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PASTA FORTIFICATION WITH TOMATO PEEL BY-PRODUCT: IMPACT ON TECHNOLOGICAL AND ANTIOXIDANT PROPERTIES

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ABSTRACT

Tomato peel is a by-product rich in bioactive compounds and dietary fibers, which are deficient in wheat pasta. The objective of this study was to investigate the impact of the addition of various levels (0, 5, 7.5, 10, 12.5 and 15%) of an industrial tomato peel by-product on selected properties of enriched pasta. The addition of tomato peel by-product significantly increased lipid, ash, pigments, total polyphenols content, and antioxidant capacity (ABTS and FRAP). In contrast, the enriched pasta showed a significant decrease in optimal cooking time and swelling index; the increase in cooking loss did not exceed the acceptable limit (8%). The tomato by-products can be successfully valorized in pasta-making because a 15% addition enhances the nutritional value of the final product without affecting the technological quality.

1. Introduction

Pasta is one of the most consumed foods in the world due to its low price, ease of preparation and long shelf life (Kamali Rousta *et al*., 2020). Currently, the increasing demand of the consumers for healthy food products rich in bioactive compounds with beneficial effects on human health and/or the reduction of chronic disease has encouraged food producers to develop various new functional food products (Bianchi *et al*., 2021; Mercier *et al*., 2016).

Pasta is commonly made from durum wheat semolina that has a high content in carbohydrates, but low contents in dietary fibers, minerals, proteins, vitamins and free phenolic compounds (Bouasla *et al*., 2020; Brandolini *et al*., 2011). However, the World Health Organization and the Food and Drug Administration consider the fortification of pasta with high-value-added ingredients of great nutritional importance because pasta can be a suitable carrier for the addition of healthy compounds (Bianchi *et al*., 2021). Consequently, considerable efforts have been made towards the development of fortified pasta with various ingredients such as plant-based flours (e.g. cereals, germinated cereals, pseudo-cereals, pulses and dietary fibers), animal-based ingredients (e.g. egg products), protein concentrates and isolates, nutraceutical compounds, plants, microalgae and agro-industrial by-products (Bouasla *et al*., 2022;

Ćetković *et al.*, 2022; Cota-Gastélum *et al.*, 2019; Hidalgo *et al.*, 2020; Padalino *et al.*, 2013).

Tomato (*Solanum lycopersicon*) is one of the most consumed crop in the world (Padalino *et al.*, 2017). Tomato is rich in many beneficial components such as carotenoids (lycopene, α-carotene and β-carotene), phenolic compounds (phenolic acids and flavonoids), organic acids, vitamins (ascorbic acid, vitamin A, and folic acid) and glycoalkaloids (tomatine) (Chaudhary *et al.*, 2018; Lu *et al.*, 2019). These health-promoting phytochemicals help in preventing various chronic degenerative diseases because they have antioxidant, anti-inflammatory, anti-proliferative, anti-mutagenic, and anti-atherogenic activities. Hence, the health promoting bioactivity of tomatoes make them useful ingredient for the development of functional foods (Chaudhary *et al.*, 2018). Tomato is consumed as fresh vegetable or in the form of various processed products (paste, sauce, juice, and ketchup) (Hidalgo *et al.*, 2017; Lu *et al.*, 2019). However, industrial tomato processing generates large amounts of by-products consisting of peels, pulp residues and seeds (Calvo *et al.*, 2007; Domínguez *et al.*, 2020), which can successfully be used in the formulation of new products (Betrouche *et al.*, 2022; Nakov *et al.*, 2022). Tomato peels are the most important part of these by-products because they are rich in bioactive compounds (lycopene and flavonoids) (George *et al.*, 2004).

Waste management as well as the promotion of health, well-being and sustainable lifestyles are among the goals of the 2030 United Nations Agenda (Bianchi *et al.*, 2021). In this context, many studies have been carried out on the valorization of by-products for their use in human food, cosmetics and pharmaceutical products. These new ingredients could be of great interest because their use could reduce industrial costs and justify new investments in equipment, while providing a correct solution to the problem of pollution linked to food processing (Calvo *et al.*, 2007; Padalino *et al.*, 2017). Furthermore, the conversion of industrial by-products into ingredients to produce new food is in the frame of circular economy and sustainability (Bianchi *et al.*, 2021).

Nevertheless, pasta fortification can impact the sensory attributes and the technological properties of pasta. Therefore, developing enriched pasta products with suitable quality is often a challenge and requires a compromise between processing ease, consumer acceptability and nutritional gain.

This study aims to valorize the tomato peel by-product (TPBP) in the production of enriched pasta evaluating the impact of TPBP on the technological and nutritional properties of durum wheat pasta.

2. Materials and methods

2.1. Raw materials

Durum wheat semolina was bought from a local market (Constantine, Algeria) and sifted to obtain semolina with particles size below 0.5 mm.

The tomato pomace was supplied by CAB Company (Guelma, Algeria). Seeds were removed by flotation as described by Padalino *et al.* (2017) and tomato peel by-product was dried at 40 °C in an air oven (Memmert, Schwabach, Germany) until a constant weight was reached. The dried tomato peel by-product (6% residual moisture) was then ground using a knife mill (Philips 2102, Drachten, The Netherlands) and sifted to obtain tomato peel by-product powder with granulation below 0.5 mm.

2.2. Preparation of pasta

The pasta was made according to the method described by Bouasla *et al.* (2022), with modifications. The control pasta (P0) was prepared by hydrating the durum wheat semolina with distilled water (48 mL/100 g) and kneaded manually for 15 min to obtain homogeneous, firm and non-sticky dough, which was rested for 10 min and then sheeted using the Marcato Ampia 150 pasta machine (Campodarsego, Italy) to obtain pasta sheets which were pre-dried in ambient temperature for 30 min. The pre-dried sheets were cut using the same pasta machine to produce fettuccine-type pasta with a 6.5 mm width, 1 mm thickness and

150 mm length. The pasta was dried at room temperature (25°C) for 24 h (moisture content less than 12.5%) then stored in hermetically sealed plastic boxes.

The enriched pasta was produced as described for the control pasta with three modifications: (i) durum wheat semolina was replaced by TPBP in the amounts of 5, 7.5, 10, 12.5 and 15% (w/w), and the pasta samples were coded P1, P2, P3, P4 and P5, respectively, (ii) before hydration, TPBP was mixed with durum wheat semolina for 5 min, (iii) the dough hydration level was gradually increased up to 67.5 mL/100 g.

2.3. Chemical composition

The proximate composition of TPBP and pasta samples was determined in duplicate according to AACC approved methods (AACC, 2000) for fat (n. 30-10) and ash (n. 08-01), and according to AOAC approved methods (AOAC, 2007) for proteins (n. 930.25). Fibers content was determined according to the standard method ISO 5498:1981 (ISO, 1981).

2.4. Antioxidant properties

2.4.1. Extract preparation

The extracts were obtained according to the method described by Bouasla *et al.* (2022). Samples of 1 g of ground dried cooked pasta were extracted three times with 20 mL of acetone (75%), stirred using a magnetic stirrer for 30 min and separated by centrifugation (1700 *g*, 5 min, 4°C). The combined extracts were concentrated under vacuum and the dry extract obtained was used for the evaluation of total polyphenols content (TPC) and antioxidant activities.

2.4.2. Total polyphenols content

The TPC was determined in triplicate in a microplate using the Folin-Ciocalteu method (Singleton and Rossi, 1965). A volume of 20 µL of dry extract prepared in methanol (1 mg/mL), 100 µL of Folin-Ciocalteu reagent diluted in distilled water (1:10), and 75 µL of Na_2CO_3 (7.5%) were mixed and left in the dark for 2 h, then the absorbance was read at 765 nm. A blank was prepared in the same way, replacing the extract with methanol. The TPC was expressed in mg gallic acid equivalent (GAE)/100 g dry matter (dm).

2.4.3. Quantification of pigments

The determination of the pigments of the TPBP and pasta samples was carried out according to Nagata and Yamashita (1992). A 1 g aliquot of the sample was weighed into a 200 mL amber flask. Analyses were performed in the dark to avoid carotenoids degradation and isomerization. A mixture of 10 mL of solvent (acetone/hexane 4:6) was added to the flask and sonicated continuously for 10 min (Misonix Ultrasonic Liquid Processor, USA). The resulting extract was transferred to a separating funnel and the optical density of the supernatant (the non-polar hexane layer containing the carotenoids) was measured at 663 nm, 645 nm, 505 nm and 453 nm and the values of lycopene, β-carotene and chlorophylls a and b were estimated in triplicate and the results are then expressed in mg/100 g dry matter:

$$\text{Lycopene (mg/100 mL)} = -0.0458 \times A_{663} + 0.204 \times A_{645} + 0.372 \times A_{505} - 0.0806 \times A_{453} \quad (1)$$

$$\beta\text{-carotene (mg/100 mL)} = 0.216 \times A_{663} - 1.22 \times A_{645} - 0.304 \times A_{505} + 0.452 \times A_{453} \quad (2)$$

$$\text{Chlorophyll a (mg/100 mL)} = 0.999 \times A_{663} - 0.0989 \times A_{645} \quad (3)$$

$$\text{Chlorophyll b (mg/100 mL)} = -0.328 \times A_{663} + 1.77 \times A_{645} \quad (4)$$

2.4.4. DPPH radical scavenging capacity assay

The scavenging capacity of the stable free radical 1,1-diphenyl-2-picrylhydrazyl (DPPH) was determined by the method described by Yilmaz *et al.* (2015): 160 µL of a solution of DPPH (1 mM) in methanol were mixed with 40 µL of the extract (4 mg/mL). Absorbance was read at 517 nm after 30 min using a microplate reader (Enspire, PerkinElmer, MA, USA). A blank was prepared in the same way, replacing the extract with the methanol. The concentration was calculated using the equation obtained from a Trolox calibration curve. The test was repeated three times and the results were expressed in mg Trolox Equivalent Antioxidant Capacity (TEAC)/100 g dm.

2.4.5. Ferric reducing antioxidant power assay

The reducing power of iron (Fe^{3+}) was determined according to the method described by Oyaizu (1986) with modifications for a microplate protocol: 10 µL of the extract (4 mg/mL) were mixed with 40 µL of a phosphate buffer solution (pH = 6.6) and 50 µL of a solution of potassium ferricyanide $K_3Fe(CN)_6$ to (1%). The whole was incubated at 50°C for 20 min, then 50 µL of trichloroacetic acid at 10%, 40 µL of H_2O and 10 µL of the aqueous solution of $FeCl_3$ at 0.1% were added. The absorbance of the reaction medium was read at 700 nm against a similarly prepared blank, replacing the extract with methanol. The concentration was calculated using the equation obtained from a Trolox calibration curve. The test is repeated three times and the results were expressed in mg TEAC/100 g dm.

2.5. Color measurement

The color profile of uncooked pasta was measured in quadruplicate according to the method described by Zhou *et al.* (2015) with slight modifications, using a computer vision system (CVS), including a lighting system (a mini photo studio with a white background), a Cannon EOS-1200D digital camera (18 Mpx CMOS, 3x 18 –55mm f/3.5–5.6) and a computer with image processing software. An Adobe Photoshop CS4 system (Adobe Systems Inc., USA) was used to obtain the color values: lightness (L*: 0 black to 100 white), greenness-redness (a*: greenness when the values are negative and redness when the values are positive) and yellowness-blueness (b*: yellow when values are positive and blue when values are positive), which were converted to CIE LAB values (L*, a* and b*):

$$L^* = \frac{L}{2,5} \quad (5)$$

$$a^* = \frac{240 \times a}{255} - 120 \quad (6)$$

$$b^* = \frac{240 \times b}{255} - 120 \quad (7)$$

The total color difference (ΔE) was also calculated:

$$\Delta E = [(L^*_{sample} - L^*_{control})^2 + (a^*_{sample} - a^*_{control})^2 + (b^*_{sample} - b^*_{control})^2]^{0.5} \quad (8)$$

2.6. Determination of pasta cooking quality

The optimal cooking time (OCT, min) was determined in triplicate by cooking 25 g of pasta in 300 mL of boiling distilled water (cooking water/sample ratio of at least 10:1). Every 30 s during cooking, a strand of pasta was sampled and then pressed between two transparent glass plates. The OCT was recorded as the time when the dry core of the pasta disappeared (AACC, 2000).

The swelling index (SI) was determined in triplicate by cooking pasta (25 g) in boiling distilled water (300 mL) to the OCT. The cooked pasta was then rinsed with water, drained for 5 min and weighed. The SI was calculated by dividing the weight of cooked pasta by the weight of uncooked pasta (Bouasla *et al.*, 2022).

Cooking losses (CL) were determined in triplicate by evaporating the water from pasta cooking and rinsing to constant weight in an oven at 100 °C. The residue obtained was weighed and the cooking losses were calculated (AACC, 2000):

$$CL (\%) = (\text{weight of dry residue} / \text{weight of dry pasta}) \times 100 \quad (9)$$

2.7. Statistical analysis

The data were subjected to one-way analysis of variance using the Statistica 10.0 software (StatSoft, Inc., Tulsa, OK, USA) and means were compared by *post hoc* Fisher LSD test at a significant 0.05 level. Correlation coefficients (r) between variables were also determined by Person correlation with a 95% confidence level using the same software.

3. Results and discussions

3.1. Chemical composition of TPBP and raw pasta

The chemical composition of the control pasta and the TPBP-enriched pasta samples is shown in Table 1. As expected, the incorporation of TPBP caused a significant increase in protein content, starting from 10% of TPBP (r=0.91), fibers content, starting from 5%

of TPBP (r=0.97), lipid content, starting from 12.5% of TPBP (r=0.84), and ash content, with 15% of TPBP (r=0.78). These increases are due to the content of TPBP in these nutrients, as shown by its composition: protein, 15.89 g/100 g dm; dietary fibers, 54.08 g/100 g dm; lipid, 3.40 g/100 g dm; and ash, 4.51 g/100 g dm. TPBP composition is in line with the results reported by Lu *et al.* (2019): 10.08-23.26 g/100 g dm for proteins, 1.63-5.50 g/100 g dm for lipid, and 1.04-25.64 g/100 g dm for ash.

Table 1. Chemical composition (g/100 g dm) of control pasta and enriched pasta.

Pasta	TPBP %	Protein	Fibers	Lipid	Ash
P0	0	10.59±0.12[a]	0.60±0.01[a]	0.12±0.01[a]	0.76±0.01[a]
P1	5.0	10.68±4.70[a]	3.22±0.01[b]	0.13±0.00[a]	0.76±0.01[a]
P2	7.5	10.86±0.12[a]	4.65±0.03[c]	0.16±0.01[ab]	0.76±0.01[a]
P3	10.0	11.34±0.06[b]	6.97± 0.04[d]	0.24±0.10[abc]	0.95±0.27[a]
P4	12.5	11.55±0.25[b]	7.19±0.16[de]	0.26±0.01[bc]	1.13±0.01[a]
P5	15.0	11.60±0.19[b]	7.33±0.22[e]	0.32±0.09[c]	1.70±0.27[b]

The results are expressed as mean value±standard deviation (N=2) and means with different letters in superscript within the same column are significantly different (p<0.05).
P0: control pasta (100% durum wheat semolina); TPBP: tomato peel by-product.

3.2. Antioxidant properties of pasta

Enriching pasta with TPBP brought a significant increase in TPC, passing from 51.80 mg GAE/100 g dm for control pasta (P0) to 109.56 mg GAE/100 g dm for P5 (r=0.97) (Table 2). Compared to the control pasta, the TPC increased 15.1%, 51.5%, 84.1%, 100.6%, and 111.5% for P1, P2, P3, P4, and P5 respectively. This increase could be due to the richness of tomato pomace in phenolic compounds such as flavonoids (kaempherol, naringenin, quercetin, rutin) and phenolic acids (caffeic acid, ferulic acid, gallic acid, syringic acid) (Betrouche *et al.*, 2022; Domínguez *et al.*, 2020; Nakov *et al.*, 2022; Valdez-Morales *et al.*, 2014). Indeed, Waqas *et al.* (2017) reported a TPC of tomato peels of 270.30 mg/100 g dm, while Betrouche *et al.* (2022) and Nakov *et al.* (2022) reported respectively total free-phenolics of 1137.8 mg/kg dm and 1211.4 mg/kg dm.

Table 2. Total polyphenol content (mg GAE/100 g dm) and pigments content (mg/100 g dm) of pasta samples.

Pasta	TPBP %	TPC	β-carotene	Lycopene	Chlorophyll a	Chlorophyll b
P0	0	51.80±0.92[a]	2.76±0.03[a]	1.97±0.01[a]	3.72±0.01[a]	5.90±0.01[a]
P1	5.0	59.60±1.25[b]	2.79±0.02[a]	1.98±0.01[a]	3.79±0.02[b]	5.90±0.01[a]
P2	7.5	78.47±1.68[c]	2.79±0.01[a]	2.00±0.01[b]	3.86±0.01[c]	5.93±0.01[a]
P3	10.0	95.38±1.88[d]	3.00±0.01[b]	2.03±0.01[c]	3.87±0.01[c]	5.99±0.01[b]
P4	12.5	103.92±0.90[e]	3.15±0.01[c]	2.13±0.02[d]	4.03±0.01[d]	6.14±0.04[c]
P5	15.0	109.56±1.12[f]	3.90±0.05[d]	2.39±0.02[e]	4.41±0.04[e]	7.19±0.05[d]

The results are expressed as mean value±standard deviation (N=3) and means with different letters in superscript within the same column are significantly different (p<0.05).
P0: control pasta (100% durum wheat semolina); TPBP: tomato peel by-product; TPC: total polyphenol content.

An increase in TPC was also observed for pasta enriched with different ingredients, such as spinach (Abrol *et al.*, 2017), buckwheat (Biney and Beta, 2014), carob fibers (Biernacka *et al.*, 2017), parsley leaves (Bouasla *et al.*, 2022), fibers from by-products of orange (Crizel *et al.*, 2015), okara (Kamble *et al.*, 2019), and onion skin (Michalak-Majewska *et al.*, 2020). The use of phenolic compounds from natural sources in foods is an interesting opportunity because of the biological activities of these compounds, in particular the antioxidant capacity (Crizel *et al.*, 2015). Phenolic compounds could potentially have a protective role against a wide range of diseases, including cancer and cardiovascular disease, as well as diabetes and Alzheimer (Cianciosi *et al.*, 2018). In addition, they are linked to anti-inflammatory, anti-allergic, antihypertensive and antimicrobial properties (Bhuyan and Basu, 2017).

The pigment contents of TPBP were 5.56 mg/100 g dm of β-carotene, 18.19 mg/100 g dm of lycopene, 25.70 mg/100 g dm of a chlorophyll and 30.84 mg/100 g dm of b chlorophyll. Tomato pomace is an excellent source of carotenoids, mainly in the form of lycopene and β-carotene (Azabou *et al.*, 2020; Betrouche *et al.*, 2022; Nakov *et al.*, 2022; Yagci *et al.*, 2022). Studies performed on tomato peels have reported lycopene yields ranging from 0.639 to 73.40 mg/100g depending on extraction method and type of raw material (Ho *et al.*, 2015; Kaur *et al.*, 2008; Knoblich *et al.*, 2005; Shi *et al.*, 2009).

Enrichment of pasta with TPBP resulted in a significant increase in the content of β-carotene (r=0.81), lycopene (r=0.80), chlorophyll a (r=0.86) and chlorophyll b (r=0.71).

The increase in antioxidant capacity is a primary goal of pasta fortification (Pasqualone *et al.*, 2016). The addition of TPBP significantly increased the reducing power from 38.78 mg TEAC/100 g dm for P0 to 86.51 mg TEAC/100 g dm for P5 (r=0.96) (Table 3). DPPH free radical scavenging capacity also increased ($p<0.05$) with increasing TPBP levels in pasta, growing from 6.62 mg TEAC/100 g dm for P0 to 15.37 mg TEAC/100 g dm for P5 (r=0.88).

Table 3. Antioxidant capacity of control and enriched pasta.

Pasta	TPBP %	FRAP (mg TEAC/100 g dm)	DPPH-SA (mg TEAC/100 g dm)
P0	0	38.78±0.98^{a}	6.62±0.12^{a}
P1	5.0	50.84±0.81^{b}	7.88±0.16^{b}
P2	7.5	72.29±1.80^{c}	7.92±0.08^{b}
P3	10.0	79.45±1.66^{d}	8.91±0.14^{c}
P4	12.5	86.02±1.55^{e}	11.32±0.24^{d}
P5	15.0	86.51±1.25^{e}	15.37±0.29^{e}

The results are expressed as mean value±standard deviation (N=3) and means with different letters in superscript within the same column are significantly different ($p<0.05$).

P0: control pasta (100% durum wheat semolina); TPBP: tomato peel by-product; FRAP: ferric reducing antioxidant power; DPPH-SA=1,1-diphenyl-2-picrylhydrazyl scavenging capacity; TEAC: Trolox equivalent antioxidant capacity.

According to Abrol *et al.* (2017), the antioxidant capacity depends on pigments (such as carotenoids and anthocyanin), ascorbic acid and total polyphenols of the product. So the increase in antioxidant capacity in enriched pasta could be linked to the richness of the tomato pomace in total polyphenols such as flavonoids and phenolic acids and in carotenoids (Betrouche *et al.*, 2022; Domínguez *et al.*, 2020; Nakov *et al.*, 2022). Indeed, FRAP and DPPH are strongly correlated with TPC (r=0.97 and r=0.84 respectively). Furthermore, lycopene is considered one of the most powerful natural antioxidants and acts by inhibiting free radicals (Rodriguez-Amaya, 2001; Silva *et al.*, 2019). Chlorophyll and its derivatives are also known for their antioxidant capacity (Barros *et al.*, 2011).

Similar results have been reported by other authors by incorporating various ingredients for pasta fortification: spinach (Abrol *et al.*, 2017), carob fibers (Biernacka *et al.*, 2017), parsley leaves (Bouasla *et al.*, 2022), orange by-product fibers (Crizel *et al.*, 2015), soy okara (Mamble *et al.*, 2019) or onion skin (Michalak-Majewska *et al.*, 2020).

3.3. Color of raw pasta

The color profiles of the control pasta and the enriched pasta are shown in Table 4. Pasta color is the first property that the consumers evaluate when choosing a product in the market, and as such is a very important quality attribute that greatly influences consumer acceptance (Bouasla *et al.*, 2022). The control pasta showed higher *L** and lower *a** than the durum wheat pasta tested by Brandolini *et al.* (2018), because of the different drying temperatures, but the *b** values were similar. The lightness (*L**) of the pasta decreased ($p<0.05$) with increasing TPBP levels ($r=-0.91$), thus indicating that the enriched pasta became darker than the control. This decrease may be due to the dark color of TPBP as well as to the oxidation of carotenoid pigments resulting from the high oxygen permeability of enriched pasta (Mercier *et al.*, 2016).

Table 4. Color profile of control and fortified pasta.

Pasta	TPBP %	*L**	*a**	*b**	*ΔE*
P0	0	94.83±0.80^{c}	-7.25±0.28^{a}	16.39±0.31^{a}	
P1	5.0	87.46±0.88^{b}	-2.29±0.29^{b}	31.68±0.46^{b}	17.71±0.16^{a}
P2	7.5	86.30±1.71^{b}	-0.96±0.74^{c}	32.46±1.40^{b}	19.29±1.70^{ab}
P3	10.0	86.86±1.51^{b}	-0.21±0.53^{c}	34.62±0.91^{c}	21.15±1.04^{b}
P4	12.5	81.79±1.58^{a}	3.80±0.74^{d}	39.77±1.67^{d}	28.97±2.23^{c}
P5	15.0	82.59±0.73^{a}	4.88±0.47^{e}	43.63±0.42^{e}	32.24±0.58^{d}

The results are expressed as mean value±standard deviation (N=4) and means with different letters in superscript within the same column are significantly different ($p<0.05$).
P0: control pasta (100% durum wheat semolina); TPBP: tomato peel by-product.

Moreover, *a** values increased significantly with the increase in enrichment rate ($r=0.98$), varying from -7.25 for P0 to 4.88 for P5, thus indicating that the color of the enriched samples tends towards red. Similarly, the enrichment of the pasta with TPBP significantly increased the yellowness (*b**) from 16.39 for P0 to 43.63 for P5 ($r=0.96$). This was expected, since TPBP is characterized by its red color due to the presence of carotenoid pigments, in particular lycopene (18 mg/100 g in the TPBP used in the present study). Previous studies reported similar trends for pasta enriched with apple peel (Lončarić *et al.*, 2014) and carrot pomace (Gull *et al.*, 2015). Differently, the addition of carrot waste extract encapsulates produced a lighter pasta because of the presence of the encapsulate carrier while the high content of β-carotene increased *a** and *b** (Šeregelj *et al.*, 2022).The total color difference (ΔE) between control pasta and TPBP-enriched pasta increased ($p<0.05$) with increasing TPBP levels ($r=0.94$) ranging from 17.91 to 32.24. The color difference can be detected visually by an experienced observer when ΔE is greater than 3.5, and by an inexperienced observer when ΔE is greater than 5 (Bouasla *et al.*, 2022). Therefore, this indicates that the TPBP-enriched pasta samples are different from the control pasta and that significant differences could be visible to the naked eye.

3.4. Cooking quality of pasta

The incorporation of TPBP caused a significant reduction in OCT ($r=-0.86$) which varied from 4.5 min for the P0 to 3 min for P5 (Table 5). This result agrees with previous reports on pasta enriched with tomato by-product (Padalino *et al.*, 2017), apple peel by-products (Lončarić *et al.*, 2014), soy okara (Kamble *et al.*, 2019), olive pomace (Simonato *et al.*, 2019), onion skin (Michalak-Majewska *et al.*, 2020), and persimmon by-product (Lucas-González *et al.*, 2020). A higher OCT was reported by Vimercati *et al.* (2020) in a thicker pasta enriched with 8.9% dried-tomato.

Table 5. Cooking quality of control and enriched pasta.

Pasta	TPBP %	Optimal cooking time (min)	Swelling index	Cooking loss (%)
P0	0	4.50±0.01[c]	3.18±0.07[c]	4.03±0.15[a]
P1	5.0	3.50±0.01[b]	2.98±0.17[b]	4.75±0.07[a]
P2	7.5	3.00±0.01[a]	2.87±0.12[b]	5.70±0.70[b]
P3	10.0	3.00±0.01[a]	2.83±0.03[b]	5.73±0.67[b]
P4	12.5	3.00±0.01[a]	2.59±0.06[a]	5.73±0.32[b]
P5	15.0	3.00±0.01[a]	2.90±0.08[b]	6.80±0.26[c]

The results are expressed as mean value±standard deviation (N=3) and means with different letters in superscript within the same column are significantly different ($p<0.05$).
P0: control pasta (100% durum wheat semolina); TPBP: tomato peel by-product.

The decrease in cooking time may be due to the addition of TPBP which could induce changes in the composition and microstructure of the pasta (Mercier *et al.*, 2016). Additionally, the amount of water required for starch gelatinization can be decreased with fortification by diluting the starch content of pasta. The incorporation of TPBP reduces the amount of durum wheat semolina and therefore decreases the glutenin fraction which has a higher molecular weight and a longer hydration time. In addition, the physical disruption of the gluten matrix by the fibers-rich fractions of TPBP facilitated water penetration into pasta containing non-traditional ingredients, resulting in shorter cooking time (Mercier *et al.*, 2016; Petitot *et al.*, 2010).

The swelling index provides information on the water absorption capacity. All the enriched pasta had a significantly lower SI (2.90-2.98) than the control pasta (3.18) (r=-0.70). Similar results have been reported for pasta enriched with tomato by-product (Padalino *et al.*, 2017) and persimmon by-product (Lucas-González *et al.*, 2020). The decrease in water absorption for the enriched pasta could be explained by the entrapment of the starch granules by the fibers particles, thus reducing their swelling during cooking. On the other hand, starch dilution can decrease the amount of water required for gelatinization and the amount of water absorbed during cooking (Bouasla *et al.*, 2020). For pasta made from durum wheat, the appropriate weight of cooked pasta is about three times the dry weight (Sissons *et al.*, 2012) which was the case for all pasta samples.

Cooking loss is considered an important factor for the cooking quality of pasta (Mercier *et al.*, 2016) because provides information on the ability of pasta to retain its structural integrity during cooking (Kamble *et al.*, 2019). The addition of 5% TPBP did not lead to a significant change in the CL compared to the control pasta, which had the lowest CL (4.03%). However, from 7.5% of TPBP, a significant increase in the CL, which ranged from 4.75% for P2 to 6.80% for the P5 paste (r=0.88), was noticed. This result agrees with Padalino *et al.* (2017), who found that the incorporation of tomato by-product (10 and 15%) brought about an increase in CL. Similar trends were also found for pasta enriched with plant-based by-products: mango peel, soy okara, onion peel, apple peel, and olive pomace (Ajila *et al.*, 2010; Kamble *et al.*, 2019; Lončarić *et al.*, 2014; Michalak-Majewska *et al.*, 2020; Simonato *et al.*, 2019). Vimercati *et al.*

(2020) reported a cooking loss around 7% in tomato enriched pasta.

The increased cooking loss with the incorporation of TPBP may be associated with structural changes in the protein network caused by the addition of dietary fibers from TPBP (Crizel *et al.*, 2015) which is a non-glutinous material and dilutes the gluten content, therefore disrupting the protein-starch matrix which is responsible for maintaining the physical integrity of the pasta during cooking. They also cause the unequal distribution of water in the pasta matrix due to the competitive hydration tendency of the fibers (high water absorption capacity). This leads to more solids leaching from pasta during cooking (Bouasla *et al.*, 2020; Mercier *et al.*, 2016; Padalino *et al.*, 2017). Moreover, the drying conditions applied in the present study could lead to the formation of micro-cracks that could be responsible for the high dry matter loss during cooking (Bouasla *et al.*, 2022). Indeed, Mercier *et al.* (2016) showed that the increase in cooking losses for enrichment less than 15% was doubled with low temperature drying (≤60°C) compared to high temperature drying (>60°C). According to the same authors, at low temperature, there is no coagulation of proteins that cause the strengthening of the gluten network. Although cooking losses increased with increasing enrichment level, all pasta samples were of good quality because cooking losses were less than 8% (Sissons *et al.*, 2012).

4. Conclusion

The incorporation of TPBP improved the nutritional quality of pasta by increasing the content of protein, fibers, ash and, more importantly, the content of pigments, total polyphenols and antioxidant capacity. However, the addition of TPBP caused a reduction in the optimal cooking time, the swelling index and an increase in cooking losses, without exceeding the acceptable limit. These results indicate that the incorporation of up to 15% TPBP in pasta improves its nutritional quality without penalizing the cooking quality and therefore presents a good material to enrich with bioactive components pasta or other food products.

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