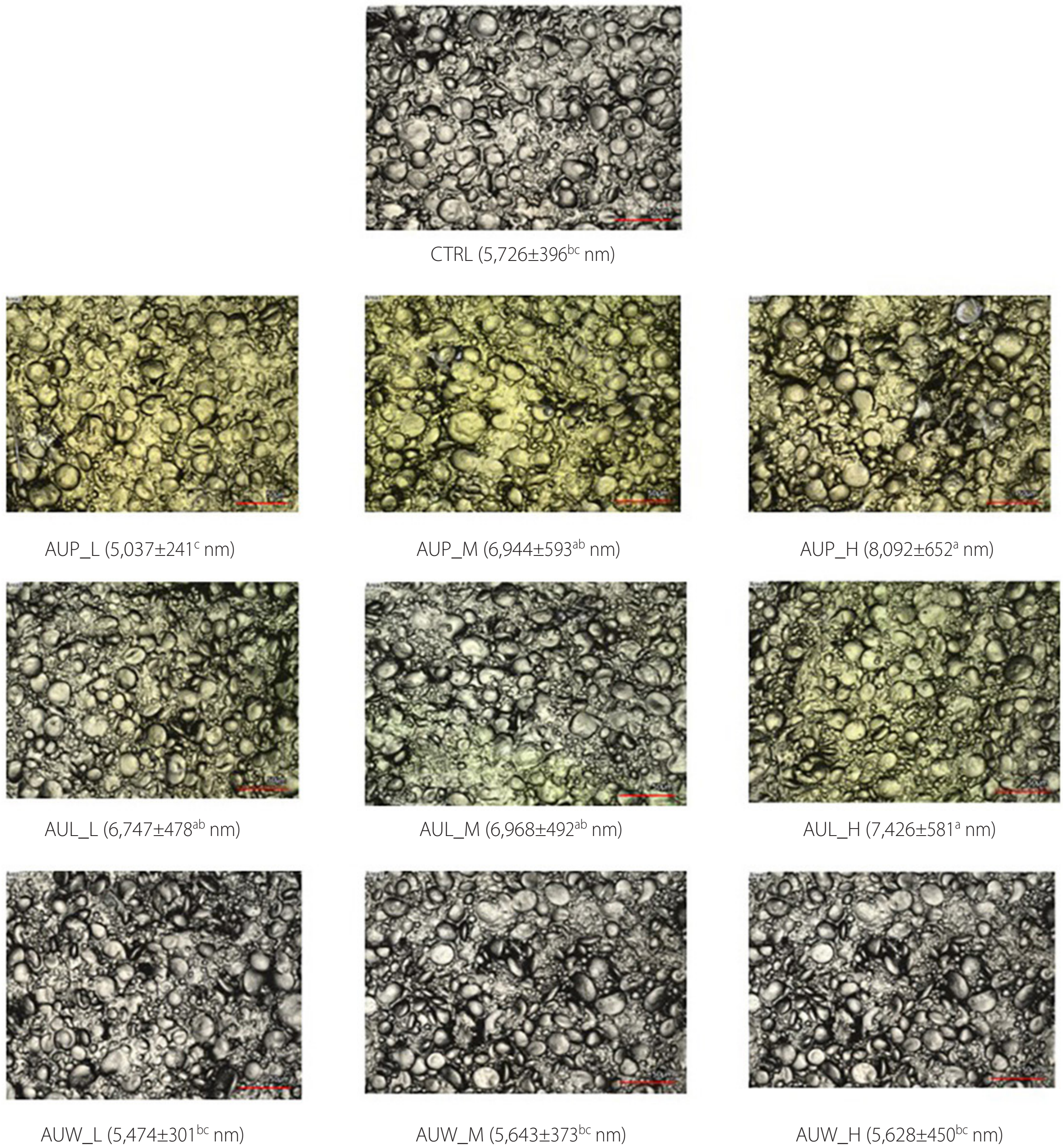

Figure 2. Confocal microscopy images and arithmetical mean height (shown in parentheses as mean ± standard deviation, n=3, and marked with different superscript letters for values that are significantly different, p<0.05) as a roughness parameter of raw pasta enriched with *Allium ursinum* L. leaf powder (AUP), blanched and chopped leaves (AUL), and water by-product of leaf blanching and chopping (AUW). Pasta coding: CTRL, control without wild garlic; AUP_L, AUP_M and AUP_H, pasta produced with 5%, 10% and 15% (*w/w*) substitution of wheat flour by AUP, respectively; AUL_L, AUL_M and AUL_H, pasta produced with 30%, 60% and 90% (*w/w*) substitution of mixing liquid by AUL, respectively; AUW_L, AUW_M and AUW_H, pasta produced with 30%, 70% and 90% (*w/w*) substitution of mixing liquid by AUW, respectively.

flour by *A. ursinum* leaf powder and was significantly (p<0.05) higher for AUP_M and AUP_H samples when compared to control pasta. Potentially large amounts of *A. ursinum* powder that remained embedded or partially exposed on the dough's surface could cause microtextures and irregularities. Powder particles may have caused the dough to become less uniform during extrusion, resulting in a rougher surface texture. Pasta with blanched and chopped leaves, as opposed to CTRL, contained larger, irregularly shaped particles that made the mixture rougher. During the extrusion and drying processes, the fibrous structure of the leaves could result in additional irregularities. The uneven distribution of the leaves in the dough also affected the roughness of the AUL pasta. Because it was evenly incorporated into the dough, using different amounts of wild garlic by-product (AUW) in pasta production proved to have no effect on the surface roughness of the dough when compared to the control.

A recent study examined changes in dried pasta during cooking, focusing on surface morphology [Ohmura *et al.*, 2023].

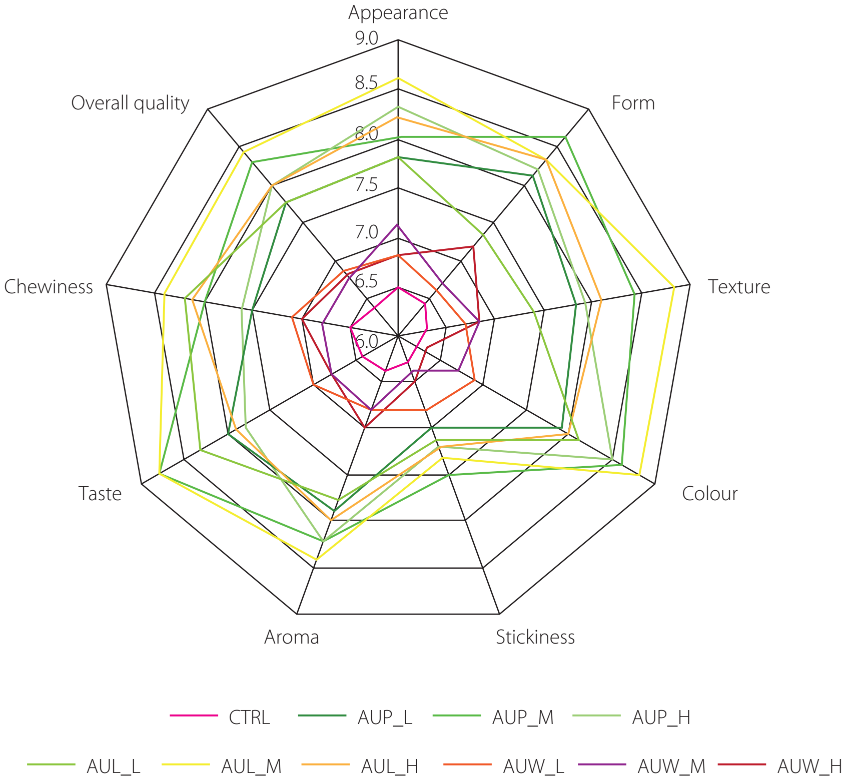

Figure 3. The sensory evaluation of cooked pasta enriched with *Allium ursinum* L. leaf powder (AUP), blanched and chopped leaves (AUL), and water by-product of leaf blanching and chopping (AUW). Pasta coding: CTRL, control without wild garlic; AUP_L, AUP_M and AUP_H, pasta produced with 5%, 10% and 15% (*w/w*) substitution of wheat flour by AUP, respectively; AUL_L, AUL_M and AUL_H, pasta produced with 30%, 60% and 90% (*w/w*) substitution of mixing liquid by AUL, respectively; AUW_L, AUW_M and AUW_H, pasta produced with 30%, 70% and 90% (*w/w*) substitution of mixing liquid by AUW, respectively.

The results did not indicate significant variations in light microscopy images. However, surface roughness measurements showed higher scores in the high-temperature dried pasta compared to the low-temperature dried pasta. As the drying temperature increased, the roughness parameters decreased, showing notable differences between the two types of cooked pasta. Using laser microscopy, it was demonstrated that, as the drying temperature increased, the variation in pasta height decreased, meaning that the surface roughness of cooked pasta (dried at high temperatures) was minimal. Cooked pasta (dried at low temperatures) showed superior surface roughness compared to other pastas, correlating with the results of cooking loss and fluorescence microscopy. The explanation was related to the fact that the more disrupted gluten network of the pasta led to a greater degree of starch granule swelling, thereby causing increased release of gluten from the outer periphery of boiled pasta. Such increases in the release of starch granules and gluten may be accountable for greater degree of surface roughness of pasta after boiling, which is also consistent with our findings.

Due to the presence of high molecular weight starch polymers that are naturally resistant to digestion and the protein matrix around gelatinized starch granules, formed during the boiling process, pasta consumption provides a source of slowly digestible carbohydrates with a moderate glycaemic index [Bustos *et al.*, 2015]. However, Colonna *et al.* [1990] noted that the starch granules were not completely enveloped by the gluten matrix and exhibited enough porosity to facilitate the diffusion of α-amylase.

Sensory scores of cooked pasta enriched with formulations from wild garlic leaves

The results obtained from the sensory evaluation of the pasta samples are presented in **Figure 3**. The scores varied, not only between the different samples but also among the evaluated sensory attributes. The attributes that mainly differentiated the pasta samples were appearance, colour, taste, and texture, which showed the greatest variability in panelist scores. Differences in visual and structural uniformity (especially due to deformation and curling in the samples with a high content of blanched and chopped wild garlic leaves) significantly affected the appearance and texture ratings. Although most sensory attributes remained constant or above 8.0, stickiness was also a differentiating factor, scoring lower (7.0–7.5) across all formulations. These elements contributed to the overall differentiation in consumer acceptability. A sensory difference was noted between the pasta samples fortified with wild garlic powder or blanched and chopped leaves and those supplemented with wild garlic by-products. Among the evaluated variants, pasta enriched with a medium level of blanched and chopped leaves (AUL_M) received the highest overall sensory score, averaging 8.43 points, followed closely by the sample with a medium content of wild garlic powder (AUP_M), with an average of 8.26 points. The classification used in this study is based on the nine-point hedonic scale, originally developed by Peryam & Pilgrim [1957]. According with this scale, scores 8 and 9 correspond to the highest levels of consumer acceptance, interpreted as "very pleasant" and "extremely pleasant". This classification is further supported by the Society of Sensory Professionals (https://www.sensorysociety.org) which confirms these score descriptors and their use in sensory research protocols. Pasta produced with low and high contents of wild garlic powder or chopped leaves (AUP_L, AUL_H, AUP_H, AUL_L) received scores ranging between 7.75 and 7.98, placing them in the "pleasant" to "moderately pleasant" range. In contrast, the samples formulated with wild garlic by-products (AUW_L, AUW_M, AUW_H) scored between 6.76 and 6.84, which was comparable to the control sample (CTRL), which had an average score of 6.38, corresponding to a "neutral" to "slightly pleasant" sensory perception.

The study conducted by Filipčev *et al*. [2023] revealed that the addition of wild garlic powder in amounts of 5%, 7%, and 9% was favorably accepted by panelists, with the resulting pasta types ranking highly in sensory evaluations. Likewise, in our previous study, where different egg concentrations in the pasta dough were used along with an established amount of 20 g of chopped wild garlic leaves, consumers appreciated the presence of wild garlic in this form in pasta [Rosan *et al*., 2024].

CONCLUSIONS

This study investigated the effects of using wild garlic leaves in different forms (powder, blanched and chopped leaves, and by-products from leaf blanching and chopping) in pasta production at three levels (low, medium, and high). Our investigation included an in-depth assessment and comparison of cooking properties, contents of total phenolics and flavonoids, antioxidant capacity, colour, surface roughness and preliminary sensory analysis of the wild garlic-based pasta variants. All pasta formulations evaluated had satisfactory cooking qualities, though there were differences based on the type and quantity of wild garlic used. Every formulation with leaf powder and with blanched and chopped leaves significantly increased the total phenolic and total flavonoid contents and antioxidant capacity of the pasta, and higher levels of incorporation resulted in higher contents of bioactive ingredients. Despite a lower total phenolic content and antioxidant capacity of pasta with the by-product of leaf blanching and chopping compared to the other enriched pasta variants, its potential for food waste valorisation remains considerable. The colour parameters of pasta with wild garlic leaf formulations showed significant changes before and after cooking, reflecting the impact of wild garlic enrichment on the pasta's visual properties. Surface roughness analysis indicated that the medium and high levels of substitution of wheat flour by *A. ursinum* leaf powder in pasta significantly increased roughness compared to the control. Blanched and chopped leaves introduced larger, irregular particles, thereby intensifying the roughness. Although the highest substitution level by wild garlic leaf powder and blanched and chopped leaves enhanced phenolic content and antioxidant capacity, it did not yield the highest sensory scores. The pasta variants with a medium content of wild garlic blanched and chopped leaves and leaf powder were the most appreciated.

Although the present study has shown the potential of wild garlic-enriched pasta as a functional food, further research is needed to ascertain the post-consumption bioavailability of phenolic compounds. The health benefits of these compounds could be better understood if this research was done *in vivo* or using models of simulated digestion. *A. ursinum*-enriched pasta recipes for commercial use may also be improved by full consumer acceptance studies that concentrate on sensory requirements. Additionally, it is crucial to assess the long-term stability and antioxidant capacity of pasta. By-products from blanching and chopping of wild garlic leaves have shown encouraging results, which highlights the importance of considering sustainability while aiming to create functional foods that are friendly to the environment.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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