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Original article

By-product of raspberry juice as a functional ingredient: effects on the properties and qualitative characteristics of enriched pasta

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Summary Raspberry pomace, the main by-product of the raspberry juice extraction process, consists mainly of raspberry peels and seeds, rich in polyphenols and fibres. The recovery of this waste by drying and fine grinding gives a powder suitable for many applications. This study aimed to assess the technical quality, functional properties, and consumer acceptability of five pasta samples produced by replacing durum wheat semolina (*Triticum durum*) with 3.70%, 5.61%, 7.69%, 9.88%, and 12.00% raspberry powder. The control sample was 100% hard semolina pasta. The cooked pasta (RP) with 7.69% raspberry powder replacement showed higher acceptability values, a slight decrease in hardness, compactness, and time of optimal cooking (OCT) than the control semolina pasta (CP). Furthermore, the "half of the maximum inhibitory concentration" (IC_{50}), evaluated through the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulphonic) acid (ABTS) tests, showed an increase of about twice the antioxidant activity compared to the semolina paste, both before and after cooking.

Keywords ABTS, antioxidant properties, by-products, cooking loss, DPPH, functional pasta, OCT, raspberry powder, sensory evaluation, texture.

Introduction

The growing attention of consumers towards healthy eating and a correct lifestyle has increased the appeal of functional food products (Torres-León *et al.*, 2018). In addition to ensuring the nutritional supply, the functional foods must perform some function in the health and well-being of the organism.

At the same time, the growing attention to the environment has led to the study of new procedures for reducing chemical additives and waste in the food sector (Pellegrini *et al.*, 2006; Maltese *et al.*, 2009; Fraga *et al.*, 2021; Liu *et al.*, 2021; Mesquita *et al.*, 2021).

Among the solutions to the severe problem of industrial waste, in addition to the design of less impacting lines, the search for systems for waste reduction/requalification by recovering valuable components from being used as food supplements or preservatives is currently very active.

According to eco-friendly principles, our goal was to recover and requalify a waste product from raspberry juice extraction, still rich in bioactive components. In a recent article (Krivokapić *et al.*, 2021), the high functional value of this by-product was confirmed by analysing the total phenolic content (TPC) and the total flavonoid content (TFC), and the total anthocyanin content (TAC), and antioxidant capacity.

In particular, the objective was to qualify processing waste with high potential to increase the biological value of high-consumption foods such as pasta, as experimented with by other authors using different matrices (Aravind *et al.*, 2012; Heiniö *et al.*, 2016; Recchia *et al.*, 2019; Zarzycki *et al.*, 2020).

A recent review (Dziki, 2021) highlighted the enrichments experimented on pasta, from other cereals (barley, oats, rice, *etc.*) to flours of different origins, such as unripe banana, green leaf spinach, buckwheat in dried amaranth leaf, peanuts, lupins, mushrooms, lentils, peas, defatted soy, and many others, analysing the improvement features related to the different integrations.

Berries (Bustos *et al.*, 2019), such as raspberries, blackberries, currants, and gooseberries, were also tested for their high phenolic content, starting with dried and chopped fruit, rather than the by-products of a food chain, such as that of small fruit juices.

Among the small fruits, our interest has focused on raspberries which are, like all berries, a rich source of phytochemicals, as well as bioflavonoids, anthocyanins, and many other classes of phenolic compounds, including ellagitannins, flavan-3-ols, procyanidins,

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flavonols, and hydroxybenzoate derivatives (Klesk *et al.*, 2004; Kim *et al.*, 2013; Koziol *et al.*, 2014; Yazdankhah *et al.*, 2019).

For this reason, various scientific researches document the contribution of the consumption of berries to a series of benefits such as maintaining health, reducing the risk of obesity, and preventing some chronic and degenerative diseases related to food (Ferlemi & Lamari, 2016).

Given the higher concentration of phytochemical residues in the skins and seeds, the recovery of this fraction could allow the capitalisation of bioactive substances otherwise lost as waste.

Considering that the authors, in a previous study (De Santis *et al.*, 2022), characterised the bioactivity of the steam extract of raspberry leaves, the present research aimed to study another by-product of the raspberry crop: peels and seeds dried and milled into raspberry flour.

The pasta produced by partially replacing semolina with raspberry flour at the estimated optimal enrichment rate was analysed to evaluate the improvement of the functional properties connected to the integration.

Materials and Methods

Chemicals

2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulphonic) acid (ABTS), 2,2-diphenyl-1-picrylhydrazyl (DPPH), Folin–Ciocalteau phenol reagent, and gallic acid were purchased from Sigma-Aldrich (St. Louis, MO, USA). Methanol (analytical grade) for extraction was acquired from Merck (Darmstadt, Germany).

Raspberry powder preparation

The raspberries (*Rubus idaeus L.* var. Heritage) juice extraction solid residue (seeds and peels) was oven-dried (48 °C ± 2) for about 16 h up to 10.87% ± 0.032 moisture, then reduced to fine particles by grinding in a stone flour mill for home and sieved through a stainless-steel sieve with 300 μm gauge mesh.

Pasta manufacturing

The durum wheat semolina flour and 30% w/w low mineral water (289 mg L^{-1} fixed residues at 180 °C) were mixed for 8 min to obtain a homogeneous dough.

Subsequently, the bronze drawn pasta was cut into slices with a length of 3.11 ± 0.15 cm, a thickness of 0.69 ± 0.04 cm, an external diameter of 1.94 ± 0.03 cm, and a diameter of internal of 1.51 ± 0.05 cm. Finally, pasta samples were placed in a hot air dryer at a temperature between 42 and 55 °C and 18% relative humidity for 28 h, up to about 12.5 ± 1.05% moisture.

For the pasta type raspberry (RP), the procedure differed only for the raspberry powder replacing the semolina flour with an enrichment percentage of 3.70% (RP1), 5.61% (RP2), 7.69% (RP3), 9.88% (RP4), and 12.00% (RP5), respectively (Table 1). The control was represented by conventional pasta 100% semolina prepared. Finally, the pasta samples, wrapped in the polypropylene package, were kept at room temperature and in dark for the following analysis.

Three distinct preliminary processes were carried out to verify the variability between production batches, from which three samples were taken for each and analysed separately for moisture (g 100 g^{-1}) and phenolic content (milligrams of gallic acid equivalent (mg GAE) 100 g^{-1}) values.

From the first survey, it emerges that by keeping the production process constant, the variability between batches, deduced from the analyses mentioned above, stood at the variability values found between replicates of the same batch (<10% in moisture and <7% in TPC).

We, therefore, proceeded by combining the products of the three batches in a single sample by type and analysed three aliquots of the same for each test.

Proximate analysis

Moisture and ash were determined according to the American Association of Cereal Chemists (AACC) method (AACC, 2009) on raw and cooked pasta. Four replicates were made for both types of pasta. The thickness, length, and diameter of pasta (raw and cooked) were measured using a calliper.

Cooking characteristics of pasta

The optimal cooking time (OCT) of pasta, cooking loss, and cooked weight were determined according to the AACC approved method (2000).

Optimal cooking time and cooking loss

The optimal cooking time (OCT), defined as the time required for the thin central white line on the cut cooked pasta to disappear, was determined according to the ISO procedure (2016).

After cooking the pasta, the cooking loss was evaluated as the total weight of the solid dispersed in water according to the AACC 66-50.01 method (AACC, 2000).

The pasta was cooked until OCT maintaining the ratio of 1:10 (pasta:water). Collecting the pasta cooking water and drying it in an oven at 105 °C until constant weight, the cooking loss was expressed as the ratio between the total weight of the residues and the initial mass of raw pasta used.

Table 1 Ingredients (g 100 g^{-1}) of the pasta conventional (CP) and pasta samples raspberry powder enriched (RP)

	Conventional pasta (CP)	Raspberry pasta (RP1)	Raspberry pasta (RP2)	Raspberry pasta (RP3)	Raspberry pasta (RP4)	Raspberry pasta (RP5)
Water	30.00	30.00	30.00	30.00	30.00	30.00
Wheat durum flour (semolina)	70.00	67.50	66.75	65.00	63.25	62.50
Raspberry flour	0.00	2.50	3.75	5.00	6.25	7.50
Enrichment %	0.00	3.70	5.61	7.69	9.88	12.00

Swelling index and water absorption

Swelling index and water absorption of cooked pasta were measured by using the method described by Tudoric *et al*. (2002).

Swelling index of cooked pasta (gram of water per gram of dry pasta) was evaluated by drying pasta samples to constant weight at 105 °C and expressed as follows:

$$Swelling\ index = (cooked\ pasta(g) - dehydrated\ pasta(g))/(dehydrated\ pasta(g))$$

Water absorption of drained pasta was determined as follows:

$$Water\ absorption = (cooked\ pasta(g) - raw\ pasta(g))/(raw\ pasta(g)) \times 100$$

Sensory estimation cooking quality

The pasta samples were evaluated by nine trained assessors, according to the standard procedure indicated in the ISO 7304 standard (ISO, 2016), to identify the highest dose enrichment, ensuring optimal pasta cooking quality.

The assessors, recruited among the expert sensory members of the departmental panel (ISO 8586, 2014), became familiar with the product and the descriptive sensory terminology in three preliminary sessions.

All samples cooked according to the determined OCT, cooled in water and drained were served simultaneously at room temperature on white plates codified with 3-digit random codes.

The assessors seated in single booths of the sensory laboratory (UNI EN ISO 8589, 2014) evaluated each sample for the attributes of firmness, stickiness (starch release), homogeneity, and overall quality according to a scale of values from 20 to 100 (UNI EN ISO 8589, 2016) (Table 2).

The pasta cooking quality was high if the summation of the panel's judgements for the attributes reached a total value of nearly 300, while it was acceptable for a value of at least 250 total.

A low overall value led to the exclusion of the thesis due to insufficient quality.

Texture profile analysis

The texture properties of cooked pasta were carried out by the texture profile analysis (TPA), using a Universal Testing Machine (UTM 3342 model; Instron Instruments Ltd, High Wycombe), equipped with a 1000-N load and controlled through a custom software (Bluehill 2.33.893 hotfix; Instron Instruments Ltd, High Wycombe).

Three units of pasta, at a time, aligned and inserted on steel bars, were tested with a trapezoidal cutting probe (32 mm height, 1.2 mm minor base, 20 mm major base) according to the standard test of the Barilla Group (Ballestrieri *et al*., 2015).

Setting the probe speed at 1 mm s^{-1}, at 25 °C temperature, and at ambient relative humidity, two compression cycles per sample were conducted, the first at

Table 2 Definitions and pasta sensory attributes' rating scales according to ISO 7304:, 2016

Sensory attributes	Firmness	Stickiness	Homogeneity	Overall quality
Definitions	Force required to bite down on pasta between the molars	Starch release during ooking	Regularity of the structure during chewing	Preference / acceptability overall
Rating scales	100 - very high 80 - high 60 - medium 40 - low ≤20 - very low	100 - very low 80 - low 60 - medium 40 - high ≤20 - very high	100 - very high 80 - high 60 - medium 40 - low ≤20 - very low	100 - very high 80 - high 60 - medium 40 - low ≤20 - very low

30% and the second at 90% of the original height. For the texture profile of each pasta type, five replicates were carried out.

The peak force of the first and second compression cycles was defined as pasta hardness at 30% (F30) or 90% (F90) deformation. The area under curve (F30) after peak force (A2), divided by the area under curve before peak force (A1), represented the cooked pasta resilience (RCP). The RCP was used to evaluate the capacity of cooked pasta to regain its original shape.

Pasta colour

The colour of the raw and cooked pasta was assessed in triplicate using the tristimulus colour system CIELAB, using a spectrophotometer (Konica Minolta, Tokyo, Japan) model CM-2600d. After calibration, the three CIELAB coordinates L* (lightness value), a* (green/red), and b* (yellow/blue) were evaluated. Colour measurements were performed before and after cooking.

In addition, the total colour difference (ΔE) between all pasta samples cooked and raw was evaluated using the formula: $\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$.

Powder extraction

For raspberry powder extraction, 0.2 g of powder was mixed with 10 mL of methanol 80% and treated with an ultrasonic bath (model DU32, Argo Lab, Carpi, Italy) on ice for 15 min and 40 kHz. Then, the extract was centrifuged (NEYA 16R, Remi Elektrotechnik LTD, Palghar, India) at 1400 r.p.m. for 20 min. The supernatant was recovered and kept at −20 °C until use.

Pasta extraction

Raw and cooked pasta, frozen with liquid nitrogen and ground in a blender, was extracted according to previous methods (Boroski *et al.*, 2011; Khan *et al.*, 2013) with minor modifications. One gram of sample mixed with 10 mL of MeOH (1% HCl) was treated with an ultrasonic bath (model DU32, Argo Lab, Italy) on ice for 15 min, 40 kHz.

Subsequently, the samples were centrifuged (NEYA 16R, Remi Elektrotechnik LTD, India) at 4100 r.p.m. for 20 min, and the supernatants were collected and stored at −20 °C until analyses. The labelled pasta extracts were CP (conventional-raw-pasta), RP (raspberry-raw-pasta), and CPc (CK semolina 100% pasta cooked). Extractions were carried out in triplicate for each sample.

Total Phenolic Content

Total phenolic content (TPC) was investigated using the Folin–Ciocalteau method (Bacchetti *et al.*, 2020) with minor modifications. Briefly, 1580 μL of decarboxylated distilled water was mixed with 20 μL of sample and 100 μL of the Folin reagent and left for 5 min in dark conditions at room temperature. Then, a 300 μL of 20% sodium carbonate (Na_2CO_3) solution was added, and the mixture was incubated at 40 °C for 30 min before reading the absorbance at 765 nm *via* a spectrophotometer (Jasco V-630 UV–VIS Spectrophotometer, Easton, MD, USA). A standard calibration curve of gallic acid was used as a reference. Results are expressed as mg of gallic acid equivalents (GAE) 100 g^{-1} of dry pasta weight.

Antioxidant Assays

Antioxidant activity was investigated using 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) methods.

DPPH assay

The capacity to scavenge DPPH free radical, following the method described by Xiao *et al.* (2020), adapted to 96-well plates to evaluate the antioxidant property of samples, was adopted.

Twenty microlitres of samples at different concentrations (diluted 1:2) was mixed with 100 μL of 0.2 mM DPPH solution and 80 μL of Tris–HCl buffer and incubated in the dark and at room temperature for 30 min. The absorbance was read against blank at 517 nm with a microplate reader (Tecan, Sunrise, Männedorf, Switzerland). The radical scavenging activity (RSA - %) was obtained using the following equation:

$$RSA_{DPPH}(\%) = \frac{(Abs_{DPPH} - Abs_{SAMPLE})}{Abs_{DPPH}} \times 100$$

where Abs_{DPPH} is the absorbance of the DPPH solution without the sample, while Abs_{SAMPLE} is the absorbance of the testing sample solution.

The results were expressed as micromole Trolox equivalent (μM TE) per 100 g of powder and as IC_{50} (half maximal inhibitory concentration) per pasta sample.

IC_{50} (half maximal inhibitory concentration) was the effective concentration of the antioxidant extract required to scavenge 50% of the DPPH radicals. Results expressed as IC_{50} (mg mL^{-1}) of each pasta extract were calculated by interpolation of the graph of radical scavenging activity against percentage of each sample concentration.

ABTS assay

The ABTS radical cation scavenging activity was evaluated according to Re *et al.* (1999), starting from a stock solution of ABTS (7 mM in water), activated (2.45 mM final concentration) with potassium persulfate solution. Before use, ABTS + solution was diluted with ethanol to an absorbance of 0.7 ± 0.02 at 734 nm.

Twenty microlitres of the sample was added to 980 µL of ABTS + solution and left to react for 5 min. After this time, the solution's absorbance was read at 734 nm.

All determination was performed in triplicate. As for the DPPH assay, the IC_{50} was calculated by interpolation of plotted inhibition values (y) obtained using the formula:

$$RSA_{ABTS}(\%) = \frac{(Abs_{ABTS} - Abs_{SAMPLE})}{Abs_{ABTS}} \times 100$$

against sample concentrations (x). Results were expressed as IC_{50} (mg mL^{-1}).

The results were expressed as micromole Trolox equivalent (µmol TE) per 100 g of powder and as IC_{50} per pasta sample.

Consumer sensory evaluation

The consumer acceptability/preference test was conducted exclusively on pasta samples that met the acceptable level required by ISO 7304 (2016).

The forty consumers (19 males and 21 females, aged between 22 and 48 years) recruited from students and employees at Tuscia University (Viterbo, Italy) were more than once-a-week pasta consumers.

Five units of each type of pasta, boiled in water for optimal cooking time, then chilled to 20 °C, were served on white plates, labelled with 3-digit random numbers (UNI EN ISO 8589, 2014); non-sparkling mineral water, to neutralise the mouth during the test, was used.

The test was performed in the single booths of a sensory evaluation laboratory (ISO, 2014), under artificial red light and at a controlled temperature (between 22 and 24 °C), ensuring good air exchange between a group of tasters and the next.

Consumers were asked to evaluate the five sensory characteristics of the cooked pasta samples using a 9-point hedonic scale (9 = like extremely, 1 = dislike extremely). The pasta descriptors on the sheet profile were homogeneity, flavour, taste, firmness, stickiness, and overall quality. The judges received an accurate definition for each attribute of the profile sheet before the test.

Statistical analysis

All analytical tests performed on the samples were replicated at least three times.

The IC_{50} was calculated by the nonlinear regression analysis using Prism 4.0 version for Windows (GraphPad Software, San Diego, CA). One-way analysis of variance (ANOVA) was used to analyse the data followed by the Least Significant Difference (LSD) test ($P < 0.05$) and Kruskal–Wallis test using XL-Stat (Addinsoft, 2019).

Results and discussion

Chemical composition and antioxidant capacity of raspberry powder

The dried raspberry powder used for pasta enrichment exhibited a moisture value of about 10.87 +/− 0.03 and ashes 1.66 +/− 0.01 g per 100 g of powder.

The TPC values of 2511,76 ± 162 mg GAE, of ABTS 2440 ± 196, and DPPH of 1770 ± 121, expressed as µM TE per 100 g of powder, confirm its qualities as a source of antioxidant. These values in nature can vary even in the same plant species because they are influenced by numerous factors ranging from the cultivation system to the pedoclimatic conditions. In our work, the results did not differ much from the values reported in previous studies on similar matrices (Četojević-Simin *et al.*, 2015; Gao *et al.*, 2018; Veljković *et al.*, 2019; Wu *et al.*, 2019).

Physicochemical characteristics of pasta samples

For the chemical composition of conventional pasta (CP) and raspberry powder-enriched pasta (RP), the water content ranged from 12.5% to 13.5%, and the ash content from 0.87% to 1.26% for the pasta samples. Neither showed significant differences ($P < 0.05$) between the theses.

Optimal cooking time and cooked pasta features

The OCT variation ranged from a maximum of 13′ in control paste to a minimum of 11′, 20″ for the sample enriched in 12% raspberry powder (PR5), as shown in Table 3.

The enrichment of the raspberry powder showed a decrease in the optimal cooking time (OCT) of the pasta compared to the conventional one, slightly influenced by the semolina replacement level. As noted in many other enriched pasta samples (Chung *et al.*, 2012; Zhao *et al.*, 2017; Bustos *et al.*, 2019) with gluten-free flour, the effect could be attributed to interferences in the structure of the pasta.

Furthermore, the cooking loss is increased in enriched pasta due to the reduction in the degree of gelatinisation of the starch granules due to the inhibition of the development of the gluten network for flour replacement (Sivam *et al.*, 2010; Rekha *et al.*, 2013; Silva *et al.*, 2013). Despite this, the cooking loss for all the pasta samples was still much lower than 12%, a value considered by the AACC (Delcour & Hoseney, 2010) to be the limit for quality pasta.

Table 3 Optimal cooking time (OCT) and cooked pasta features

	CP	RP1	RP2	RP3	RP4	RP5
OCT	13′00″a	12′45″a	12′05″b	11′50″b	11′00″c	10′10″d
Moisture	12.50 ± 0.98	13.51 ± 1.04	12.60 ± 0.99	13.02 ± 1	12.80 ± 0.91	13.55 ± 0.87
Ash	1.26 ± 0.01	0.87 ± 0.05	0.89 ± 0.02	0.88 ± 0.03	0.92 ± 0.02	1.16 ± 0.05
Water absorption %	142.54 ± 1.32a	135.82 ± 1.15b	123.13 ± 1.09c	123.88 ± 1.56c	112.69 ± 0.99d	114.93 ± 1.05d
Cooking loss %	5.38 ± 0.18a	6.40 ± 0.22b	6.12 ± 0.30b	6.38 ± 0.16b	6.11 ± 0.21b	6.70 ± 0.15c
Swelling index	1.56 ± 0.08a	1.53 ± 0.11a	1.51 ± 0.09a	1.41 ± 0.10a	1.28 ± 0.09b	1.31 ± 0.08b

Note: CP (Conventional pasta 100% semolina flour), RP (raspberry powder pasta % enrichment): RP1 (3.70), RP2 (5.61), RP3 (7.69), RP4 (9.88), and RP5 (12.00). Values followed by different letters indicate significant difference (P value ≤0.05) according to Tukey's test.

Semolina pasta (CP) has slightly higher values for the two indices. However, the swelling index, an indicator of water absorption due to protein hydration and starch gelatinisation during pasta cooking and water absorption during cooking, showed slight significant differences ($P < 0.05$) among the pasta formulations. The swelling index better discriminates the samples by greater significant differences for the PR4 and PR5 samples with a raspberry powder enrichment of 9.8% and 12%, respectively.

Sensory estimation cooking quality

To reduce the number of pasta samples, discarding the less performing ones on which there would be no reason to continue the study, a trained panel evaluated the samples according to the standard procedure indicated in ISO 7304 (2016).

The morphology of the pasta allowed us to consider three sensory attributes, homogeneity to chewing, firmness, and the stickiness, the latter linked to release of starch (Table 2).

For the consumer acceptance/preference test, raspberry pasta with higher powder enrichment (PR3), which had reached the quality level required by the ISO standard (7304: 2016), was used. The reference sample for the tasters was semolina pasta (CP) to verify the changes imposed by the enrichment.

Samples PR4 and PR5, enriched with 9.88% and 12% raspberry powder, were rejected because they did not reach the score of 250 in the overall quality required by the standard (Table 4). This value results from the combination of the indices of hardness, stickiness, and perceived sensory homogeneity, result consistent with the water absorption and swelling values recorded for PR4 and PR5 with physical tests.

Pasta colour

The flours used have strongly influenced the colour of the pasta, as happens in whole-meal pasta. As expected, powdered raspberry pasta had a lower "brightness" index (5.38% lower) than conventional

Table 4 Sensory estimation of cooking quality

	PC	PR1	PR2	PR3	PR4	PR5
Firmness	100	100	95	90	80	80
Stickiness	100	95	90	95	80	80
Homogeneity	100	95	95	95	85	80
Overall quality	300	290	280	280	245	240

Note: CP (Conventional pasta 100% semolina flour), RP (raspberry powder pasta % enrichment): RP1 (3.70%), RP2 (5.61), RP3 (7.69), RP4 (9.88), and RP5 (12.00).

pasta. On the order hand, a* value (direction of redness) was the most affected coordinate, with the highest increase (1.68 times) and a further growth (8.14 times) after cooking (Table 5).

Overall, cooking reduces the brightness value and increases all samples' b* value (yellowness direction).

As expected, cooking increases the differences (ΔE), 5.66 ± 1.93 for conventional pasta and 18.18 ± 2.43 for enriched pasta.

A ΔE of 22.18 ± 2,20 was recorded between the conventional and the raspberry powder-enriched pasta samples, approximately three times the difference between the same raw samples.

Table 5 Colour of the four different pasta samples and total colour difference (ΔE) between the different measurements recorded

	L*	a*	b*
CP	67.02 ± 1.99	1.49 ± 0.02	12.67 ± 0.77
CP_C	64.78 ± 0.55	−0.85 ± 0.16	16.57 ± 2.8
RP	63.41 ± 1.22	2.51 ± 0.11	5.15 ± 0.45
RP_C	45.99 ± 1.3	6.92 ± 0.39	7.86 ± 0.27

	$CP–CP_C$	$RP–RP_C$	CP–RP	$CP_C–RP_C$
ΔE	5.66 ± 1.93	18.18 ± 2.43	8.48 ± 1.06	22.18 ± 2.20

Note: CP (CK semolina 100% pasta raw), CPc (CK semolina 100% pasta cooked), RP (raspberry powder pasta enriched raw), and RPc (raspberry powder pasta enriched cooked).

Table 6 Texture profile analysis (TPA) of cooked pasta samples

TPA	F30	F90	Resilience
CP_C	0.803 ± 0.03 *a*	4.78 ± 0.563 *a*	0.61 ± 0.02 *a*
RP_C	0.457 ± 0.04 *b*	3.94 ± 0.184 *b*	0.68 ± 0.04 *a*

Note: Values are expressed as N ± standard deviation at peak force F30 (30% deformation) and F90 (90% deformation). Values followed by different letters indicate significant difference (*P* value ≤0.05) according to Tukey's test. CPc (semolina 100% pasta cooked) *versus* RPc (raspberry powder pasta enriched cooked).

Texture profile analysis

The evaluation of the compression force on the samples led to characterising the consistency of the two types of cooked pasta. Table 6 shows that the selected sample (PR3), incorporated with 5 100 g^{-1} of raspberry powder, significantly reduced ($P < 0.05$) the hardness by approximately 18% on the two bite test.

Our results showed a firmness loss in powder-enriched Rubus paste, while the resilience did not differ significantly. This could find an explanation by adding gluten-free flour, which dilutes the gluten network and makes it weaker, as confirmed by other authors in pasta samples with non-gluten flour enriched (Albors *et al.*, 2016; Parizad *et al.*, 2020).

TPC and Antioxidant Activity

Thanks to the high concentration of natural bioactive components, the consumption of berries is recommended for the beneficial effects on health. Many of the functional properties are attributable to the high content of phenolic constituents, which are well known for their antioxidant activity, indicating that raspberry is an exciting ingredient for functional foods.

In general, the TPC of cooked 5% enriched pasta showed a significantly higher polyphenol value than the control pasta ($P < 0.05$), suggesting that the polyphenols were well retained in the structure of the pasta, enhanced nutritional and pro-health value of the samples. The addition of fruit pomace in the pasta, as reported in previous studies (Sivam *et al.*, 2013; Sun-Waterhouse *et al.*, 2013; Bustos *et al.*, 2019), strongly increases the antioxidant properties of the integrated pasta, being a powerful source of many active substances that inhibit and counteract cellular oxidative stress.

Moreover, polyphenol content was affected by the cooking process. The results showed that both raw pasta extracts provide a lower TPC than cooked pasta (Table 7). The uncooked pasta presented 38 mg gallic acid equivalent (GAE) *100^{-1} g in TPC and antioxidant activity of 73.37 DPPH and 95.18 ABTS mg mL^{-1} as IC_{50} calculated. The raspberry powder integrated into the paste significantly increased the TPC concentration by approximately double that of the control and reduced the IC_{50} by around 30% in ABTS and 20% in DPPH in the samples before cooking.

As noted by other authors (Merendino *et al.*, 2014; Kowalczewski *et al.*, 2019), the antioxidant activity increased values in DPPH and ABTS after the cooking treatment.

The IC_{50} of raspberry pasta cooked (RPc) reduces the value by about 40% and 59% measured, respectively, in DPPH and ABTS compared to semolina pasta (CPc) (Table 7). Furthermore, the increase in cooking treatment is considerable (upper 30%).

The increase in antioxidant capacity with the thermal cooking process detected in the samples, as hypothesised in the works cited above, could be due to the release of active molecules retained by the gluten bond or to the formation of complexes by the Maillard reaction with antioxidant activity.

Consumer sensory analysis

The data describing the effect of the two cooked pasta samples on sensory attributes expressed by the judges are reported in Table 8. The data, processed through a non-parametric test (Kruskal–Wallis) to avoid the distortions created by a non-homogeneous use of the scale of values, highlighted the attributes that determine significant differences between the two samples (Fig. 1). As expected, the consumers recognised the two samples of pasta as different in consistency and stickiness, differences already highlighted by the

Table 7 Total phenolic content (TPC) and antioxidant activity of pasta samples and methanolic extract of *Rubus idaeus* powder

	CP	*ds*(±)	RP	*ds*(±)	CP_C	*ds*(±)	RP_C	*ds*(±)
TPC mg GAE 100 g^{-1}	38.20*a*	*4.01*	75.15*b*	*5.10*	44.22*a*	*4.23*	96.14*d*	*4.18*
DPPH (IC_{50} mg mL^{-1})	73.37*a*	*4.59*	58.5*c*	*1.47*	67.23*b*	*2.05*	40.29*d*	*1.39*
ABTS (IC_{50} mg mL^{-1})	95.18*a*	*2.70*	68.29*b*	*3.05*	89.51*a*	*4.49*	36.21*c*	*3.65*

Note: Values followed by different letters indicate significant difference (*P* value ≤0.05) according to Tukey's test.
CP (CK semolina 100% pasta raw), CPc (CK semolina 100% pasta cooked), RP (raspberry powder pasta enriched raw), and RPc (raspberry powder pasta enriched cooked).

Table 8 Mean values and standard deviations of the sensory attributes

	CP_C	(±) d.s.	RP_C	(±) d.s.
Homogeneity*	8.00	0.82	6.50	0.58
Flavour intensity*	4.50	1.29	7.50	0.58
Mineral	4.25	0.96	3.75	1.26
Sourness	2.75	0.96	3.00	0.00
Bitterness	2.00	0.82	2.20	0.82
Taste	6.75	0.50	7.00	0.82
Firmness*	7.75	0.50	6.50	0.58
Stickiness*	1.75	0.50	3.25	0.50
Overall quality*	6.50	1.02	8.50	0.54

Note: Asterisked attributes show significant differences (P value <0.05). CPc (CK semolina 100% pasta cooked), RPc (raspberry powder pasta enriched cooked).

technical qualitative parameters on pasta. Although the enrichment of the pasta with raspberry powder leads to a slight loss of consistency, consumers have shown to appreciate the product, giving it a significantly higher preference score than the conventional pasta.

The profile that emerged from the spider plot highlights, in addition to the differences in consistency, even higher values attributed by the judges to the aroma and overall quality of the pasta with raspberry (Fig. 2). This preference could depend on the more intense aroma of raspberry pasta compared to the semolina pasta consumed without condiment and on the perception of healthy food that pasta with a natural ingredient such as raspberry powder could have.

Conclusions

Our study confirmed the hypothesis that raspberry powder, obtained by drying the waste from juice extraction, is a very high-quality active product, suitable for employment in pasta enrichment, increasing functional properties, and integrating well with the substrate.

The process adopted for the enriched raspberry powder pasta satisfies the pasta's quality parameters. A semolina substitution more significant than 8% could excessively penalise the consistency, causing weakness of the gluten mesh, with consequent release of starch during cooking and increased stickiness. With a replacement raspberry powder percentage of 7.69, however, our pasta maintained an excellent cooking quality, was appreciated by consumers, and significantly increased (about 40%) the antioxidant properties of the product compared to traditional pasta.

We can therefore conclude that raspberry pasta is an easily consumable food with a pleasant taste,

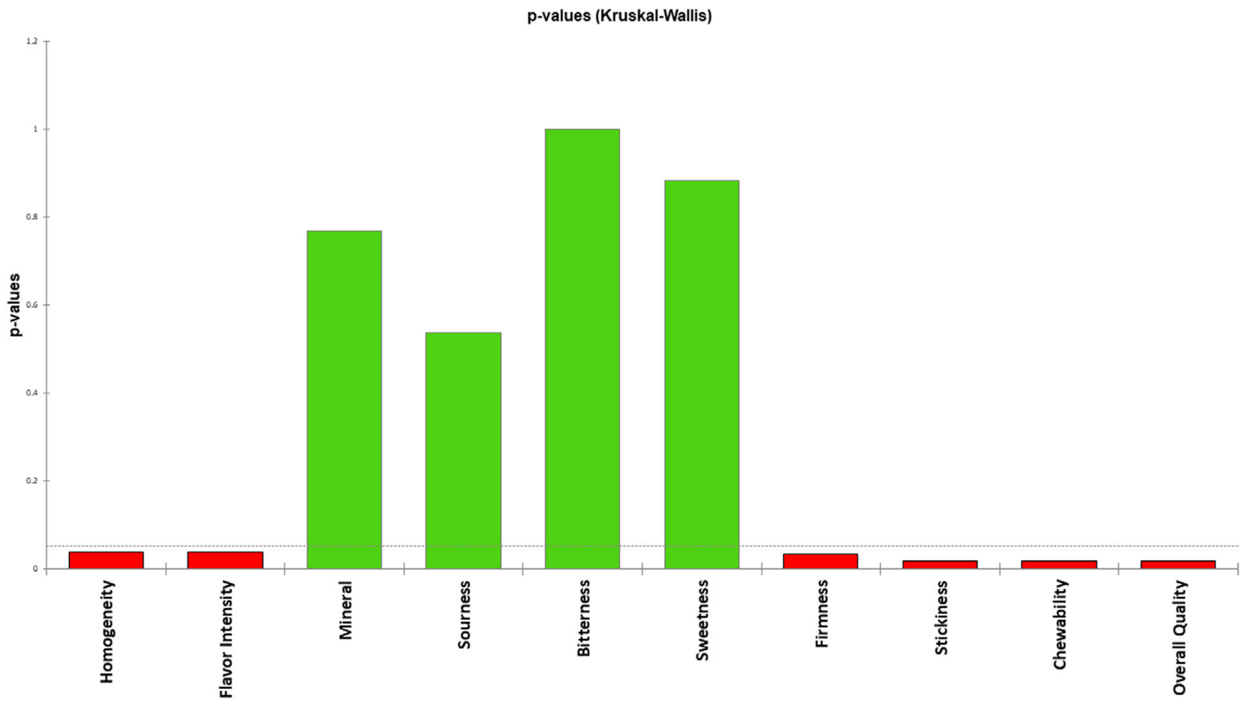

Figure 1 Sensory attributes of pasta samples by consumer sensory evaluation. The red bars indicate a significant difference at $P < 0.05$ (Kruskal–Wallis test).

Figure 2 Sensory profiles of cooked pasta samples (conventional CPC pasta and RPC raspberry pasta). Attributes asterisk-marked showed a significant difference ($P < 0.05$) between the pasta samples.

capable of causing a high increase in the antioxidant substances taken during a meal.

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Author contributions

Diana DeSantis: Conceptualization (equal); data curation (lead); formal analysis (supporting); funding acquisition (lead); investigation (equal); methodology (equal); project administration (lead); resources (lead); software (equal); supervision (lead); validation (equal); visualization (equal); writing – original draft (lead); writing – review and editing (lead). **Serena Ferri:** Data curation (supporting); formal analysis (equal); methodology (equal); visualization (equal); writing – original draft (supporting). **Alice Rossi:** Conceptualization (equal); data curation (supporting); formal analysis (equal); investigation (supporting); writing – original draft (supporting). **Riccardo Frisoni:** Formal analysis (equal); investigation (supporting); methodology (supporting). **Giovanni Turchetti:** Conceptualization (equal); data curation (supporting); formal analysis (equal); investigation (equal); methodology (equal); writing – original draft (supporting).

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The authors declare no conflicts of interest

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Data availability statement

Data available on request from the authors: ;;The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

AACC. (2009). AACC International Method 44-15.02 - Moisture-Air-Oven Methods. AACC International Approved Methods https://doi.org/10.1094/aaccintmethod-44-15.02

AACC International, 2000 Approved Methods of the American Association of Cereal Chemist, 10th Ed. Method 66-50. The Association: St. Paul, MN.

Albors, A., Raigon, M.D., García-Martinez, M.D. & Martín-Esparza, M.E. (2016). Assessment of techno-functional and sensory attributes of tiger nut fresh egg tagliatelle. *LWT - Food Science and Technology*, **74**, 183–190.

Aravind, N., Sissons, M., Egan, N. & Fellows, C. (2012). Effect of insoluble dietary fibre addition on technological, sensory, and structural properties of durum wheat spaghetti. *Food Chemistry*, **130**, 299–309.

Bacchetti, T., Morresi, C., Bellachioma, L. & Ferretti, G. (2020). Antioxidant and pro-oxidant properties of *Carthamus tinctorius*, hydroxy safflor yellow A, and safflor yellow A. *Antioxidants*, **9**, 119.

Ballestrieri, D., D'Alessandro, A., & Carnevali, P. (2015). Texture profile analysis of cooked long pasta. MP-000515 Barilla Tests.

Boroski, M., de Aguiar, A.C., Boeing, J.S. *et al.* (2011). Enhancement of pasta antioxidant activity with oregano and carrot leaf. *Food Chemistry*, **125**, 696–700.

Bustos, M.C., Paesani, C., Quiroga, F. & León, A.E. (2019). Technological and sensorial quality of berry-enriched pasta. *Cereal Chemistry*, **96**, 967–976.

The work compares the pasta made with the berries of various types. The data reported for raspberry provided valuable comparison.

Četojević-Simin, D.D., Velićanski, A.S., Cvetković, D.D. *et al.* (2015). Bioactivity of Meeker and Willamette raspberry (Rubus idaeus L.) pomace extracts. *Food Chemistry*, **166**, 407–413.

Chung, H.J., Cho, A. & Lim, S.T. (2012). Effect of heat-moisture treatment for utilization of germinated brown rice in wheat noodle. *LWT - Food Science and Technology*, **47**, 342–347.

De Santis, D., Carbone, K., Garzoli, S., Laghezza Masci, V. & Turchetti, G. (2022). Bioactivity and Chemical Profile of Rubus idaeus L. Leaves Steam-Distillation Extract. *Foods*, **11**, 1455.

Delcour, J.A. & Hoseney, R.C. (2010). Principles of cereal science and technology authors provide insight into the current state of cereal processing. *Cereal Foods World*, **55**, 21–22.

Dziki, D. (2021). Current Trends in Enrichment of Wheat Pasta: Quality, Nutritional Value and Antioxidant Properties. *Processes*, **9**, 1280.

Ferlemi, A.V. & Lamari, F.N. (2016). Berry leaves: An alternative source of bioactive natural products of nutritional and medicinal value. *Antioxidants*, **5**, 17.

Fraga, S., Domingues Nasário, F., Gonçalves, D. *et al.* (2021). Caferana seeds (*Bunchosia glandulifera*) as a new source of nutrients: evaluation of the proximal composition, solvent extraction, bioactive compounds, and δ-lactam isolation. *Food Chemistry: X*, **12**, 100161.

Gao, W., Shuai, W.Y., Hwang, E. *et al.* (2018). Rubus idaeus L. (red raspberry) blocks UVB-induced MMP production and promotes type I procollagen synthesis via inhibition of MAPK/AP-1, NF-κβ and stimulation of TGF-β/Smad, Nrf2 in normal human dermal fibroblasts. *Journal of Photochemistry and Photobiology B: Biology*, **185**, 241–253.

Heiniö, R.L., Noort, M.W.J., Katina, K. *et al.* (2016). Sensory characteristics of wholegrain and bran-rich cereal foods - A review. *Trends in Food Science and Technology*, **47**, 25–38.

ISO 8586:2014 Sensory analysis: General guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors, 1–28. Retrieved from https://www.iso.org/standard/45352.html

ISO 7304-1,2 (2016). Durum wheat semolina and alimentary pasta - Estimation of cooking quality of alimentary pasta by sensory analysis - Part 1: Reference method. ISO n 7304–1, 2–7.

The reference is fundamental because it dictates the rules for executing qualitative tests on pasta.

By adopting official procedures, the scientific data are comparable.

Applying the method indicated in the standard made it possible to discriminate based on objective qualitative parameters.

Khan, I., Yousif, A., Johnson, S.K. & Gamlath, S. (2013). Effect of sorghum flour addition on resistant starch content, phenolic profile and antioxidant capacity of durum wheat pasta. *Food Research International*, **54**, 578–586.

Kim, J.G., Kim, H.L., Kim, S.J. & Park, K.S. (2013). Fruit quality, anthocyanin and total phenolic contents, and antioxidant activities of 45 blueberry cultivars grown in Suwon, Korea. *Journal of Zhejiang University: Science B*, **14**, 793–799.

Klesk, K., Qian, M. & Martin, R.R. (2004). Aroma extract dilution analysis of cv. Meeker (*Rubus idaeus* L.) red raspberries from Oregon and Washington. *Journal of Agricultural and Food Chemistry*, **52**, 5155–5161.

Kowalczewski, P.Ł., Pauter, P., Smarzyński, K. *et al.* (2019). Thermal processing of pasta enriched with black locust flowers affect quality, phenolics, and antioxidant activity. *Journal of Food Processing and Preservation*, **43**, 1–11.

Koziol, A., Stryjewska, A., Librowski, T. *et al.* (2014). An Overview of the Pharmacological Properties and Potential Applications of Natural Monoterpenes. *Mini-Reviews in Medicinal Chemistry*, **14**, 1156–1168.

Krivokapić, S., Vlaović, M., Vratnica, B.A., Perović, A. & Perović, S. (2021). Biowaste as a Potential Source of Bioactive Compounds-A Case Study of Raspberry Fruit Pomace. *Food*, **10**, 1–11.

The work confirms the value of the by-products of the raspberry supply chain.

The results confirm the properties of this waste.

Liu, Y., Benohoud, M., Galani Yamdeu, J.H., Gong, Y.Y. & Orfila, C. (2021). Green extraction of polyphenols from citrus peel by-products and their antifungal activity against *Aspergillus flavus*. *Food Chemistry: X*, **12**, 100144.

Maltese, F., van der Kooy, F. & Verpoorte, R. (2009). Solvent Derived Artifacts in Natural Products Chemistry. *Natural Product Communications*, **4**, 447–454.

Merendino, N., Molinari, R., Costantini, L. *et al.* (2014). A new "functional" pasta containing tartary buckwheat sprouts as an ingredient improves the oxidative status and normalizes some blood pressure parameters in spontaneously hypertensive rats. *Food and Function*, **5**, 1017–1026.

Mesquita, P.C., Rodrigues, L.G.G., Mazzutti, S., da Silva, M., Vitali, L. & Lanza, M. (2021). Intensified green-based extraction process as a circular economy approach to recover bioactive compounds from soursop seeds (*Annona muricata* L.). *Food Chemistry: X*, **12**, 100164.

Parizad, P.A., Marengo, M., Bonomi, F. *et al.* (2020). Bio-functional and structural properties of pasta enriched with a debranning fraction from purple wheat. *Food*, **9**, 1–13.

Pellegrini, N., Serafini, M., Salvatore, S., Del Rio, D., Bianchi, M. & Brighenti, F. (2006). Total antioxidant capacity of spices, dried fruits, nuts, pulses, cereals and sweets consumed in Italy assessed by three different in vitro assays. *Molecular Nutrition and Food Research*, **50**, 1030–1038.

Re, R., Pellegrini, N., Proteggente, A., Yang, M. & Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology & Medicine*, **26**, 1231–1237.

Recchia, L., Cappelli, A., Cini, E., Pegna, F.G. & Boncinelli, P. (2019). Environmental sustainability of pasta production chains: An integrated approach for comparing local and global chains. *Resources*, **8**, 56.

Rekha, M.N., Chauhan, A.S., Prabhasankar, P., Ramteke, R.S. & Venkateswara Rao, G. (2013). Influence of vegetable purees on quality attributes of pastas made from bread wheat (*T. aestivum*). *CYTA - Journal of Food.*, **11**, 142–149.

The pasta qualitative characterization was made by adopting similar methods. The results of the cited work helped to interpret the behaviour of the raspberry-enriched pasta.

Silva, E., Sagis, L.M.C., van der Linden, E. & Scholten, E. (2013). Effect of matrix and particle type on rheological, textural and structural properties of broccoli pasta and noodles. *Journal of Food Engineering*, **119**, 94–103.

Sivam, A.S., Sun-Waterhouse, D., Quek, S.Y. & Perera, C.O. (2010). Properties of bread dough with added fiber polysaccharides and phenolic antioxidants: A review. *Journal of Food Science*, **75**, 1–2.

Sivam, A.S., Waterhouse, G.I.N., Zujovic, Z.D., Perera, C.O. & Sun-Waterhouse, D. (2013). Structure and Dynamics of Wheat Starch in Breads Fortified with Polyphenols and Pectin: An ESEM and Solid-State CP/MAS 13C NMR Spectroscopic Study. *Food and Bioprocess Technology*, **6**, 110–123.

Sun-Waterhouse, D., Jin, D. & Waterhouse, G.I.N. (2013). Effect of adding elderberry juice concentrate on the quality attributes, polyphenol contents and antioxidant activity of three fibre-enriched pastas. *Food Research International*, **54**, 781–789.

Torres-León, C., Ramírez-Guzman, N., Londoño-Hernandez, L. *et al*. (2018). Food Waste and Byproducts: An Opportunity to Minimize Malnutrition and Hunger in Developing Countries. *Frontiers in Sustainable Food Systems*, **2**, 1–17.

Tudoric , C.M., Kuri, V. & Brennan, C.S. (2002). Nutritional and physicochemical characteristics of dietary fiber enriched pasta. *Journal of Agricultural and Food Chemistry*, **50**, 347–356.

UNI EN ISO 8589. (2014). Sensory analysis - General guidance for the design of test rooms. International Organization for Standardization. Geneva: ISO Central Secretariat.

Veljković, B., Dordević, N., Dolićanin, Z. *et al*. (2019). Antioxidant and anticancer properties of leaf and fruit extracts of the wild raspberry (Rubus idaeus L.). *Not Bot Horti Agrobot Cluj-Napoca*, **47**, 359–367.

Wu, L., Liu, Y., Qin, Y., Wang, L. & Wu, Z. (2019). HPLC-ESI-qTOF-MS/MS characterization, antioxidant activities and inhibitory ability of digestive enzymes with molecular docking analysis of various parts of raspberry (Rubus ideaus L.). *Antioxidants*, **8**, 1–18.

Xiao, F., Xu, T., Lu, B. & Liu, R. (2020). Guidelines for antioxidant assays for food components. *Food Frontiers*, **1**, 60–69.

Yazdankhah, S., Hojjati, M. & Azizi, M.H. (2019). The Antidiabetic Potential of Black Mulberry Extract-Enriched Pasta through Inhibition of Enzymes and Glycemic Index. *Plant Foods for Human Nutrition*, **74**, 149–155.

Zarzycki, P., Sykut-Domańska, E., Sobota, A. *et al*. (2020). Flaxseed enriched pasta—chemical composition and cooking quality. *Food*, **9**, 1–10.

Zhao, D., Zhou, Y., Liu, H., Liang, J., Cheng, Y. & Nirasawa, S. (2017). Effects of dough mixing time before adding konjac glucomannan on the quality of noodles. *Journal of Food Science and Technology*, **54**, 3837–3846.