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Feeding pigs with hazelnut skin and addition of a concentrated phenolic extract from olive-milling wastewaters during pork processing: Effects on salami quality traits and acceptance by the consumers

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ABSTRACT

Two groups of ten barrows received a conventional- (CTRL) or an experimental- (HZL) finishing diet containing 11% of hazelnut skin. From each barrow, two types of salami (namely, NITR, and PHEN) were obtained. NITR salami was added with E250 and E252. The latter were replaced by a phenolic concentrated extract from olive-milling wastewaters in PHEN salami. Salami fatty acids (FA), antioxidant capacity, lipid and color stability during refrigerated storage were assessed. A consumer test was also performed.

Feeding strategy minimally affected the investigated parameters. PHEN salami had lower TBARS than NITR salami (P-value <0.001) during refrigerated storage despite comparable antioxidant capacity and similar PUFA content. Moreover, within CTRL group, lipid oxidation was lower in PHEN than NITR salami (P-value = 0.040).

At the blind taste, dietary treatment did not affect salami sensorial properties nor consumer acceptance, whereas NITR salami showed better color (P-value = 0.036). Interestingly, HZL and PHEN salami showed improved sensorial properties and consumer acceptance after that consumers received information on salami origin.

1. Introduction

Processed pork products are specialty foods in many countries and represent a remarkable market share both locally and globally. The Italian prosciutto, the Hungarian winter salami, kiełbasa from Eastern Europe, the Mexican chorizo, and the Canadian bacon from North America, are just few examples. However, meat processing may promote oxidative processes (Longato et al., 2019). In the case of salami, mincing meat may expose oxidation-prone substrates (i.e. unsaturated lipid and heme iron) to pro-oxidant factors such as oxygen, light, and temperature. Lipid oxidation during processing and storage may detriment to product nutritive value by reducing polyunsaturated fatty acids (PUFA) and vitamins content as well as generating aldehydes and ketones responsible for off-flavors or other potentially toxic PUFA derivatives (Galanakis, 2018; Maqsood & Benjakul, 2011). Also, in the case of meat products, the interaction between lipid and heme iron is pivotal both in the oxidative degradation of PUFA and color (Carlsen, Møller, & Skibsted, 2005). Commonly, adding spices and antioxidant compounds (either natural or synthetic) during meat processing represents one of the most effective approaches to prevent these problems. Nitrates and nitrites salts are widely used by meat processing industry as they are effective against microorganisms and play an important role in maintaining the organoleptic properties of the products, such as color by binding heme iron. The effect of nitrites and nitrates salts on human health is still under debate. When provided by vegetables and fruit (the main source of these molecules in the human diet), they may support cardiovascular function (Hord, Tang, & Bryan, 2009). However, nitrites and nitrates from processed meat have been related to non-communicable diseases (Abid, Cross, & Sinha, 2014). Thus, the reduction of synthetic additives in food products has become a major request by consumers (Asioli et al., 2017). Conversely, the use of natural antioxidants or fortification with antioxidants from natural sources positively affects consumers acceptability and willingness to pay (Di Vita et al., 2019; Kumar, Yadav, Ahmad, & Narsaiah, 2015). In this context, the use of agro-industrial by-products as a source of bioactive compounds is gaining particular attention, though its effectiveness should be

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demonstrated.

Olive-milling wastewater (OMW) represents one of the major wastes resulting from the production of olive oil. It consists of the water used in different phases of oil extraction process plus the aqueous fraction of the drupe. Different extraction technologies can generate variable amounts of wastewater, ranging from less than 0.1 m^3/tons (two-stage separation) to more than 1-m^3/tons (three-stage separation) (Bottino et al., 2020). The richness in phenolic compounds, mainly represented by polyphenols, is a peculiarity of OMW. From the one side, this confers phytotoxicity to OMW, that must be treated as a special waste, representing a significant burden on the olive-milling industry. From the other side, OMW polyphenols such as hydroxytyrosol and oleuropein derivatives are a valuable resource that can be suitable for animal feeding, cosmetics, food, or pharmaceuticals due to their antimicrobial properties and free radical and active oxygen scavenging capacity. It has been observed that incorporating polyphenols from olive plant during food processing can improve color stability and contrast the initiation and propagation of lipid oxidation (Fernández-Bolaños, Rodríguez, Rodríguez, Guillén, & Jiménez, 2006; Galanakis, 2018; Obied et al., 2005; Roila et al., 2022; Servili et al., 2011). Thus, the use of a phenolic concentrated extract from olive-milling wastewater as a food additive could be suitable to improve shelf-life and health traits of food products.

Another viable approach to reduce the deterioration of meat products is to intervene upstream through the animal diet. Targeted feeding strategies can reduce the content of oxidation-sensitive polyunsaturated fatty acids (PUFAs) in favor of monounsaturated fatty acids (MUFAs), which have greater oxidative stability. Also, the integration of antioxidant molecules such as phenolic compounds and tocopherols in the diet can help to preserve quality and extend shelf life of food products (Bekhit, Hopkins, Fahri, & Ponnampalam, 2013; Biondi et al., 2020; Menci et al., 2021). Hazelnut skin could be used for these purposes. Hazelnut (*Corylus avellana* L.) kernels are largely used all over the world in the production processes of chocolate and pastry. Skin is commonly removed from the kernels intended for the pastry industry to prevent miscolorations and off-flavors, thus generating by-products that can be quantified in 2.5% of the kernel weight (Alasalvar et al., 2003). Due to fiber, fat, and protein content, hazelnut skin (HS) can be a partial replacer of traditional animal feeds, contributing to reduce feed-to-food competition and improving product quality (Campione et al., 2020; Menci et al., 2023; Priolo et al., 2021). Moreover, HS is rich in phenolic compounds, which account up to 12.7% of its weight (Del Rio, Calani, Dall'Asta, & Brighenti, 2011). These include flavan-3-ols, phenolic acids, and tannins, molecules with a remarkable antioxidant capacity that, administered with the diet to the animals, improved animal health and several quality traits in the meat and meat products both in mono- and polygrastric through different mechanism (Wu, Bak, Goran, & Tatiyaborworntham, 2022). Also, it is a natural source of oleic acid, which represents the majority of HS fatty acids, and vitamin E (Menci et al., 2023; Özdemir, Yılmaz, Durmaz, & Gökmen, 2014). Oleic acid is known for its preventive action on coronary heart disease, diabetes, and cholesterol-related issues (Ros & Mataix, 2006), and is more resistant to oxidative processes than 18-carbon PUFA. Vitamin E, besides anticancer properties and preventive effects against cardiovascular and various degenerative diseases (Rizvi et al., 2014; Sozen, Demirel, & Ozer, 2019; Wallert et al., 2019) is known as the major lipophilic antioxidant able to contrast oxidation (Traber & Atkinson, 2007).

In recent decades, research has focused on recycling agro-industrial by-products as substitutes for traditional feedstuffs as this can reduce farming environmental footprint, improve product characteristics and have positive social, ethical, and economic impacts (Biondi et al., 2020; Kasapidou, Sossidou, & Mitlianga, 2015; Salami et al., 2019; Santana-Méridas, González-Coloma, & Sánchez-Vioque, 2012). It is, therefore, of great interest to work in the perspective of a circular economy, valorizing by-products and increasing inter-chain dynamism.

In light of the above, we hypothesized that salami quality traits (i.e. fatty acid composition and oxidative stability) could be affected by the dietary administration of HS to pigs and by the use of a concentrated phenolic extract obtained from OMW to replace sodium nitrates and nitrates salts during pork processing. Therefore, the aim of this study was to investigate i) the quality traits of salami produced with meat from pigs fed hazelnut skin; ii) the effect of replacing nitrites and nitrates salts by OMW phenolic extract in the recipe for salami production; iii) the interactive effect of the two previous strategies on the quality of salami and iv) the sensory properties and consumer's acceptability of the salami obtained from pigs fed hazelnut skin or added with OMW phenolic extract.

2. Materials and methods

2.1. Animals and dietary treatments

The study was approved by the Bioethical Committee of the University of Perugia (approval number 90284/2021) and carried out at a commercial farm located in Umbria (Italy). The animals were handled in accordance with European legislation (Directive 2010/63/EU). Twenty crossbreed barrows ((Large White x Landrace) x Cinta Senese) were selected from a same group of animals raised on the native farm and fed an equal amount of a commercial concentrate until 7 months of age. Then, after recording the initial body weight (88 ± 4.63 [SD] kg), the animals were allocated in individual pens and randomly assigned to one of the two feeding treatments. During 7 days, pigs were adapted to their respective diet, which was administered for a 78-day finishing period. The animals were fed a restricted diet consisting of 7% of metabolic weight calculated as Live $Weight^{0.75}$ of a commercial concentrate for the Control group (CTRL, $n = 10$) or a concentrate containing 11% hazelnut skin (on a dry matter basis) for the Hazelnut group (HZL, n = 10). The hazelnut skin was milled together with the other components of the experimental concentrate (0.6 mm particle). Table 1 reports ingredients and chemical composition of the diets. Feeds were provided twice daily at 7:00 am and 4:00 pm, while water was always available. Restricted feeding is a common practice in farms oriented on pig production for cured pork.

2.2. Feedstuff sampling and analyses

Hazelnut skin was kindly provided by Nestlè Italia S.p.a. (Viale San Sisto, Perugia, Italy). For each experimental concentrate feed, aliquots were taken fortnightly, vacuum-packed, and stored at −30 °C. At the end of the trial, the feeds aliquots were mixed to obtain representative samples of the two diets. Samples of hazelnut skin and CTRL and HZL diets were analyzed for crude protein, ether extract, and ash according to AOAC methods (AOAC, 1995). Fiber fractions were determined as described by Van Soest, Robertson, and Lewis (1991). Total phenolic compounds were analyzed as reported by Makkar, Singh, Vats, and Sood (1993) with modifications as follows. Feed was grounded and 200 mg sample were vortex-mixed with 10 mL acetone 70% (*v*/v). Samples were sonicated for 30 min in a 4 °C water bath under attenuated light and centrifuged (30 min, 2500 ×*g*, 4 °C). The supernatant was collected, the solvent evaporated using a rotary evaporator system (Büchi, R-114, Switzerland) and the residue was dissolved in methanol 70% (v/v). Folin-Ciocalteu reagent 1 N was prepared just prior to use by mixing Folin-Ciocalteu solution (2 N) and distilled water in equal amount. The quantification of total phenolic compounds was performed by mixing 100 μL of feed extract diluted in 900 μL of water with 500 μL of Folin-Ciocalteu reagent 1 N. NaOH 20% (*w/v*) was added after a 10 min and the samples were vortex-mixed, incubated in the dark for 40 min, and centrifuged (20 min, 2500 ×*g*, 4 °C). The absorbance at 725 nm was read using a double-beam UV/VIS spectrophotometer (UV-2550; Shimadzu Corporation, Milan, Italy). Non-tannin phenols were obtained by treating an extract:distilled water mixture (1:1, v/v) with 100 mg of polyvinylpolypyrrolidone (PVPP). Samples were incubated for 20 min at 4 °C and centrifuged (20 min, 2500 ×*g*, 4 °C). The quantification of non-

Table 1
Ingredients and chemical composition of the experimental diets and hazelnut skin.

	Hazelnut skin	Dietary treatment[1]	
		CTRL	HZL
Ingredients, g/100 g dry matter (DM[2])			
Corn		30.0	26.0
Wheat middlings		20.0	20.0
Barley		20.0	20.0
Soybean meal		13.0	14.0
Wheat Bran		8.0	–
Wheat		7.0	7.0
Calcium		1.3	1.3
Lysine		0.2	0.2
Vitamin and mineral mix		0.5	0.5
Hazelnut Perisperm		–	11.0
Chemical composition, g/kg DM			
Crude Protein	78.6	183.1	169.2
Ether extract	255.6	30.5	54.5
NDF[3]	503.8	225.8	229.8
ADF[4]	387.7	91.8	120.7
ADL[5]	202.8	19.3	41.3
Hemicellulose	116.1	134.0	109.1
Cellulose	184.9	72.5	79.4
Ash	18.6	47.1	46.7
Phenolic compounds, g/100 g DM			
Total phenols[6]	140.27	3.25	16.30
Total tannins[6]	59.01	0.65	7.98
Energy values (MJ/kg DM)			
ED[7]	–	13.32	12.45
EM[8]	–	12.66	11.83
Fatty acids composition (g/100 g)			
C14:0	0.10	0.41	0.34
C16:0	7.04	27.46	16.64
C18:0	2.59	3.07	3.69
C18:1 *c*9	74.90	26.13	54.00
C18:2 *c*9*c*12	13.70	34.03	19.32
C18:3 *c*9*c*12*c*15	0.21	2.07	1.06

[1] Treatments were: control diet (CTRL); diet containing 11% of hazelnut skin (HZL).
[2] Dry matter.
[3] Neutral detergent fiber.
[4] Acid detergent fiber.
[5] Acid detergent lignin.
[6] Expressed as tannic acid equivalents.
[7] Digestible Energy.
[8] Metabolizable Energy.

tannin phenols was performed by mixing 200 μL of supernatant and 800 μL of distilled water, measuring the absorbance as reported above. Total tannins were calculated by subtracting non-tannins phenols from total phenols. Results were expressed as tannic acid equivalents/kg of dry matter (DM) using standard solutions of tannic acid ranging between 0 and 100 μg/mL.

Lipids from feeds were extracted and converted to fatty acid methyl esters (FAME) by a 1-step procedure using chloroform and 2% (*v*/v) sulfuric acid in methanol (Biondi et al., 2020). Nonadecanoic acid was used as an internal standard (C19:0, Larodan, Solna, Sweden). Individual FAMEs were separated and quantitatively determined by gas chromatography as later described for salami fatty acids.

2.3. Olive-milling wastewater phenolic extract (OMWPE) production and analysis

Olive-milling waste waters phenolic extract was obtained, purified, and analyzed as reported by Ianni et al. (2021). Briefly, a crude phenolic extract was obtained by first treating olive-milling wastewaters with pectinase/hemicellulose for enzymatic hydrolysis during 12 h at 20 °C (O-Max S, OE Italia S.r.l., Marsala, Italy), and then by microfiltration, ultrafiltration, and reverse osmosis performed on a pilot-scale filtration plant. The crude phenolic concentrate was mixed with ethyl acetate and the organic phase recovered. Residual water was removed from the organic phase by anhydrous sodium sulphate and ethyl acetate evaporated using a rotary vapor system (Büchi, R-114, Switzerland) at 35 °C. Eventually, the extract was dissolved in ethanol to obtain the final OMWPE. Phenolic compounds reported in Table 2 were determined by reversed-phase high-performance liquid chromatography with diode-array detection (HPLC-DAD) system (Agilent Technologies system Mod. 1100) as detailed by Ianni et al. (2021).

2.4. Slaughtering procedures and salami preparation

At the end of the trial, pigs were weighed to determine the average daily gain (ADG) and moved to a commercial abattoir (about 30 km far from the farm) the day before sacrifice. Animals were slaughtered according to the European Union welfare guidelines. The carcasses were individually weighed immediately after the sacrifice and after 24 h storage at 4 °C to determine hot and cold carcass weight, respectively. On each carcass, the pH (Orion star A111 pH meter, Thermo Scientific, Milano, Italy) was measured 30 min and 24 h after slaughter. Prior to pH measurements, a two-point calibration (pH 7 and pH 4) with temperature compensation was performed. After 48 h storage at 4 °C, the carcasses were transferred to a local meat factory (Italia Authentica S.r.l., Italy) for salami production. Individual salamis were obtained using shoulder and neck meat, throat fat, and back fat removed from each animal. For each animal, 10 kg of meat (80% lean, 20% fat) were weighed and coarsely chopped by knife, minced by a meat grinder (diameter: 3 mm, C/E680N, Minerva Omega group s.r.l., Bologna, Italy), then refrigerated in a cell at 4 °C for 24 h. The 10 kg mass was split into two 5 kg sub-masses: one sub-mass was intended for salamis production according to a conventional recipe that includes 0.15 g/kg of sodium nitrite (E250) and 0.15 g/kg of potassium nitrate (E252) (namely, NITR salamis). The second sub-mass was intended for salamis production according to an experimental recipe where E250 and E252 additives were replaced by 100 mL of 30% OMWPE in a hydroalcoholic solution (namely, PHEN salamis). An equal amount of hydroalcoholic solution, free of phenolic extract, was added to the sub-mass intended for NITR salamis. Both salami recipes included the following spices: salt 23 g/kg, sugar 10 g/kg, ground black pepper 1 g/kg, peppercorn 1 g/kg, and granular garlic 0.4 g/kg. Both the sub-masses were inoculated with starter containing *Staphylococcus carnosus, Staphylococcus xylosus,* and *Lactobacillus sakei* (Eurostarter MI Rapid, MEC Import, Roma, Italy,) at a dose of 0.15 g/kg. The mix was refrigerated at 4 °C (12*h*) and then mechanically stuffed into synthetic intestine so that 5 salamis of 1 kg each were obtained. Thus, a total of 4 types of salamis were produced. Specifically, 1) CTRL+NITR, consisting of control pork + E250 and E252; 2) CTRL+PHEN, consisting of control pork + OMWPE; 3) HZL + NITR, consisting of HZL pork + E250 and E252; 4) HZL + PHEN, consisting of HZL pork + OMWPE. At the end of 52-day curing period, salamis were packed under the vacuum and stored frozen at −80 °C until

Table 2
Phenolic compounds in the olive-milling wastewaters phenolic extract.

Compounds[1]	
3,4-DHPEA	70.3 ± 0.10
p-HPEA	12.5 ± 0.02
Vanillic acid	0.73 ± 0.00
Verbascoside	25.9 ± 0.30
3,4-DHPEA-EDA	497 ± 2.80
p-HPEA-EDA	5.00 ± 0.20
Total phenols	612 ± 2.80

[1] Expressed as mg/g of the extract.

analyses.

2.5. Salami laboratory analysis

Fatty acids were evaluated on total lipids extracted from 5 g of salami using a 2:1 (*V*/V) chloroform:methanol solution as reported by Folch, Lees, and Sloane Stanley (1957) and methylated by the mean of sodium methoxide in methanol (0.5 N) followed by methanolic hydrochloric acid (Valenti et al., 2021). Nonadecanoic acid was used as internal standard. Qualitative and quantitative determination of FAMEs was conducted using a Thermo Finnigan Trace GC equipped with a flame ionization detector (FID; ThermoQuest, Milan, Italy) and a 100-m-long highly polar capillary column (25 mm i.d., 0.25 μm; SP. 24,056 Supelco Inc., Bellefonte, PA) and the conditions reported by Cherif et al. (2018). Specifically, 1 μL of sample was injected and carried by a constant flow (1 mL/min) of helium, the split ratio was 1:80. Oven temperature was set as follows: 50 °C for 4 min, increased by 10 °C/min until 120 °C, 120 °C for 1 min, increased 5 °C/min to 180 °C and held for 18 min, then increased of 2 °C/min until 230 °C and held at 230 °C for 19 min. The injector temperature was 270 °C, detector temperature was 300 °C. Individual FAMEs were identified by comparison with retention times of a commercial mixture of standard FAMEs mixture (GLC-674, Nu-Chek Prep Inc., Elysian, MN, USA) and individual standard FAME (Larodan Fine Chemicals, Malmo, Sweden) and expressed as mg/g of salami. The highly peroxidizable fatty acids index (HP-PUFA) was obtained by summing all PUFAs quantified according Luciano et al. (2012).

Atherogenic index (AI) and thrombogenic index (TI; Ulbricht & Southgate, 1991), the hypocholesterolemic to hypercholesterolemic fatty acids ratio (h:H; Bolletta et al., 2022), and peroxidability index (PI; Luciano et al., 2013) were calculated as follows:

$$\mathrm{AI} = (\mathrm{C12:0} + 4^{*}\mathrm{C14:0} + \mathrm{C16:0})/(\mathrm{MUFA} + \mathrm{PUFA}\ \omega-6 + \mathrm{PUFA}\ \omega-3)$$

$$\mathrm{TI} = (\mathrm{C14:0} + \mathrm{C16:0} + \mathrm{C18:0})/[(0.5^{*}\mathrm{C18:1}) + (0.5^{*}\text{other MUFA}) + (0.5^{*}\ \mathrm{PUFA}\ \omega-6) + (3^{*}\ \mathrm{PUFA}\ \omega-3) + (\mathrm{PUFA}\ \omega-3/\mathrm{PUFA}\ \omega-6)]$$

$$\mathrm{h:H} = (\mathrm{C18:1}\ c9 + \mathrm{PUFA})/(\mathrm{C12:0} + \mathrm{C14:0} + \mathrm{C16:0})$$

$$\mathrm{PI} = \left(\sum \text{Dienoic fatty acids}^{*}1\right) + \left(\sum \text{Trienoic fatty acids}^{*}2\right) + \left(\sum \text{Tetraenoic fatty acids}^{*}3\right) + \left(\sum \text{Pentaenoic fatty acids}^{*}4\right) + \left(\sum \text{Hexaenoic fatty acids}^{*}5\right)$$

Salamis antioxidant capacity was estimated by Trolox Equivalent Antioxidant Capacity (TEAC) and Ferric Reducing Antioxidant capacity (FRAP) essays on an extract prepared in attenuated light conditions as follows: 1.5 g of sample was homogenized (IKA, T-18 basic UltraTurrax, KA-Werke GmbH & Co.KG, Staufen, Germany) in 10 mL of distilled water in ice-cold water bath for 1 min, sonicated for 6 min in ice-cold bath and filtered through a Whatman n.1 filter.

TEAC was determined as reported by Re et al. (1999). The 2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) ($ABTS^{+}$) radical solution was prepared by mixing 10 mL of 14 mM ABTS and 10 mL of 4.9 mM $K_2S_2O_8$ and stored overnight in the dark. The $ABTS^{+}$ radical solution was then diluted with H_2O until an absorbance of 0.75 (± 0.02) was reached. 20 μL of salami extract was added to 2 mL of diluted $ABTS^{+}$ radical solution and incubated for 60 min at 30 °C in the dark. The absorbance was then read at 734 nm (UV-VIS spectrophotometer, Shimadzu UV-2550). The absorbance of a blank sample was read both immediately after the preparation (A0) and after the incubation (A60). The percentage of decolorization of $ABTS^{+}$ was calculated as follows:

$$Inhibition_X(\%) = \frac{Abs_{A0-Bl} - Abs_{A60}}{Abs_{A0-Bl}} \times 100$$

The results were expressed as μmol of TROLOX equivalents per gram of salami, using a seven-point calibration curve ranging from 0.5 to 2.0 mM TROLOX.

The FRAP assay was performed on the aqueous extract as reported by Benzie and Strain (1996), modified as follows. Briefly, the FRAP solution was prepared by combining respectively 10, 20, and 1 vol of acetate buffer (300 mM), ferric chloride hexahydrate (0.02 M), and 2,4,6-Tris(2-pyridyl)-*s*-triazine (TPTZ) in 0,04 M HCl solution (0.01 M) in distilled water. Samples were incubated in the dark at 37 °C for 60 min and the absorbance at 593 nm was read (Shimadzu UV-2550, 1 Shimadzu Corporation, Milan, Italy).

The results were expressed as mmol of Fe^{2+} equivalent per gram of salami using a six-point calibration curve daily prepared using ferrous sulfate heptahydrate 1 mM.

Three slices 2 cm thick were cut from each salami and intended for color parameters determination. Lightness (*L**), chroma (C*), redness (*a**), and yellowness index (*b**), and hue angle (h*) were measured on one slice 30 min after slicing (T0) by a portable spectrophotometer (Minolta CM-700d, d/8° geometry; Minolta Co., Ltd. Osaka, Japan) using illuminant A, 10° standard observer, and 6 mm diameter area view. The other two slices were placed in polystyrene trays, covered with an oxygen-permeable plastic film, and stored for 3 (T1) and 7 days (T2) at 4 °C prior to color parameters determination. Immediately after color measurement, each slice was vacuum-packed and stored at −80 °C pending thiobarbituric acid reagent substances (TBARS) analyses, described later (Siu & Draper, 1978). Briefly, 2.5 g of salami was homogenized (T-18 basic UltraTurrax, KA-Werke GmbH & Co.KG, Staufen, Germany) with 12.5 mL distilled water for 2 min in a cold-water bath, added with 12.5 mL of 10% trichloroacetic acid and vortex-mixed. Samples were filtrated through a Whatman n.1 filter. In pyrex tubes, 1 mL of 0.06 M TBA was added to 4 mL of filtrate and incubated for 90 min at 80 °C. Spectrophotometric analysis was conducted at 532 nm (Shimadzu UV-2550, Shimadzu Corporation, Milan, Italy). The assay was calibrated with solutions of known concentration of 1,1,3,3,-tetraethoxypropane (TEP) in distilled water, and results were expressed as mg of malonaldehyde (MDA)/kg of salami.

2.6. Consumer tests

Two different central location tests (each composed of a single session) were performed to evaluate salami sensory properties and acceptability by untrained panelists. One of the two tests was dedicated to assess the effect of the dietary treatment (CTRL vs HZL). The other one, performed on a different day, tested the effect of the salami recipe (NITR vs PHEN). A total of 192 habitual cured meat consumers (i.e. consuming cold cuts at least once per week) were randomly selected and assigned to one of the two consumer tests ensuring a balanced representation of different age, gender, and occupation.

The panelists evaluating the effect of dietary treatment (n = 100) were different from those (n = 92) evaluating recipe effect. This to prevent any influence of previously received information on salami preparation.

In order to test the effect of the animal dietary treatment, consumers were offered salamis produced from CTRL and HZL pork following the conventional recipe (CTRL+NITR vs HZL + NITR). The effect of the recipe was tested by offering consumers salamis made with CTRL pork processed with the addition of E250 and E252 or OMWPE (CTRL+NITR) vs CTRL+PHEN).

During each consumer test, salami slices, one per type and arranged on a white plate according to a randomized block system, were offered at room temperature. Water and unsalted crackers were provided to the participants for palate cleansing between samples. The salami descriptors (Color, Aroma, Taste, Texture, and Overall liking) were scored by a progressive 9-point scale, ranging from 1 to 9. First, a blind taste test was conducted. Subsequently, after receiving information on the animal feeding treatment or the salami recipe, consumers were only

asked (no tasting was performed) to express their expected Overall liking for the different types of salami using the same scale as for the descriptors (from 1 meaning dislike to 9 meaning like). Finally, an informed test was conducted, asking the consumers to taste and score the different slices of salami again.

2.7. Statistical analysis

Data on salami fatty acid composition, TEAC, and FRAP assays were analyzed using a mixed model to evaluate the effect of the diet (D; CTRL and HZL) and recipe (R; PHEN and NITR) as fixed factors and their interactions (D × R). Data on colorimetric parameters and TBARS were analyzed using an ANOVA mixed model for repeated measures to study the effect of diet (D; CTRL and HZL), recipe (R; PHEN and NITR), and time of storage (T; 0, 3 and 7 days), set as fixed factors, and their interaction. Individual animal from which the salami was obtained was included as random factor. Regarding data collected during consumer test, a mixed model was used to assess the effect of dietary treatments (CTRL vs HZL) or recipe (NITR vs PHEN), test type (blind/informed), and their interaction on salami descriptors. Individual consumer was used as random factor. Tukey's test was used to highlight any significant differences between pairwise comparisons. Significance was stated for $P \leq 0.05$ and differences were considered a trend towards statistical significance when $0.05 < P \leq 0.10$.

3. Results

Though the study was not planned for investigating animal performances, the latter were monitored because of the major effect they can play on salami quality. Despite the diets were not fully isoenergetic and metabolizable energy (EM) was 6.53% lower for the HZL diet in comparison with CTRL, the inclusion of HS in the diet of finishing pigs did not affect ADG (0.44 ± 0.12 vs 0.49 ± 0.14 kg/day; for CTRL and HZL, respectively; $P = 0.325$) nor the final weight (121.5 ± 9.70 vs 127.0 ± 8.01 kg, for CTRL and HZL, respectively for; $P = 0.221$).

Table 3 reports data on the effect of animal dietary treatment (CTRL vs HZL) and used recipe (NITR vs PHEN) on salami fatty acid profile. Dietary treatment did not affect total saturated (SFA), monounsaturated

Table 3
Effect of the animal diet and of the recipe on salami fatty acid composition.

	Dietary treatment[1] (D)		Recipe[2] (R)		SEM[3]	*P*-value[4]		
	CTRL	HZL	NITR	PHEN		D	R	D × R
Fatty Acids (mg/g salami)								
C12:0	0.200	0.192	0.200	0.212	0.010	0.932	0.915	0.995
C14:0	3.010	2.767	2.748	2.975	0.125	0.319	0.205	0.523
C14:1*c*9	0.035	0.029	0.025	0.028	0.003	0.085	0.276	0.648
C15:0	0.150	0.134	0.131	0.144	0.008	0.469	0.306	0.932
C16:0	53.52	49.92	49.46	52.84	2.120	0.416	0.204	0.418
C16:1*c*9	4.789	4.297	4.092	4.506	0.225	0.039	0.281	0.660
C17:0	0.821	0.725	0.720	0.764	0.046	0.323	0.296	0.616
C17:1*c*9	0.646	0.545	0.524	0.578	0.035	0.017	0.266	0.613
C18:0	29.26	27.94	28.07	29.41	1.210	0.984	0.263	0.337
C18:1 *c*9	87.60	83.28	83.65	88.49	3.140	0.574	0.183	0.255
C18:1 *c*11	7.301	6.645	6.530	6.992	0.283	0.034	0.174	0.398
C18:2 *c*9*c*12	23.00	21.16	20.83	22.09	0.849	0.281	0.456	0.435
C18:2 *c*9*t*11	0.251	0.224	0.215	0.232	0.015	0.137	0.882	0.912
C18:3 *c*9*c*12*c*15	1.042	0.947	0.922	0.985	0.042	0.139	0.690	0.329
C20:0	0.425	0.415	0.427	0.446	0.016	0.884	0.189	0.370
C20:1 *c*11	2.011	1.842	1.844	2.001	0.077	0.145	0.111	0.373
C20:2 ω-6	1.118	1.011	0.990	1.051	0.042	0.069	0.360	0.353
C20:3 ω-6	0.191	0.181	0.183	0.184	0.009	0.235	0.871	0.550
C20:3 ω-3	0.184	0.164	0.158	0.171	0.008	0.028	0.615	0.568
C20:4 ω-6	0.637	0.622	0.608	0.622	0.026	0.317	0.503	0.695
C20:5 ω-3	0.032	0.027	0.026	0.026	0.002	0.054	0.851	0.316
C22:0	0.043	0.051	0.066	0.057	0.006	0.226	0.851	0.586
C22:2 ω-6	0.019	0.016	0.013	0.014	0.002	0.010	0.207	0.530
C22:4 ω-6	0.206	0.189	0.189	0.198	0.009	0.100	0.946	0.781
C22:5 ω-3	0.146	0.130	0.127	0.133	0.008	0.072	0.615	0.761
C22:6 ω-3	0.045	0.043	0.044	0.047	0.003	0.926	0.806	0.703
SFA	8.646	8.269	8.891	8.024	3.430	0.589	0.219	0.386
MUFA	10.39	9.772	10.59	9.574	3.740	0.409	0.181	0.278
PUFA	2.687	2.448	2.636	2.498	0.988	0.238	0.493	0.434
PUFA ω-3	0.145	0.125	0.136	0.133	0.059	0.099	0.768	0.388
PUFA ω-6	2.517	2.302	2.476	2.343	0.922	0.257	0.476	0.435
ω-6/ω-3	17.51	18.58	18.31	17.77	2.740	0.050	0.304	0.703
AI[5]	0.503	0.500	0.505	0.498	0.053	0.742	0.532	0.699
TI[6]	1.234	1.260	1.258	1.237	0.132	0.342	0.445	0.903
HP-PUFA[7]	0.248	0.218	0.233	0.233	0.010	0.124	0.987	0.477
PI[8]	3.068	2.782	2.992	2.858	0.113	0.217	0.559	0.442
H:h[9]	2.028	2.063	2.032	2.059	0.226	0.452	0.568	0.783

[1] Treatments were: control diet (CTRL); diet containing 11% of hazelnut skin (HZL).
[2] NITR salami was added with 0.15 g/kg of nitrites and nitrates salts; PHEN salami was added with 0.8 g/kg of olive-milling wastewater phenolic extract.
[3] Standard error of mean.
[4] *P*-value of the effect of the dietary treatment.
[5] Atherogenic index, (C12:0 + 4*C14:0 + C16:0) / (MUFA + PUFA ω- 6 + PUFA ω-3).
[6] Thrombogenic index, (C14:0 + C16:0 + C18:0) / [(0.5*C18:1) + (0.5*other MUFA) + (0.5* PUFA ω-6) + (3* PUFA ω-3) + (PUFA ω-3/ PUFA ω-6)].
[7] Highly peroxidizable polyunsaturated fatty acids calculated as the sum of PUFA with three or more double bonds.
[8] Peroxidability index, (∑Dienoic fatty acids) + (∑Trienoic fatty acids*2) + (∑Tetraenoic fatty acids*3) + (∑Pentaenoic fatty acids*4) + (∑Hexaenoic fatty acids*5).
[9] Hypocholesterolemic to hypercholesterolemic fatty acids ratio (C18:1c9 + PUFA) / (C12:0 + C14:0 + C16:0).

(MUFA), and polyunsaturated fatty acids (PUFA). Conversely, individual fatty acids differed between CTRL and HZL salami. Specifically, the concentration of C16:1 *c*9, C17:1 *c*9, C18:1 *c*11, C20:3 ω-3, C20:5 ω-3 (EPA), and C22:2 ω-6 was greater ($P \leq 0.05$) in salami obtained from animals fed the CTRL diet, which also showed a greater PUFA ω-6/ω-3 ratio ($P = 0.050$). Also, C20:2 ω-6, C22:4 ω-6, C22:5 ω-3, and total PUFA ω-3 tended to be greater in the CTRL salami ($0.05 < P \leq 0.100$). Conversely, none of the identified fatty acids nor the calculated indices were affected by the recipe.

Ferric reducing and trolox equivalent antioxidant capacity were comparable ($P > 0.05$) between the different types of salami (Table 4). Differences due to the used recipe ($P \leq 0.05$) were observed in the color parameters and their evolution over time. Specifically, L^* and b^* values decreased over storage time ($P < 0.001$ and $P = 0.031$, respectively), while an interactive R × T (recipe × time of storage) effect ($P \leq 0.001$) was observed for a^*, C* and h* (Fig. 1). The a^* (Fig. 1A) and C^* (Fig. 1B) of NITR salami progressively decreased from T0 to T2, whereas they were quite constant over time for PHEN salami, at levels similar to that reached by NITR salami at the end of refrigerated storage. Regarding h*, PHEN salami always had higher values than NITR salami, but the two recipes showed different evolution over time: PHEN salami had the highest value at T1, while NITR salami showed the highest value at T2 (Fig. 1C).

Regarding lipid oxidation, an interactive effect D × T (Diet × Recipe, $P = 0.040$) and R × T (Recipe × Time of storage, $P \leq 0.001$) on TBARS was recorded (Fig. 2). Specifically, TBARS increased over time for NITR salami, while PHEN salami showed constant TBARS levels in a range between NITR salami values at T0 and T1 (Fig. 2A). Moreover, as compared to nitrites and nitrates, the addition of OMWPE in the salami made from CTRL pork lowered the level of TBARS, while no difference was observed in salami made from HZL pork (Fig. 2B).

Regarding the consumer tests, Table 5 reports the lack of animal dietary treatment or tasting type effect ($P > 0.05$) on salami sensory properties. Conversely, an interactive animal dietary treatment × tasting type effect ($P \leq 0.05$) was recorded for salami taste and overall like (Fig. 3). In particular, the taste (Fig. 3A) of HZL salami improved switching from blind to informed test. Conversely, the overall like of CTRL salami scored lower on informed test compared to both CTRL salami on blind test and HZL salami on informed test (Fig. 3B). Regarding the consumer test performed to evaluate the effect of the salami recipe, an interactive recipe × tasting type effect was recorded for all the descriptors ($P \leq 0.05$, Fig. 4). Specifically, NITR salami color (Fig. 4A) scored better than PHEN salami only on blind test. Also, aroma, taste, and overall like (Fig. 4B,C,E) of PHEN salami received a greater score than NITR salami during the informed test, whereas they did not differed during the blind test. Moreover, texture (Fig. 4D) improved for PHEN salami when switching from blind to informed test, also scoring higher than NITR salami on informed test.

Table 4
Effect of the animal diet and of the recipe on salami antioxidant capacity.

	Dietary treatment[1] (D)		Recipe[2] (R)		SEM[3]	*P*-value[4]		
	CTRL	HZL	N	P		D	R	D × R
FRAP[5]	15.1	15.1	15.1	15.0	0.718	0.983	0.953	0.452
TEAC[6]	5.16	5.31	4.89	5.59	0.336	0.844	0.281	0.283

[1] Treatments were: control diet (CTRL); diet containing 11% of hazelnut skin (HZL).
[2] NITR salami was added with 0.15 g/kg of nitrites and nitrates salts; PHEN salami was added with 0.8 g/kg of olive-milling wastewater phenolic extract.
[3] Standard error of mean.
[4] P-value of the effect of the dietary treatment.
[5] Ferric Reducing Antioxidant Capacity expressed as mmol of Iron (II) equivalent per gram of cheese.
[6] Trolox Equivalent Antioxidant Capacity expressed as mmol of trolox equivalent per gram of cheese.

4. Discussion

This is the first research paper investigating the utilization of hazelnut skin as a dietary components for pigs and the relative effect on the quality of pork processed meat. Moreover, the combined effect on salami quality of this dietary strategies dietary with a phenolic extract from olive mill wastewaters employed as an additive for meat processing to replace nitrites and nitrates salts in salami production has not been previously tested. The investigated quality parameters range from the fatty acid profile, crucial for nutritional characteristics appealing to consumers to the antioxidant capacity and oxidative stability of product, a focal point for the food industry. The latter has been assessed by monitoring color and lipid component stability. Ultimately, an evaluation of consumer acceptance was conducted regarding the innovative strategies implemented in animal feeding and meat processing. These assessments sheds light on the potential and/or limitations of these strategies.

4.1. Fatty acids composition of salami

Lammers, Pralle, and Wellnitz (2021) reported that dietary hazelnut by-product can alter pork rib fat composition by increasing C18:1 *c*9 and reducing C16:0. In the present study, we have observed that C20:3 ω-3 (eicosatrienoic acid, ETA) and EPA were greater, and C22:5 ω-3 (DHA) tended to be greater in the salami of CTRL group. These three fatty acids derive from linolenic acid (C18:3 *c*9*c*12*c*15) through the activity of the elongase and desaturase enzymes in tissues (Wood et al., 2008). Other authors observed that feeding pig with a source of linolenic acid increased the concentration of longer-chain ω-3 PUFA in pork (Enser, Richardson, Wood, Gill, & Sheard, 2000; Scerra et al., 2022) as pigs are monogastric and homolipoid. In our experimental conditions, a reduced intake of C18:3 *c*9*c*12*c*15, due to the lower content of this fatty acid in the hazelnut skin included in the diet of HZL group could have reduced the substrate available to produce EPA, ETA, and DHA. Despite the differences between mono- and polygastrics in lipid metabolism, a similar result was observed by Priolo et al. (2021) even in lambs fed a concentrate containing 15% hazelnut skin. A previous paper comparing pork quality from Montanera, Recebo, or intensive production system showed that animals from Montanera had a higher proportions of C18:1 n-9, total MUFA, and PUFA n-3, reflecting the fatty acid profile of the dietary acorn and grass (Tejerina, García-Torres, Cabeza de Vaca, Vázquez, & Cava, 2012). Hazelnut skin is rich in oleic acid, therefore an increased percentage of this fatty acid in HZL salami could have been predictable. Nevertheless, C18:1 *c*9 did not differ between salami obtained from the two feeding groups. However, it should be considered that, whatever the diet, C18:1 *c*9 increases in the intramuscular and in the subcutaneous fat along with age and fatness (Wood et al., 2008), which could have partially masked the effect of the feeding treatment. Similar to our results, Szyndler-Nędza, Świątkiewicz, Migdał, and Migdał (2021) found comparable concentration of oleic acid in meat from pigs finished on acorns (rich in oleic acid) and a control diet, explaining that the low incorporation level of acorn in the diet could have played a role on this finding. Even in our conditions, the inclusion level of HS in the HZL diet could have played a role. Regarding recipe, processing meat by adding nitrites and nitrates salts or OMWPE did not altered the fatty acid composition of the salami.

4.2. Lipid oxidation of salami

Due to post-mortem modifications and meat processing, the initial compartmentalization of the intact muscle is progressively loss. As a result, various reactants may come into contact leading to the formation of non-physiological reactions. A typical example is given by heme iron that at relative low pH and low pressure of oxygen act as a catalyst

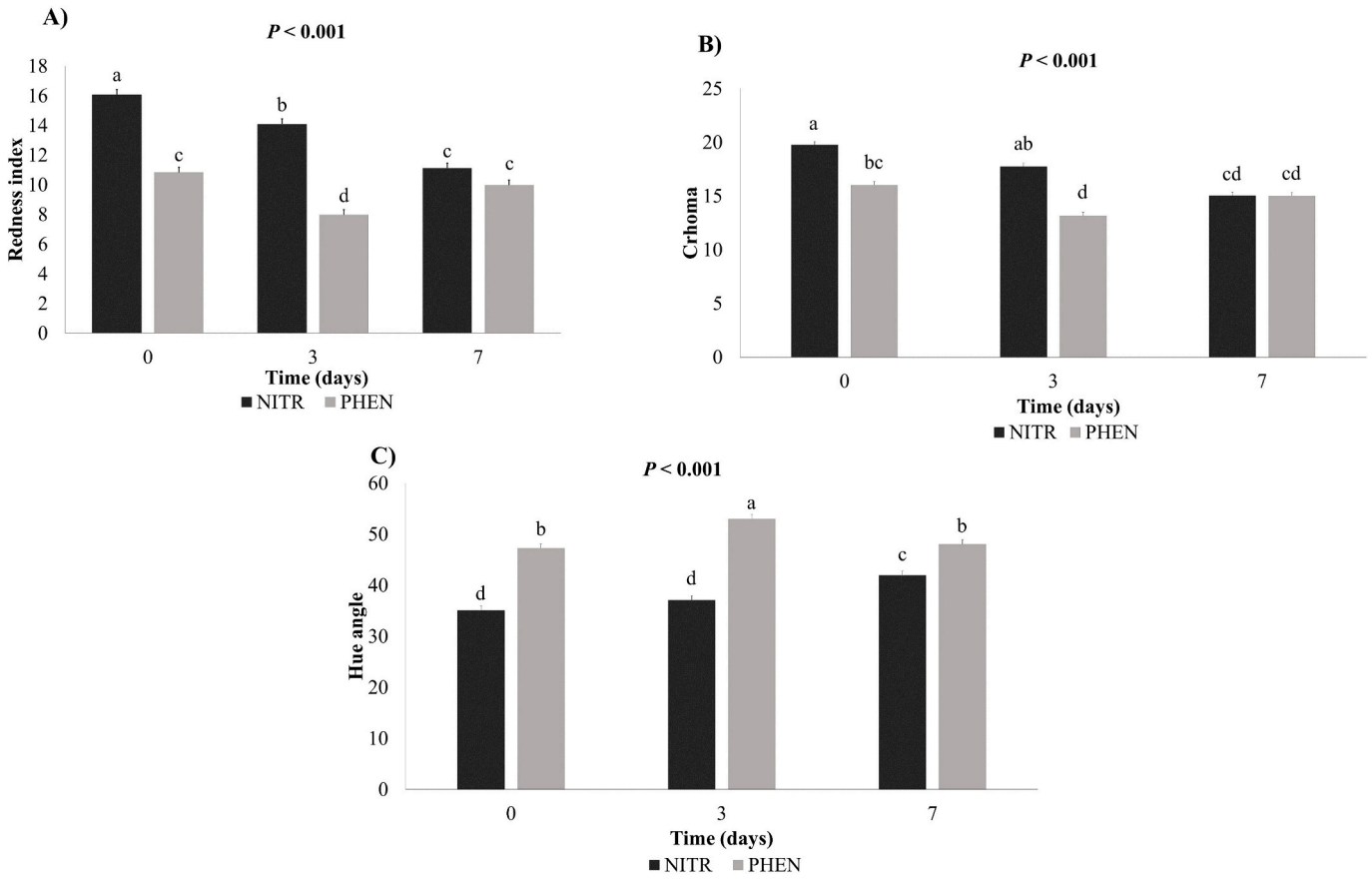

Fig. 1. Interactive effect of the salami recipe (NITR: salami was added with 0.15 g/kg of nitrites and nitrates salts; PHEN: salami was added with 0.8 g/kg of olive-milling wastewaters phenolic extract) and time of refrigerated storage (days 0, 3 and 7 days) on salami redness index (A) chroma (B) and hue angle (C). Values presented as the calculated averages and standard error bars. [a,b,c,d] Different letters indicate differences ($P \leq 0.05$) between mean values tested by Tukey's Test.

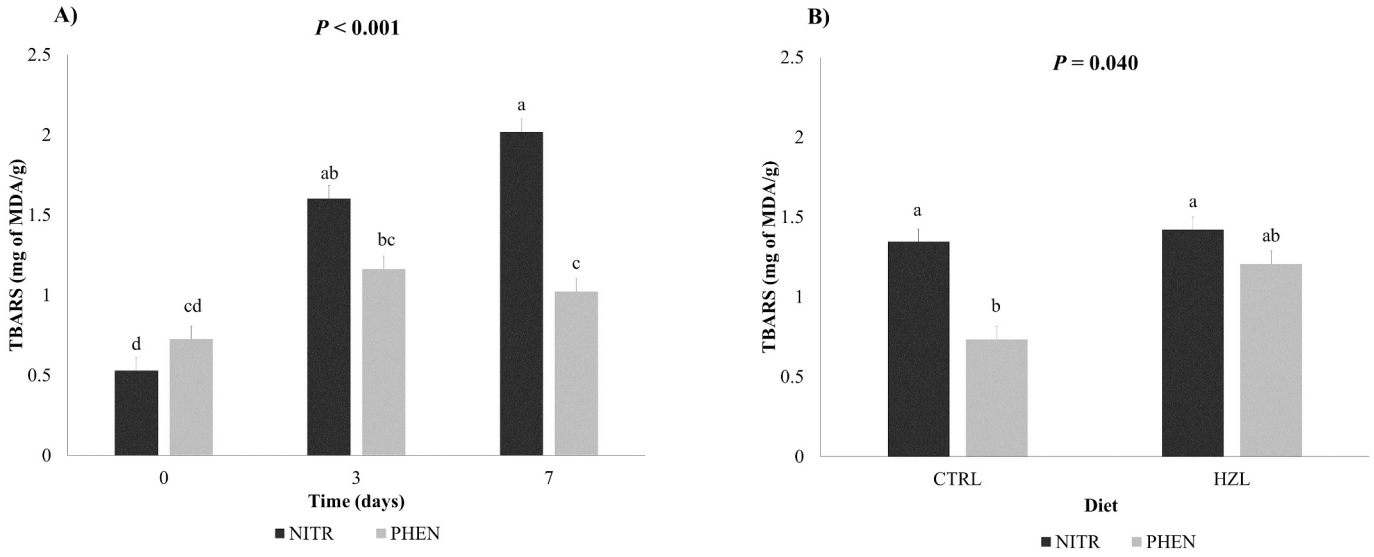

Fig. 2. Interactive effect of A) the salami recipe (NITR: salami was added with 0.15 g/kg of nitrites and nitrates salts; PHEN: salami was added with 0.8 g/kg of olive-milling wastewaters phenolic extract) and time of refrigerated storage (days 0, 3 and 7 days), and B) the salami recipe and the diet offered to the pigs (CTRL: control diet; HZL: diet containing 11% of hazelnut skin) on lipid oxidation. Values presented as the calculated averages and standard error bars. [a,b,c] Different letters indicate differences ($P \leq 0.05$) between mean values tested by Tukey's Test.

(Baron & Andersen, 2002). Under such circumstances, oxidation of unsaturated lipid can be initiated, generating hydroperoxides as primary products, which can undergo further oxidative modifications, ultimately culminating in the formation of malonaldehyde (Carlsen et al., 2005). In the present study, results of the TBARS assay seem to suggest a greater effectiveness of the phenolic extract over nitrogen salts in preventing

Table 5
Effect of animal diet and tasting type on the perception of the sensorial parameters of salami.

	Dietary treatment[1] (D)		Tasting type [2] (R)		SEM[3]	*P*-value[4]		
	CTRL	HZL	Blind	Informed		D	R	D × R
Color	7.02	7.01	6.98	7.05	0.077	0.578	0.992	0.138
Aroma	6.78	6.84	6.72	6.90	0.086	0.277	0.839	0.116
Taste	6.88	6.95	6.85	6.99	0.085	0.287	0.620	0.022
Texture	6.88	6.86	6.85	6.88	0.081	0.782	0.967	0.231
Overall like	7.09	7.14	7.15	7.08	0.079	0.569	0.714	0.040

[1] Treatments were: control diet (CTRL); diet containing 11% of hazelnut skin (HZL).
[2] Salami tasting was performed before (blind) and after (informed) receiving information on the dietary treatment received by the animals.
[3] Standard error of mean.
[4] *P*-value of the effect of the dietary treatment.

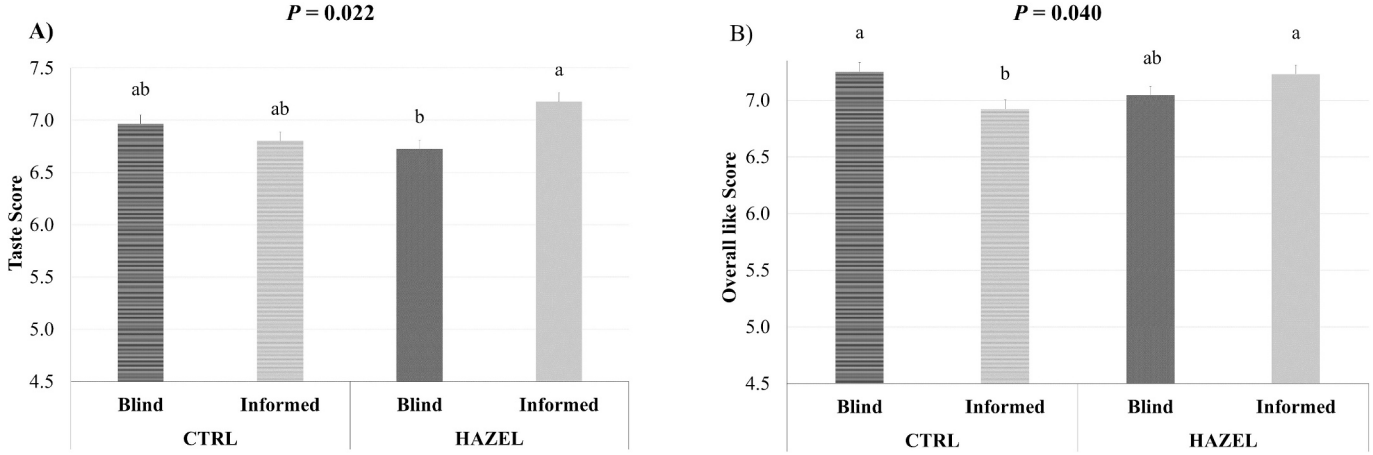

Fig. 3. Interactive effect of animal diet (CTRL: control diet; HZL: diet containing 11% of hazelnut skin) and tasting type [tasting was performed before (Blind) and after (Informed) receiving information on the recipe used for salami production] on the consumers perception of Taste (A) and Overall like (B) of salami. Values presented as the calculated averages and standard error bars. [a,b,c] Different letters indicate differences ($P \leq 0.05$) between mean values tested by Tukey's Test.

lipid oxidation. Indeed, despite the similar content of HP-PUFA and peroxidability index between NITR and PHEN salami, monitoring salami lipid oxidation during refrigerated storage revealed that TBARS increased from 0 to 3 and 7 days of storage only in NITR salami. Different mechanisms may have contributed to this result. The phenolic compounds contained in the OMWPE are known to exert modulatory activity towards microbial metabolism (Yakhlef et al., 2018), which may have partially inhibited the enzymatic lipases of the microbial starters, thus reducing the availability of free fatty acids for degradation processes. Though, in the ruminal environment, a similar lipases inhibition was observed by Cappucci et al. (2018). In addition, polyphenols and vitamin E, typical of the olive plant, show remarkable antioxidant properties (Servili et al., 2013) that could have lowered the development of free radicals in PHEN salami during maturation. Consistently with these hypotheses, Hayes et al. (2009) observed a reduction in lipid oxidation in beef and pork following the addition of olive phenolic extracts, and Balzan et al. (2017) reported a reduction in the concentration of peroxides in fresh and cooked pork sausages treated with polyphenols recovered from the olive wastewaters. Animal diet did not affect TBARS concentration, however, an interaction between diet and recipe was observed. Specifically, NITR salamis obtained from animals fed the CTRL diet had higher levels of oxidation than PHEN salami obtained from the same animals. In opposition, salami obtained from animals fed the HZL diet had comparable levels of lipid oxidation regardless of the use of nitrites and nitrates salts or phenolic extract. This could be partially due to the greater concentration of antioxidants in the hazelnut skin fed to the HZL group. Besides vitamin E, HS is a source of phenolic compounds, mainly tannins, (Özdemir et al., 2014), which were respectively 5 and 12 times greater in the experimental diet than in the CTRL one. An extensive literature available on the effect of dietary administration of a source of these bioactive compounds on meat quality indicates that they can be effective to lower oxidative damage in meat and meat products by different mechanisms reviewed by Wu et al. (2022). Echegaray et al. (2021) explained the lower lipid oxidation observed in the *Longissimus thoracis et lumborum* muscle in Celta pigs finished on a chestnut-containing diet by the high content of dietary tannins. Similarly, Menci et al. (2024), observed lower TBARS concentration and slower TBARS development during refrigerated storage in pork from animals fed a concentrated tannin extract from *Tara spinosa* than a control diet. Similarly, a reduced oxidative damage was observed in pork and salami when a source of non-tannins phenols was provided to heavy-pigs (Scerra et al. (2022).

4.3. Colorimetric indices of salami

Meat and meat products color is a key factor during the consumers purchasing processes (Mancini & Hunt, 2005). Myoglobin is a sarcoplasmic heme protein and its content and the redox status of the heme-Fe are determinant for meat color. Although the evolution of myoglobin is species- and muscle- specific, a few major isomers of myoglobin have been identified as responsible for the meat color development. Deoxymioglobin (Fe^{2+}) is encountered in oxygen deficiency and is associated with a purplish color. When exposed to oxygen, deoxymioglobin can evolve into oxymyoglobin (Fe^{2+}, cherry-red color) and then be oxidated into metmyoglobin (Fe^{3+}), resulting in meat discoloration (Mancini & Hunt, 2005; Suman & Joseph, 2013). However, many strategies can contribute to stabilizing the color of meat and meat products. Previous studies evaluating the potential of supplying pigs with feeds or dietary additives rich in bioactive compounds to improve product color and color stability during storage report controversial results. Sirtori,

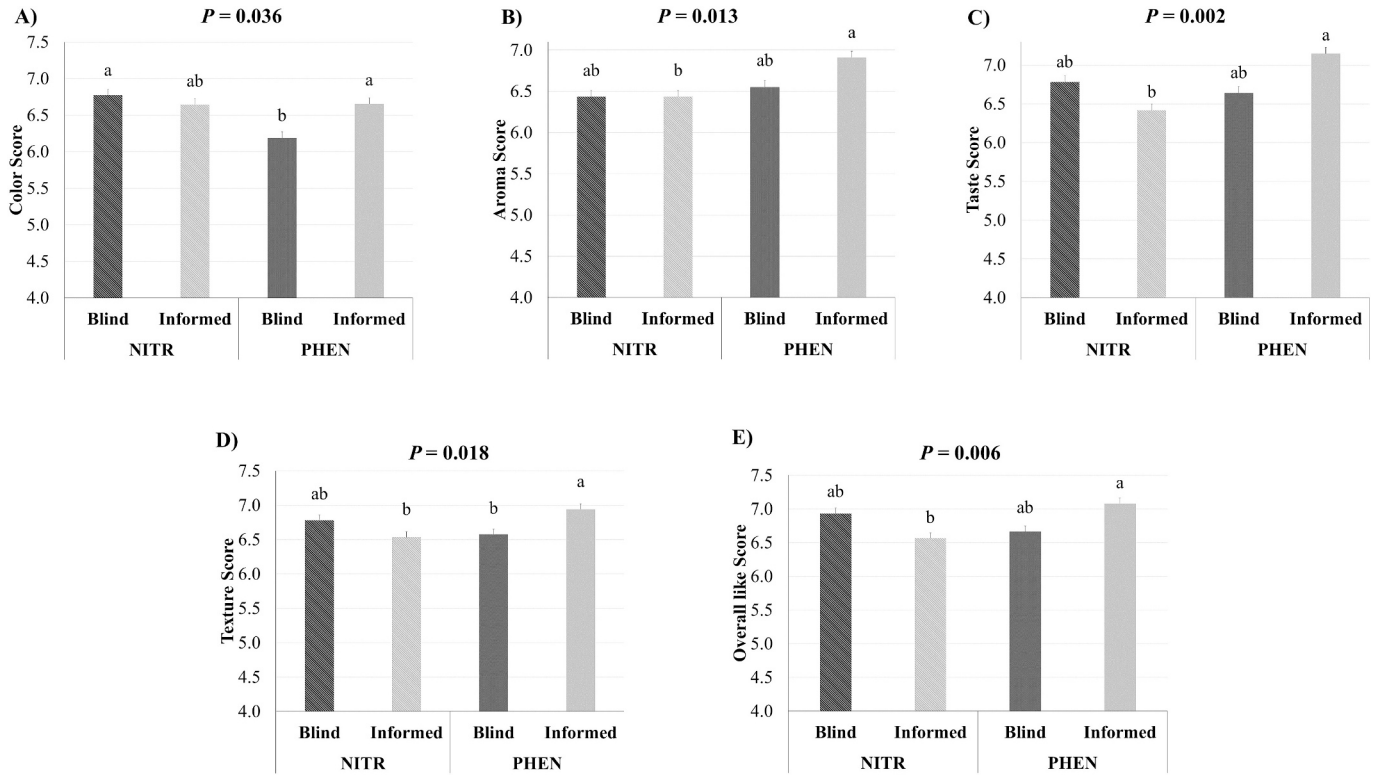

Fig. 4. Interactive effect of the salami recipe (NITR: salami was added with 0.15 g/kg of nitrites and nitrates salts; PHEN: salami was added with 0.8 g/kg of olive-milling wastewaters phenolic extract) and tasting type [tasting was performed before (Blind) and after (Informed) receiving information on the recipe used for salami production] on the consumers perception of Color (A), Aroma (B), Taste (C), Texture (D), and Overall like (E) of salami. Values presented as the calculated averages and standard error bars. [a,b,c] Different letters indicate differences ($P \leq 0.05$) between mean values tested by Tukey's Test.

Pugliese, Parenti, D'Adorante, and Franci (2012) evaluated the effect of fattening pigs for 1 or 3 months with chestnuts and both experimental diets resulted in meat with higher values of L^*, a^*. and b^* than the control diet. Similarly, Tejerina et al. (2012) found improved color in meat from pig finished on grass and acorns than pig raised on conventional system. Conversely, other authors found no effect on meat color parameters in animals supplemented with chestnut, olive leaves, or tannin extract (Echegaray, Domínguez, Franco, Lorenzo, & Carballo, 2018; Menci et al., 2024; Paiva-Martins, Barbosa, Pinheiro, Mourão, & Outor-Monteiro, 2009). In our experimental conditions, the dietary treatment showed no effect on colorimetric parameters. As hypothesized for the fatty acid profile, the weaker-than-expectable effect could lie in the inclusion level of HS in the HZL diet. Moreover, as observed by O'Grady, Carpenter, Lynch, O'Brien, and Kerry (2008), the effects on pork color can differ based on the source and type of phenolic compound.

Unlike what was observed for lipid oxidation, OMWPE was not able to prevent color degradation compared to nitrites and nitrates salts as indicated by the worse redness and hue angle (h*, which is related to browning) recorded for PHEN salami. Also, the color evolution during refrigerated storage confirmed the known ability of nitrites and nitrates salts in stabilizing and improving the color of salami (Ferysiuk & Wójciak, 2020) and indicated better performance than OMWPE. Indeed, over time, a^* was higher for NITR salami, except on the last day of refrigerated storage. In addition, within PHEN salami, a^* value at day 0 was similar to that recorded at day 3 and 7 of refrigerated storage. Similarly, h* was always lower in NITR salami than PHEN salami. Moreover, while for PHEN salami the browning was already significantly higher after 3 days of refrigerated storage, in NITR salami it was detectable only after 7 day storage.

The role of nitrites and nitrates on the color of cured meats is widely known: they can preserve the bright red color by stabilizing the oxidative state of the iron contained in the heme group of myoglobin (Ferysiuk & Wójciak, 2020). Thus, the lower redness value reported for PHEN in comparison with NITR salami was likely due to the inability to form the nitroso-myoglobin complex responsible for the bright red stability in salami. Our findings seem to contrast with Barbieri et al. (2021), where a phenolic extract from olive by-product was used for beef burger preparation. However, it should be highlighted that in that study the olive-phenols-treated product was compared to an untreated one. Indeed, as observed by Difonzo, Totaro, Caponio, Pasqualone, and Summo (2022), the addition of increasing doses of olive leaf phenolic extract to seasoned sausages was ineffective in improving color parameters in comparison with the use of nitrites and nitrates salts.

4.4. Antioxidant capacity of salami

In this study, salami antioxidant capacity was assessed by measuring its radical scavenging activity and reducing power (TEAC and FRAP essay, respectively). Our findings indicate that salami antioxidant capacity was not affected by the experimental factors. Regarding diet, as HS has not been previously tested in pigs, a comparison can be done only with other dietary source of phenolic compounds or antioxidants. Tejerina et al. (2012) observed that the grater content in phenolic compounds of the diet for finishing pigs (due to acorn administration) resulted in a greater antioxidant capacity of the meat as compared to meat from conventionally fed pigs. Opposite, Echegaray et al. (2021) despite the observed a lower radical scavenging activity and reducing power in meat from pork fed chestnut than a conventional feed greater antioxidant capacity of dietary chestnut. These contrasting results indicate that phenolic compounds intake seems not the only factor affecting the antioxidant capacity of animal products. In our study, the lack of dietary effect, despite the higher phenolic compounds content in HZL feed, could be partially explained by the HS percentage of inclusion.

Moreover, Surai (2014) reviewed that the accumulation of phenolic compounds in meat cannot be straightforwardly related to their dietary content. Regarding the additives used during meat processing, no differences were observed between NITR and PHEN salami. This could be related with the presence of substances with antioxidant capacity in both NITR salami (added with E250 and E252) and PHEN salami (added with OMWPE). In fact, the reducing capacity of polyphenols found in olive derivatives is well documented and is related to the number and the position of the hydroxyl groups of the aromatic ring binding site (Servili et al., 2013). Rather, the antioxidant capacity of nitrogen additives is mainly related to the ability of nitrite to bind heme and non-heme iron (Karwowska, Kononiuk, & Wójciak, 2019).

4.5. Consumer acceptability of salami

The consumer test did not highlighted difference between CTRL and HZL salami in both blind and informed conditions, except for the taste descriptor that improved for HZL during informed tasting. This indicates that feeding pigs with hazelnut skin does not compromise salami appreciation by the consumers but has the potential to positively affect its perception. Conversely, the recipe affected the evaluation of salami descriptors: once again, NITR salami showed better color performance than PHEN salami. This is consistent with what was obtained from colorimetric analysis and reiterating the effectiveness of nitrites and nitrates on improving the color of processed pork. Interestingly, despite the color difference, which is one of the most important factors that drives purchasing choices, the consumers indicated a similar value for the general satisfaction parameters. Moreover, the salami produced with addition of phenolic extract was more appreciated by the consumers during the informed test. Indeed, color seemed to lose importance compared to the better perception of aroma, taste, and overall-liking. This improved appreciation after receiving information on salami recipe could stem from a better perception of nitrites- and nitrates-free products and the good image of natural phenols perceived by the consumer (Hung, de Kok, & Verbeke, 2016), especially when derived from valuable food chain such as olive oil production. A similar result was observed by Bolletta et al. (2022) when a consumer test was performed on cheese obtained with milk from sheep fed a traditional diet or a diet integrated with olive leaves. This hypotheses seem further confirmed by the greater expectation in terms of overall liking that consumers had towards the experimental salami in comparison with the traditional one.

5. Conclusions

The results presented in this study suggest that hazelnut skin can be included in the diet of finishing pigs without adverse effects on salami quality traits. Regarding the use of a phenolic extract obtained from olive mill wastewaters as an alternative to nitrogenous compounds for salami production, our results seem to indicate that it acts on different targets molecules than nitrites and nitrates. Specifically, the addition of the phenolic extract was effective in protecting lipid from degradation, while the nitrogen salts better exerted their action as a color stabilizer. Except for the color, the consumers did not highlighted differences in the taste and in the appearance of the salami. This indicates that the strategies proposed in this study could be a viable approach to reduce the use of synthetic additives in pork processing. Finally, as suggested by the improved perception of the experimental salami during the informed taste, the use of bioactive compounds may be particularly attractive and competitive to move towards a clean label in the market.

Considering the weaker-than-expected effect of dietary hazelnut skin on salami quality and the high fiber content as a limiting factor for its utilization in pigs diet, it would be worthwhile exploring the potential incorporation of an extract obtained from this by-product as a novel ingredient for pig feed. The content of bioactive compounds of an HS extract could allow for an enhancement of the impact on animal metabolism and product quality. Additionally, given the distinct target molecules observed for the phenolic extract and nitrogen salts, the potential combined effect of these two additive could be explored.

CRediT authorship contribution statement

Viviana Bolletta: Investigation, Formal analysis, Visualization, Writing – original draft. **Ruggero Menci:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Bernardo Valenti:** Conceptualization, Methodology, Investigation, Formal analysis, Project administration, Writing – review & editing. **Luciano Morbidini:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision. **Maurizio Servili:** Validation. **Agnese Taticchi:** Investigation. **Emanuele Lilli:** Investigation. **Mariano Pauselli:** Conceptualization, Supervision, Methodology, Writing – review & editing.

Declaration of competing interest

Authors declare no conflict of interest.

Data availability

Data will be made available on request.

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