Effects of hazelnut skin addition on the cooking, antioxidant and sensory properties of chicken burgers

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Abstract The aim was to evaluate the effects of hazelnut skin (HS) addition on the oxidation and sensorial properties of chicken burgers during storage and after cooking. Burgers were prepared and divided in five groups: [C] control without HS addition, [CAA] control with ascorbic acid, and [HS1] 1%, [HS2] 2% and [HS3] 3% HS addition. Burgers for each batch were prepared in triplicate and analysed raw and cooked after 1 and 4 days of refrigerated storage (4 ± 1 °C), respectively. Lipid oxidation was assessed by monitoring malonaldehyde formation with a 2-thiobarbituric acid reactive substances assay, and antioxidant capacity was assessed with 2,2-diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) methods. A sensory evaluation was performed by twenty experienced panellists, and the attributes that were measured were: colour, greasiness, flavour, odour, juiciness, granulosity, chewiness and overall acceptability. Lipid oxidation values were higher in the HS burgers than in the C and CAA burgers, except for the cooked burgers at day 4. HS addition had a significant effect with a decrease in diameter and an increase in fat retention. In all treatments, FRAP was lower in the C and HS groups than in the CAA group, except for cooked

burgers at day 4, where the values of the HS2, HS3 and CAA groups were similar. The DPPH assay showed higher values on both days for the raw and cooked burgers treated with CAA or HS compared to the control group. HS addition influenced only meat colour among the sensorial parameters that were considered.

Keywords Antioxidant · *Corylus avellana* · Nuts · Meat · Lipid oxidation · Poultry

Introduction

Poultry meat is one of the most widely consumed meats, and it is second only to pork in Europe and the United States. The OECD/FAO estimates that it will become the most popular meat by 2023 (OECD/FAO 2015). Its growth in popularity is linked to the relatively low and competitive prices compared to other meat products, and its production is expected to rise in countries where eating poultry meat is culturally preferable (Magdelaine et al. 2008). Moreover, in recent years, the poultry meat industry has had advances in preservation techniques for fresh poultry products in addition to expanding the variety of processed foods that meet modern consumer preferences for ready-to-eat or ready-to-cook meat products (Hui and Guerrero-Legarreta 2010). However, ground meats for processed products are much more susceptible to lipid peroxidation than unprocessed ones since they are more exposed to oxidation. To mitigate this undesirable effect, meat processing strategies that incorporate natural antioxidants and/or mixed or purified natural antioxidants into the meat have been developed (Kumar et al. 2015).

Among natural antioxidants, those extracted from agro-food industry by-products have been tested as food

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additives to improve meat product quality and safety along with interesting results from economical and human health perspectives (Peiretti and Gai 2015). Plant antioxidant sources from tree nuts, and their by-products in particular, have demonstrated a strong antioxidant capacity due to their phenolic compound content with potential bioactivity (Shahidi et al. 2007). Among edible tree nuts, the hazelnut (*Corylus avellana* L.) is one of the most popular tree nuts consumed worldwide (FAOSTAT 2012). It is used by the food industry as an ingredient for processed foods and generates a considerable amount of by-products during processing that are a rich source of polyphenolic components, including phenolic acids and flavanols (Jakopic et al. 2011), flavan-3-ols, and condensed tannins (proanthocyanidins) (Alasalvar et al. 2006). Among them, hazelnut skin (HS) has been investigated for its composition in an attempt to add economic value to this by-product. Del Rio et al. (2011) found that the total antioxidant capacity of the HS samples was approximately three times higher than the antioxidant capacity of whole walnuts and was 25 times higher compared to blackberry antioxidants for the main polyphenolic subclass identified as monomeric and oligomeric flavan-3-ols, which could be responsible for the potential health effects of this hazelnut by-product.

The antioxidant potential of HS (Agourram et al. 2013) as well as its cholesterol-lowering effect (Caimari et al. 2015) has attracted the interest of food scientists. HS itself or its phenolic extracts have been added to a wide variety of foods, such as bread (Anil 2007) and coffee (Contini et al. 2012) to investigate its effects on final products as a source of dietary fibre and a potential source of antioxidants, respectively. Additionally, the use of HS in food with animal origins has been tested with the supplementation of HS from different varieties of roasted hazelnuts in yogurt to increase dietary fibre and polyphenol content (Bertolino et al. 2015). The study found that the highest values of dietary fibre, total polyphenol content, and antioxidant capacity were recorded for products supplemented with HS at a content of 6%, although the consumer preference at this percentage was low.

To the best of our knowledge, no studies to date have been carried out on the use of HS in poultry meat and meat products. The one study on beef burgers (Turhan et al. 2005) described the use of hazelnut pellicle as a dietary fibre in the production of low-fat beef burgers and showed that its addition was effective for improving cooking properties, such as a reduction in the cooking yield and beef burger diameter and thickness. No study has been carried out to test the antioxidant properties of HS added to chicken burgers; therefore, the aim of this study was to evaluate the shelf-life, qualitative, antioxidant, and sensory properties of raw and cooked chicken burgers with

different concentrations of HS to improve the quality of ready-to-cook poultry products.

Materials and methods

Plant material and proximate analyses

Raw HS was obtained from Nocciolo Marchisio S.p.A. (Cortemilia, CN, Italy) and prepared by grinding the HS in a Cyclotec mill (Tecator, Herndon, VA, USA). HS was analysed for dry matter, crude protein, ether extract, crude fibre, and ash by ignition to 550 °C according to AOAC procedures (AOAC 2000), while gross energy was determined using an adiabatic bomb calorimeter (C7000, IKA, Staufen, Germany). The proximate composition of HS is reported in Table 1.

Extraction of phenolic compounds from HS

Phenolic compounds were extracted from HS defatted with hexane using 80% (v/v) methanol according to the methods of Karamać et al. (2015). Conditions of extraction: 15 min at 75 °C in a 1:10 (w/v) ratio of solid material to solvent. Extraction was performed in triplicate, and the extract was filtered after each step. The filtrates were combined, and methanol was evaporated under vacuum using a rotary evaporator (Büchi, Flawil, Switzerland). The remaining aqueous solution was freeze-dried.

Total phenolic content and antioxidant activity of HS

The total phenolic content (TPC) of the HS methanolic extract was determined using a colorimetric method with Folin and Ciocalteu's phenol (FCP) reagent, as described elsewhere (Amarowicz et al. 1996). TPC is expressed as mg catechin equivalents/g of extract. The antioxidant activity of the HS extract was investigated using 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) (Re et al. 1999), ferric-reducing antioxidant power (FRAP) (Benzie and Strain 1990), and 2,2-diphenyl-1-picrylhydrazyl (DPPH) (Amarowicz et al. 2008) assays. The results are expressed as mmol Trolox equivalent/g (ABTS assay), mmol Fe²⁺/g (FRAP), and EC₅₀ (DPPH), respectively.

Chicken burger preparation

The following ingredients were used to prepare the chicken burgers: breast meat 75%, pork back fat 25%, ice 8%, and NaCl 1% (% of non-meat components are related to 100% meat). Burgers were prepared using the procedure described by Longato et al. (2017). Five batches were divided

Table 1 Proximate composition (g/kg dry matter), yield and antioxidant characteristics of hazelnut skins (mean $\pm$ SD; $n = 3$)

Proximate composition	Content
Dry matter (g/kg fresh matter)	953.96 $\pm$ 0.54
Ash	25.55 $\pm$ 0.27
Crude protein	73.69 $\pm$ 0.44
Ether extract	292.16 $\pm$ 0.19
Crude fiber	242.38 $\pm$ 2.14
Gross energy (MJ/kg dry matter)	24.00 $\pm$ 0.06
Yield (mg/g dry matter)	319.60 $\pm$ 24.58
Total phenolic contents (mg catechin/g extract)	52.61 $\pm$ 3.22
Trolox equivalent antioxidant capacity (mmol Trolox/g extract)	6.69 $\pm$ 0.15
Ferric-reducing antioxidant power (mmol Fe ²⁺ /g extract)	9.78 $\pm$ 0.50
Inhibitory concentration IC ₅₀ (mg/ml)	2.10 $\pm$ 0.07

from the same meat batter as follows: control without any addition [C]; control with 0.3% ascorbic acid [CAA]; 1% HS powder added [HS1]; 2% HS powder added [HS2]; and 3% HS powder added [HS3]. Burgers for each batch were prepared in triplicate and treated according to the methods of Longato et al. (2017).

Cooking and sampling

Burgers were cooked according to the specifications reported by Longato et al. (2017) in a convection oven at 150 ± 2 °C. After refrigerated storage (4 ± 1 °C) periods of 1 and 4 days, the burgers were analysed raw and after cooking.

pH and meat colour

The pH of the burger samples was measured using a pH/Ion 510 pH meter (Eutech Instruments Pte Ltd., Singapore) equipped with a LE427 puncture electrode. Colour was evaluated using a spectrophotometer (CM-2600D, Minolta Camera Co., Osaka, Japan) with illuminant D₆₅ with a 2° observer, Diffuse/O mode, and 8-mm aperture for illumination and 8-mm for measurement. Colour was described by coordinates: lightness (L*), redness (a*), and yellowness (b*). Nine replicate measurements (3×3) were taken for each sample according to the American Meat Science Association (1995) guidelines for colour measurement.

Cooking properties

From each batch, five burgers were cooked as reported in the cooking and sampling paragraph. Burger weight, thickness, and diameter were measured at room temperature before and after cooking. Cooking characteristics were calculated according to Longato et al. (2017). Moisture content was determined according to the AOAC method (AOAC 2000).

Lipid oxidation measurement

Lipid oxidation was assessed by the 2-thiobarbituric acid (TBA) method used in Buege and Aust (1978). Thiobarbituric acid reactive substances (TBARS) values were calculated from a standard curve of malondialdehyde (MDA) and expressed as mg MDA/kg sample.

Antioxidant capacity

To obtain the extracts for sample preparation, 1 g of burger meat was placed in a capped centrifuge tube, and 30 mL of methanol was added, after which the mixture was homogenized at 18,000 rpm for 3 min in an Ultra-Turrax (IKA, T25D, Staufen, Germany). Successive steps for the sample preparation were performed according to the methods of Longato et al. (2017).

The extracts obtained after 1 and 4 days of storage were used to determine the antioxidant properties according to two methods, which were the stable radical DPPH (Brand-Williams et al. 1995) and the potassium ferricyanide-ferric chloride methods (Oyaizu 1986). DPPH results were expressed as μ g Trolox equivalent/g sample, while the reducing power was reported in mg Trolox equivalent/g sample.

Sensory evaluation

Twenty experienced panellists carried out the sensory evaluation test according to protocols described in a previous study (Longato et al. 2017) and approved by the ECCR Ethics Committee (Vega Baja Hospital, Orihuela, Alicante).

Five burgers from each batch were cooked as previously described and were kept warm in an oven until testing within 3–8 min. Rectangular pieces approximately 1.5×2 cm were cut from the centre of burgers and served at room temperature (ASTM 1988). Each panellist

evaluated three replicates of all burger samples, and the presentation order was randomized for each panellist. Tap water was provided between samples to cleanse the palate. The selected attributes and their descriptors were chosen according to the method of Longato et al. (2017). At the end of the sensorial analysis performed on cooked burgers at day 1, the overall acceptability score was reported on a scale from 1 to 10 by the panellists.

Statistical analysis

The statistical analyses were performed using SPSS statistical software (SPSS Statistics, Ver. 17.0). All parameters were analysed by one-way analysis of variance (ANOVA) followed by Tukey's test as a post hoc procedure. A spider plot was created to provide a graphic representation of the cooked chicken burger sensory descriptors. The fixed factor was the treatment. Significant differences were considered at the $P < 0.05$ level.

Results and discussion

Antioxidant activity of HS

Since HS can be considered an inexpensive source of natural antioxidants, different assays were used to measure the antioxidant efficacies of crude HS extract (Table 1). HS showed a good extraction yield with a TPC of 52.6 mg catechin equivalents/g extract, an antioxidant activity of 6.7 mM Trolox equivalents/g extract, and 9.8 mM Fe^{2+} /g extract; the EC_{50} was 2.1 mg/mL.

Bertolino et al. (2015) reported a TPC content of 153–196 μg gallic acid equivalents/g dry matter and a free radical scavenging activity for HS extract that ranged from 0.854 to 1.005 mM Trolox equivalents/g dry matter in three different varieties of hazelnut. They concluded that their results could not be compared to the results of other studies because of the different data expression methods and different extraction methods.

Colour changes

Colour parameters of the raw and cooked burgers measured at day 1 are reported in Table 2. A significant decrease ($P < 0.05$) in lightness and an increase ($P < 0.05$) in redness in both raw and cooked burgers with HS were observed compared to the control and CAA burgers. The yellowness had an increase and a decrease ($P < 0.05$) in raw and cooked burgers with HS, respectively, compared to the other groups. Sánchez-Zapata et al. (2010) found that the addition of more than 5% tiger nut fibre in pork burger formulations resulted in brighter samples with higher

Table 2 Colour parameters of raw and cooked chicken burgers containing ascorbic acid (CAA) and hazelnut skins (HS1—1%, HS2—2%, HS3—3%; mean $\pm$ SD; $n = 3$)

Parameter	Raw	Cooked
L*		
Control	53.83 $\pm$ 4.48 ^a	64.98 $\pm$ 2.55 ^a
CAA	51.95 $\pm$ 3.24 ^a	66.00 $\pm$ 2.90 ^a
HS1	44.52 $\pm$ 2.41 ^b	53.78 $\pm$ 3.31 ^b
HS2	45.74 $\pm$ 6.13 ^b	47.46 $\pm$ 5.42 ^c
HS3	41.30 $\pm$ 6.32 ^b	47.21 $\pm$ 4.66 ^c
a*		
Control	0.30 $\pm$ 0.69 ^b	1.64 $\pm$ 0.55 ^c
CAA	1.31 $\pm$ 0.22 ^b	1.55 $\pm$ 0.73 ^c
HS1	4.78 $\pm$ 0.72 ^a	2.87 $\pm$ 0.51 ^b
HS2	4.76 $\pm$ 1.05 ^a	3.82 $\pm$ 0.85 ^a
HS3	5.46 $\pm$ 1.96 ^a	3.87 $\pm$ 0.97 ^a
b*		
Control	9.12 $\pm$ 1.80 ^c	15.48 $\pm$ 1.15 ^a
CAA	10.12 $\pm$ 0.75 ^{bc}	16.78 $\pm$ 1.71 ^a
HS1	12.56 $\pm$ 1.00 ^a	12.79 $\pm$ 0.91 ^b
HS2	12.02 $\pm$ 1.05 ^a	12.15 $\pm$ 2.49 ^b
HS3	11.11 $\pm$ 2.15 ^{ab}	11.81 $\pm$ 1.06 ^b

Means in columns (a–c) not sharing the same letter are significantly different ($P < 0.05$)

lightness values than the control and 5% tiger nut fibre formulations. They concluded that increasing fibre content resulted in decreased redness and increased yellowness due to the higher amounts of yellow components from the tiger nuts that remained in the by-products. An earlier study (Aleson-Carbonell et al. 2005) reported some differences in lightness, yellowness, and redness in beef burgers with added lemon albedo, which is an ingredient that also has a large number of yellow components.

pH changes

The changes in pH values during storage (raw and cooked burgers) are given in Table 3. No significant differences were noted in the pH of the raw and cooked burgers at day 1. At day 4, the pH of the burgers with added extracts (HS1 and HS2) was constant and higher ($P < 0.05$) than the control burgers (raw and cooked). The pH of the raw and cooked burgers was increased during storage (from 1 to 4 days).

Longato et al. (2017) showed that the pH values of burgers with added amaranth or pumpkin seeds were lower compared to raw control samples at day 1, and there were no significant differences between the amount of ingredient added and concentration (1 or 2%). They described a buffer

Table 3 pH and thiobarbituric acid reactive substances (TBA) values of raw and cooked chicken burgers containing ascorbic acid (CAA) and hazelnut skins (HS1—1%, HS2—2%, HS3—3%) during 1 and 4 days of refrigerated storage (mean $\pm$ SD; n = 3)

Parameter	Raw		Cooked	
	Day 1	Day 4	Day 1	Day 4
pH				
Control	5.79 $\pm$ 0.01 ^{aD}	5.90 $\pm$ 0.01 ^{cC}	5.98 $\pm$ 0.01 ^{aB}	6.19 $\pm$ 0.03 ^{cA}
CAA	5.80 $\pm$ 0.04 ^{aC}	5.92 $\pm$ 0.02 ^{bcB}	5.98 $\pm$ 0.01 ^{aB}	6.34 $\pm$ 0.03 ^{aA}
HS1	5.80 $\pm$ 0.02 ^{aC}	6.00 $\pm$ 0.02 ^{aB}	6.00 $\pm$ 0.01 ^{aB}	6.30 $\pm$ 0.02 ^{abA}
HS2	5.77 $\pm$ 0.02 ^{aC}	5.97 $\pm$ 0.01 ^{abB}	6.00 $\pm$ 0.02 ^{aB}	6.29 $\pm$ 0.02 ^{abA}
HS3	5.76 $\pm$ 0.04 ^{aC}	5.96 $\pm$ 0.01 ^{abB}	5.97 $\pm$ 0.00 ^{aB}	6.26 $\pm$ 0.02 ^{bcA}
TBA (mg MDA/kg)				
Control	0.07 $\pm$ 0.02 ^{dB}	0.17 $\pm$ 0.14 ^{bB}	0.22 $\pm$ 0.07 ^{dAB}	0.44 $\pm$ 0.04 ^{abA}
CAA	0.05 $\pm$ 0.03 ^{dA}	0.09 $\pm$ 0.01 ^{bA}	0.03 $\pm$ 0.02 ^{eA}	0.29 $\pm$ 0.27 ^{bA}
HS1	0.34 $\pm$ 0.04 ^{cA}	0.55 $\pm$ 0.08 ^{aA}	0.57 $\pm$ 0.06 ^{cA}	0.48 $\pm$ 0.17 ^{abA}
HS2	0.53 $\pm$ 0.07 ^{bB}	0.53 $\pm$ 0.08 ^{aB}	0.97 $\pm$ 0.07 ^{bA}	0.49 $\pm$ 0.11 ^{abB}
HS3	1.09 $\pm$ 0.10 ^{aA}	0.77 $\pm$ 0.13 ^{aB}	1.19 $\pm$ 0.05 ^{aA}	0.79 $\pm$ 0.05 ^{aB}

Means in columns (a–e) not sharing the same letter are significantly different ($P < 0.05$)

Means in rows (A–C) not sharing the same letter are significantly different ($P < 0.05$)

effect from pumpkin and amaranth addition: the pH of the burgers with amaranth or pumpkin seeds added was constant after cooking, while the pH values of the raw burgers were higher than the cooked control burgers.

Lipid oxidation

Lipid oxidation was measured by determining the TBA values at 1 and 4 days of refrigerated storage (Table 3). The TBA values were higher ($P < 0.05$) in the raw burgers with added HS on both day 1 and day 4 compared to the other formulations. The TBA in cooked burgers increased with the increasing HS content on day 1, while significant differences ($P < 0.05$) were reported only for the HS3 and control group on day 4. Therefore the supplementation with HS showed a pro-oxidant activity, probably due to the polyphenolic compounds contained in HS as demonstrated by several studies on polyphenols. In particular, pro-oxidant activities of hazelnut extracts were reported by Amarowicz and Pegg (2001), that find hazelnut crude extracts exhibited a slight, but noticeable pro-oxidant activity as assessed by an increase in TBARS in a pork model system.

In our study, the storage period had a significant effect ($P < 0.05$) on lipid oxidation in the raw and cooked HS3 burgers with a significant decrease in TBA values on day 4 compared to day 1, whereas a significant decrease in TBA values on day 4 was observed in the raw and cooked HS2 burgers compared to the HS2 burgers cooked on day 1. In contrast, a significant increase ($P < 0.05$) in TBA values was noted in the control cooked burgers on day 4 compared to the control raw burgers. In general, the cooked burgers were more susceptible to lipid oxidation than the raw

burgers because heating accelerates oxidative reactions in meat (Sampaio et al. 2012). In our study, all burger formulations had lower values than 2 mg MDA/kg sample, which is considered the maximum acceptable level, and therefore, they were considered suitable for consumption. The concentration of the natural antioxidants used in this study was sufficient for maintaining the oxidative stability of the chicken product for 4 days of refrigerated storage.

Cooking characteristics

Dimensional changes are important parameters for the quality standards of meat burgers. Table 4 presents the cooking properties (diameter reduction, thickness increase, fat and moisture retention, and cooking yield) of chicken burgers with added HS compared to the control and CAA groups after 4 days of refrigerated storage. HS addition had no effect on burger thickness or moisture retention, whereas significant changes ($P < 0.05$) in diameter, fat retention, and cooking yield were observed. After cooking, diameter reduction was greatest (20.83%) in the control burgers, followed by the CAA burgers and the three HS formulations with the lowest value (1.07%) recorded for the HS1 burgers. A previous study reported similar results for dimensional changes in beef burgers containing hazelnut pellicle, which is a by-product obtained during hazelnut roasting (Turhan et al. 2005). The authors found that reduction in diameter was lowest in the meat with 3% and 2% added hazelnut pellicle levels.

Fat retention increased with HS concentration up to 2% for all HS groups, and that outcome was significantly different ($P < 0.05$) compared to the control and CAA burgers. This effect could be due to the dietary fibres

Table 4 Cooking properties of chicken burgers containing ascorbic acid (CAA) and hazelnut skins (HS1—1%, HS2—2%, HS3—3%) during 4 days of refrigerated storage (mean $\pm$ SD; $n = 3$)

Property	Day 4
Diameter reduction (%)	
Control	20.83 $\pm$ 3.44 ^a
CAA	17.58 $\pm$ 9.99 ^{ab}
HS1	1.07 $\pm$ 3.63 ^c
HS2	7.46 $\pm$ 3.82 ^{bc}
HS3	14.52 $\pm$ 4.10 ^{ab}
Thickness increase (%)	
Control	17.91 $\pm$ 18.12 ^a
CAA	22.42 $\pm$ 15.93 ^a
HS1	36.04 $\pm$ 10.11 ^a
HS2	22.80 $\pm$ 5.74 ^a
HS3	32.80 $\pm$ 7.20 ^a
Fat retention (%)	
Control	57.39 $\pm$ 2.87 ^c
CAA	55.50 $\pm$ 1.85 ^c
HS1	67.38 $\pm$ 1.77 ^{ab}
HS2	69.74 $\pm$ 1.90 ^a
HS3	63.70 $\pm$ 1.64 ^b
Moisture retention (%)	
Control	64.01 $\pm$ 3.22 ^a
CAA	62.18 $\pm$ 4.30 ^a
HS1	65.32 $\pm$ 3.41 ^a
HS2	66.39 $\pm$ 3.03 ^a
HS3	65.68 $\pm$ 2.24 ^a
Cooking yield (%)	
Control	61.23 $\pm$ 1.35 ^{ab}
CAA	59.61 $\pm$ 1.96 ^b
HS1	63.43 $\pm$ 0.76 ^a
HS2	62.21 $\pm$ 1.37 ^{ab}
HS3	61.60 $\pm$ 1.05 ^{ab}

Means in columns (a–c) not sharing the same letter are significantly different ($P < 0.05$)

contained in the HS that have a high ability to keep moisture and fat in the matrix. These findings are shared by studies that utilized other types of fibre, such as tiger nut fibre in pork burgers (Sánchez-Zapata et al. 2010) or ground walnuts in restructured beef steaks (Serrano et al. 2007).

Finally, the highest cooking yield was noted for the HS1 burgers, which differed significantly ($P < 0.05$) from the CAA burgers but not from the other formulations.

Antioxidant activity

Diverse methods can be used to evaluate the antioxidant capacity of a product, but none can be considered official. In fact, it is not a single substance, but rather a mixture with a different mechanism of action that contributes to the

antioxidant capacity of a food (Prior et al. 2005). In this study, we used two different methods to evaluate the antioxidant capacity of chicken burgers: the reducing power and the DPPH free radical-scavenging assay (Table 5).

The FRAP assay performed on raw burgers showed a higher value ($P < 0.05$) for the CAA group than the control and HS groups at 1 and 4 days. No significant differences were found between the burgers with different added concentrations of HS. Similarly, higher values ($P < 0.05$) were observed at day 1 for the cooked CAA burgers compared to the control or HS burgers. At day 4, higher values ($P < 0.05$) were noted for the CAA burgers and with the 2% and 3% HS burgers compared to the control and HS1 burgers. Moreover, a significant increase ($P < 0.05$) in the FRAP value was observed in all cooked burgers in comparison to raw burgers for both days.

The DPPH assay showed higher values ($P < 0.05$) on day 1 and day 4 for the raw CAA burgers compared to the other formulations. The increase in DPPH values in the burgers with added HS was directly proportional to the amount of HS. After storage under refrigerated conditions, a decrease ($P < 0.05$) in value at day 4 was noted only for the CAA burgers, whereas no significant differences were found for the other formulations. For the cooked burgers, a lower value ($P < 0.05$) at day 1 was noted for the control burgers compared to the CAA and HS burgers; no significant differences were found between these groups. At day 4, the values were higher for the CAA, HS2 and HS3 burgers compared to the control and HS1 burgers. After storage, antioxidant capacity was found to be stable only in the burgers with 2% and 3% added HS compared to others in which it was decreased.

The antioxidant properties of HS extract have been evaluated in several studies (Locatelli et al. 2010); however, no studies to date have investigated its antioxidant effect on chicken burgers. Our findings are shared by Bertolino et al. (2015), who evaluated the addition of hazelnut peels on antioxidant capacity and phenolic compounds of yogurt during 3 weeks of storage. During storage, the antioxidant capacity of the products containing hazelnut peels was increased compared to the controls, which suggested that the functional ability of these products was stable or increased during storage.

Sensory evaluation

A trained sensory panel was performed on day 1 to detect the possible effects of HS addition on the sensory traits of cooked chicken burgers. Among the sensorial parameters (odour, flavour, greasiness, juiciness, chewiness, and granulosity), the HS addition influenced only the colour (Fig. 1). Colour scores were higher ($P < 0.01$) for the chicken

Table 5 Antioxidant properties (FRAP and DPPH methods) of extracts from raw and cooked chicken burgers containing ascorbic acid (CAA) and hazelnut skins (HS1—1%, HS2—2%, HS3—3%) during 1 and 4 days of refrigerated storage (mean $\pm$ SD; $n = 3$)

Parameter	Raw		Cooked	
	Day 1	Day 4	Day 1	Day 4
FRAP (mg Trolox eq./g)				
Control	0.77 $\pm$ 0.06 ^{bB}	0.46 $\pm$ 0.08 ^{cB}	1.39 $\pm$ 0.22 ^{bA}	1.49 $\pm$ 0.14 ^{cA}
CAA	2.12 $\pm$ 0.31 ^{aBC}	1.84 $\pm$ 0.12 ^{aC}	2.97 $\pm$ 0.06 ^{aA}	2.27 $\pm$ 0.06 ^{aB}
HS1	0.81 $\pm$ 0.13 ^{bB}	0.65 $\pm$ 0.05 ^{bcB}	1.98 $\pm$ 0.17 ^{bA}	1.92 $\pm$ 0.13 ^{bA}
HS2	0.79 $\pm$ 0.03 ^{bB}	0.68 $\pm$ 0.05 ^{bB}	1.92 $\pm$ 0.73 ^{bA}	2.20 $\pm$ 0.12 ^{aA}
HS3	0.82 $\pm$ 0.06 ^{bC}	0.80 $\pm$ 0.10 ^{bC}	1.67 $\pm$ 0.05 ^{bB}	2.31 $\pm$ 0.09 ^{aA}
DPPH(μ g Trolox eq./g)				
Control	21.50 $\pm$ 2.08 ^{cC}	12.43 $\pm$ 0.80 ^{cC}	165.88 $\pm$ 16.89 ^{bA}	112.19 $\pm$ 18.26 ^{cB}
CAA	63.29 $\pm$ 0.01 ^{aC}	62.24 $\pm$ 0.12 ^{aD}	317.47 $\pm$ 0.25 ^{aA}	315.58 $\pm$ 0.65 ^{aB}
HS1	32.56 $\pm$ 2.52 ^{dC}	29.03 $\pm$ 2.17 ^{dC}	303.17 $\pm$ 5.16 ^{aA}	272.97 $\pm$ 6.53 ^{bB}
HS2	43.91 $\pm$ 0.93 ^{cB}	37.73 $\pm$ 1.13 ^{cB}	309.89 $\pm$ 5.01 ^{aA}	305.36 $\pm$ 3.43 ^{aA}
HS3	51.38 $\pm$ 3.73 ^{bB}	56.58 $\pm$ 3.30 ^{bB}	314.85 $\pm$ 0.48 ^{aA}	313.10 $\pm$ 0.48 ^{aA}

Means in columns (a–e) not sharing the same letter are significantly different ($P < 0.05$)

Means in rows (A–D) not sharing the same letter are significantly different ($P < 0.05$)

Fig. 1 Spider plot of the sensory qualities of cooked chicken burgers ($n = 3$) containing ascorbic acid (CAA) and hazelnut skins (HS1—1%, HS2—2%, HS3—3%)

burgers with added HS (at any concentration) compared to the control and CAA burgers. The meat with added HS was perceived by the panellists to be darker than the meat of the control and CAA burgers. This outcome correlated with colorimetric measurements that showed increased redness and decreased lightness and yellowness, respectively, in the cooked burgers with added HS (Table 2). These results agree with the results reported by Turhan et al. (2005), who found similar colorimetric values for beef burgers containing increasing amounts of hazelnut pellicle content. Meat colour was not considered among the sensory traits of cooked beef burgers; an analysis of appearance, juiciness, flavour, and overall acceptability showed that the burgers

containing hazelnut pellicle had the lowest scores for all parameters that were considered. A possible explanation for these results could be attributed to the physicochemical properties of HS that require less mastication and consequently mask the meat flavour. Similar findings were also observed in studies with a preference test on fortified yogurts with roasted HS (Bertolino et al. 2015) or vanilla ice cream with added hazelnut kernel skin (Dervisoglu 2006). In both studies, the low acceptance of the HS-fortified foods could be ascribed to the HS fibre content.

Conclusion

The results suggest that hazelnut skins (a by-product from hazelnut industry) could be successfully used as natural ingredients in the manufacture of chicken burgers in which they were found to improve the cooking characteristics and antioxidant properties. Sensorially, only the colour of chicken burgers was affected, which resulted in darker burgers, and that aspect did not modify the overall acceptability scores. In contrast, lipid stability during refrigerated storage was negatively affected by higher levels of hazelnut skin. Further studies on the lipid stability would be of great interest when using this ingredient in the manufacture of chicken burgers and ultimately contribute to the value of this type of by-product.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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