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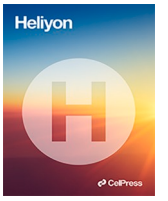

Research article

Quality and sensorial evaluation of beef burgers added with Sicilian sumac (*Rhus coriaria* L)

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ABSTRACT

The Sicilian sumac (*Rhus coriaria* L.) is considered an excellent source of natural polyphenols whose antioxidant activity is able to affect specific technological functions. The effect of the *Rhus coriaria* addition on the quality of beef burgers before and after cooking was evaluated, by pH, colour, protein (-SH) and lipid oxidation, total phenol content and antioxidant activity (ABTS assay). The sumac in burgers (THs) resulted in a significant increase in all dry matter components ($P < 0.05$), while water content and pH value decreased. Furthermore, THs, compared with control burgers (CHs), were characterised by lower L* and peroxidation values and higher a* and b* values ($p < 0.05$). The *Rhus* added in the burgers positively influenced the total phenolic content and antioxidant activity values. Cooking reduced content of phenols, –SH groups and antioxidant activity. However, in THs the reduction of –SH, phenols and antioxidant activity was more limited than in CHs ($p < 0.05$). Sensory analysis showed a higher appreciation for THs by consumers for all the considered attributes. The ground meat incorporated with sumac could be a valid strategy to improve its quality and sensorial evaluation.

1. Introduction

Meat has always played a central role in the history and development of man. It is in fact an excellent source of proteins with high biological value, bioavailable mineral elements (iron, selenium, zinc, phosphorus, potassium, manganese), group B vitamins and different bioactive substances. These are capable of carrying out an antioxidant, antihypertensive and anti-inflammatory activity, protecting human health [1]. Nevertheless, meat and meat products are highly susceptible to quality deterioration due to nutritional composition. Furthermore, technological procedures could promote microbial proliferation and accelerate lipid oxidation responsible for changes in colour, consistency, flavour and nutritional quality [2]. Minced meat is the product of meat processing which undergoes a grinding process and, consequently, a high exposure to oxidation. This process can be prevented or reduced by the addition of antioxidant components with the result of an improvement of the qualitative characteristics of the food. Furthermore, the addition of natural antioxidant compounds responds to the growing demand from consumers seeking safe and natural products as valid substitutes for sulphites and nitrites/nitrates in meat. Rodriguez-Garcia et al. [3] confirmed the willingness of consumers and food industries to seek natural alternatives to guarantee the safety and quality of food. Synthetic substances could be replaced by natural products obtained from plants, ensuring quality and safety during the life cycle [4,5]. In addition, natural products and secondary metabolites are now used due to their antimicrobial, antioxidant and bio-preservative properties, but also because they are biocompatible,

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biodegradable, slightly toxic, very safe and economical [6,7]. Natural products include many herbs and spices that can be used as ingredients able to provide both sensorial and healthy benefits [6–8]. These include the Sicilian sumac (*Rhus coriaria* L.) belonging to the Anacardiaceae family, which is widespread mainly in the middle east and Southern Europe, preferring territories up to 800–1000 m above sea level [9]. In traditional medicine this plant is known for its analgesic, antidiarrheal, antiseptic, anorexic and anti-hyperglycemic properties [7,10], but also for the antibacterial activity [10,11], which is extremely useful for food production [12,13]. *Rhus coriaria* is characterized by several polyphenols such as gallic acid, methyl gallate, kaempferol, quercetin [7,14] and hydrolysable tannins, which have a strong antioxidant effect [13]; furthermore, it is rich in organic acids (malic, citric, succinic, oleic, stearic, linoleic, maleic [15]), anthocyanins [7], mineral salts (phosphorus, potassium, copper, iron, zinc, magnesium, calcium and sodium [16]), fibre, essential oils and B complex vitamins [7,17]. The sumac fruit has been widely used in cooking for many years, as an oil or as a spice [18] but also as a preparation for seasoning salads, fish and meat [19]. In Iran, Palestine, Turkey [18] and Italy [20] it is appreciated not only for enriching dishes but also for its beneficial effects on both human (anti-obesity, anti-diabetic, anti-cancer and cardiovascular health activities [20]) and animal health as a food additive to improve the performance of laying hens and broiler chickens [21]. The aim of our study was to evaluate the quality parameters of sumac added beef burgers. Beef burger called also "Swiss beef" (pressed beef meat mixed with salt) is one of the most consumed foods in the world, both in the best restaurants and in fast food [22].

2. Materials and methods

2.1. Experimental design and burgers manufacturing

Fresh beef (minced rib) was purchased from a supermarket in Potenza, Basilicata, Southern Italy, while powdered *Rhus coriaria* L. fruits were purchased from Terza Luna (http://www.terzaluna.com/product/sumach-or-sumaco/). The phytochemical characteristics of *Rhus coriaria* L. were reported in a previously published study [14]. Four kg of beef was mixed with salt (26 mg NaCl/100 g of meat) to obtain a homogeneous "*Swiss*" type hamburger mixture. The dough was divided in two parts (batches): the first one was used for the control burgers (CH), whereas the second one was used for the preparation of burgers with powdered dried fruit of *Rhus coriaria* or "Sumac" at 5% (TH). A total of 20 hamburgers were obtained for each batch by pressing the mixture into a special circular mould of 7 cm × 1.5 cm for 100 g of meat. CHs and THs were stored at refrigerated temperature (+4 °C) until analysis.

2.2. Chemical composition

Standard Official Methods of Analysis (*AOAC, 1995)* methods were used to determine dry matter (DM; method 950.46), protein (method 990.03), fat (method 920.39), ash (method 920.153). The pH measurement was performed using a pH-meter (model PHM 92, Radiometer, Copenhagen, Denmark) in distilled water extract with a 1:1 meat to water ratio (20 °C), after 1 h of extraction. All raw and cooked meat samples were analysed in triplicate.

2.3. Colour measurement

Colour measurement was performed immediately after hamburger preparation in order to prevent colour degradation. Colour coordinates (CIE L*, a*, b*) were obtained using a MINOLTA CR-300 Chromameter (Minolta Camera Corp., Meter Division, Ramsey, NJ, USA) (Standard observer illuminating D65/0° and 0.8 cm port/observation area). Before use, the colorimeter was standardized using a white tile. The following colour coordinates were determined on each sample: L* (lightness), a* (red-green) and b* (yellow-blue). The analysis was performed in quadruplicate.

2.4. Lipid oxidation analysis

The Peroxide Value (PV) was used to quantify the primary products of lipid oxidation, using the iodometric titration method suggested by Domínguez et al. [23]. An automatic titrator (TitroLine 7800, Xylem Analytics, Mainz, Germany) coupled with a platinum electrode (Pt 62) was used to determine the end point of the titration. The analysis was performed in four replicates and the results were expressed in milliequivalents of active oxygen/kg of fat ($meqO_2$/Kg of fat).

2.5. Cooking hamburgers

The cooking process was performed as suggested by Shen et al. [24], with some modifications. A convection steam oven (Küppersbusch CPE 110, Küppersbusch Grobküchentechnik GmbH, Gelsenkirchen, Germany) was used to cook 10 burgers for each batch (CH and TH) at 120 °C. The cooking process was considered complete when the temperature of 75 ± 3 °C was reached at the core of the sample. Soon after, meat samples were cooled in an ice bath and stored at −20 °C until analysis. All cooked burgers, CH and TH, were analysed for antioxidant activities. Each burger was weighed at room temperature before and after cooking and the weight losses were calculated in %.

2.6. Extraction for antioxidant activity measurement

The method suggested by Savaş et al. [25] was used to determine the total phenolic content and antioxidant capacity of the CH and TH samples. An aliquot of meat (25 g) was added with 75 mL of methanol and distilled water (CH_3OH:H_2O; 80: 20, v/v) and homogenized for 60 s using an IKA T25 digital Ultra-Turrax (IKA®-Werke GmbH & Co. KG, Staufen, Germany). Then, the homogenate was sonicated for 15 min at room temperature and centrifuged at 4193×*g* (T = 4 °C for 15′). The supernatant was filtered through a 0.45 μm pore filter (Acrodisc® LC PVDF syringe filter; Pall Gelman Laboratory, Montreal, QC, Canada) and analysed in triplicate.

2.7. Determination of total phenol content (TPC)

The total phenolic content was estimated following the modifications described by Grassi et al. [26] of the Folin–Ciocalteu assay. Briefly, 100 μL of sample extracts were added to 100 μL Folin–Ciocalteu:H_2O reagent (1:10, v/v) and mixed. After 3 min, 3.0 mL of 7.5% (w/v) $NaCO_3$ was added. The mixture was incubated at 20 °C for 1 h, and the absorbance at 765 nm was read using a UV-1800 spectrophotometer (Shimatzu Corporation, Kyoto, Japan). A gallic acid standard curve (0–100 μg gallic acid/mL) was made to determine the total phenolic content expressed in milligrams of gallic acid equivalents (GAE) per g of meat. The analysis was performed in triplicate.

2.8. 2-2′-Azino-di-[3-Ethylbenzthiazoline Sulfonate] (ABTS) radical scavenging activity

The antioxidant capacity of the extract was evaluated using the method suggested by Re et al. [27], with slight modifications. ABTS radical cation (7.00 mM) was produced by reaction with potassium persulfate (2.45 mM) and incubation in the dark at room temperature for 12–16 h before use. Before analysis, the ABTS stock solution was diluted with distilled water to reach an absorbance of 0.700 ± 0.020 at 734 nm. An aliquot of extract (100 μL) was added to 2.9 mL of the ABTS solution and incubated at room temperature for 30 min. Readings were obtained at 734 nm and the Trolox standard curve (0–2.0 μg Trolox/mL) was made for quantification of ABTS radical scavenging activity. All results were expressed as μg Trolox equivalents (TE)/g of meat. The analysis was performed in triplicate.

2.9. Thiols group

Thiols are organic compounds containing sulfhydryl groups and are capable of neutralizing the action of reactive oxygen species (ROS). The free thiol content was quantified using the method suggested by Grassi et al. [26]. The reagent *5,5′-Dithio – bis 2 – nitrobenzoic acid* (DTNB) reacts with free sulfhydryl groups, changing the colour from clear yellow to intense yellow. 250 μL of reaction buffer (0.1 M phosphate buffer containing 1 mM EDTA, pH 8.0); 50 μL of Ellman's reagent (3 Mm DTNB in 0.1 M phosphate buffer containing 1 mM EDTA, pH 8.0) and 250 μL of sample were placed in a cuvette and incubated at 37 °C for 15 min. The reduction of the DTNB was read at 412 nm, considering the variation in absorption observed in 15 min (ΔA 15 min) and the molar extinction coefficient of the DTNB ($\varepsilon = 14150\ M - 1\ cm - 1$):

$$c(\mu moli - SH\ /\ g) = \frac{\Delta A}{\varepsilon. \times b}$$

where: ΔA = change in absorbance in 15 min at 412 nm, ε = molar extinction coefficient (14150 $M^{-1\ cm\ -1}$), b = optical path (cm). Thiols were expressed as μmol- SH/mg of protein. The analysis was performed in triplicate.

2.10. Acceptability test

The acceptability test was carried out on a group of 150 consumers selected on the basis of regular hamburger consumption, gender (78 females and 72 males) and age (18–55 years), and was used as a representative sample [28]. The control and treated hamburger samples were administered in the same way to each subject and a hedonic form was associated to evaluate the acceptability test. The test aims to evaluate the satisfaction of each individual product by assigning a score, for each attribute considered, on a 9-point scale (1 = extremely unpleasant; 9 = extremely pleasant). Each consumer was asked to evaluate both cooked samples, coded with three-digit codes, for appearance, color, smell, taste and finally to express a general acceptability opinion. The order of presentation was randomized and balanced across subjects and per session such that all possible sample combinations were evaluated the same number of times. All procedures performed in this study involving human participants were in accordance with the 1964 Helsinki Declaration and its later amendments. In addition, we followed the Regulation (EU) 2016/679 of the European Parliament and of the Council of April 27, 2016 on the protection of natural persons regarding the processing of personal data and on the free movement of such data.

2.11. Statistical analysis

The data obtained were subjected to analysis of variance using the GLM procedure [29]. Before fixing the values, expressed in percentage terms, they were subjected to the arcsine transformation [30]. To evaluate the results relating to the hamburger samples, a bifactor model with interaction was considered:

Table 1
Chemical composition and physical characteristics of control hamburgers (CH) and treated hamburgers (TH).

	Beef hamburgers	
	CH	TH
pH	5.67 ± 0.26[a]	5.15 ± 0.16[b]
Dry matter (%)	27.23 ± 0.76[a]	29.16 ± 1.34[b]
Fat (% DM^{-1})	16.23 ± 0.81[a]	16.70 ± 0.70[b]
Protein (% DM^{-1})	78.80 ± 3.47[a]	81.06 ± 0.95[b]
Ash (% DM^{-1})	4.96 ± 0.25[a]	5.76 ± 0.26[b]
PV (meqO_2/Kg)	18.60 ± 6.95[a]	11.43 ± 2.49[b]
L*	41.53 ± 1.52[a]	39.80 ± 1.55[b]
a*	14.56 ± 4.40[a]	15.60 ± 1.25[b]
b*	14.00 ± 1.32[a]	15.01 ± 1.45[b]

PV = peroxide value; L* = lightness; a* = redness; b* = yellowness.
[a,b] means in the same row with different letters are statistically different ($p < 0.05$).

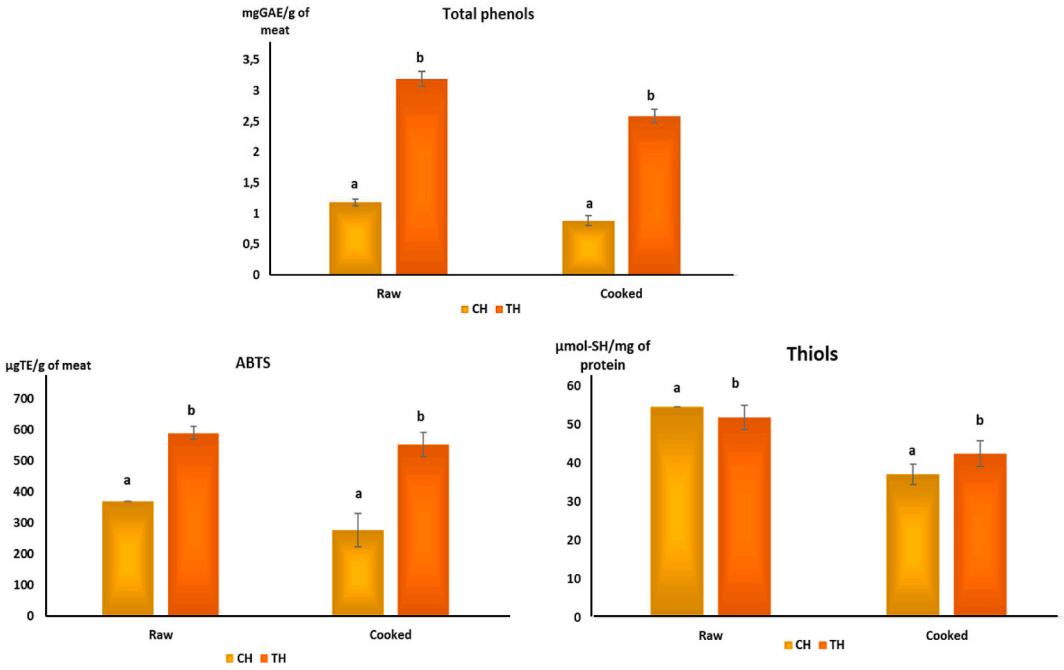

Fig. 1. Content in total phenolics (mg GAE/g of meat) and antioxidant activity evaluated by ABTS assay (µg TE/g of meat) and thiols (µmole-SH/mg of protein) in control (CH) and treated (TH) hamburgers, raw and cooked; ([a,b] = $p < 0.05$).

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha x \beta)_{ij} + \varepsilon_{ijk}$$

where y_{ijk}: experimental observation; µ: means; α_i: the treatment effect (control/treated); β_j: the effect of the state (raw, cooked); $(\alpha x \beta)_{ij}$ = 1st order interaction, $_i(1, 2)$; $_j(1, 2)$; ε_{ijk} = experimental error. The Student *t*-test was used and differences were considered significant when $p < 0.05$. Results are presented as mean ± standard deviation (±SD).

3. Results and discussion

3.1. Chemical composition of burgers

The average chemical composition of CH and TH hamburgers is shown in Table 1.

The results reported in Table 1 are consistent with those reported by other authors who investigated the quantitative-qualitative characteristics of beef burgers [31]. As expected, the presence of sumac in the burgers resulted in a significant increase in all dry matter components ($p < 0.05$). Moisture content significantly decreased with the addition of sumac ($p < 0.05$) compared to the control, while fat and protein significantly increased ($p < 0.05$). Of course, both the decrease in moisture and the added sumac content could be responsible for the observed increase in fat, protein and ash. Furthermore, the addition of sumac significantly reduced the pH values of

the samples ($p < 0.01$), as also suggested by Savas et al. [25]. This could be related to the acidic structure of the sumac fruit containing malic, citric and fumaric acids, all organic acids that could lower the pH of the meat [13,32]. Wang et al. [4] observed that increasing the amount of added sumac resulted in a dose-dependent reduction in the pH values of ground meat samples. The colorimetric values (L*, a* and b*) of CH and TH samples shown in Table 1 were significantly affected by the addition of *Rhus*. In particular, as also observed by Wang et al. [4], CH value for L* was significantly higher (41.53 *vs* 39.8) and those for a* (14.56 *vs* 15.60) and b* (14.00 *vs* 15.01) significantly lower than values observed for TH ($p < 0.05$). The a* value of the TH may have been influenced by the anthocyanin content of the spice, which increased its value. Anthocyanins are influenced by a number of factors such as pH, temperature or oxidizing factors [33]. These are stable at medium-low pH which in the case of TH was lower than that of CH. Furthermore, the colour stability as well as the concentration of anthocyanins is also influenced by the concentration and intensity of pigments such as caffeic acid, coumaric acid, chlorogenic acid and vanillic acids which determine a hyperchromic effect influencing the final color [14,34]. The results obtained from this study are in line with several authors who confirmed the ability of spices to stabilize the colour of minced meat [4,35]. Redness is a fundamental chromatic parameter for monitoring the oxidation of meat, with the consequence that if this index is extremely low it could be unacceptable for the beef consumer [36]. Meat has a complex chemical composition that is highly susceptible to oxidation: iron, myoglobin (Mb), hydrogen peroxide (H_2O_2) and ascorbic acid could be the components responsible for the formation of ROS which trigger the oxidation of fats [23]. Factors that negatively influence the oxidative stability of meat can be intrinsic as meat components and extrinsic as processing and handling methods, preservation methods, added ingredients [23]. Meat mincing negatively affects the oxidative stability of meat due to cellular breakdown, light and oxygen exposure which favour the oxidation of deposits and membrane lipids [37]. In this study, we evaluated the oxidative stability of hamburger samples by analysing the Peroxide Value (PV). This value gives an indication of the concentration of primary products of lipid oxidation (conjugated dienes and peroxides) which could negatively impact the consumer's health if ingested [37]. As shown in Table 1, the PV value in the TH was significantly lower than the CH value (11.43 vs 18.60 meqO_2/Kg; $p < 0.001$). Our findings are in agreement with Li et al. [38], who observed that a mixture of spices and herbs added to meat favoured the decrease in the number of peroxides and Jaworska et al. [39], who reported a positive effect on the significant reduction of the oxidation of minced meat in the presence of spices such as pepper, thyme and oregano. This decrease is thought to be due to the tannins, phenolic compounds, and antioxidant capacity of sumac [16,20].

3.2. Antioxidant activity in raw burgers

In Fig. 1, the phenolic content and antioxidant activities of the raw CH and TH samples are shown. In agreement with data of Kang et al. [40] in cattle meat, the TPC value of CH was 1.18 mg GAE/g of raw meat. Many authors investigated the effect of a diet enriched with antioxidant components but the results are conflicting. Salami et al. [41] reported that an increase in polyphenols in the diet of animals does not result in an increase in TPC in meat. Bodas et al. [42] observed that supplementation of a citrus flavonoid in the diet of lambs resulted in accumulation of this flavonoid in the liver but not in the muscle of lambs. Indeed, the liver is considered the main organ involved in the metabolism of dietary polyphenols, resulting in the formation of different metabolites before being absorbed for excretion [43]. However, the detected phenolic values could be attributed to the phenolic groups of protein amino acids detected by the Folin-Ciocalteau assay. In fact, the Folin–Ciocalteu assay is characterised by a notable disadvantage since it does not evaluate only the truly present phenolic compounds, but also other non-phenolic reducing agents such as sugars, aromatic amines, ascorbic acid, and other organic acids which interfere in the determination of total phenolic groups and, consequently, lead to an overestimation of the results [44]. Furthermore, it is a highly sensitive test to temperature variations and pH conditions which could lead to an uncorrected result [45].

As expected, TH samples, compared to CH ones, showed a significant increase in TPC (3.19 mg GAE/g of meat *vs* 1.18 mg GAE/g of meat; $p < 0.01$). The TPC is closely related to the antioxidant activity measured by ABTS and thiols assay. ABTS activity and thiol content of CH and TH are shown in Fig. 1. Spectrophotometric assay of ABTS is a widely used method as it analyses the antioxidant activity of both hydrophilic and lipophilic components [27]. The thiol assay, on the other hand, measures the number of thiol groups (-SH), as well as glutathione and thiol groups in proteins, which play an essential role as antioxidants. These compounds can act as free radical scavengers and metal ion chelators. Under conditions of oxidative stress, free sulfhydryl groups decrease and disulfides increase [46]. The antioxidant capacity assessed by ABTS and thiol assay in raw CH was 371.11 μg TE/g of meat and 54.6 μmole-SH/mg of protein, respectively. Many authors reported that meat proteins and peptides have an important antioxidant action due to their ability to scavenge free radicals and chelate metals [47]. The antioxidant capacity could derive both from the composition and amino acid sequence of the proteins and from the different concentration of important proteolytic enzymes in the post-mortem phase, such as calpain and cathepsin [48]. Furthermore, the presence of –SH groups in amino acids and proteolysis by endogenous enzymes lead to the formation of several peptides that may exhibit reactive thiol groups. This result is probably due to the presence of –SH in the amino acid sequence but also to the muscle proteolytic degradation which, as reported by Grassi et al. [26] and Simonetti et al. [49] could exhibit reactive thiol groups by the action of endogenous enzymes. In support, Tong et al. [50] showed that the sulfhydryl groups deriving from cysteine are active in inhibiting the autoxidation of lipids. The antioxidant activities of burgers were significantly increased by sumac addition. The total $ABTS^{\bullet+}$ scavenging capacity of raw TH was 590.49 μg TE/g meat, with an increase in ABTS value of 37% compared to the control. The antioxidant activity exerted by sumac could be attributed to unbound components that contain phenolic hydroxyl groups and double bonds such as gallic acid, flavonoids and others that increase the ABTS value of TH compared to CH. The obtained results also showed that the thiol content of TH samples (51.8 μmole-SH/mg of protein) significantly decreased compared to CH ones (see Fig. 1; $p < 0.05$). This result could be related to the hydrogen (H) bonding interaction of thiols with phenols, thus reducing the number of free –SH measured with Ellman's reagent. Specifically, this test measures sulfhydryl groups with the DTNB thiol reagent, which forms *5-thionitrobenzoic acid* and a mixed disulfide. Under conditions of oxidative stress, there is an

Table 2
Average scores of the sensory profile of the descriptors (appearance, colour, smell, flavour, taste, consistency and overall acceptability) of the control beef burgers and the *Rhus* burgers.

Attributes	CH	TH
Appearance	6.50 ± 1.00^{a}	7.25 ± 0.50^{b}
Color	6.75 ± 1.26^{a}	7.25 ± 0.82^{b}
Smell	7.50 ± 0.58^{a}	7.50 ± 0.58^{a}
Flavor	5.00 ± 0.82^{a}	7.00 ± 1.15^{b}
Taste	5.25 ± 0.50^{a}	7.25 ± 1.50^{b}
Consistency	6.75 ± 1.26^{a}	7.00 ± 0.82^{a}
Overall Acceptability	6.25 ± 1.26^{a}	7.75 ± 0.50^{b}

^{a,b} means in the same row with different letters are statistically different ($p < 0.05$).

increase in disulfides [51]. This assay could also be used as an indicator of protein oxidation [52]. It is known that proteins can bind to polyphenols forming reversible or irreversible interactions which may affect the total antioxidant activity (TAC) measured [53].

3.3. Cooked hamburgers

Meat samples were steamed for approx. 20 min, until reaching 75 °C at the core of the product. Cooking brings structural and compositional changes that influence the biological activities of meat [54]. The meat cooking process influenced all the parameters considered, since cooking led to a loss in water and, consequently, to an increase in the other parameters in raw meat. Regarding the CH and TH samples studied, the cooked meat samples showed the same differences observed in the raw meat ones. The cooking loss was on average equal to 21.55% ± 1.70. The presence of sumac resulted in a lower cooking loss (19.60 ± 1.30%) compared to the CH (23.50 ± 1.70%) although the differences were not significant. This could be due to the presence of sumac in the TH which promotes fat and water retention according to Uzun et al. [5]. The cooking process resulted in colour changes mainly due to the denaturation of myoglobin and the oxidation of heme iron into its ferric form [55]. The lightness (L*) and the yellowness (b*) increased, while the redness (a*) decreased, in line with other authors. In the comparison between cooked CH and TH, it was observed that L* was lower in TH (44.97 vs 46.76; $p < 0.05$) while a* (10.6 vs 9.036) and b* (17.20 vs 15 0.96) were significantly higher in TH ($p < 0.05$). The value of a* depends on the chemical state of the myoglobin and the results observed in cooked THs suggest that pigment oxidation is less. The addition of *Rhus* to the hamburger samples determined a protective effect which can be attributed to the antioxidant capacity of the phenolic compounds present in the fruit. The stabilizing effect of natural antioxidants on meat colour has been observed in several studies with other different antioxidants such as rosemary extract and lemon balm in pork [56] and green tea in beef [57]. The average values of the phenolic content and antioxidant activity of cooked-CH and TH are shown in Fig. 1. As previously observed [26], the heat treatment reduced the antioxidant activity of the burgers ($p < 0.05$). After the cooking process, the average phenolic content was 0.88 mg GAE/g of meat in CH and 2.59 mg GAE/g of meat ($p < 0.05$) in TH, showing a decrease of 25.42 % and 18.8 %, respectively compared to raw meat. The cooking process, indeed, favours the generation of ROS and the phenolic compounds interact with these free radicals, significantly decreasing their availability [58]. Furthermore, many of these compounds, being water-soluble, were released into the cooking liquid, as reported by Simonetti et al. [58].

The average free thiol content also decreased in all burgers (see Fig. 1; $p < 0.001$) The decrease in thiol content could be determined by the oxidation of proteins after cooking with loss of thiol groups. In fact, following the cooking process, the oxidation of cysteine can induce the cross-linking of proteins through the formation of intermolecular disulfide bridges, with the consequence that the higher level of free thiol groups is associated with the lower oxidation of cysteine [56]. Finally, Grassi et al. [26] reported that the lower thiol content in cooked meat could also be due to the loss of cooking juices. After cooking, CH had a thiol content of 36.98 μmol SH/mg of protein, while TH had a significantly higher thiol content (42.33 μmol SH/mg of protein; $p < 0.05$), and the losses compared to the raw sample were found to be 32.4 % and 18.3 %, respectively. In fact, cooked-CH showed a loss of thiol content approximately 1.15 times higher than cooked-TH, which indicates a better oxidative stability of the latter. This result is in agreement with data reported by Jia et al. [59] who studied the behaviour of phenolic compounds, such as rutin and quercetin, which could interfere with the elimination of free radicals, resulting in a protective effect for the SH group and Vaithiyanathan et al. [60], in a study conducted on the effect of pomegranate phenolic juice on chicken meat, demonstrating the inhibition of the loss of total –SH group and protein-bound –SH group.

A 25% decrease in ABTS values was observed in cooked-CH (278.83 μg TE/g of meat; $p < 0.05$; see Fig. 1) and could be due to the thermo-oxidation of various components of the muscle foods with consequent consumption of antioxidant substances and accumulation of oxidized proteins and loss of functionality of active meat peptides. Furthermore, heating could favour the degradation of endogenous antioxidant factors such as vitamin E, vitamin C, carotenoids, polyphenols and cellular thiols with a decrease in antioxidant capacity. The added sumac, rich in polyphenols, reduced the loss of ABTS values of cooked hamburgers (552.62 μg TE/g of meat; $p < 0.05$; see Fig. 1), highlighting a decrease of only 6% compared to raw-TH, resulting in line with data reported by Bergamaschi et al. [61] in pork burgers formulated with non-compliant green coffee bean extract.

3.4. Acceptability test of burger

Sensory analysis based on consumer perception is generally used in the early stage of development of new food products. In this study, to evaluate the degree of acceptability of hamburgers prepared with beef meat, with and without *Rhus coriaria*, an acceptability

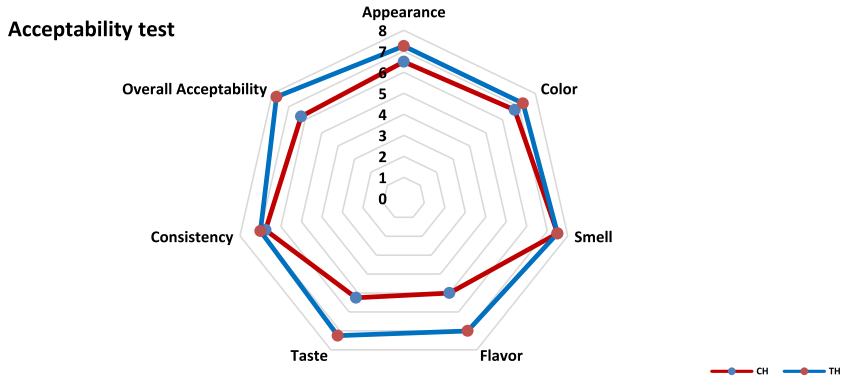

Fig. 2. Descriptors (appearance, colour, smell, flavour, taste, consistency, overall acceptability) of acceptability test of cooked-control beef burgers and cooked beef *Rhus* burgers. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

test was conducted on 150 consumers selected on the basis of habitual consumption of hamburgers, sex (78 females and 72 males) and age (18–55 years). In the sensorial profile, the perception of the following descriptors was determined: appearance, colour, odour, taste, consistency and overall acceptability. The results of the sensory profile of CH and TH samples are summarized in Table 2. All the hamburgers, control and treated, were appreciated by the consumers for the evaluated descriptors and showed statistical differences ($p < 0.05$). The addition of sumac positively influenced the satisfaction rating, TH presented a significantly higher score for the colour, flavour, taste and general acceptability attributes, compared to CH ($p < 0.05$). For data related to odour and texture, no significant differences were detected. In particular, TH samples had higher scores for flavour (7.00) and taste (7.25) compared to CH samples 5.00 and 5.25, respectively. This could be due to the presence of *Rhus* which favours a greater perception of flavour and taste, thanks to the presence of several components that contribute positively to the acceptability of the product [20,25]. The colour attribute was also more appreciated in the TH samples (7.25 *vs* 6.75), as a possible consequence of the richness of sumac in phenolic components, tannins, flavonoids which are also responsible for the pigmentation of foods [20].

Finally, the addition of *Rhus* determined a positive effect on the evaluation of the overall acceptance of THs compared to CHs (see Fig. 2).

4. Conclusion

The possibility of using minced meat added with *Rhus coriaria* L. fruit powder for the production of fortified products could allow the development of new functional foods. The results of our research highlighted that the addition of sumac represents a strong ally in improving the negative perception of meat by the consumer. From the study conducted it can be deduced that the addition of sumac allowed to increase the functional and antioxidant power of the meat, avoiding the use of synthetic additives. However, the cooking process decreased the phenol content and antioxidant activity, also decreasing its oxidative stability. The addition of sumac positively and significantly influenced the antioxidant content in raw and cooked samples. Furthermore, the addition was more appreciated by consumers for all analysed parameters. These results suggest that ground meat incorporated with sumac could be a valid strategy to improve its sensory characteristics.

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Ethical approval

Review and/or approval by an ethics committee was not necessary for this study because it does not address the ethical considerations of animal, cellular, and human testing. The appropriate protocols for protecting the rights and privacy of all participants were utilized during the execution of the research, e.g. no coercion to participate, full disclosure of study requirements and risks, written or verbal consent of participants, no release of participant data without their knowledge, ability to withdraw from the study at any time. Moreover, the products tested were safe for consumption.

Data availability statement

The data will be made available upon request by the corresponding author.

CRediT authorship contribution statement

Giulia Grassi: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paola Di Gregorio:** Writing – review & editing, Writing – original draft, Conceptualization. **Andrea Rando:** Writing – review & editing, Writing – original draft. **Anna Maria Perna:** Project administration, Methodology, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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