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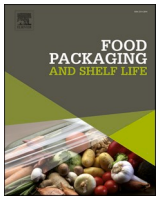

Effect of hazelnut skin and dry tomato peel on the oxidative stability, chemical and sensory properties of pork burgers during refrigerated storage

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ABSTRACT

The quality deterioration of meat products due to lipid oxidation could be controlled by utilizing agri-food by-products rich in antioxidants. This study evaluated the effect of adding hazelnut skin and dry tomato peel to pork burgers against oxidation phenomena. Three types of burgers were prepared: a control (C) with a basic formulation, and two formulations with 2.5% hazelnut skin (HS) or with 2.5% dry tomato peel (DTP). Microbiological, sensorial, and physio-chemical analyses were performed during 7 days of refrigerated storage (0–4 °C). Results showed a high inhibition of oxidation in HS burgers at all sampling times, both raw and cooked burgers, while in DTP burgers this phenomenon occurred only when cooked. Both by-products provided a significant amount of fiber, increased the polyunsaturated fatty acids (PUFA) content, and improved the omega-6/omega-3 ratio.

1. Introduction

Consumers nowadays are very concerned with the quality of the food they eat every day, but they are also becoming more aware of how food production affects the environmental impact. Regarding meat and meat products, healthiness plays a pivotal role in consumer choices. Consequently, the meat production chain is oriented to improve meat quality, and the main strategies adopted are the reduction of drugs in animal farming and the replacement of synthetic compounds with natural antioxidants in animal feed (Corino, Rossi, Cannata & Ratti, 2014) and in meat processing (Teixeira & Rodrigues, 2021; Saldaña et al., 2021), the reduction of fat content, improving fat composition by animal's nutritional strategies aimed to increase the omega 3 fatty acids (Lo Fiego, Belmonte, & Mezzetti, 2018). Lipid oxidation is the main non-microbial process responsible for the quality deterioration of meat and meat products (Domínguez et al., 2019). There are intrinsic factors that cause meat oxidation, such as the proportion of antioxidant molecules in animal tissues and the degree of lipid unsaturation (Ladikos & Lougovois, 1990). Among the different kinds of meat, pork is one of the most prone to lipid oxidation due to the high content of unsaturated fatty acids that are most susceptible to oxidative stress (Juntachote, Berghofer, Siebenhandl, & Bauer, 2006; Alvarez-Parrilla et al., 2014). Usually, the parameters in which a qualitative alteration is most obvious are color, texture, and flavor due to the appearance of rancid smells and flavours. In addition, this oxidative mechanism also gives rise to toxic compounds implicated in several pathologies such as atherosclerosis, cancer, inflammatory processes, and aging (Domínguez et al., 2019). Moreover, this phenomenon is promoted by mechanical actions such as grinding, cooking, and boning that cause the breakdown of muscle membranes (Ladikos & Lougovois, 1990). Due to the production process, items like burgers are highly delicate from an oxidative point of view. A possible strategy to control lipid oxidation processes could be the utilization of agri-food by-products rich in antioxidant compounds. In the Italian agri-food sector, there is a large availability of by-products from the tomato and hazelnut industries. Due to their characteristics and qualities, these co-products are already well-known and extensively studied in the research community (Navarro-González, García-Valverde, García-Alonso, & Periago et al., 2011; Elbadrawy & Sello, 2016; Del Valle et al., 2006; Özdemir et al., 2014; Locatelli et al., 2010; Taş & Gökmen, 2015; Müller et al., 2020; Pelvan et al., 2018; Del Rio, Calani, Dall'Asta, & Brighenti, 2011). These attributes are mostly related to the intake of macronutrients such as fiber and unsaturated fatty acids as well as the presence of phenolic compounds, which have strong antioxidant properties. Tomato peels consist mainly of peel, residual pulp, and tomato

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seeds and correspond to about 7–7.5% of the raw material (Nour et al., 2018). This indicates that on average, just under 500 k tons are produced annually in Italy, with an average yearly production of tomatoes of about 6 million tons throughout the period of 2011–2021 (FAOSTAT, 2021). In addition to the high fiber content, the bioactive compounds that in tomato peels attract interest, mainly for their antioxidant and coloring properties, are carotenoids, phenolic compounds, vitamins, and glycoalkaloids (Viuda-Martos et al., 2014; Andres et al., 2017). These constituents are extremely interesting for their anticarcinogenic, cardioprotective, antimicrobial, anti-inflammatory, and antioxidant potential, among others (Viuda-Martos et al., 2014). However, it's important to underline that the amount of active compounds present depends on the tomato variety, agricultural practices, environmental conditions, and industrial transformation processes (Valdez-Morales et al., 2014). Among all, lycopene is the most representative (80–90% of total pigments) (Doménech-Asensi et al., 2013) and promising bioactive compounds present for the implications associated with nutrition and human health thanks to the ability to interact with ROS and consequently mitigate the harmful effect of oxidation (Luisa García et al., 2009). As regards hazelnut skin, it is removed from the core during the roasting process and represents about 2.5% of the weight of the whole hazelnut, in shell (Alasalvar et al., 2009). This indicates that about 3k tons of hazelnut skin are made in Italy each year from an average annual hazelnut production of about 110k tons (FAOSTAT, 2021). In addition to excellent fiber content, several phenolic compounds, including flavan-3-ols, phenolic acids (mostly gallic acid), and procyanidins, are present in this by-product, which is now the subject of extensive research (Renna et al., 2020; Rondanelli et al., 2023). Despite being closely related to the cultivar (Taş & Gökmen, 2015), this results in the skin having an extremely higher total phenol content than natural hazelnut or roasted without skin (Pelvan et al., 2018), as well as an antioxidant capacity that is three times higher than nuts, 25 times higher than blackberries (Del Rio et al., 2011). These factors make hazelnut skin interesting from a health perspective because dietary traits like it have been connected to improvements in colon metabolism, a drop in total cholesterol and LDL, and a decrease in heart disease, hypertension, diabetes, and gastrointestinal disorders (Lairon et al., 2005; Liu et al., 1999; Montonen et al., 2003; Petruzziello et al., 2006; Whelton et al., 2005). Although the food industry is gradually recognizing and utilizing these by-products, particularly tomato peels, considerable progress remains to be made in establishing them as co-products and not just waste, which currently imposes economic burdens on companies and contributes to environmental pollution. This study aimed to evaluate the effect of hazelnut skin (HS) and dry tomato peel (DTP) on the oxidative stability, and chemical and sensory properties of pork burgers during refrigerated storage.

2. Materials and methods

2.1. Characterization of by-products

The dry tomato peel was obtained from Packtin S.r.l. (Reggio Emilia), which utilizes an innovative circular drying process at low temperatures (35–40 °C) while hazelnut skin was sent by Azienda Agricola Cascina Loreto (Piagera di Gabiano, Alessandria) and was mechanically separated during the hazelnut toasting process. Both by-products were reduced to powder, using a home mixer Moulinex DPA 141 (Moulinex Italy), and then sieved with a mesh width of 500 μm.

2.1.1. Proximate composition

The chemical composition of hazelnut skin and dry tomato peel was determined according to the AOAC official methods (AOAC, 1995) and the results were expressed on wet basis.

2.1.2. Microbiological analysis

For the microbiological analysis, 10 g of each by-product were diluted with 90 g of sterile sodium hypochlorite solution (0.9% NaCl), homogenized for 90 s in a laboratory Stomacher 400 blender (Seward Limited, Worthing, UK) and serial dilutions were created. Pour plate analysis was done using Plate Count Agar (PCA, Tryptic Glucose Yeast Agar, Biolife, Milan, Italy) for the aerobic mesophilic count and Violet Red Bile Glucose Agar for the Enterobacteriaceae count (VRBGA, Biolife, Milan, Italy). The plates underwent 24–48-hour and 48–72-hour incubations, respectively, at 30 °C. The bacterial load was expressed in terms of logarithm of colony-forming units (CFU) per g of by-products.

2.1.3. Fatty acid composition

Lipids from by-products were extracted with chloroform-methanol according to Folch, Lees, & Sloane Stanley (1957) and the fatty acid profile was determined by capillary gas chromatography. As reported by Zappaterra et al. (2020), 50 mg of lipid extract were diluted with 2 mL of hexane and methylated with 200 μl of 2 N-methanolic potassium hydroxide solution (KOH supplied by Carlo Erba, Milan, Italy, and methanol supplied by ITW Reagents, Barcelona, Spain). Subsequently, the fatty acid methyl esters (FAMEs) were analyzed using a TRACE™GC Ultra gas chromatograph (Thermo Electron Corporation, Rodano, Milano, Italy) equipped with Flame Ionization Detector, a PVT injector, and TR-FAME Column (30 m long, 0.25 mm i.d., 0.2 μm film thickness) supplied by Thermo Fisher Scientific (Rodano, Milano, Italy). At this point 1 μl of the methylated esters sample was injected into the GC with a split flow rate of 10 mL/min, operating at a constant flow of 1 mL/min of helium as a carrier gas. The working temperature for the injector and detector was 240 °C. The temperature program was raised from 140 °C to 250 °C. After 2 min at 140 °C temperature increased by 4 °C/min till 250 °C, and it was then maintained for 5 min. The Chrom-card software (version 2.3.3, Thermo Electron Corporation Rodano, Milano, Italy) was used to record, identify, and integrate the peaks area. A solution of known concentrations standard FA mix (Supelco 37 Component FAME mix, PUFA standard n.2, Animal Source, Supelco, Bellafonte, PA, USA, and single FAMEs standard, Larodan, Fine Chemicals AB, Malmö, Sweden) was used to identify the retention times of the FAMEs. The amount of each FAME was expressed as its relative percentage of the total amount of FAMEs using the normalized and correct area method.

2.1.4. Antioxidant activity and phytochemicals

The extraction of free phenolic compounds from hazelnut skin and dry tomato peel was carried out following the procedure reported by Martini, Conte, & Tagliazucchi (2017) with some modifications. Briefly, 1 g of each by-product was homogenized with 20 mL of methanol/water/acetic acid solution (70:29:1, *v*/v/v) with an Ultra-Turrax homogenizer (IKA, Germany) for 1 min. The suspension was then centrifuged (6000 rpm, 15 min, 4 °C). The supernatant was collected, and the pellet was resuspended with 20 mL of new solution. This procedure was repeated four times until the complete extraction of the phenolic compounds contained in the initial sample (1 g) was achieved. The obtained polyphenol-rich extracts were stored at 0–4 °C and then used for the subsequent analyses.

2.1.4.1. ABTS assay. To assess the antioxidant activity of by-products, the ABTS method was used according to the protocol described by Re et al. (1999). The ABTS test involves the use of chromogen 2, 2 -azinobis-(3-ethylbenzothiazoline-6-sulfonic) (ABTS, AppliChem GmbH). The antioxidant activity is evaluated as a reduction of the absorbance at 734 nm of the ABTS+ • radical cation in the presence of antioxidants. The ABTS radical cation (ABTS+•) was generated by mixing a total of 7 mM aqueous solution of ABTS with 2.45 mM potassium persulfate allowing the mixture to react in the dark for 16 h. The ABTS+ • solution was diluted in methanol to obtain an absorbance value (A_0) of 0.705 ± 0.005 at 734 nm. Then 100 μl of the diluted sample was mixed with 1400 μl of ABTS+ • solution and stored at 20 °C for 15 min in darkness. The final absorbance at 734 nm (A_f) was read and the percentage of scavenging (S

%) was calculated using the following Eq.:

$$S\ \% = (A_0\text{-}A_f)/A_0) \times 100$$

Where A_0 indicates the initial absorbance (control), while A_f indicates the final absorbance (sample). Trolox (6-hydroxy 2,5,6,7-tetramethyl chroman-2-carboxyl acid) was used as standard and the ABTS scavenging capacity was expressed as mmol of Trolox equivalent per g of by-product, by means of a calibration curve obtained with Trolox 50–500 mmol/L, in the same assay conditions.

2.1.4.2. FRAP assay. The antioxidant activity was measured also as ferric reducing/antioxidant power by using FRAP assays (Benzie & Strain, 1999). The method is based on the reduction of the Fe^{3+} −2,4, 6-tripyridyl-s-triazine (TPTZ) complex to its ferrous form at low pH. Briefly, 3 mL of FRAP assay solution (consisting of 20 mM ferric chloride solution, 10 mM TPTZ solution, and 0.3 M acetate buffer at pH 3.6) was prepared daily and mixed with 100 μl of the sample. The absorbance was measured at 593 nm at room temperature after 6 min of incubation. Results were expressed as μM of $FeSO_4$ per g of by-product.

2.1.4.3. Total phenolic compounds (TPC). The total phenolic compounds were determined using the Folin-Ciocalteu test (Singleton, Orthofer, & Lamuela-Raventos, 1999) with some modifications: 1975 μl of distilled water was mixed with 25 μl of phenolic compounds extract and 125 μl of Folin-Ciocalteu reagent. The solution was stirred and stored in the dark for 1 min 375 μl of 20% (w/w) Na_2CO_3 solution was added and incubated for 2 h in the dark at room temperature. Then the absorbance value at 765 nm was measured. Gallic acid was used as a phenolic standard to create a calibration curve (concentration range of 0–500 mg/L). The results were expressed as mg of gallic acid equivalent/g by-products (mg GAE/g).

2.2. Manufacture of pork burgers

The raw pork loin (*longissimus dorsi* muscle) and the subcutaneous adipose tissue were purchased refrigerated, and vacuum-packed from a commercial market at each starting cycle of analyses. Burgers were formed using a conventional burger maker (50 ± 0.5 g patty, 1 cm thickness, and 6 cm diameter), and three different types of pork burgers were formulated: a basic burger (control group; C), with 88.5% of *longissimus dorsi* muscle, 10% of subcutaneous adipose tissue, and 1.5% of sodium chloride, and two groups with addiction of 2.5% hazelnut skin (HS) or 2.5% dry tomato peel (DTP), respectively. The concentration of the two by-products was chosen based on results from the literature. While higher concentrations could have been used for tomato peels, excellent results were also obtained with the addition of DTP from 0.30% to 4.5% (w/w) (Alves, Bragagnolo, da Silva, Skibsted, & Orlien, 2012; Kim et al., 2013; Luisa García et al., 2009). For hazelnut skin, good results were obtained with the addition of 1% and 2% (Turhan, Sagir, & Sule Ustun, 2005), while higher concentrations, such as 3%, negatively affected the sensory evaluation of the product. Therefore, to ensure comparability of results, the same concentration was chosen for both by-products. A moderate value of 2.5% was selected, which allowed for optimal technological performance without affecting the acceptability of the product.

The research was divided into four cycles, in which 54 pork burgers were produced, 18 for each type for a total of 216 burgers. For each test, 12 burgers of each group were packed in resealable polypropylene containers, without modifications in atmospheric gas concentration, and stored at 4 ± 1 °C, for subsequent analyses carried out at 4 and 7 days of storage; the remaining 6 burgers were analyzed at day 0. On each sampling day (SD0, SD4, SD7) the samples were subjected to weight and diameter measurements, microbiological analysis, pH, color detection, water content, and oxidative status (TBARs) evaluation. Moreover, at day 0 chemical composition and fatty acid profile were determined. Subsequently, all burgers were cooked by a home electric double cast grill plat (Bosch, Germany) at 180 °C for 3 min and subjected to weight, diameter, color, moisture, and TBARs content measurements. Three burgers for treatments were destined for the sensory test.

2.3. Pork burgers analyses

2.3.1. Proximate composition

The chemical composition (moisture, crude lipids, crude protein, and crude fiber) of raw burgers was determined according to the AOAC methods (AOAC, 1995). The results were expressed as percentage of wet matter.

The fatty acid composition of raw burgers was done as previously described in Section 2.1.3. Lipids were extracted with chloroform-methanol according to Folch, Lees, & Sloane Stanley (1957) and the fatty acid profile was determined by capillary gas chromatography after methylation as reported by Zappaterra et al. (2020). The results were expressed as the relative percentage of the total amount of FAMEs using the normalized and correct area method.

2.3.2. Microbiological analysis

The microbial load of raw burgers was performed according to the technique and with the soils described in the by-product characterization. The analyses were performed in duplicate, and the results were expressed as the logarithm of colony-forming units (CFU) per g of burgers.

2.3.3. Physicochemical analyses

The pH value of each raw burger was determined in duplicate using a pH-meter CyberScan 310 (Thermo Fisher Scientific Inc., Waltham, MA, USA) equipped with a Xerolite electrode (Crison Instrument, Allela, Spain).

Color was determined from the surface of raw and cooked burgers using a Minolta CM-600d spectrophotometer (Konica Minolta Holdings, Inc, Osaka, Japan) with a window diameter of 8 mm and D65 as the illuminant source. Before color measuring the instrument was calibrated against a white plate supplied by the manufacturer. Each sample was measured at three different points and the measurements were averaged. Color detection was performed according to the CIE Lab color convention (CIE, 1986), where three basic coordinates are: L* - "lightness", a* - "redness", and b* - "yellowness". Further, Chroma (C*), the expression of the saturation index and color intensity, was calculated as $(a^{*2}+b^{*2})^{0.5}$, and Hue angle (h*) was calculated as arctan (b*/a*).

2.3.4. Diameter variation and cooking loss

A Borletti caliper was used and two measurements with different angles were made to define the diameter of the burger better. The measurement was carried out, before (RD) and after (CD) cooking on a home electric double-cast grill plat (Bosch, Germany) at 180 °C for 3 min.

(RD – CD)/RD* 100 represents the diameter variation due to the cooking process.

The cooking loss was expressed as the difference (%) between the raw weight (RW) and cooked weight (CW) of burgers, according to the equation:

$$(RW\text{-}CW)/RW*100$$

2.3.5. Lipid oxidation analysis of raw and cooked burgers

The oxidative stability of raw and cooked burgers was evaluated according to Siu and Draper (1978), slightly modified. Approximately 2.5 g of minced sample were homogenized in 12.5 mL of distilled water for 2 min at 9500 rpm using an Ultra-Turrax tissue homogenizer (IKA, Germany). After that time 12.5 mL of 10% trichloroacetic acid (TCA)

Table 1
Proximate composition, fatty acid composition, total phenolic contents (TPC), microbiological count, and antioxidant activity (ABTS and FRAP) of hazelnut skin and dry tomato peel (Mean ± SD).

	Hazelnut skin (n = 3)	Dry tomato peel (n = 3)
Moisture %	5.30 ± 0.001	5.05 ± 0.002
Crude lipids %	24.44 ± 1.30	11.36 ± 0.02
Crude protein %	5.99 ± 0.24	17.10 ± 0.10
Crude fiber %	21.70 ± 1.82	43.40 ± 1.95
Saturated fatty acids (SFA) %	9.20 ± 0.60	21.90 ± 0.20
Monounsaturated fatty acids (MUFA) %	77.20 ± 0.05	22.30 ± 0.50
Polyunsaturated fatty acids (PUFA) %	13.60 ± 0.01	55.80 ± 0.20
Aerobic mesophilic count (log UFC/g)	2.11 ± 0.21	4.19 ± 0.04
Enterobacteriaceae count (log UFC/g)	n.d.	3.14 ± 0.08
TPC (mg GAE/g)	125.91 ± 5.10	0.94 ± 0.07
ABTS (μM Trolox eq/g)	1041.26 ± 54.33	1.81 ± 0.13
FRAP (μM $FeSO_4$/g)	296.39 ± 5.92	–

n.d.: not detectable.
TPC: Total phenolic compounds
ABTS: 2, 2 -azinobis-(3-ethylbenzothiazoline-6-sulfonic)
FRAP: Ferric reducing antioxidant power

solution (Sigma-Aldrich, Milan, Italy) were added and then the sample was centrifugated at 2000 rpm for 20 min at 4 °C. The supernatant was filtered through a paper filter (Whatman No. 5), and 4 mL of the clear filtrate were transferred into 15 mL pyrex test tubes. Then 1 mL of 0.06 M 2-thiobarbituric acid (TBA, Sigma-Aldrich, Milan, Italy) was added and the samples were kept in a water bath at 80 °C for 90 min. At the same time, the blank was run (2 mL of distilled water+2 mL of TCA solution+1 mL of TBA). The samples were cooled before reading and absorbance at 532 nm was measured against blank sample, using a Jasco spectrophotometer (Model V550, UV/VIS, Tokyo, Japan). Using 1,1,3,3 tetraethoxypropane (TEP, Sigma-Aldrich, Milan, Italy) as a standard, TBARS were expressed as mg of malondialdehyde (MDA) per kg of burger. In addition, the antioxidant potential, expressed as percentage of antioxidant activity (AOA), was calculated by the equation (Wijewickreme & Kitts, 1998):

$$\%\mathrm{AOA} = \frac{[TBARS\ value\ of\ the\ control - TBARS\ of\ the\ test\ sample]}{[TBARS\ value\ of\ the\ control]} x100$$

2.3.6. Sensory properties

The cooked burgers were arranged in randomized order and served to the panelist at the same temperature and the participants were provided with unsalted crackers and water. A panel of 9 judges was selected among the staff of the Department. The subjects were equally distributed by gender, with an age range of 20–40 years. All participants had previous familiarity with sensory analysis and had been previously trained for the specific type of test chosen. Additionally, the judges were all regular consumers of hamburgers and pork, and the analyses were conducted in a teaching laboratory with natural lighting and a minimum distance of one and a half meters between each judge.

An acceptability test with a hedonic scale (from 0 to 5) was used; it was required to express an opinion on 7 parameters: color (0 =not acceptable; 5 =acceptable), olfactory evaluation (0 =unpleasant aroma; 5 =pleasant aroma), tenderness (0 =not tender; 5 =very tender), bitterness (0 =absent; 5 =high), sapidity (0 =not sapid; 5 =very savory), astringency (0 =not astringent; 5 =very astringent), overall liking (0 =not appreciated; 5 =greatly appreciated).

2.4. Statistical analysis

Data regarding the characterization of by-products (proximate composition, crude fiber, TPC, ABTS, microbiological load, and fatty acid composition were expressed as mean ± standard deviation (SD) of three different samples analyzed in triplicate. Data from burger analyses were submitted to analysis of variance using the GLM procedure of SAS (SAS Institute Inc., Cary, NC, USA), assuming a level of at least $P < 0.05$ for statistical significance. The statistical models included as fixed effect the treatments (C, HS, and DTP) for moisture, crude protein, crude fat, crude fiber, and fatty acid composition of raw burgers. Treatments, storage days (0, 4, 7), and relative interactions were included for sensory analysis, pH, cooking loss, diameter variation, and microbiological load. Moreover, for MDA content and color parameters, cooking treatment was included in the model. The differences between means were tested by t-test (SAS/GLM PDIFF option).

Table 2
Effect of treatment on chemical composition (%) and fatty acid content (% of total fatty acid detected) of pork burgers.

	C	HS	DTP	R-MSE ($)
Moisture	64.53	64.60	66.41	4.65
Crude lipids	10.24	10.23	11.13	1.95
Crude protein	24.84	24.97	25.14	2.08
Crude fiber	Tr(§) c	0.58b	1.03a	0.12
SFA	39.75a	37.52b	39.17a	1.04
MUFA	48.01b	49.71a	47.04c	1.02
PUFA	12.24c	12.77b	13.78a	0.59
ω3	0.65	0.80	0.78	0.08
ω6	11.59b	11.98b	13.00a	0.55
ω6/ω3	18.28a	15.09c	16.78b	1.73

C: control burger; HS: hazelnut skin burger; DTP: dry tomato peel burger.
(§): Traces.
($): Root Mean Square Error
a, b, c: different letters on the same line indicate differences for $P < 0.05$.

3. Results and discussion

3.1. By-product characterization

The results of by-products characterization are shown in Table 1.

In the present study, the moisture content of dry tomato peels agrees with Navarro-González et al. (2011); in contrast, Darwish, El-Hakim, El-Rahman, & Megali (2019) found a higher value. This difference may be directly related to the technological process the product goes through and, as a result, to the amount of residual pulp that is still present. The total lipid was found to be substantially higher in percentage than the values in the literature (Del Valle et al., 2006; Navarro-González et al., 2011; Elbadrawy & Sello, 2016; Darwish et al., 2019) and this could be due to the presence of seeds traces in our by-product that raised the level of lipids. The same goes for protein values that in other studies ranged from 10.50% to 24.67%, so our results were within the range (Elbadrawy & Sello, 2016). The fiber content and fatty acid composition were also comparable to that observed by other Authors (Darwish et al., 2019; Elbadrawy & Sello, 2016).

The chemical properties of the hazelnut peel vary greatly depending on the cultivar examined. Our results agree with Longato et al. (2019). This could be because the Authors used hazelnuts from a similar geographical region to ours. The moisture content has been found to be below the literature average (Locatelli et al., 2010; Longato et al., 2019). Instead, the lipid content has been found to be higher than most published research (Anil, 2007; Bertolino et al., 2015). While protein and, particularly, fiber contents were deficient compared to the values observed by other Authors (Locatelli et al., 2010; Turhan et al., 2005). The fatty acid composition was consistent with the literature (Özdemir et al., 2014).

From a microbiological standpoint, hazelnut skin had low loads while a significant microbial load was found in the dry tomato peel (Table 1) but given that there are no regulations governing microbiological limits for these by-products, keeping in mind those of vegetable products and meat to be consumed after cooking, these two by-products fell within the established limits (ICMSF, 1986; EC No 2073/2005).

Dry tomato peels exhibited values for TPC and ABTS that were lower

Table 3
Effect of treatment and storage time on pH, cooking loss, diameter variation, and microbial load of pork burgers.

	TREATMENT									R-MSE [($)]
	C			HS			DTP			
	SD0	SD4	SD7	SD0	SD4	SD7	SD0	SD4	SD7	
pH	5.58	5.48	5.52	5.53	5.42	5.42	5.53^{a}	5.36^{b}	5.36^{b}	0.14
Cooking loss (%)	13.91^{e}	13.14^{e}	13.94^{e}	11.06^{f}	9.55^{f}	9.43^{g}	10.57^{f}	10.32^{f}	12.41^{e}	2.91
Diameter variation (%)	3.34	5.59	4.07	3.29	4.77	2.93	5.23	4.48	3.90	2.90
Aerobic mesophilic count (log UFC/g)	5.03^{c}	6.47^{b}	7.14^{a}	4.53^{c}	6.68^{b}	7.37^{a}	4.62^{c}	6.60^{b}	7.40^{a}	0.56
Enterobacteriaceae count (log UFC/g)	3.97^{b}	4.93^{a}	5.18^{a}	3.99^{b}	5.16^{a}	5.26^{a}	3.95^{b}	5.29^{a}	5.21^{a}	0.57

C: control burger; HS: hazelnut skin burger; DTP: dry tomato peel burger; SD: storage days.
[a, b, c]: different letters on the same line indicate differences for $P < 0.05$ between storage days within each treatment.
[e, f, g]: different letters on the same line indicate differences for $P < 0.05$ between treatments within the same storage day.
[($)]: Root Mean Square Error

than those determined by Darwish et al. (2019); this finding may be explained by the genetic type of the cultivar as well as the fractions of peel, seeds, and pulp present (Chandra et al., 2012). Hazelnut skin had a lower level of total phenolic compounds and FRAP, but ABTS value according to other Authors (Del Rio et al., 2011; Özdemir et al., 2014; Bertolino et al., 2015).

3.2. Proximate composition of burgers

The effect of treatment on the chemical composition and fatty acid profile of pork burgers are reported in Table 2.

Based on the data (Table 2), it can be observed that adding 2.5% of hazelnut skin did not have a significant effect on moisture, crude lipid, and crude protein contents of pork burgers. This is consistent with a study by Turhan et al. (2005) who did not observe an increase in protein content in beef burgers with the addition of hazelnut skin. As regards dry tomato peel the result showed that its addition tended to increase slightly moisture, protein, and fat content. This tendency is in contrast with a study by Candogan (2002), in which no increase in protein and fat content was observed in beef balls added 5% and 10% of tomato paste.

As shown in Table 2, the fiber content was 0.58% for burgers with hazelnut skin and 1.03% for burgers with dry tomato peels. This indicated that the addition of these by-products provided fiber intake ($P < 0.05$) in pork burgers, which commonly lack this component. The levels reached can be further improved to meet the nutritional requirements of increasingly elaborate diets. Therefore, it is necessary to precisely establish the levels of these by-products to be incorporated into meat-based products without altering their sensory characteristics that are acceptable to consumers.

Regarding the effect of by-products on the fatty acid composition, hazelnut skin led to a significant increase ($P < 0.05$) in monounsaturated and polyunsaturated fatty acids, while dry tomato peel resulted in a significant increase ($P < 0.05$) in polyunsaturated and omega-6 fatty acids. Both treatments contributed to a decrease significantly ($P < 0.05$) in the omega-6/omega-3 ratio. Making this kind of change in the product is important because nutritional guidelines (e.g., FAO/WHO, 2008) suggest that in order to reduce the incidence of various non-infectious diseases, such as diabetes, some forms of cancer, and cardiovascular disease (CVD), the intake of total fat, saturated and polyunsaturated fatty acids (SFAs and PUFAs), and the ratio of ω6: ω3 PUFAs should be within well-defined limits. Despite the significant reduction, we are still far from the optimal level, which should range between 1:1 and 4:1 (Simopoulos, 2002; 2010). However, it should be noted that this value is recommended for the specific diet, and therefore, this reduction can still be considered a contribution to the nutritional improvement of the product.

The effect of treatment and storage time on pH value, cooking loss, diameter variation, and microbial load of pork burgers were reported in Table 3.

The pH values of both treated groups showed a tendency to be lower than the control group, although the difference was not statistically significant ($P > 0.05$). This finding is consistent with previous studies on hazelnut skin, where it was observed that this by-product did not cause a significant decrease in pH value in beef burgers (Turhan et al., 2005) and chicken burgers (Longato et al., 2019). Regarding DTP, Luisa García et al. (2009) reported a significant reduction in pH with an increase in the concentration of DTP in beef burgers. In our research, during the storage period, the pH value significantly decreased ($P < 0.05$) only in the samples with DTP from day 0 to day 4. The diameter of the burgers was not influenced by the treatments or storage time. Both by-products reduced significantly ($P < 0.05$) the cooking loss, instead storage time did not affect this parameter (Table3). Our results agree with Turhan et al. (2005), who observed that hazelnut skin added to beef burgers reduced cooking loss. The microbial load was not influenced by the by-products inclusion but increased significantly ($P < 0.05$) during storage for both classes of microorganisms sought. Considering the limits reported by Regulation (EC) No. 2073/2005 the microbial load fell within these limits until the 4th day of storage, on the 7th day the limit was exceeded. This may be due to the mode used of storage that did not involve changes in atmospheric gas concentration in the container,

Table 4
Effect of treatment and storage time on color parameters of raw pork burgers.

	TREATMENT									R-MSE [($)]
	C			HS			DTP			
	SD0	SD4	SD7	SD0	SD4	SD7	SD0	SD4	SD7	
L*	$50.39^{b\ e}$	$52.68^{ab\ e}$	$54.51^{a\ e}$	35.84^{f}	36.68^{g}	37.87^{g}	48.39^{e}	48.66^{f}	49.97^{f}	3.09
a*	$6.39^{a\ f}$	$3.51^{b\ g}$	$2.21^{c\ g}$	$6.36^{a\ f}$	$5.92^{ab\ f}$	$4.82^{b\ f}$	$15.72^{a\ e}$	$12.51^{b\ e}$	$10.37^{c\ e}$	1.69
b*	$13.97^{a\ f}$	$12.46^{ab\ f}$	$12.12^{b\ f}$	8.27^{g}	7.97^{g}	7.71^{g}	24.21^{e}	22.92^{e}	23.03^{e}	3.22
C*	$15.42^{a\ f}$	$12.97^{b\ f}$	$12.34^{b\ f}$	10.45^{g}	9.94^{g}	9.12^{g}	$28.89^{a\ e}$	$26.13^{b\ e}$	$27.27^{b\ e}$	4.26
h*	$65.72^{c\ e}$	$74.39^{b\ e}$	$79.78^{a\ e}$	$52.46^{b\ g}$	$53.38^{b\ g}$	$57.75^{a\ g}$	$57.11^{c\ f}$	$61.42^{b\ f}$	$65.71^{a\ f}$	5.67

C: control burger; HS: hazelnut skin burger; DTP: dry tomato peel burger; SD: storage days.
[a, b, c]: different letters on the same line indicate differences for $P < 0.05$ between storage days within each treatment.
[e, f, g]: different letters on the same line indicate differences for $P < 0.05$ between treatments within the same storage day.
[($)]: Root Mean Square Error

Table 5
Effect of treatment and pre-cooking storage time on color parameters of cooked pork burgers.

	TREATMENT									R-MSE [($)]
	C			HS			DTP			
	SD0	SD4	SD7	SD0	SD4	SD7	SD0	SD4	SD7	
L*	61.28$^{b\ e}$	64.46$^{a\ e}$	65.23$^{a\ e}$	40.86$^{b\ g}$	42.90$^{ab\ g}$	45.00$^{a\ g}$	*56.05*$^{b\ f}$	55.22$^{b\ f}$	59.18$^{a\ f}$	3.09
a*	5.50$^{a\ f}$	3.91$^{b\ g}$	3.26$^{b\ g}$	6.45^{f}	5.67^{f}	5.50^{f}	11.80$^{a\ e}$	11.96$^{a\ e}$	10.08$^{b\ e}$	1.69
b*	21.60$^{a\ f}$	18.72$^{b\ f}$	17.92$^{b\ f}$	11.95^{g}	10.89^{g}	10.64^{g}	31.07$^{a\ e}$	27.46$^{ab\ e}$	27.00$^{b\ e}$	3.22
C*	22.35$^{a\ f}$	19.15$^{b\ f}$	18.23$^{b\ f}$	13.60^{g}	12.30^{g}	11.99^{g}	28.89$^{a\ e}$	30.01$^{b\ e}$	28.84$^{a\ e}$	4.26
h*	76.34$^{b\ e}$	78.70$^{a\ e}$	79.97$^{a\ e}$	61.64^{g}	62.23^{g}	62.47^{g}	67.90$^{b\ f}$	66.96$^{b\ f}$	69.52$^{a\ f}$	5.67

C: control burger; HS: hazelnut skin burger; DTP: dry tomato peel burger; SD: storage days.
[a, b, c]: different letters on the same line indicate differences for $P < 0.05$ between storage days within each treatment.
[e, f, g]: different letters on the same line indicate differences for $P < 0.05$ between treatments within the same storage day.
[($)]: Root Mean Square Error

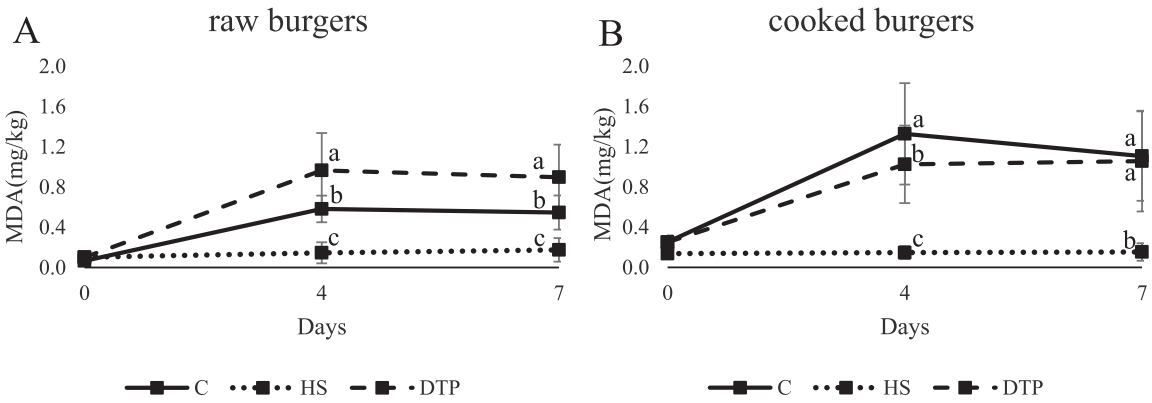

Fig. 1. Lipid oxidation of (A) raw and (B) cooked burgers (MDA mg/kg) at different days of refrigerated storage. C: control burgers; HS: hazelnut skin burgers; DTP: dry tomato peel burgers. Treatment: [a,b,c] $P < 0.05$. Day: $P < 0.05$ only for C and DTP between 0 and 4 and 0–7 days in both raw and cooked burgers.

regardless of the formulation of the hamburger.

3.3. Effect of treatment, storage time, and cooking on color parameters of pork burgers

The data presented in Table 4 and 5, respectively for raw and cooked burgers, show that the color parameters of burgers were significantly affected ($P < 0.05$) by treatment and storage time.

The addition of hazelnut skin and tomato peel has respectively given a brown and red color to the burgers. The brown color of the hazelnut film is evident from the values of L* and b* , which are always lower ($P < 0.05$) than the other two groups both in row (Table 4) and cooked (Table 5) burgers. On the other hand, DTP samples show higher ($P < 0.05$) values of a* , b* , and C* than C and HS raw and cooked burgers, indicating a reddish coloration and a higher intensity of color, as also reported in previous research (Candogan, 2002; Luisa García et al., 2009; Kim et al., 2013). The color changed significantly ($P < 0.05$) over time (Table 4) mostly in C and DTP groups, as it appeared brighter on day 0 and decreased in intensity on days 4 and 7 of storage, as evidenced by the lower ($P < 0.05$) values of the parameters a* , b* , and C* , while the HS group showed more stability. As regards cooked burgers (Table 5), their higher L* values than raw burgers could be explained by a surface coating of melted fat that formed during cooking. The same trend could be observed in b* , C* , and h* values while the a* value was lower in cooked than in raw burgers except for the HS group, and these variations may be due to the Maillard reaction effects on cooking color changes (Luisa García et al., 2009).

3.4. Lipid oxidation of raw and cooked burgers

The results highlighted that HS burgers exhibited a high inhibition of oxidative phenomenon during all storage times of 7 days in both raw and cooked burgers (Fig. 1). This group showed very high AOA% values, with peaks of 88% in raw samples and 94% in cooked samples (data not shown).

There are few studies that have explored the use of hazelnut skin in meat preparations; Longato et al. (2019) reported that increasing the amount of hazelnut skin in chicken burgers decreased oxidative stability over a storage period of 4 days, attributing this to the high content of polyphenols, which can have a pro-oxidizing effect. This result contrasts with Olszowy (2019) that attributes to polyphenols an antioxidant effect as confirmed in our study.

During storage time, dry tomato peels did not have any protective effect in raw samples, where MDA values were higher ($P < 0.05$) than the other two groups both at the 4th and 7th days of refrigerated storage. A possible explanation of this result could be that in general the antioxidant effect of this by-product may be dose- and time-dependent, as verified by Candogan (2002), in which increasing the percentage of tomato by-products in beef burgers resulted in increased antioxidant capacity and by Kim and Chin (2013) who found that the tomato powder added to pork sausages did not show an antioxidant effect until after 21 days of storage. In cooked DTP samples, however, an effect against the oxidative phenomenon occurred, indicating that the by-product protected the lipids during cooking, but only on 4th day of storage. Overall (data not shown), regardless of storage period and treatments, the cooking process increased the MDA content of burgers by 42% (0.40 vs 0.69 mg/kg, $P < 0.05$) but the increase was different between the three groups (+169% in C, $P < 0.05$, +26.2% in DTP, $P < 0.05$ and +6.3% in HS, $P < 0.05$) showing a strong antioxidative activity of hazelnut skin.

Although there are no legal limits for these types of products regarding MDA content, it is believed, as reported by Trindade et al. (2010) for beef and by Longato et al. (2019) for chicken, that the level of MDA during storage should be kept below 2 mg/kg. In the present study, the MDA value was found to be significantly lower even after cooking in

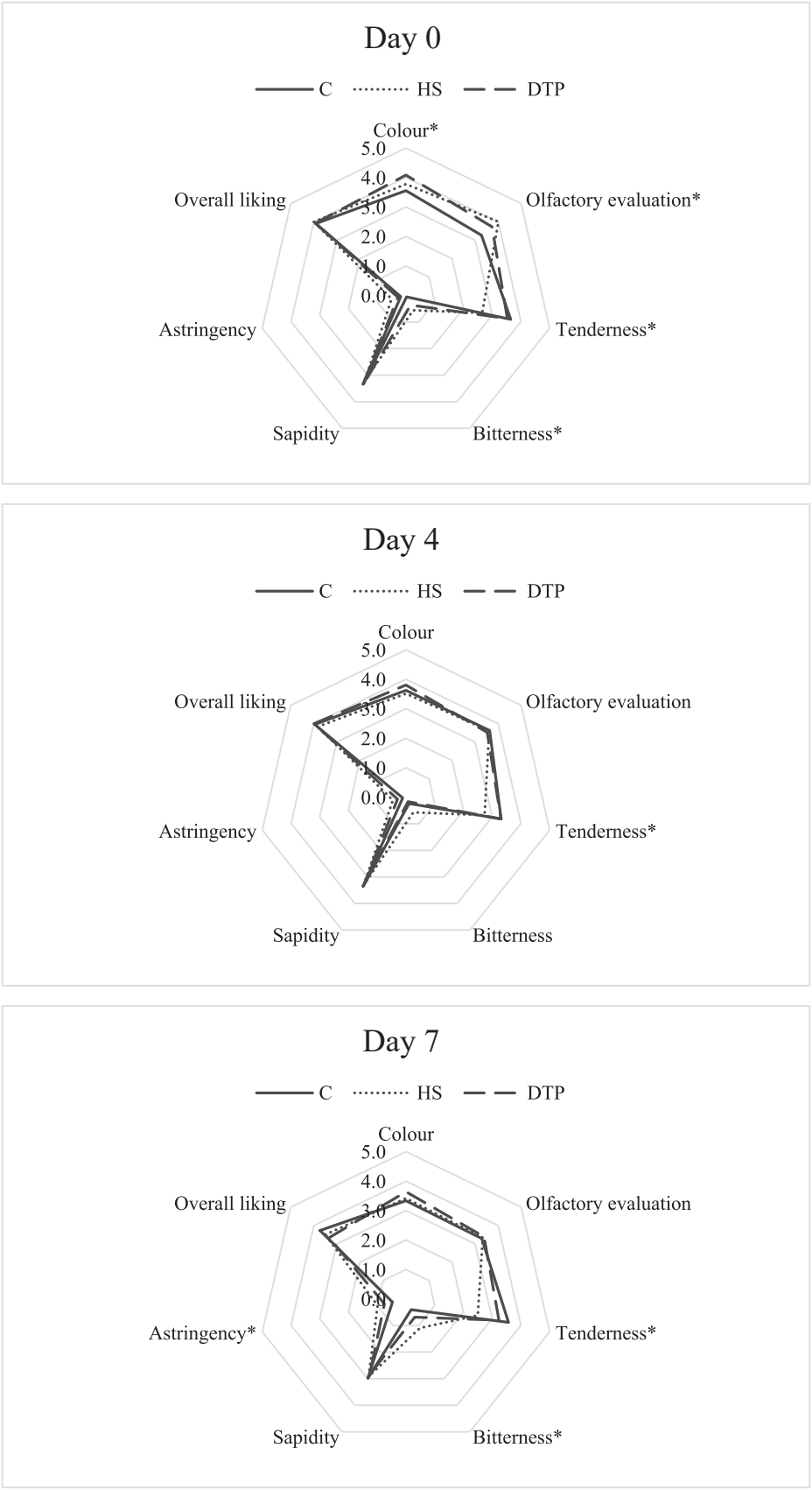

Fig. 2. Sensory evaluation of the pork burgers at different sampling days. C: control burger; HS: hazelnut skin burger; DTP: dry tomato peel burger. * Treatment: $P < 0.05$.

all formulations used, further highlighting the protective effect exerted by the hazelnut skin.

3.5. Sensory evaluation

Overall, the sensory properties of the burgers were not significantly impacted by the addition of by-products, except for bitterness, astringency, and tenderness, which were negatively influenced by the treatments (Fig. 2).

Bitterness and astringency had higher values in HS and DTP samples, inversely tenderness tended to decrease in supplemented burgers compared to the control group. However, it is important to note that these negative effects did not reach critical values and did not significantly affect overall satisfaction, which was always equal in the treated groups compared to the control. The negative effects on tenderness may be attributed to the fibrous component present in the by-products, which can alter the chewability of the finished product. Additionally, tannins present in the hazelnut film may cause a common sensation of astringency on the palate. Similar results were found in studies conducted by Longato et al. (2019) on chicken burgers with hazelnut skin and by Eyiler and Oztan (2011) on sausages containing tomato powder, where tenderness was compromised by the added products. On the other hand, some sensory qualities such as color and smell were found to be improved by the presence of by-products, as reported in studies conducted by Kim et al. (2011), Kim et al. (2013), and Longato et al. (2019). These improvements may be due to the flavor produced by the by-products during cooking and to the color properties that they apport that can mask the characteristic smell and white color of cooked pork meat, which is not appreciated by everyone. It is worth noting that during refrigerated storage, even for a short period of only 7 days, all sensory parameters tended to worsen in all treatments, regardless of the presence of by-products. This could be due to the type of storage that only involved refrigeration without modification of the atmosphere inside the box.

4. Conclusions

Our work demonstrates that the presence of hazelnut skin in pork burgers reduced lipid oxidation making the product more stable both during storage and cooking. While dry tomato peel presented a protective potential only in cooking, suggesting that research on this by-product should be implemented perhaps changing the dose and storage time. Both by-products provided a significant contribution to the amount of fiber, especially in the case of dry tomato peel, and affected the fatty acid composition of burgers by increasing PUFA, contributing to a decrease in the omega-6/omega-3 ratio. According to these results incorporating hazelnut skin and dry tomato peel into pork burgers improves their nutritional profile maintaining microbial stability without affecting sensory acceptability. This innovative approach offers a sustainable solution for utilizing food by-products and producing healthier meat products.

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CRediT authorship contribution statement

Katia D'Ambra: Data curation, Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Giovanna Minelli:** Methodology, Supervision, Writing – review & editing. **Domenico Pietro Lo Fiego:** Resources, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The Authors declare the following financial interests/personal relationships which may be considered as potential competing interests, Domenico Pietro Lo Fiego reports financial support was provided by PRIN 2020 National Project.

Data Availability

Data will be made available on request.

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