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Functional Pasta with Tomato By-product as a Source of Antioxidant Compounds and Dietary Fibre

Lucia PADALINO[1], *Amalia CONTE*[1], *Lucia LECCE*[1], *Desislava LIKYOVA*[1], *Vincenzo SICARI*[2], *Teresa Maria PELLICANÒ*[2], *Marco POIANA*[2] *and Matteo Alessandro DEL NOBILE*[1]*

[1]*University of Foggia, Services Center of Applied Research, Foggia, Italy;* [2]*Mediterranean University of Reggio Calabria, Agricultural Department, Reggio Calabria, Italy*

**Corresponding author: matteo.delnobile@unifg.it*

Abstract

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Tomato peels are abundant by-products of tomato processing and therefore represent a cost of disposal and an impact on the environment. For this reason, the aim of the present study was to valorise tomato peels to enrich pasta, being these ingredients still rich in antioxidants like carotenoids that are well-known to protect against degenerative diseases. To the aim of the work, in the first step, tomato peel flour was added to wholemeal flour in different amounts until the overall quality of cooked pasta reached its acceptability threshold (tomato peel flour at 15% w/w of semolina weight). Even though the pasta enriched with tomato peels showed high levels of carotenoids and dietary fibre, lower sensory scores for elasticity, odour, and firmness were recorded than in the control. Therefore, the second step was aimed to improve the sensory quality of the 15% enriched spaghetti by means of proper addition of hydrocolloids. Final results confirmed the ability of the structuring agents to enhance adhesiveness and bulkiness of pasta, without compromising other physical and chemical properties.

Keywords: food by-products; durum wheat; enriched pasta; pasta quality; eco-friendly processing

Pasta is traditionally manufactured using only durum wheat semolina, but it is possible to incorporate other flours or ingredients into pasta to increase its nutritional value, compared to conventional pasta. Presently, producers are striving to create products with new properties, given by dietary fibre or antioxidants. In particular, phenolics and carotenoids can impart health benefits being able to scavenge reactive oxygen species and protect against degenerative diseases like cancer and cardiovascular diseases. Tomatoes, among vegetables, are widely consumed and can provide a significant proportion of antioxidants in the diet (Martinez-Valvercle *et al.* 2002). Tomatoes constitute the predominant source of lycopene and β-carotene (Lin & Chen 2005; Radzevičius *et al.* 2009) but their potential addition as nutrients could be quite costly for the producer of food commodities.

On the other hand, it is worth considering that in the fruit and vegetable industry, the preparation and processing procedures lead to one third of the product being discarded. Food by-products usually represent an environmental problem for the industry, and many studies have been carried out about the potential re-utilisation of several by-products of vegetable origin for their inclusion in human diet. These new ingredients could be of great interest for the food and pharmaceutical industry because their use could reduce industrial costs and justify new investments in equipment, providing a correct solution to the pollution problem connected with food processing (Lario *et al.* 2004). The skin of

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fruits and vegetables is commonly removed because it is thought to be indigestible and contain low levels of nutrients. Approximately one third of the total weight of tomatoes in the form of skin and seeds is discarded during the processing of tomatoes into paste (Al-Wandawi *et al*. 1985). The waste from tomato processing has been shown to be an excellent and inexpensive source of carotenoids because these compounds are contained in the peels (Reboul *et al*. 2005). Recently, Pasqualone *et al*. (2016) produced functional semolina pasta by adding a lyophilised tomato powder matrix with high lycopene content.

The incorporation of fibre from by-products into traditional foods could alter the sensory and cooking properties of the product, thus suggesting that careful selection of the type and amount of ingredient is needed to develop food with satisfactory taste. When pasta is taken into account, to solve the disadvantage created by the addition of new ingredients with functional properties, hydrocolloids are generally used (Glicksman 1982) because they are well-known to impart the required quality in terms of stability, texture and appearance (Padalino *et al*. 2013b).

The objective of the present study was to develop durum wheat wholemeal spaghetti enriched with tomato peel powder, rich in phytochemicals such as carotenoids and dietary fibre. Specifically, the study was organised in the following steps: in the first one, two amounts of tomato peel flour were added to the dough (10 and 15%). The next experimental step was aimed to improve the overall sensory quality of spaghetti enriched with the most abundant tomato peel amount by adding hydrocolloids. All spaghetti types were then examined in terms of cooking characteristics, sensory properties, carotenoids, and dietary fibre content.

MATERIAL AND METHODS

Raw materials. Durum wheat seeds (cultivar PR22D89) were provided from the Agricultural Research Council (Italy). The wholemeal flour was produced by grinding the seeds with a stone mill (Mod MB-250; Partisani S.r.l., Italy).

Tomato skins were obtained from a pool of elongated shape tomato cultivars: Ulisse, Docet, Ercole, Player, Herdon, Fuzzer, and Komolix grown as field crops in the Regions of Campania and Apulia (southern Italy) in the crop year 2012–2013. Four industries were involved in the tomato processing. After tomato washing, the berries were peeled and the pulp was separated from a mix composed of seeds and peels. Then, the seeds were separated from the peels by flotation. Tomato skins were dehydrated by exposure to sunlight and then in the oven (40–50°C). The tomato peel flour (7% moisture) was produced by a hammer mill (16/BV; Beccaria S.r.l., Italy).

Spaghetti preparation. Spaghetti pasta was produced with wholemeal flour of durum wheat using the following operating conditions: flour was mixed with water in a rotary shaft mixer (Namad, Italy) at 25°C for 20 min so as to obtain dough with 30% moisture content. In the first experimental phase, the wholemeal flour was replaced by tomato peel (TP) flour at 10 and 15% (w/w) levels. Then, the formulation at 15% tomato peel flour was added 2% hydrocolloids and mixed with water so as to obtain dough with 30% moisture content. In order to ensure the solubility of the hydrocolloids, the powder was previously dissolved in water. In particular, agar (AG), Carbossi-methylcellulose (CMC), guar seed flour (GUAR), and xanthan gum (XAN) were used (all the hydrocolloids were bought from Farmalabor S.r.l., Italy). Spaghetti based only on wholemeal flour were also manufactured and used as the reference sample (CTRL). In both steps dough was extruded with a 60VR extruder (Namad, Italy). The extrusion pressure was about 4 MPa, whereas the temperature of the spaghetti after extrusion was about 27–28°C.

The extruder was equipped with a screw (30 cm in length, 5.5 cm in diameter) which ended with a bronze die (diameter hole of 1.70 mm). The screw speed was 50 rpm. Subsequently, the pasta was dried in a dryer (SG600; Namad, Italy). The process conditions applied were as follows: 1st step, time 20 min at 60°C and 65% moisture (external drying); 2nd step, time 130 min at 90°C and 79% moisture (wrapping); 3rd step, time 150 min at 75°C and 78% moisture (drying); 4th step, time 160 min at 45°C and 63% moisture; 5th step, time 1040 min at 50°C and 50% moisture. The 4th and 5th steps are used for the cooling phases of spaghetti.

Sensory analysis. Dry spaghetti samples were submitted to a panel of fifteen trained tasters (six men and nine women, aged between 28 and 45) in order to evaluate the sensory attributes. The panellists were selected on the basis of their sensory skills (ability to accurately determine and communicate the sensory attributes such as appearance, odour, taste, and texture of the product). The panellists were also

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trained in sensory vocabulary and identification of particular attributes by evaluating durum wheat commercial spaghetti (ISO 7304-2:2008). They were asked to indicate colour and resistance to break of uncooked spaghetti. Elasticity, firmness, bulkiness, adhesiveness, fibrous nature, colour, odour, and taste were evaluated for cooked spaghetti (Padalino *et al.* 2013a). To this aim, a nine-point scale, where 1 corresponded to extremely unpleasant, 9 to extremely pleasant, and 5 to the acceptability threshold, was used to quantify each attribute (Petitot *et al.* 2010). On the basis of the above-mentioned attributes, panellists were also asked to score the overall quality of the product using the same scale.

Chemical determination. Dry spaghetti samples were ground to fine flour on a Tecator Cyclotec 1093 (International PBI, Sweden) laboratory mill (1-mm screen – 60 mesh). Protein content (% N × 5.7) was analysed using the micro-Kjeldahl method according to AACC method 46–13 (AACC 2000). Total dietary fibre (TDF), water-soluble dietary fibre (SDF), and water-insoluble dietary fibre (IDF) contents were determined by means of the total dietary fibre kit (Megazyme International Ireland Ltd., Ireland) based on the method of Lee *et al.* (1992). The available carbohydrates (ACH) were determined according to the method of McCleary and Rossiter (2006), as described in the ACH assay kit (Megazyme International Ireland Ltd., Ireland). For the carotenoid determination, the spectrophotometric analysis was carried out after extraction. Before chemical extraction, spaghetti were homogenised in a blender and an aliquot of 10 g of the sample was weighed into a 200 ml amber coloured flask wrapped with aluminium foil. The analyses were carried out in darkness to prevent carotenoid degradation and isomerisation. A 100 ml of the solvent mix (hexane/acetone/methanol 2 : 1 : 1 v/v/v) was added to the flask and sonicated continuously for 10 min (Misonix Ultrasonic Liquid Processor, USA). The extraction was repeated until the sample became colourless. The combined extract was transferred to a separating funnel and 5 ml of distilled water was added to separate polar and nonpolar phases. The nonpolar hexane layer containing carotenoids was collected and concentrated in a rotary evaporator (Heidolph, Germany) till dryness. The residue was dissolved in 10 ml of hexane. Lycopene and β-carotene contents were determined according to Fish *et al.* (2002) by a spectrophotometric method using a UV-Vis spectrophotometer (Agilent 8453 Technologies, Italy). As reported in the work of Fish *et al.* (2002), to minimise the interference from other carotenoids, the concentration of lycopene was calculated at λ = 503 nm using the molar extinction coefficient $\varepsilon = 17.2\ 10^4\ M^{-1}\cdot cm^{-1}$. For β-carotene, the absorbance was measured at λ = 450 nm and the quantification was carried out using a standard curve. All the nutritional analyses were done in triplicate and the results were expressed as mean ± standard deviation (SD).

Spaghetti cooking quality. The optimal cooking time (OCT) was evaluated according to the AACC-approved method 66-50 (2000). The cooking loss and the amount of the solid substance lost into the cooking water were determined according to the AACC-approved method 66-50 (2000). The swelling index of cooked pasta was determined according to the procedure described by Cleary and Brennan (2006). The swelling index was expressed as follows:

(weight of cooked spaghetti) – (weight of spaghetti after drying) / (weight of spaghetti after drying)

The water absorption of drained pasta was determined as follows:

(weight of cooked spaghetti) – (weight of raw pasta) / / (weight of raw pasta)

Three measurements were performed for each analysis, and the mean values were calculated.

Hardness and adhesiveness. For each test, three spaghetti strands (40 mm length) were cooked at the OCT. After cooking, the spaghetti samples were gently blotted and submitted to hardness and adhesiveness analysis by means of a Zwick/Roell model Z010 Texture Analyser (Zwick Roell Italia S.r.l., Italy) equipped with a stainless steel cylinder probe (2 cm diameter). The three samples were put side by side on the lower plate, and the superior plate was moved down onto the spaghetti surface. Both hardness (mean maximum force, N) and adhesiveness (mean negative area, Nmm) were measured. Six measurements for each spaghetti sample were performed. Trial specifications were as follows: preload of 0.3 N; load cell of 1 kN; percentage deformation of 25%; crosshead speed constant of 0.25 mm/s (Padalino *et al.* 2013a).

Statistical analysis. Experimental data were compared by one-way analysis of variance (ANOVA). Duncan's multiple range test, with the option of homogeneous groups ($P < 0.05$), was carried out to determine significant differences between spaghetti samples. Statistica 7.1 for Windows (StatSoft, Inc, USA) was used for this aim.

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RESULTS AND DISCUSSION

Sensory quality. The overall sensory quality of uncooked and cooked spaghetti made only with wholemeal flour (CTRL) was significantly higher in comparison with samples supplemented with tomatoes peel (Table 1a). Colour and break resistance are the most critical parameters for the enriched samples, due to the abundant amount of vegetable peels rich in carotenoids and hence in lycopene (Reboul *et al.* 2005) that conferred to pasta a dark brown colour. Nochai and Pongjanta (2013) observed that wheat noodle sample enriched with tomato lycopene (20%) recorded the greatest colour score as compared to CTRL sample made of 100% wheat flour. Regarding the cooked spaghetti, the incorporation of peels determined a decline of the overall quality of samples with 15% TP, due to the poor elasticity and the higher firmness compared to the control pasta. The reduction of pasta elasticity relates to the disruptive behaviour of fibre on the protein-starch binding during the pasta matrix formation (Tudorica *et al.* 2002). A possible explanation of the high firmness might also be related to the incorporation of dietary fibre (mainly insoluble fibre) that, due to its high hydrophilicity, preferentially absorbs water by inhibiting the swelling of the starch granules (Rakhesh *et al.* 2015). On the other hand, spaghetti enriched with tomato peel flour were firmer, having a much greater capacity to absorb water during pasta making and reducing starch swelling and water absorption. Therefore, the addition of vegetable matter rendered the texture firmer due to non-starchy nature of vegetables (Yadav *et al.* 2014). These data suggest that the incorporation of tomato peel flour had an impact on the fibrous nature of spaghetti samples most probably for the high fibre content in the peels. Pasta with tomato peels showed a general increase in adhesiveness and bulkiness also related to the increasing fibre concentration. The colour of cooked samples was slightly improved. Rekha *et al.* (2012) also observed a reduction in the colour intensity of cooked pastas enriched with vegetable flour, probably due to the pasta swelling and to the conversion of pigments resulting in a yellowness increase. Besides, the odour and the taste of spaghetti enriched with tomato peels were slightly lower than the CTRL, accordingly with Pasqualone *et al.* (2016).

To sum up, the results obtained in the first experimental step highlighted that from a sensory point of view the concentration of peels that affected spaghetti

Table 1. Sensory characteristics of uncooked and cooked (a) dry spaghetti samples enriched with different percentage of tomato peel flour; (b) dry spaghetti 15% TP sample enriched with different hydrocolloids

	Uncooked spaghetti			Cooked spaghetti							
	colour	break to resistance	overall quality	elasticity	firmness	fibrous	bulkiness	adhesiveness	colour	odour	taste	overall quality
(a)												
CTRL	7.00 ± 0.21^a	6.20 ± 0.30^a	7.08 ± 0.30^a	7.06 ± 0.30^a	7.00 ± 0.24^a	6.96 ± 0.32^a	6.62 ± 0.20^a	6.40 ± 0.34^a	7.06 ± 0.21^a	7.00 ± 0.28^a	7.04 ± 0.27^a	7.05 ± 0.24^a
10%TP	5.70 ± 0.35^b	5.35 ± 0.30^b	5.30 ± 0.30^b	5.00 ± 0.30^b	5.70 ± 0.36^b	4.96 ± 0.37^b	6.10 ± 0.24^b	6.07 ± 0.37^a	6.05 ± 0.33^b	6.90 ± 0.28^a	6.91 ± 0.44^b	5.77 ± 0.42^b
15% TP	5.27 ± 0.36^b	4.5 ± 0.36^c	5.00 ± 0.47^b	3.88 ± 0.31^c	5.25 ± 0.26^b	3.94 ± 0.43^c	5.10 ± 0.28^c	5.20 ± 0.31^b	5.96 ± 0.36^b	6.86 ± 0.26^a	6.20 ± 0.26^b	4.38 ± 0.38^c
(b)												
CTRL	7.00 ± 0.21^a	6.20 ± 0.30^a	7.08 ± 0.30^a	7.06 ± 0.30^a	7.00 ± 0.24^a	6.96 ± 0.32^a	6.62 ± 0.20^a	6.40 ± 0.34^a	7.06 ± 0.21^a	7.00 ± 0.28^a	7.04 ± 0.27^a	7.05 ± 0.24^a
15% TP	5.27 ± 0.36^b	4.57 ± 0.36^b	5.00 ± 0.47^b	3.88 ± 0.31^b	5.25 ± 0.26^c	3.94 ± 0.43^b	5.10 ± 0.28^c	5.20 ± 0.31^b	5.96 ± 0.36^b	6.86 ± 0.26^a	6.20 ± 0.26^b	4.38 ± 0.38^d
15% TP/CMC	5.00 ± 0.33^b	5.30 ± 0.47^b	5.40 ± 0.27^b	4.20 ± 0.30^b	5.90 ± 0.33^b	4.06 ± 0.24^b	6.22 ± 0.36^{ab}	6.05 ± 0.30^a	6.07 ± 0.24^b	6.84 ± 0.20^a	6.14 ± 0.30^b	5.94 ± 0.25^b
15%TP/GUAR	4.80 ± 0.38^b	5.25 ± 0.34^b	5.15 ± 0.34^b	4.00 ± 030^b	5.93 ± 0.25^b	4.01 ± 0.25^b	6.27 ± 0.23^{ab}	6.24 ± 0.30^a	6.15 ± 0.32^b	6.91 ± 0.22^a	6.24 ± 0.24^b	5.84 ± 0.2^b
15% TP/XAN	4.86 ± 0.46^b	5.28 ± 0.46^b	5.35 ± 0.34^b	4.06 ± 0.25^b	5.76 ± 0.30^{bc}	4.03 ± 0.31^b	5.91 ± 0.36^b	5.95 ± 0.25^a	6.16 ± 0.29^b	6.90 ± 0.24^a	6.20 ± 0.24^b	5.12 ± 0.30^c
15% TP/AG	4.90 ± 0.34^b	5.30 ± 0.36^b	5.20 ± 0.27^b	4.15 ± 0.28^b	5.94 ± 0.34^b	4.23 ± 0.30^b	5.87 ± 0.24^b	5.85 ± 0.34^a	6.10 ± 0.24^b	6.87 ± 0.24^a	6.31 ± 0.28^b	5.53 ± 0.35^{bc}

$^{a–d}$means in the same column followed by different superscript letters differ significantly ($P < 0.05$); TP – tomato peel

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acceptability was 15%, then the subsequent step was aimed at improving the sensory quality of spaghetti produced at this concentration.

Specifically, CMC, GUAR, XAN, and AG were added at a 2% (w/w) level to improve the quality of pasta samples enriched with peels. Table 1b highlights that the overall quality of uncooked spaghetti enriched with hydrocolloids slightly rose with respect to the other samples, mainly due to a small improvement of the resistance to break. Padalino *et al.* (2013a) also reported that hydrocolloids have strong affinity to starch, thus promoting the formation of a continuous network, which in turn results in the high value of pasta quality. The incorporation of hydrocolloids considerably increased the overall quality of cooked spaghetti supplemented with tomato peels (Table 1b). In fact, all spaghetti samples enriched with hydrocolloids showed a slightly decline in adhesiveness and bulkiness in comparison with the 15% TP sample. Specifically, the GUAR and CMC recorded the highest adhesiveness and bulkiness values. Tudorica *et al.* (2002) observed that adhesiveness and stickiness dropped at a low guar gum concentration (2–3%). Also Komlenic *et al.* (2006) observed an improvement in sensory scores for CMC pasta, due to the lower stickiness than that of the control sample (100% wheat flour). This behaviour can be due to the chemical groups of hydrocolloids that are capable to form hydrogen bonds. This structure has more affinity to starch and forms a stable polymeric network, important for the entrapment of carbohydrates and good pasta quality (Padalino *et al.* 2013b). Chillo *et al.* (2007) found that the presence of CMC slows down diffusion of amylose molecules from the internal part to the spaghetti surface. Concerning colour, taste, and odour, the sensory evaluation indicated that there was no significant difference between the spaghetti samples with and without hydrocolloids.

Cooking quality. Cooking performances of the investigated spaghetti samples in terms of optimum cooking time, cooking loss, water absorption, swelling index, hardness, and adhesiveness are shown in Table 2. It is worth noting that the fortification of pasta with tomato peel flour had a noticeable impact on cooking quality (Table 2a). The optimum cooking time decreased by increasing the amount of tomato peel flour (Table 2a). Specifically, the OCT dropped from 10.2 min for CTRL to 9 min for 15% TP. Most probably, the incorporation of vegetable flour caused a reduction in the overall proportion of gluten in the pasta. In fact, the gluten is primarily responsible for the development of the starch-protein structure, which in turn is the primary determinant of pasta texture and cooking properties (Brennan *et al.* 1980), so a dilution of these components will reduce the cooking time as observed.

Cooking loss of optimally cooked pasta is commonly used to predict the pasta cooking quality and is an indicator of the capability of the starch-protein matrix to retain its physical integrity during cooking. Table 2a shows a small increase in cooking loss in the spaghetti samples enriched with tomato peel flour. Cooking losses could be attributed to the changes in

Table 2. Cooking quality of (**a**) dry spaghetti samples enriched with different tomato peel flour percentage and (**b**) dry spaghetti sample 15% TP enriched with different hydrocolloids

Sample	OCT (min)	Cooking loss (%)	Swelling index (g water/g dry spaghetti)	Water absorption (%)	Adhesiveness (Nmm)	Hardness (N)
(**a**)						
CTRL	10.20	7.20 ± 0.09^{c}	2.04 ± 0.04^{a}	156 ± 0.50^{a}	0.62 ± 0.03^{b}	6.87 ± 0.15^{b}
10% TP	9.20	7.60 ± 0.03^{ab}	1.88 ± 0.16^{ab}	144 ± 0.38^{b}	1.04 ± 0.10^{a}	14.60 ± 1.13^{a}
15% TP	9.00	7.76 ± 0.05^{a}	1.83 ± 0.05^{a}	140 ± 0.40^{c}	1.15 ± 0.09^{a}	15.26 ± 1.23^{a}
(**b**)						
CTRL	10.20	7.20 ± 0.39^{b}	2.04 ± 0.04^{a}	156 ± 0.50^{b}	0.62 ± 0.03^{b}	6.87 ± 0.15^{b}
15% TP	9.00	7.76 ± 0.05^{a}	1.83 ± 0.05^{b}	140 ± 0.40^{d}	1.15 ± 0.09^{a}	15.26 ± 1.23^{a}
15% TP/CMC	9.30	6.58 ± 0.28^{c}	1.96 ± 0.03^{ab}	153 ± 0.96^{c}	0.65 ± 0.08^{b}	14.45 ± 0.67^{a}
15% TP/GUAR	9.30	7.22 ± 0.13^{b}	1.92 ± 0.10^{ab}	157 ± 0.86^{ab}	0.70 ± 0.08^{b}	14.05 ± 0.67^{a}
15% TP/XAN	9.30	7.47 ± 0.21^{ab}	1.95 ± 0.14^{ab}	158 ± 0.61^{a}	0.75 ± 0.05^{b}	15.26 ± 0.96^{a}
15% TP/AG	9.30	6.60 ± 0.38^{c}	1.94 ± 0.05^{ab}	153 ± 0.69^{c}	0.68 ± 0.05^{b}	14.26 ± 0.51^{a}

$^{a-c}$means in the same column followed by different superscript letters differ significantly ($P < 0.05$); TP – tomato peel

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the gluten protein network because of the interference of tomato peel powder, which is rich in dietary fibres. Earlier, Tudorica *et al*. (2002) reported that the increase in cooking loss could be due to the disruption of protein-starch matrix by the fibre and uneven distribution of water within the pasta matrix due to the competitive hydration tendency of the fibre. This result is in accordance with Padalino *et al*. (2013a), who found that the incorporation of yellow pepper flour reduced the quantity of gelatinised starch by causing higher cooking losses compared to the CTRL sample (100% maize flour). Tam *et al*. (2004) also found that the starch gelatinisation can help reducing the cooking loss.

Concerning the water absorption and the swelling index, the spaghetti samples with tomato peel flour recorded the lowest values (Table 2a). These results can be interpreted in terms of competition between the fibre and starch for water absorption. During cooking, owing to unlimited water availability, pasta enriched with fibre where the starch-protein matrix is disrupted reaches the level of water absorption corresponding to OCT more swiftly in comparison with the control pasta, meaning that the starch component had absorbed less water at OCT, giving rise to the lower swelling indices observed. Therefore, increasing the amount of fibre thus generally results in the lower swelling of starch and lower swelling index.

The texture attributes of cooked spaghetti, such as adhesiveness and hardness, are also reported in Table 2a. Results show that the spaghetti samples enriched with tomato peel flour resulted more adhesive in comparison with the CTRL. In particular, the sample with 15% TP had the greatest adhesiveness value (1.15 Nmm) when compared to the other samples. These results support data obtained by sensory analysis and cooking loss. The hardness values of the spaghetti sample with tomato peel flour were statistically higher than those of the CTRL sample. In fact, the hardness changed from 6.87 N in the CTRL sample to 15.26 N in the 15% TP sample. Also Nochai and Pongjanta (2013) observed a decrease in the hardness as the lycopene amount in wheat noodle sample increased. This result could be due to the fact that the water absorption significantly decreased as the tomato peel flour was incorporated into the pasta (Table 2a).

Table 2b documents that slightly higher values of OCT for the spaghetti samples with hydrocolloids were found (9.3), compared to the other samples, due to the fact that hydrocolloids decreased water diffusion through the spaghetti matrix, increasing the time that water needs to reach the pasta centre during cooking (Padalino *et al*. 2013a). The addition of hydrocolloids also caused a significant drop of cooking loss. In particular, the samples 15% TP/CMC (6.58%) and 15% TP/AG (6.60%) recorded the lowest values of cooking loss. It is possible that the hydrocolloids form a network around the starch granules, encapsulating them during cooking and restricting excessive swelling and diffusion of the amylose content. Concerning the swelling index and the water absorption, the sample with hydrocolloids recorded the greatest value (Table 2b). The higher swelling index obtained for pasta containing hydrocolloids may be explained by the greater capacity of substances to absorb and retain water within a very well developed starch-protein-polysaccharide network (Tudorica *et al*. 2002). Spaghetti samples with hydrocolloids presented the adhesiveness very comparable to the CTRL sample, probably due to the fact that hydrocolloids form a strong gluten network with the gluten proteins that entraps the starch granules, slowing down the amylose release during cooking (Kovacs & Vamos 1993; Tudorica *et al*. 2002). On the contrary, samples with hydrocolloids had the hardness value more similar to the 15% TP sample than to the CTRL one.

Chemical composition. The chemical composition of pasta samples is listed in Table 3. It can be seen that the addition of peels caused a noticeable decline in protein content and an increase in soluble and insoluble dietary fibre (Table 3a). In particular, the sample with 15% TP had the lowest protein content and the highest SDF and IDF content (10.07% for protein; 6.11 and 13.64% for SDF and IDF, respectively) as compared to the CTRL sample (15.85% for protein, 4.27 and 8.56% for SDF and IDF, respectively) (Knoblich *et al*. 2005). On the contrary, the sample enriched with tomato peel flour had the lowest ACH content when compared to the CTRL sample (74.27 g/100 g). These results could be due to the fact that the rise in dietary fibre caused a drop in carbohydrates responsible for the increase in the glycaemic response. In fact, the dietary fibre is actually defined as 'edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine' (Mongeau 2003). Therefore, the enrichment of semolina with nutritionally rich tomato peel flour could enhance the nutritional quality of the product. As regard the carotenoid content, the lycopene

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Table 3. Chemical composition of (**a**) dry spaghetti samples enriched with different tomato peel flour percentage and (**b**) dry spaghetti sample 15% TP enriched with different hydrocolloids

	Protein (%)	IDF (%)	SDF (%)	TDF (%)	ACH (g/100g)
(**a**)					
CTRL	15.85 ± 0.04[a]	8.56 ± 0.16[c]	4.27 ± 0.33[c]	12.83 ± 0.17[c]	68 ± 0.16[a]
10% TP	10.35 ± 0.12[b]	11.56 ± 0.00[b]	5.24 ± 0.33[b]	16.80 ± 0.23[b]	63 ± 1.00[b]
15% TP	10.29 ± 0.18[b]	13.64 ± 0.71[a]	6.11 ± 0.00[a]	19.75 ± 0.50[a]	60 ± 0.30[c]
(**b**)					
CTRL	15.85 ± 0.04[a]	8.56 ± 0.16[c]	4.27 ± 0.33[e]	12.83 ± 0.17[d]	68 ± 0.16[a]
15% TP	10.29 ± 0.18[b]	13.64 ± 0.71[b]	6.11 ± 0.00[d]	19.75 ± 0.50[c]	60 ± 0.30[b]
15% TP/CMC	10.07 ± 0.16[bc]	13.63 ± 0.61[b]	7.04 ± 0.00[b]	20.67 ± 0.60[b]	58 ± 1.00[c]
15% TP/AG	10.25 ± 0.13[b]	14.78 ± 0.09[a]	7.33 ± 0.23[ab]	22.11 ± 0.20[a]	58 ± 1.00[c]
15% TP/GUAR	10.00 ± 0.01[c]	14.60 ± 0.09[a]	6.63 ± 0.00[c]	21.23 ± 0.09[b]	58 ± 1.00[c]
15% TP XAN	10.25 ± 0.09[b]	15.22 ± 0.84[a]	7.45 ± 0.26[a]	22.67 ± 0.50[a]	58 ± 0.50[c]

TDF – total dietary fibre; SDF – soluble water dietary fibre; IDF – insoluble water dietary fibre; ACH – available carbohydrates; [a–c]means in the same column followed by different superscript letters differ significantly ($P < 0.05$)

and β-carotene level in dry spaghetti is shown in Table 4a. Data are expressed in mg/100 g spaghetti. There were significant differences ($P < 0.05$) between the samples. The tomato skin by-product contained average contents of lycopene and β-carotene equal to 12.94 and 7.93 mg/100 g, respectively. Obtained data show that spaghetti with 15% TP has a higher value of lycopene (1.12 mg/100 g) and β-carotene (13.36 mg/100 g) compared to the sample enriched with 10% TP. As expected, the higher incorporation of dried tomato by-product into pasta significantly enhanced the concentration of carotenoids.

As can be seen from Table 3b, the incorporation of hydrocolloids caused significant differences in protein content as compared to 15% TP sample, with exception of the sample 15% TP/GUAR and 15% TP/CMC. Specifically, these samples recorded the smallest protein values. Besides, all the spaghetti samples with hydrocolloids showed a significant rise in TDF content and a slight decline in ACH content when compared to samples without hydrocolloids. These results could be due to the fact that hydrocolloids are mainly composed of carbohydrates such as dietary fibre that are resistant to digestion and absorption in the human small intestine and undergo complete or partial fermentation in the large intestine (Trowel & Burkitt 1986). As regard the carotenoid content, Table 4b shows that there are significant differences ($P < 0.05$) between the samples enriched with CMC, GUAR, XAN, and AG. In general, the presence of hydrocolloids decreases carotenoid content in all samples in comparison with spaghetti enriched with 15% TP. The samples of pasta enriched with CMC and GUAR have similar values of the lycopene content like the spaghetti sample enriched with only 15% TP, while the lowest level of lycopene were found in the sample enriched with AG and XAN (0.69 and 0.88 mg/100 g, respectively). The content of β-carotene is the lowest in the sample enriched with AG, while the highest value was obtained in the sample enriched with GUAR.

Table 4. Carotenoids content (mg/100 g spaghetti) of (**a**) dry spaghetti samples enriched with different tomato peel flour percentage and (**b**) dry spaghetti sample 15% TP enriched with different hydrocolloids

	Lycopene	β-carotene
(**a**)		
CTRL	0.032 ± 0.00[c]	4.04 ± 0.08[c]
10% TP	0.62 ± 0.03[b]	5.16 ± 0.06[b]
15% TP	1.12 ± 0.07[a]	13.36 ± 0.03[a]
(**b**)		
CTRL	0.032 ± 0.00[d]	4.04 ± 0.08[f]
15% TP	1.12 ± 0.07[a]	13.36 ± 0.03[a]
15% TP/AG	0.69 ± 0.09[c]	6.79 ± 0.05[e]
15% TP/ CMC	1.08 ± 0.03[a]	9.81 ± 0.06[d]
15% TP/GUAR	1.11 ± 0.06[a]	11.16 ± 0.04[b]
15% TP/XAN	0.88 ± 0.06[b]	10.28 ± 0.06[c]

[a–f]means in the same column followed by different superscript letters differ significantly ($P < 0.05$)

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CONCLUSIONS

In this work, the impact of tomato peel flour addition on chemical composition, cooking and sensory quality of wholemeal durum wheat spaghetti was evaluated. In the first experimental step, the amount of tomato peel flour added to spaghetti was continuously increased until the sensory quality decreased to the threshold value, which was reached at the tomato peel flour concentration of 15%. The incorporation of tomato peels increased the content of carotenoids (lycopene and β-carotene) and dietary fibre (soluble and insoluble dietary fibre) in spaghetti samples as compared to the CTRL sample. The study on cooking quality and textural evaluation of spaghetti samples reported that the addition of tomato peel flour caused a slight increase of cooking loss and consequently the pasta was more adhesive and hard when compared to the CTRL sample. The overall quality of tomato peel-enriched spaghetti decreased significantly because the pasta showed low elasticity, unpleasant odour, and high firmness with respect to the CTRL sample. In the second experimental step, hydrocolloids such as CMC, GUAR, XAN, and AG were used to improve the sensory quality of the wholemeal spaghetti enriched with 15% tomato peels. Specifically, GUAR and CMC improved the sensory characteristics of pasta due to low adhesiveness and bulkiness. The incorporation of hydrocolloids did not change the nutritional composition, except for dietary fibre content that increased compared to the 15%TP sample.

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