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Effect of varied addition of freeze-dried strawberry powder on selected quality parameters of common wheat pasta

Beata Biernacka[1], *Dariusz Dziki*[1]*, *Jolanta Piekut*[2], *Agnieszka Nawrocka*[3]

[1]Department of Thermal Technology, University of Life Sciences, Głęboka 31, 20-612 Lublin, Poland
[2]Department of Agri-Food Engineering and Environmental Management, Białystok University of Technology, Wiejska 45E, 15-351 Białystok, Poland
[3]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, 20-290 Lublin, Poland

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A b s t r a c t. Strawberries are abundant in essential nutrients such as vitamins, minerals, antioxidants, and dietary fiber. This study aimed to assess how partially substituting wheat flour with freeze-dried strawberry powder (in concentrations of 0, 3, 6, 9, and 12 g per 100 g^{-1}) would affect the physicochemical properties and sensory acceptability of common wheat pasta. Additionally, an analysis of phenolic acids and flavonoid compounds using UPLC-MS/MS was conducted, alongside an evaluation of the pasta's cooking characteristics. The findings revealed that the inclusion of freeze-dried strawberry powder significantly ($p < 0.05$) enhanced the pasta's ash and fiber content, while the levels of protein and fat were reduced. Furthermore, the enrichment process led to an increase in the redness of both raw and cooked pasta, while the lightness and yellowness were diminished. Freeze-dried strawberry also caused increase deformation up to the rapture point but without a significant change in force during the stretching of cooked pasta. The incorporation of strawberries into the pasta formulation led to a significant increase in phenolic content, antioxidant activity, and cooking loss. UPLC-MS/MS analysis indicated that the enriched pasta contained particularly high levels of ellagic acid. Pasta enriched with up to 12 g of strawberry per 100 g^{-1} of wheat flour was well-received by consumers.

K e y w o r d s: pasta, freeze-dried strawberry, quality, antioxidant properties, pheonolic compounds profile

1. INTRODUCTION

Pasta has a low glycemic index, which is why it is eagerly utilized in everyday balanced diets (Nilusha *et al.,* 2019). It appears as main dishes as well as an addition to soups and sauces. The phenomenon of this product lies in its use both in meat-based dishes and in vegan and vegetarian cuisine. Consumer expectations drive producers to introduce pasta with increasingly novel shapes and flavours into the market. Fruits, vegetables, and spices are added to the dough, resulting in a wide range of products with varying tastes, colours, and enhanced nutritional values. This encourages customers to diversify their daily menus (Dziki, 2021; Romano *et al.,* 2021).

There is a significant increase in society's interest in health-promoting products (Chang *et al.,*2016). For several years, great importance has been attached to the possibility of enriching pasta with plant-based additives (Dziki, 2021). This allows you to obtain products with health-promoting properties (Bustos *et al.,* 2011; Simonato *et al.,* 2019). As a result, alongside traditional options, various types of pasta are being produced: egg-based, whole grain, enriched with spices, vegetables, and fruits (Dziki, 2021). The widespread consumption of pasta has led to its potential use as

*Corresponding author e-mail: dariusz.dziki@up.lublin.pl

a carrier for health-promoting substances. These include compounds with antioxidant properties and various forms of dietary fiber (Biernacka *et al.,* 2023; Biernacka *et al.,* 2017).

Good pasta is characterized by a specific taste and smell, has appropriate elasticity and after hydrothermal treatment has an elastic and firm consistency (Bruneel *et al.,* 2010). The quality depends largely on the pasta raw material. It should be noted that despite correctly selected parameters and pasta production technology, product defects cannot be eliminated. They result from inadequate quality of the material (Zavalishina *et al.,* 2021). That is why the fortification of pasta based on both durum wheat and common wheat flour has become so important in recent years in order to increase the nutritional and, above all, health-promoting value and improve their quality characteristics and taste.

One of such seasonal fruits that enjoys significant popularity among consumers and food producers is the strawberry. Due to their flavourful, aromatic qualities and nutritional benefits, strawberries are highly favored by both children and adults. These fruits are rich in vitamins, particularly vitamins C and K, as well as folates, fiber, antioxidants, and mineral components such as potassium, calcium, phosphorus, magnesium, and manganese (Crecente-Campo *et al.,* 2012; Giampieri *et al.,* 2012). Furthermore, they are low in calories. However, due to their seasonal nature, freezing and drying are necessary to preserve them for a longer duration (Biernacka *et al.,* 2022). Freeze-drying is one of the most popular methods for drying products. By retaining colour, taste, shape, and nutritional properties, dried strawberries can serve as a functional addition to many food products, including pasta (Krzykowski *et al.,* 2020). Nowadays, functional food is becoming more and more popular and eagerly chosen by consumers. Awareness of dietary recommendations makes people more likely to choose health-promoting products (Battino *et al.,* 2009; Chang *et al.,* 2016). As a result, manufacturers release new, healthy products. Freeze-drying is one of the technologies of the drying industry (Basu *et al.,* 2014). It involves freezing the raw material (at atmospheric pressure). In the next stage, vacuum sublimation of ice takes place. Finally, the product is dried to obtain the appropriate final humidity (Alonzo-Macías *et al.,* 2013; Dziki, 2020).

Freeze-dried strawberries are rich in fiber, flavonoids and phytosterols. Flavonoids have strong anti-inflammatory and antioxidant properties (Orak *et al.,* 2012). Thanks to these features, they can reduce the risk of cardiovascular diseases (Giampieri *et al.,* 2012). The dried material obtained by freeze-drying is perfect for use in the production of functional foods and dietary supplements (Kowalska *et al.,* 2018; Potter *et al.,* 2013). It enriches products with good flavors and bioactive substances that increase the nutritional value (Sadowska *et al.,* 2017). According to literature data, freeze-dried strawberries have not been used so far as an addition to pasta, which is why such research was undertaken, among others, in this study.

The aim of the research was to determine the physicochemical, culinary, textural, antioxidant properties and the profile of phenolic acids and sensory properties of common wheat pasta enriched with freeze-dried strawberries depending on the additive used.

2. MATERIALS AND METHODS

In this investigation, coarse wheat flour (CWF) of type 500 was used, with around 90% of the particles ranging in size between 200 and 300 μm. The flour was sourced from Lubella (Lublin, Poland). The freeze-dried strawberries (FS) were prepared following the methodology outlined by Biernacka *et al.* (2022). All chemicals used in the study were of analytical grade.

Pasta was produced by substituting coarse wheat flour (CWF) with freeze-dried strawberry (FS) at concentrations of 0, 3, 6, 9, and 12 g per 100 g^{-1}, following Biernacka *et al.* (2023). Ingredients were measured, sifted, and mixed using a KitchenAid food processor to form dough, which was shaped into tagliatelle (2 mm thick, 5 mm wide). The pasta was dried using a KitchenAid pasta drying rack, placed in a climatic chamber at 25°C and 20% relative humidity for 24 h, until the moisture content reached 11-12% wb.

Chemical analyses were conducted on CWF, FS, raw control pasta (PS0), and pasta containing FS to assess the levels of dry matter, crude protein, crude ash, and crude fat, in accordance with Methods 44-15A, 08-01, 46-06, and 30-10, respectively. Fiber content was measured using Method 993.21 (AOAC, 2011). The available carbohydrate content was calculated by subtracting the values for dry matter, protein, fat, ash, and fiber. Each analysis was performed in triplicate according to AOAC standards (Horwitz and Latimer, 2011).

Water activity in the pasta was evaluated at 20°C using a LabMaster device (Novasina AG, CH-8853 Lachen, Switzerland), in accordance with the methodology described by Serin *et al.* (2018). For the assessment, a 2 g sample of dry pasta was placed into the measuring vessel.

The colour attributes of raw materials, uncooked, and cooked control pasta were measured using the CIELab* system with a colourimeter (CR-400C, Minolta, Japan). The L* value indicates lightness (0 for black to 100 for white), a* measures the green-red shift, and b* denotes the blue-yellow transition. Colour changes from freeze-dried strawberry powder were quantified using the colour differential index (ΔE) as described by Monteiro *et al.* (2016).

Optimal cooking time (OCT) was determined according to the AACC 66-50 (AACC, 2000). Weight increase index (WI) and cooking loss (CL) were calculated according to the methods described by Bonomi *et al.* (2012) and Biernacka *et al*. (2017), respectively.

Texture analysis was performed using a Zwick testing machine (Zwick GmbH and Co., Ulm, Germany). The cooked pasta, was subjected to a stretching test according to the methodology outlined by Wójtowicz (2011). For the test, a Tensile Kiefer Dough and Gluten Extensibility Rig on an Instron 5564 with a 50N load cell (Stable Micro Systems Ltd., UK) was utilized, with a tensile test speed set at 3.3 mm s^{-1}. A single sample of cooked pasta was placed on the test table, covered with plastic, and the stretching force was recorded using a computer program. The results are presented as the average of five replicates.

To prepare the extract, 0.5 g of ground dried material were subjected to extraction with 50% methanol, undergoing three rounds of shaking, each lasting 30 min. The resulting homogenate was subsequently centrifuged at 4000 rpm for 10 min at a temperature of 4°C (Lisiecka *et al.,* 2019).

The extraction procedure was performed twice, with the collected supernatants combined for further analysis. The total phenolic content (TPC) was measured using the Folin-Ciocalteu method (Romankiewicz *et al.,* 2017), and results were expressed as gallic acid equivalents (GAE) per gram of dry weight. Antioxidant activity (AA) was assessed using two methods:

– ABTS (2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonate)) radical scavenging, according to Re *et al.* (1999).

– DPPH (2,2-diphenyl-1-picrylhydrazyl) radical neutralization, as described by Brand-Williams *et al.* (1995).

As noted by Singh *et al.* (2020), a compound's potency is inversely related to its EC50 value; thus, a lower EC50 value indicates greater potency. Therefore, the compound with the lowest EC50 value is considered the most potent (Singh *et al.,* 2020).

500 mg of lyophilized samples were extracted 3 times with 5 ml of a methanol/water/formic acid mixture (80:19:1, v/v/v). The samples were sonicated for 15 min at room temperature. After each extraction, the samples were centrifuged for 10 min at 4 000 g at room temperature. The obtained extracts were evaporated under reduced pressure to remove all methanol, then diluted with anhydrous methanol to 5 ml. The extracts were filtered through a 0.45 µm filter (Whatman GF/C) and subjected to chromatographic analysis using a 1260 Infinity LC system coupled with a 6420 LC/MS Triple Quadrupole mass analyzer (Agilent Technologies, USA) with ESI ionization. Compound separation was performed using a ZORBAX Eclipse XDB-C18 2.1x150 mm 1.8-micron column, thermostated at 40°C. Gradient elution was performed using solvent A (1% formic acid in water) and solvent B (1% formic acid in acetonitrile). The gradient elution parameters were as follows: 0-5 min, 5% B; 5-45 min, 5-80% B; 45-55 min. The flow rate was 0.3 ml min^{-1}, and the injection volume was 10 µl. Spectra were recorded in negative ionization mode with full scanning in the mass range of 100-2000 m/z. Subsequently, selected precursor ions were subjected to MS2 analysis to obtain product ions. Polyphenolic compounds were identified based on the obtained fragmentation ions and literature data (Aaby *et al.,* 2007; Kajdžanoska *et al.,* 2010; Olennikov *et al.,* 2020; Spínola *et al.*, 2015). Free phenolic acids and flavonoids were quantified based on calibration curves for individual standard substances (Sigma-Aldrich, Germany).

The cooked pasta was evaluated based on its visual, olfactory, gustatory, and tactile attributes, including appearance, colour, smell, taste, and texture. Specific attention was given to attributes such as firmness and adhesiveness, culminating in an overall assessment. The evaluation was conducted by a panel of 63 non-expert consumers, aged 20-55, consisting of 37 women and 26 men. A hedonic scale, ranging from 1 (least acceptable) to 7 (most acceptable), was used to rate each attribute. To ensure accurate assessment of organoleptic characteristics, appropriate lighting and odor control measures were implemented, as specified in (Pop, 2023). The research was conducted in accordance with the ethical principles regarding research involving humans and confirmed by the Resolution of the University Ethical Committee for Scientific Research Involving Humans of the University of Life Sciences in Lublin, Resolution No. UKE/40/2024.

The experimental data underwent analysis through one-way Analysis of Variance (ANOVA) using STATISTICA 6 software (StatSoft, Inc., Tulsa, USA). Tukey's test was employed to ascertain the significance of variations among the means. All measurements were conducted in triplicate, with the stretching test and colour parameters being assessed in five replicates. Additionally, Pearson's correlation coefficients were calculated. Statistical significance for all tests was set at $\alpha = 0.05$.

3. RESULTS AND DISCUSSION

The chemical composition and water activity of pasta enriched with freeze-dried strawberry (FS) are presented in Table 1. Analysis of the raw materials revealed that FS had the highest ash (0.73%) and fiber content (6.63%), while coarse wheat flour (CWF) exhibited the highest protein content at 10.64%. The incorporation of FS into pasta caused minor variations in dry matter and water activity. Dry matter ranged from 87.52% in the control sample to 87.73% in pasta with the highest FS addition (PS12). Water activity decreased from 0.461 (PS0) to 0.437 (PS12), with all values ensuring microbiological stability. The chemical composition analysis showed that FS increased fiber content from 2.84 to 3.26%, while fat and protein levels decreased from 1.53 to 1.42% and from 10.61 to 10.23%, respectively. The addition of FS did not significantly affect the available carbohydrate content in the pasta. Research by Kowalczewski *et al.* (2019) showed that replacing wheat with oil cake from raspberries and strawberries resulted in an increase in the content of ash, protein and total fiber.

Table 1. Chemical composition (% dry matter) and water activity of the pasta enriched with FS

Sample	Dry matter (%)	Ash (%)	Protein (%)	Fat (%)	Fiber (%)	Water activity (–)	Available carbohydrates (%)
CWF	87.51 ± 1.57 A	0.66 ± 0.16 A	10.64±0.37 B	1.54 ± 0.39 B	2.80 ± 0.26 A	0.393 ± 0.054 B	84.29 ± 0.10 A
FS	89.33 ± 0.93 B	0.73 ± 0.12 B	7.17±0.78 A	0.57 ± 0.07 A	6.63 ± 1.06 B	0.297 ± 0.040 A	84.97 ± 1.56 A
PS0	87.52 ± 1.56 a	0.70 ± 0.16 a	10.61±0.36 a	1.53 ± 0.39 a	2.84 ± 0.25 a	0.461 ± 0.002 e	84.30 ± 0.09 a
PS3	87.56 ± 1.53 a	0.72 ± 0.13 a	10.54±0.35 a	1.51 ± 0.38 a	2.92 ± 0.23 a	0.456 ± 0.005 d	84.31 ± 0.08 a
PS6	87.62 ± 1.49 a	0.72 ± 0.11 a	10.43±0.34 a	1.48 ± 0.37 a	3.03 ± 0.19 a	0.549 ± 0.001 c	84.33 ± 0.09 a
PS9	87.67 ± 1.44 a	0.72 ± 0.09 a	10.33±0.33 a	1.45 ± 0.36 a	3.15 ± 0.15 a	0.441 ± 0.002 b	84.35 ± 0.12 a
PS12	87.73 ± 1.40 a	0.72 ± 0.14 a	10.23±0.32 a	1.42 ± 0.35 a	3.26 ± 0.11 a	0.437 ± 0.002 a	84.37 ± 0.16 a

CWF – common wheat flour, FS – freeze-dried strawberries, PS0, PS3, PS6, PS9, PS12, uncooked pasta with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries, respectively. The values designated by the different small letters (a, b, c, d, e) and big letters (A, B) in the columns of the table are significantly different (α = 0.05).

Research by Gałkowska *et al.* (2022) demonstrated that blackcurrant pomace is a rich source of both soluble and insoluble fiber, fat, and antioxidants. As a result, pasta made with a combination of durum wheat and blackcurrant pomace exhibited significantly higher levels of these components compared to pasta without the pomace (Gałkowska *et al.,* 2022). Bianchi *et al.* (2022) demonstrated that maqui berry powder has potential use as a value-added ingredient for the production of fresh pasta with a higher total dietary fiber content. The pasta samples PM 7.5 and P15 were respectively labeled as "source of fiber" or "high fiber content" thanks to the fact that maqui fruits contain a large amount of bioactive compounds (Bianchi *et al.,* 2022). Studies have shown that fettuccine pasta with fiber polysaccharides and elderberry juice concentrate (EJC) has acceptable quality and enhanced nutritional value. Adding EJC to pasta enriched with dietary fiber affects appearance, texture, cooking quality, and the nutrient and bioactive compound content. Interactions between EJC components and fiber polysaccharides result in variations in protein, pectin, and total dietary fiber content (Sun-Waterhouse *et al.,* 2013).

The colour characteristics of the raw materials, uncooked, and cooked pasta are outlined in Table 2. Coarse wheat flour (CWF) was significantly lighter than freeze-dried strawberry (FS), with L* values of 91.13 and 36.26, respectively, while FS showed a higher degree of redness. Increasing the proportion of FS in the pasta resulted in a reduction in lightness, with the L* value of uncooked pasta decreasing from 90.72 in the control sample to 73.29

Table 2. Colour parameters of uncooked and cooked pasta

Sample	L*	a*	b*	ΔE
CWF	91.13 ± 0.53 B	1.99 ± 0.05 A	13.15 ± 0.05 B	–
FS	36.26 ± 2.91 A	27.09 ± 0.60 B	12.05 ± 0.35 A	–
PS0	90.72 ± 0.81 c	2.43 ± 0.17 a	13.91 ± 0.73 b	–
PS3	78.14 ± 1.61 b	12.31 ± 0.44 b	7.01 ± 0.27 a	17.48 ± 1.52 a
PS6	72.55 ± 1.10 a	14.60 ± 0.81 c	6.68 ± 0.41 a	23.04 ± 1.46 b
PS9	73.68 ± 1.30 a	16.07 ± 0.48 d	6.35 ± 0.16 a	23.11 ± 0.71 b
PS12	73.29 ± 1.20 a	16.48 ± 0.56 d	6.23 ± 0.25 a	23.68 ± 0.87 b
CPS0	87.09 ± 1.21 d	3.57 ± 0.10 a	15.42 ± 0.59 c	-
CPS3	69.93 ± 1.51 c	9.84 ± 0.53 b	14.89 ± 0.69 bc	18.31 ± 2.19 a
CPS6	68.36 ± 1.50 c	11.80 ± 0.57 c	15.07 ± 0.59 c	20.49 ± 1.63 b
CPS9	64.84 ± 0.94 b	12.74 ± 0.46 c	13.36 ± 0.63 a	24.17 ± 0.92 c
CPS12	59.85 ± 1.42 a	13.77 ± 0.67 d	13.72 ± 0.65 ab	29.16 ± 2.43 d

CWF – common wheat flour, FS - freeze-dried strawberries, PS0, PS3, PS6, PS9, PS12, uncooked pasta with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries, respectively, CPS0, CPS3, CPS6, CPS9, CPS12, cooked pasta with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries, respectively. L* – lightness, a* – redness, b* – yellowness, ΔE – total colour difference. The values designated by the different small letters (a, b, c, d) and big letters (A, B) in the columns of the table are significantly different (α = 0.05).

in pasta containing 12 g 100 g^{-1} FS. This indicates that FS-enriched pasta was darker than the control wheat pasta (PS0). The redness (a* value) of uncooked pasta increased from 2.43 (PS0) to 16.48 (PS12) with FS addition, while yellowness (b* value) decreased, falling from 13.91 (PS0) to 6.23 (PS12). The total colour difference (ΔE) between the control and FS-enriched pasta ranged from 17.48 to 23.68, with a strong correlation between FS content and ΔE ($r = 0.83$, $p < 0.05$).

Notably, cooking the pasta intensified the colour differences between the control and FS-enriched samples. The ΔE values for cooked FS-enriched pasta ranged from 18.31 to 29.16, revealing a significant correlation between FS content and ΔE ($r = 0.91$, $p < 0.05$). A colour difference exceeding 3 is perceptible to the human eye, indicating that even the addition of 3 g 100 g^{-1} FS had a substantial impact on colour changes. Cooking also led to a significant reduction in L* values for most pasta samples, with lightness ranging from 87.09 for CPS0 to 59.85 for CPS12. Furthermore, redness (a*) increased as FS content rose, with CPS12 exhibiting the highest a* value (13.77) and CPS0 the lowest (3.57), accompanied by a strong correlation between FS content and a* ($r = 0.91$, $p < 0.05$). In terms of yellowness, FS-enriched cooked pasta exhibited slightly lower b* va-lues compared to the control, with yellowness decreasing from 15.42 in CPS0 to 13.36 in CPS9.

In summary, it was found that FS had a significant impact on the colour of the pasta both before and after cooking, leading to a reduction in lightness and yellowness while increasing redness.

A similar relationship was observed in the case of the addition of other fruits to cereal products based on wheat flour. In studies by Kowalczewski *et al.* (2019), changes in colour were observed with the increase in the addition of raspberry and strawberry oil cakes. The colour of the crumb shifted towards red and blue, and the brightness decreased (Kowalczewski *et al.,* 2019). It was proved that, the addition of carrot (Gull *et al.,* 2015) and grape pomace (Tolve *et al.,* 2020) strongly influenced on pasta colour, especially caused decrease in the lightness and increased the redness. Bianchi *et al.* (2022) demonstrated that increasing the amount of maqui berry powder (*Aristotelia chilensis*) (MBP) in pasta formulations resulted in a decrease in the lightness of both uncooked and cooked pasta. This reduction in lightness could potentially diminish the appeal of the newly developed pasta to consumers. Other authors found that the addition of different dried berry resulted increased the redness of pasta, but decrease in the lightness (Bustos *et al.,* 2019). The increase in the redness of pasta with added strawberries is due to the presence of anthocyanins in these fruits. Anthocyanins are natural plant pigments responsible for the red, purple, and blue colours in many fruits and vegetables. In strawberries, the most important anthocyanins are pelargonidin and cyanidin (Filip *et al.,* 2012).

Table 3. Cooking properties of pasta

Sample	Parameter		
	OCT (min)	WI (kg CP kg^{-1} UP)	CL (g 100 g^{-1} of pasta)
CPS0	14.33 ± 0.76 ^{d}	2.29 ± 0.02 ^{a}	1.53 ± 0.06 ^{a}
CPS3	12.17 ± 1.04 ^{c}	2.59 ± 0.02 ^{b}	2.62 ± 0.42 ^{b}
CPS6	10.50 ± 0.50 ^{bc}	2.53 ± 0.01 ^{b}	3.05 ± 0.12 ^{bc}
CPS9	10.00 ± 0.50 ^{b}	2.28 ± 0.05 ^{a}	3.20 ± 0.12 ^{bc}
CPS12	7.67 ± 0.29 ^{a}	2.19 ± 0.03 ^{a}	3.56 ± 0.00 ^{c}

CPS0, CPS3, CPS6, CPS9, CPS12, cooked pasta with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries, respectively. OCT – optimum cooking time (min), WI – weight increase index (kg kg^{-1}), CL – cooking loss (kg kg^{-1}), CP – cooked pasta, UP – uncooked pasta. Mean ± SD, n = 3. Values followed by the same letter (a, b, c, d) in the same rows are not significantly different ($p < 0.05$).

The cooking performance of pasta is a vital quality factor that greatly affects its overall quality. High-quality pasta should retain its shape and expand in volume while minimizing material loss during cooking (Bruneel *et al.,* 2010; Zavalishina *et al.,* 2021). The study revealed that the addition of FS reduced the optimal cooking time, decreasing from 14.33 min for CPS0 to 7.67 minutes for pasta with 12 g FS per 100 g^{-1} of flour (Table 3). A significant positive correlation was found between FS addition and cooking time ($r = 0.98$, $p < 0.05$). Moreover, FS led to a slight reduction in the weight increase index (WI), dropping from 2.29 (CPS0) to 2.19 (CPS12). Additionally, FS significantly increased cooking loss, rising from 1.53% for CPS0 to 3.56% for CPS12 ($r = 0.94$, $p < 0.05$). Other studies have observed a similar trend when fruits were incorporated into common wheat pasta. Nevertheless, another aspect of fiber-enriched pasta is that replacing wheat flour or durum semolina results in gluten dilution, which usually leads to a shorter cooking time (Bustos *et al.*, 2015). According to the Bustos *et al.* (2019) adding berries to pasta negatively impacts its cooking properties, especially when using freeze-dried berries. This effect is likely due to the high swelling capacity of the berries, which causes significant disruption to the gluten matrix, as well as the dilution of gluten from replacing wheat flour (Bustos *et al.,* 2019). Moreover, replacing durum wheat semolina with an increased content of maqui berry powder (*Aristotelia chilensis*) resulted in a reduction in cooking time and increase the cooking loss (Bianchi *et al.,* 2022).

The research indicates that incorporating FS into pasta resulted in a significant increase in deformation up to the point of stretching, while the force required for stretching the cooked pasta did not change significantly (Fig. 1). With the increase of FS in recipe deformation increased and a slight decrease in strength was observed. Also significant correlations between the FS and deformation was revealed

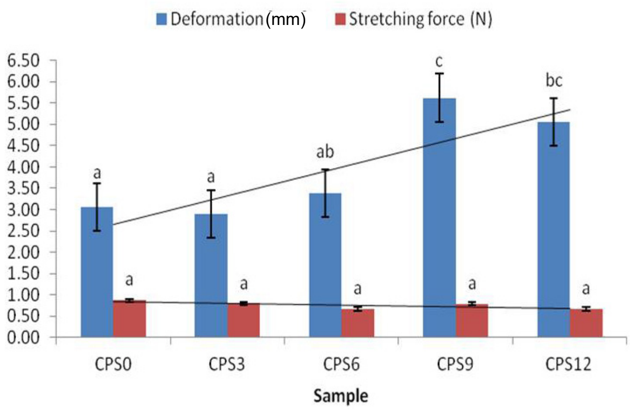

Fig. 1. Texture properties of pasta cooked with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries CPS0, CPS3, CPS6, CPS9, CPS12, respectively. Mean ± SD, n = 5. Values followed by the same letter (a, b, c) are not significantly different ($p < 0.05$).

($r = 0.85$, $p < 0.05$). Others authors found a similar trend when fruits was incorporated into common wheat pasta (Bustos *et al.,* 2019). Increasing levels of maqui berry powder in place of durum wheat semolina led to greater firmness and adhesiveness in the pasta (Bianchi *et al.,* 2022). In the studies by Kowalczewski *et al.* (2019) changes in texture were observed with the increase in the addition of oilseed cakes from raspberries and strawberries. The more ROC and SOC were introduced into the recipe, the higher the crumb hardness.

Table 4 displays the polyphenol content and antioxidant activity (AA) for both the raw materials and the pasta samples. The total phenolic content (TPC) in freeze-dried strawberry (FS) was more than six times higher than in coarse wheat flour (CWF). Additionally, FS demonstrated significantly greater antioxidant activity (AA) against both

Table 4. TPC and AA of cooked pasta

Sample	Parameter		
	TPC (mg GEA g^{-1} d.m.)	ABTS EC_{50} (mg d.m. ml^{-1})	DPPH EC_{50} (mg d.m. ml^{-1})
CWF	57.32 ± 0.06^{A}	139.54 ± 0.12^{B}	136.18 ± 0.53^{B}
FS	348.78 ± 0.49^{B}	0.57 ± 0.03^{A}	1.50 ± 0.02^{A}
CPS0	1.82 ± 0.13^{a}	44.02 ± 0.36^{c}	5.12 ± 0.13^{a}
CPS3	2.18 ± 0.03^{b}	30.87 ± 1.97^{b}	4.73 ± 0.51^{a}
CPS6	2.79 ± 0.13^{c}	8.35 ± 0.03^{a}	4.55 ± 0.06^{a}
CPS9	3.66 ± 0.01^{d}	6.74 ± 0.21^{a}	4.28 ± 0.10^{a}
CPS12	5.23 ± 0.19^{e}	7.23 ± 0.76^{a}	4.18 ± 0.59^{a}

CWF – common wheat flour, FS – freeze-dried strawberries, CPS0, CPS3, CPS6, CPS9, CPS12, cooked pasta with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries, respectively. Mean ± SD, n = 3, separate statistical analyses of TPC, ABTS and DPPH were performed, different small letters (a, b, c, d) and big letters (A, B) in the columns of the table mean significant differences between means ($p < 0.05$).

ABTS and DPPH radicals compared to CWF. FS exhibited strong radical reducing and neutralizing capabilities, with EC50 values for ABTS and DPPH being 0.57 and 1.50 mg d.m. ml^{-1}, respectively (where a higher EC50 indicates lower reducing capacity and antioxidant properties). Notable differences in TPC were observed between the control pasta and FS-enriched pasta, with TPC significantly increasing upon FS addition. For instance, the TPC of CPS0 was 1.82 mg GAE g^{-1} d.m., which increased by over 187 to 5.23 mg GAE g^{-1} d.m. in CPS12. A strong correlation between FS content and TPC was found ($r = 0.96$, $p < 0.05$). Furthermore, FS enhanced the AA of the enriched pasta compared to the control, with significant differences in AA emerging at FS concentrations of 6 g 100 g^{-1}, particularly for ABTS. The AA of the cooked pasta improved with higher FS content, as indicated by decreasing EC50 values. Specifically, the EC50 value for ABTS decreased significantly from 44.02 mg d.m. ml^{-1} in the control to 7.23 mg d.m. ml^{-1} in CPS12. A similar pattern was observed for DPPH, where FS increased the pasta's ability to neutralize DPPH free radicals, as evidenced by a decrease in EC50 from 5.12 mg d.m. ml^{-1} for CPS0 to 4.18 mg d.m. ml^{-1} for CPS12. Significant correlations were found between FS content and antioxidant activity, with r values of 0.90 and 0.98 for ABTS and DPPH, respectively. Numerous studies confirm that berries are rich in potent antioxidants and other bioactive compounds (Chang *et al.,* 2016). The increase in antioxidant activity (AA) is attributed to the bioactive compounds present in strawberries (Battino *et al.,* 2009). Previous research has demonstrated that freeze-dried strawberries (FS) are a significant source of biologically active compounds, particularly phenolic acids, which possess robust antioxidant properties (Aaby *et al.,* 2007; Chang *et al.,* 2016; Gałkowska *et al.,* 2022). FS is especially rich in various phenolic acids, such as ellagic acid (the predominant component), as well as chlorogenic, p-coumaric, gallic, and ferulic acids (Crecente-Campo *et al.,* 2012; Giampieri *et al.,* 2012). Additionally, our findings reveal a significant correlation between total phenolic content (TPC) and antioxidant activity, as measured by both ABTS ($r = 0.77$, $p < 0.05$) and DPPH assays ($r = 0.90$, $p < 0.05$). These results align with those from other studies, which have reported that partial substitution of wheat flour with fruit additives enhances antioxidant activity in pasta. Enrichment with berries has been shown to increase the levels of bioavailable polyphenols and cleansing agents in pasta. Furthermore, after in vitro digestion, the polyphenol content significantly increased compared to that in cooked pasta, especially in red and black currants, likely due to depolymerization, which enhances scavenging activity (Bustos *et al.,* 2020). Other studies indicate that adding 2.5% air-dried berries to pasta improves its technological quality and boosts polyphenol, anthocyanin, and antioxidant levels, with red currants showing the least effect. Phenolic compounds were effectively transferred to the pasta structure, increasing their activity in the ABTS test (Bustos *et al.,* 2019). In studies by Sun-Waterhouse *et al.* (2013) it was shown that fettuccine pasta prepared with black elderberry juice concentrate (EJC) retained about 70% of the total antioxidant activity (TAA) after cooking. Bianchi *et al.* (2022) demonstrated that substituting 0, 7.5, and 15 g per 100 g^{-1} of durum wheat semolina with maqui (Aristotelia chilensis) berry powder resulted in pasta with high levels of polyphenols, including anthocyanins, and enhanced antioxidant capacity. Additionally, these fruits are noted for their rich content of essential nutrients, including vitamins, minerals, antioxidants, and dietary fiber. Adding fruits to pasta increases vitamin C, vital for skin health and immune function (Battino *et al.,* 2009; Bustos *et al.,* 2020). Fruits such as raspberries, blueberries, and blackcurrants are high in antioxidants (Sun-Waterhouse *et al.,* 2013), helping combat oxidative stress and reduce the risk of chronic diseases like heart disease and cancer (Basu *et al.,* 2014).

The UPLC-MS/MS analysis, detailed in Table 5, identified ten phenolic acids and flavonoids in the pasta samples enriched with freeze-dried strawberry (FS). Notably, three specific compounds-gallic acid, quercetin, and kaempferol-were present in pasta samples with FS concentrations exceeding 3 g 100 g^{-1}. The acids chlorogenic, p-coumaric, ellagic, 4-hydroxybenzoic, and cinnamic were detected in all samples, including both the control and FS-enriched variants. The concentration of these acids increased proportionally with FS addition. Among them, ellagic acid was the most prominent, with its content rising from 0.60 µg g^{-1} dry matter (d.m.) in the control sample (PS0) to 48.80 µg g^{-1} d.m. in the sample with the highest FS concentration (PS12). Two of these acids myricetin and apigenin were not detected in all samples. Ellagic acid is one of the primary phenolic acids found in strawberries. It is known for its potent antioxidant properties, which help in neutralizing harmful free radicals in the body (Battino *et al.,* 2009). Ellagic acid is noted for its potential health benefits, which include anti-inflammatory and anticancer properties. It is thought to play a role in preventing various chronic diseases by safeguarding cells from oxidative stress and inflammation (Sadowska *et al.,* 2017). In strawberries, ellagic acid is typically found in higher concentrations in the seeds and the skin, where it accumulates due to its affinity for binding with proteins and other compounds. The presence of ellagic acid in strawberries underscores their nutritional value and potential health-promoting effects (Aaby *et al.,* 2007). Gaita *et al*. (2020) examined the addition of grape pomace skins (GPS) to pasta by replacing 3, 6, and 9% of the wheat flour. The study identified a range of phenolic compounds, including gallic, ferulic, coumaric, rosmarinic, and caffeic acids, as well as epicatechin, rutin, quercetin, kaempferol, and resveratrol. It was concluded that higher levels of GPS (grain processing by-products) enhanced both the polyphenolic content and antioxidant capacity of the pasta. Additionally, incorporating up to 6% GPS improved the pasta's sensory and functional properties (Gaita *et al.,* 2020). Similar results regarding the presence of phenolic acids in berries were shown in studies by Sadowska *et al*. (2017). The powders obtained from the fruits were characterized by a high polyphenol content. The highest concentrations of these compounds were found in freeze-dried fruit powders from chokeberry, bilberry, and cranberry. In these fruits, the presence of gallic, chlorogenic, caffeic, p-coumaric, and ferulic acids, as well as flavonoids such as quercetin, was identified.

Figure 2 displays pasta samples both before and after cooking, which have been enriched with 3-12 g 100 g^{-1} of FS.

Sensory evaluation of pasta, like other food products, requires standardization. Typically, attributes are assessed using a hedonic scale in consumer acceptance tests, with

Table 5. Phenolic acids and flavonoids content for pasta supplemented with FS

Phenolic acids (µg g^{-1} d.m.)	Sample				
	PS0	PS3	PS6	PS9	PS12
Gallic acid	–	0.38 ± 0.04 [a]	0.52 ± 0.05[a]	1.43 ± 0.26 [b]	1.68 ± 0.17 [b]
Chlorogenic acid	0.17 ± 0.02 [b]	0.50 ± 0.05 [a]	1.00 ± 0.11 [b]	1.73 ± 0.14 [b]	1.95 ± 0.20 [b]
p-Coumaric acid	0.25 ± 0.02 [c]	5.04 ± 0.50 [b]	6.96 ± 0.63 [c]	11.55 ± 0.99 [d]	15.80 ± 1.63 [d]
Ellagic acid	0.60 ± 0.06 [d]	14.84 ± 1.12 [c]	24.50 ± 1.15 [d]	37.35 ± 1.54 [e]	48.80 ± 1.88 [e]
4-Hydroxybenzoic acid	0.21 ± 0.02 [bc]	0.91 ± 0.11 [a]	1.70 ± 0.20 [b]	3.03 ± 0.42 [c]	3.40 ± 0.44 [c]
Myricetin	–	–	–	–	–
Quercetin	–	0.11 ± 0.02 [a]	0.19 ± 0.02 [a]	0.26 ± 0.03 [a]	0.32 ± 0.04 [a]
Cinnamic acid	0.07 ± 0.01 [a]	0.31 ± 0.04 [a]	0.50 ± 0.06 [a]	0.72 ± 0.06 [a]	0.95 ± 0.11 [a]
Apigenin	–	–	–	–	–
Kaempherol	–	0.17 ± 0.02 [a]	0.26 ± 0.04 [a]	0.44 ± 0.05 [a]	0.51 ± 0.06 [a]

PS0, PS3, PS6, PS9, PS12, uncooked pasta with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries, respectively. Mean ± SD, n = 3. Values followed by the same letter (a, b, c, d, e) in the same rows are not significantly different ($p < 0.05$).

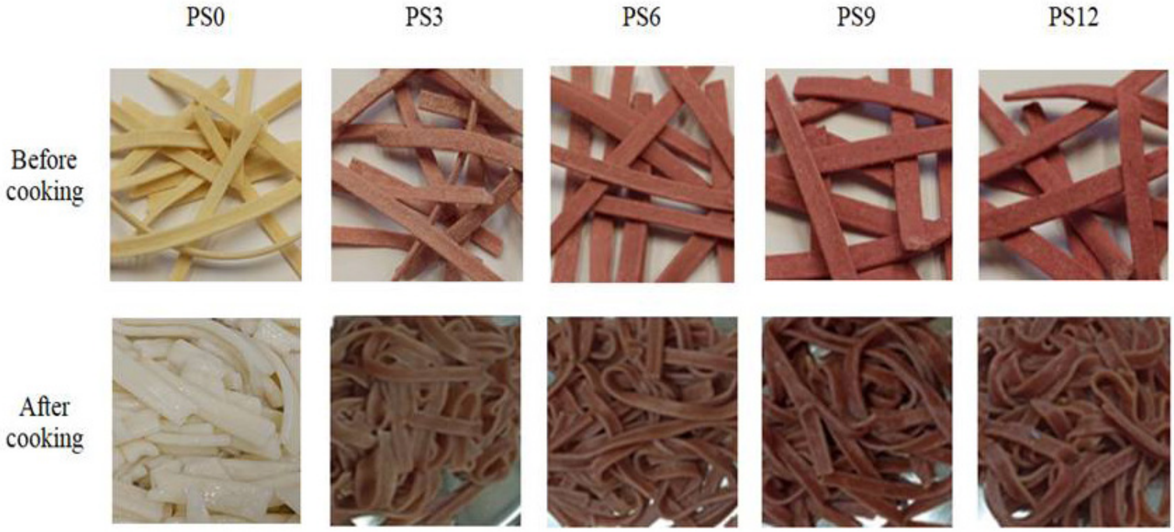

Fig. 2. Pasta before and after cooking with addition of FS, PS0, PS3, PS6, PS9, PS12 pasta with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries, respectively.

scores ranging from 1 to 9, where higher scores indicate better quality. Key sensory attributes evaluated in pasta include stickiness, surface swelling, "firmness/elasticity upon biting," and colour (Bustos *et al.,* 2015). The addition of freeze-dried strawberry (FS) up to 6 g 100 g^{-1} did not negatively impact the overall assessment of these characteristics (Table 6). In terms of appearance, CPS9 and CPS12 were rated highest (6.00), compared to CPS0, which received a slightly lower rating (5.00). FS also influenced pasta colour, which ranged from light gray to reddish brown, with CPS9 being rated the best for colour (6.67) and CPS3 the lowest (2.67). For aroma, CPS9 and CPS12 were rated highest (6.67) due to their distinct strawberry scent, whereas CPS3 and CPS6 received slightly lower ratings (5.00). Pasta samples with FS concentrations above 3 g 100 g^{-1} were rated higher in aroma compared to the control sample. In terms of taste, CPS9 and CPS12 received the highest ratings (6.67), CPS6 received slightly lower marks (5.67), and CPS0 and CPS3 were rated lowest (5.33). FS also positively affected pasta texture, with CPS0 and CPS3 rated lowest for texture (5.67). Higher FS levels (>3 g 100 g^{-1}) enhanced texture attributes. Overall, CPS9 and CPS12 received the highest scores for overall quality (6.67), while CPS3 received the lowest overall acceptability score (3.67). Sensory evaluation indicated that pasta prepared with FS up to 6 g 100 g^{-1} was well-accepted overall. Recently, Bustos *et al.* (2020) investigated the quality and nutritional properties of pasta samples by replacing wheat flour (2.5 and 7.5%) with freeze-dried raspberries, boysenberries, and red and blackcurrants. The results clearly show that the berry-enriched pasta samples were perceived as fruity, tasty, and al dente, and were considered new products likely to be regularly consumed. As a result, the berry-enriched pasta samples received high acceptance ratings and were preferred by over 70% of consumers compared to the control pasta. In previous studies Bustos *et al.* (2019) investigated the impact of adding berries on the technological and sensory quality of pasta, which was crucial for evaluating whether the addition resulted in a high-quality final product. Significantly, fruits from the genus *Ribes* exhibited

Table 6. Sensory characteristics of cooked pasta fortified FS

Sample	Sensory attribute					
	Appearance	Colour	Smell	Taste	Texture	Overall
CPS0	5.00 ± 0.00 ^{ab}	5.00 ± 0.00 ^{bc}	4.67 ± 1.53 ^{a}	5.33 ± 1.15 ^{a}	5.67 ± 0.58 ^{a}	4.67 ± 0.58 ^{ab}
CPS3	3.33 ± 1.53 ^{a}	2.67 ± 1.15 ^{a}	5.00 ± 1.73 ^{a}	5.33 ± 0.58 ^{a}	5.67 ± 0.58 ^{a}	3.67 ± 1.15 ^{a}
CPS6	4.67 ± 0.58 ^{ab}	4.33 ± 0.58 ^{ab}	5.00 ± 1.00 ^{a}	5.67 ± 0.58 ^{a}	6.33 ± 0.58 ^{a}	4.33 ± 1.53 ^{ab}
CPS9	6.00 ± 1.00 ^{b}	6.67 ± 0.58 ^{c}	6.67 ± 0.58 ^{a}	6.67 ± 0.58 ^{a}	6.00 ± 0.00 ^{a}	6.67 ± 0.58 ^{b}
CPS12	6.00 ± 1.00 ^{b}	6.00 ± 1.00 ^{bc}	6.73 ± 0.65 ^{a}	6.63 ± 0.64 ^{a}	6.00 ± 0.00 ^{a}	6.42 ± 0.76 ^{b}

CPS0, CPS3, CPS6, CPS9, CPS12, cooked pasta with 0, 3, 6, 9 and 12 g 100 g^{-1} of freeze-dried strawberries, respectively. Acceptability in 7-points hedonic scale. Mean ± SD, n = 3. values followed by the same letter (a, b, c) in the same rows are not significantly different ($p < 0.05$).

the highest level of starch hydrolysis, which was linked to a notable decline in pasta quality. In studies by Bianchi *et al.* (2022) it was shown that pasta enriched with maqui berry powder (*Aristotelia chilensis*) received good sensory reviews from the panel, and the acceptance score was higher than the acceptability threshold.

4. CONCLUSIONS

This study demonstrates that freeze-dried strawberry powder can be effectively incorporated into nutritionally enhanced pasta formulations. The addition of FS led to a modest reduction in protein and fat content, while increasing the levels of ash and fiber. FS significantly altered the colour of both uncooked and cooked pasta, notably decreasing lightness and yellowness while increasing redness. Additionally, FS affected the pasta's cooking properties by increasing cooking loss and decreasing optimal cooking time and water absorption. Although FS significantly enhanced the deformation during stretching of cooked pasta, it did not notably affect the force required. FS also markedly increased the total phenolic content and improved the antioxidant capacity of the pasta. Sensory evaluation indicated that higher FS concentrations positively impacted the pasta's appearance, colour, aroma, and taste, though it had a negative effect on texture. Importantly, the incorporation of FS (up to 12 g 100 g^{-1}) was favorably received by consumers and provided a valuable source of fiber and bioactive compounds, especially ellagic acid. These findings offer foundational guidelines for producing FS-enriched pasta from common wheat flour.

Conflicts of Interest: The Authors do not declare any conflict of interest.

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