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Effect of heat treatments on the physicochemical and sensory properties of the *longissimus thoracis* muscle in unweaned Limousin calves

Agnieszka Kaliniak-Dziura [a], Piotr Domaradzki [a,*], Marek Kowalczyk [a,*], Mariusz Florek [a], Piotr Skałecki [a], Monika Kędzierska-Matysek [a], Piotr Stanek [b], Małgorzata Dmoch [a], Tomasz Grenda [c], Edyta Kowalczuk-Vasilev [d]

[a] Department of Quality Assessment and Processing of Animal Products, University of Life Sciences in Lublin, Akademicka 13, 20-950 Lublin, Poland
[b] Department of Cattle Breeding and Genetic Resources Conservation, University of Life Sciences in Lublin, Akademicka 13, 20-950 Lublin, Poland
[c] National Veterinary Research Institute, 57, Partyzantow Avenue 24-100 Pulawy, Poland
[d] Institute of Animal Nutrition and Bromathology, University of Life Sciences in Lublin, Akademicka 13, 20-950 Lublin, Poland

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ABSTRACT

The aim of the study was to assess the effect of methods of heat treatment on selected quality parameters of *longissimus thoracis* muscle of Limousin calves, subjected to grilling, steaming, and sous vide cooking. The type of heat treatment did not significantly affect shear force or water activity. Cooking loss in the grilled and steamed meat was significantly higher than in the sous vide. While the content of vitamin E was significantly lower in the cooked meat, it was retained to the greatest degree in the grilled meat and least in the steamed meat. The TBARS index significantly increased during all cooking methods with the highest level in steamed meat. The sensory analysis revealed a preference for the sous vide and grilled meat, while the steamed meat received the lowest scores. Although veal is commonly assumed to be highly nutritious and palatable, its quality can be significantly influenced by the type of heat treatment.

1. Introduction

Meat is a valuable source of protein of high biological value, as well as iron, vitamin B_{12} and other B complex vitamins, zinc, selenium and phosphorus. Fat content and fatty acid profile, always a matter of concern in the case of meat consumption, are highly dependent on the animal species, feeding system, and cut of meat (Pereira & Vicente, 2013). In some countries red meat has been viewed negatively in recent decades due to its potential carcinogenic effect, leading to efforts to reduce its consumption (Sobral, Cunha, Faria, & Ferreira, 2018). Despite these potentially deleterious effects, meat has played a crucial role in human evolution and is in fact an important and nutritious component of a healthy and well-balanced diet (McAfee et al., 2010). Among the various types of red meat, veal occupies a special position, especially veal obtained from grazing suckling calves, traditionally regarded by consumers as a healthy product and an important source of unique biologically active components (such as conjugated linoleic acid isomers, vaccenic acid, branched-chain and long-chain polyunsaturated fatty acids, vitamins and antioxidants), with low fat content and a smooth flavour (Domaradzki, Stanek, Litwińczuk, Skałecki, & Florek, 2017; Vieira, García, Cerdeño, & Mantecón, 2005).

With certain exceptions, such as steak tartare, meat is usually eaten cooked (Sobral et al., 2018). Properly cooked meat has a better aroma, is easier to digest and nearly sterile, as well as more appealing and palatable when served hot. However, cooking affects the nutritional value of meat due to changes in certain components. In addition, cooking can result in the formation of a number of harmful chemical compounds (Oz, Aksu, & Turan, 2017).

In modern times, meat can be cooked by a variety of methods, including boiling, poaching, steaming, roasting, baking, frying,

* Corresponding authors at: Department of Quality Assessment and Processing of Animal Products, University of Life Sciences in Lublin, Akademicka 13, 20-950 Lublin, Poland.

E-mail addresses: agnieszka.kaliniak@up.lublin.pl (A. Kaliniak-Dziura), piotr.domaradzki@up.lublin.pl (P. Domaradzki), marek.kowalczyk@up.lublin.pl (M. Kowalczyk), mariusz.florek@up.lublin.pl (M. Florek), piotr.skalecki@up.lublin.pl (P. Skałecki), monika.matysek@up.lublin.pl (M. Kędzierska-Matysek), piotr.stanek@up.lublin.pl (P. Stanek), malgorzata.dmoch@up.lublin.pl (M. Dmoch), tomasz.grenda@piwet.pulawy.pl (T. Grenda), edyta.kowalczuk@up.lublin.pl (E. Kowalczuk-Vasilev).

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microwaving, grilling, barbecuing, smoking, sous vide and confit (Sobral et al., 2018). Cooking methods clearly affect the chemical composition and nutritional value of meat, which may have a significant impact on the intake of essential nutrients (Lopes, Alfaia, Partidário, Lemos, & Prates, 2015). Consumers are becoming increasingly aware of the relationship between the food they eat and their health. Moreover, they are encouraged to avoid highly processed meat products, especially those heated to a high temperature during frying, roasting or grilling (Modzelewska-Kapituła, Pietrzak-Fiećko, Tkacz, Draszanowska, & Więk, 2019). In addition, the last few decades have seen dramatic changes in meat for consumption (e.g. it is obtained from younger and leaner animals), and traditional cooking methods often result in dry and flavourless meat (Baldwin, 2012).

Alternatives to high-temperature cooking methods include steam cooking and sous vide (Baldwin, 2012), which are becoming increasingly popular for preparing beef in restaurants and households (Modzelewska-Kapituła et al., 2019). Steaming involves cooking with steam heat from boiling water. The meat is kept separate from the boiling water, having direct contact only with the steam, which is the reason for the moist texture of steamed meats (Sobral et al., 2018). Sous vide is a method in which food is cooked in heat stable vacuumed containers under controlled temperature (65–95 °C) for a specific time followed by low-temperature storage (Ayub & Ahmad, 2019). Sous vide is considered a transformation of traditional cooking into a more nutritionally, healthier cooking (Cui et al., 2021). This process allows very tender textures of tough cuts and enables a perfect control of doneness (Ruiz-Carrascal, Roldan, Refolio, Perez-Palacios, & Antequera, 2019), as well as improves quality, colour, flavour, and nutritional value of food (Cui et al., 2021). In contrast, grilling allows consumers to prepare a quick meal using a direct heat source, such as thermal radiation or direct conduction, which may vary depending on the type of grill. Direct grilling can expose food to temperatures of up to 260 °C, resulting in meat with aroma and flavour characteristics similar to those achieved by roasting (Sobral et al., 2018).

The influence of cooking methods on the quality of veal is very limited in comparison to more popular meats like beef, pork, poultry and horse meat. Therefore, in the present study the effect of grilling, sous vide and steaming on selected quality parameters of the *longissimus thoracis* muscle from Limousin suckling calves was evaluated.

2. Materials and methods

2.1. Ethical approval

The experiment was conducted according to the guidelines of the Declaration of Helsinki and in compliance with the European Union law (Directive 2010/63/UE, received in Poland by Legislative Decree 266/2015) of the European Parliament and of the Council on the protection of animals used for scientific or educational purposes. Having regard to the legal basis according to Polish law, Ethical Approval is not required for services within the scope of the Act of 18 December 2003 on animal treatment facilities, as well as agricultural activities, including rearing or breeding of animals, carried out in accordance with the provisions on the protection of animals, and activities that, in compliance with the veterinary medicine practice, do not cause pain, suffering, distress or permanent damage to the body of animals, to an extent equal to a needle stick or more intense (Act of the Protection of Animals Used for Scientific and Educational Purposes, Legislative Decree 266/2015). Therefore, without prejudice to the right, the Ethical Review and Approval is waived for this study.

2.2. Animal management and meat preparation

The experiment was carried out on *longissimus thoracis* muscles (LT, between the 7th and 12th thoracic vertebrae) taken from the carcasses of unweaned Limousin calves ($n = 12$). The animals were kept with their mothers on the pasture from birth (March–April 2019) until slaughter at 7–8 months of age. Their diet consisted of their mother's milk, grass, and haylage. The dominant plants in the pasture sward were grasses, mainly high grasses, i.e. perennial ryegrass (*Lolium perenne* L.), cocksfoot (*Dactylis glomerata* L.), meadow fescue (*Festuca pratensis*), Kentucky bluegrass (*Poa pratensis* L.), and common couch (*Elymus repens*); small-seeded legumes, i.e. white clover (*Trifolium repens* L.) and red clover (*Trifolium pratense* L.); and herbs, including dandelion (*Taraxacum officinale*), yarrow (*Achillea millefolium* L.), broadleaf plantain (*Plantago major* L.) and ribwort plantain (*Plantago lanceolata*). The milk composition of Limousin cows was determined by infrared scan (Infrared Milk Analyzer, Bentley Instruments Inc., Chaska, MN, USA) and was consisted of 4.8% fat, 3.6% protein, 3.7% lactose and 13.9% dry matter. After an average of 80 days of age, the calves had ad libitum access to concentrate, while suckler cows had access only to pasture. In the final stage of the experiment, the calves consumed about 3.5 kg of concentrate feed per day. The concentrate feed was composed of triticale (20%), oats (19%), barley (30%), flax (6%) and a protein concentrate supplement (25%) – Compagra Cielak 34% NON GMO, balanced according to IZ PIB (2014). The protein concentrate additionally contained minerals, i.e. Ca (3.3%), P (1%), Na (0.5%), Mg (0.15%), and Cu (90 mg/kg), and vitamins: biotin (700 mg/kg), niacin B (600 mg/kg), vitamin A (60,000 IU/kg), vitamin E (380 mg/kg), and vitamin D (16,000 IU/kg). Calves had free access to water and salt licks. The chemical composition of the feeds (Table 1) was determined by AOAC (2012).

The animals were randomly selected and weaned 2–3 h prior to slaughter and transported in compliance with European Union regulations (EC, 2005) directly from the pasture to the slaughterhouse, where they were weighed and slaughtered in accordance with the provisions of Council Regulation No 1099/2009 (EC, 2009). The calves were slaughtered on two dates in October 2019, two weeks apart ($n = 6$ animals per processing). The average age of the calves was 228 days ±20.0 days, their mean body weight was 298 kg ± 26.8 kg, and the carcass weight was 188.5 kg ± 23.7 kg. After 24 h post-mortem chilling at 2 °C, the carcasses were dissected and the muscles were vacuum packed (MULTIVAC C200, Wolfertschwenden, Germany) in 20/70 μm PA/PE side seal bags with oxygen permeability of <56 $cm^3/m^2/24$ h at 1 bar and water vapour permeability of <3 g/m/24 h (MULTIVAC, Bucharest, Romania), and then aged in a refrigerated cabinet (EVERLASTING s.r.l., Suzzara, Italy) until the 14th day post mortem at 4 ± 1 °C. After this period, the average pH of the *longissimus thoracis* was 5.61 ± 0.09 and the drip loss was 3.66 ± 1.04%. The pH was measured in triplicate in each muscle using a portable pH-meter with automatic buffer solutions detection and automatic temperature compensation (CP-401, Elmetron, Zabrze, Poland) and an penetrating glass electrode (ERH-12-6, Hydromet, Gliwice, Poland) calibrated at the 2 points pH 4.00 and pH 7.00 with high-accuracy pH buffer solutions (± 0.02 at

Table 1
Proximate composition and nutritive value of calf feeds.

Parameter	Haylage	Pasture grass	Concentrate
Dry matter (%)	39.3	19.0	88.4
	Per kg of dry matter		
Crude protein (g)	195	112	171.20
Crude fat (g)	51.1	42.0	51.1
Crude fibre (g)	295	301	40.8
ADF (g)	272	308	41
NDF (g)	462	508	144
Crude ash (g)	84	87	49,8
	Nutritive value per kg of dry weight		
PDIN (g)	113.4	70.3	117
PDIE (g)	76.4	76.2	113
UFL	0.62	0.73	1.25

ADF – acid detergent fibre; NDF – neutral detergent fibre; UFL – Feed Unit for meat production; PDIN – protein truly digestible in the small intestine when N limits microbial protein synthesis; PDIE – protein truly digestible in the small intestine when energy limits microbial protein synthesis.

20 °C, Elmetron, Zabrze, Poland). Drip loss was expressed as a percentage of the initial weight of muscle sample to sample's weight after storage.

Then the muscles were sliced into 2.5 cm thick steaks (average weight 157 g) and randomly divided into four groups: one as a control (raw meat) and the other three cooked by different methods (grilling, sous vide and steaming).

2.3. Heat treatment

Grilling was performed using an electrical clamshell grill (Morphy Richards Intelli Grill 48,018, Rotherham, UK) preheated to 240 °C. Steaming was performed using anelectric steam cooker (Morphy Richards Intellisteam Compact 48,775, Rotherham, UK) preheated to 100 °C in a 100% steam environment. These two heat treatments were carried out until the geometric centre of the steak reached a temperature of 72 °C. The cooking temperature was monitored by a needle thermocouple probe attached to a previously calibrated hand-held thermometer (Testo 108, Testo SE & Co. KGaA; Lenzkirch, Germany). Sous vide treatment was carried out after vacuum-packing the individual steaks in plastic bags (OPA/PP; 15 μm/75 μm; heat resistance up to 115 °C, MULTIVAC, Bucharest, Romania) in a sous vide system (HENDI GN 1/1, Rhenen, Netherlands) at 65 °C for 2.5 h. Steaks were cooked in 3 batches of 4 for each heat treatment. Then, the samples were subjected to physicochemical analyses immediately after reaching the room temperature (20–22 °C). In the case of determining TBARS, retinol and α-tocopherol content, the samples after grinding were frozen and stored at −80 °C until analysis for no longer than one month.

2.4. Proximate chemical composition

Moisture content was determined by drying (103 °C) in a Memmert UF30 universal oven (Schwabach, Germany) according to PN-ISO 1442:2000; total ash by incineration (at 550 °C) using a Heraeus M110 laboratory muffle furnace (Hanau, Germany) according to PN-ISO 936:2000; total protein content (N × 6.25) by the Kjeldahl method using the Büchi Speed Digester K-436 (Flawil, Switzerland) and the Büchi Distillation Unit B-324 (Flawil, Switzerland) according to PN-A-04018/Az3:2002; and fat content by the Soxhlet method (with n-hexane as solvent) using the Büchi Extraction System B-811 (Flawil, Switzerland) in accordance with PN-ISO 1444:2000. Total collagen was determined on the basis of hydroxyproline content (conversion factor 7.52) according to PN-ISO 3496:2000, using the Varian Cary 300 Bio spectrophotometer (Varian Australia PTY Ltd., Mulgrave, Australia). Water activity (a_w) was measured using a Rotronic HygroLab C1 analyzer (Bassersdorf, Switzerland). The AWQ mode with stabilization set to 15 min was applied after conditioning the samples at room temperature (20 ± 1 °C). For each sample three replicates were recorded.

2.5. Colour measurements

Meat colour was measured using the Konica Minolta CM-600d (Konica Minolta Sensing, Inc., Osaka, Japan) portable spectrophotometer with a pulsed xenon lamp and 8 mm aperture size. The results (illuminant D65, 10° Standard Observer) were given in the CIE L*a*b* colour space (CIE, 2004), including the following spectral values: L*, (lightness), a* (redness), b* (yellowness), C* (saturation), and h° (hue angle). The colour values of the surface of fresh cut steaks were recorded after 30 min of exposure to atmospheric oxygen at 4 °C to allow blooming. The colour of the steaks after heat treatment and chilling to room temperature (20–22 °C) was measured on the cross-section. At least three readings on different points of the sample were taken.

2.6. Cooking losses

Cooking losses (in %) were calculated based on the weight of the sample before and after each heat treatment. After cooking and before weighing, the samples were cooled (to 20–22 °C) and wiped with a paper towel to remove visible exudates.

2.7. Texture analysis

Strips of muscle (10 × 10 mm, about 20 mm long, $n = 5$) from each cooked method per batch were cut parallel to the longitudinal orientation of the muscle fibres and sheared at room temperature (20–22 °C) perpendicular to the fibres using the Zwick/Roell ProLine BDO125 FB0.5TS (Zwick GmbH and Co, Ulm, Germany) equipped with a V-shaped shear blade, at a crosshead speed set at 100 mm/min. Warner Bratzler shear force (WBSF, N) and shear energy (mJ) were evaluated using device-specific testXpert II software.

2.8. TBARS index

Lipid oxidation was determined by measuring 2-thiobarbituric acid reactive substances (TBARS) according to Witte, Krause, and Bailey (1970). The absorbance was measured at 530 nm using the Varian Cary 300 Bio spectrophotometer (Varian Australia PTY Ltd., Mulgrave, Australia) and expressed in mg of malondialdehyde (MDA) per kg of sample.

2.9. Retinol and α-tocopherol content

Retinol and α-tocopherol content were determined by an accredited method (No AB 512; Reference document SOP M.001 7th edition of 27.01.2020) based on the procedure of Eitenmiller, Landen Jr, and Ye (2007), by high performance liquid chromatography using UV-VIS and fluorescence detectors for retinol and α-tocopherol detection, respectively. Vitamin content was expressed as μg per 100 g of sample.

2.10. Sensory evaluation

Sensory analysis of veal steaks was performed on warm samples (50 °C) by six non-smokers experienced in meat sensory analysis (3 women and 3 men in an age range of 25 to 40 years), selected from the staff of the Department of Quality Assessment and Processing of Animal Products, University of Life Sciences in Lublin. Prior to testing the panel took part in a preparatory session concerning the descriptive profile of sensory attributes to allow the panellists to discuss and clarify each attribute to be evaluated. Samples were cut into approximately 4 mm thick slices, coded with three-digit numbers, and served. All testing was carried out under controlled conditions (room temperature of approx. 20 °C, free of noise and odour, under fluorescent lighting). Water and bread were provided between samples to cleanse the palate. The sensory analysis was carried out using the scaling method according to PN-ISO 4121:1998. A 10 cm long unstructured linear graphical scale with a specific edge point was used to assess the following attributes: aroma (undetectable; very intense), juiciness (very dry; very juicy), tenderness (very tough; very tender), flavour (undetectable; very intense), and overall quality (highly undesirable; extremely desirable). Each panellist participated in 2 sessions and during each session evaluated three replicates from all heat treatment in randomized order.

2.11. Statistical analysis

All data were analysed using Statistica 13 software (TIBCO Software Inc., Palo Alto, CA, USA). The Shapiro–Wilk test was used to analyse the normal data distribution of the variables, and variance homogeneity was analysed by Levene's F test.

Analysis was performed using the mixed model ANOVA. The data were analysed as a factorial arrangement to assess the significance of experimental factors on all traits with exception of the sensory analysis. Individual records of physicochemical traits were processed in terms of cooking method as a fixed effect and slaughter day and cooking batch as random effects. In addition, scores of sensory analysis was averaged over panellists and replicates, and in the statistical model the panellists and the sessions were considered as random effects. Differences among the means were compared by using Tukey's (HSD) test. Statistical significance was set at $P < 0.05$. Means and standard error are given in the tables.

3. Results

Table 2 shows the effect of the cooking method on the chemical composition (expressed in % of fresh weight) and water activity of the *longissimus thoracis* muscle. A significant ($P < 0.05$) decrease in moisture content and at the same time a significant ($P < 0.05$) increase in protein, collagen and fat content was observed. The highest ($P < 0.05$) protein and collagen content was found in grilled (by 7.04 pp. and 0.28 pp., respectively) and steamed meat (by 6.3 pp. and 0.20 pp), and the highest fat content in the steamed samples (by 0.67 pp.; $P < 0.05$). Only grilled samples contained significantly ($P < 0.05$) more ash than the raw samples (by 0.19 pp). The cooking method did not have a significant impact on a_w, which also did not differ significantly between the raw and cooked samples.

The influence of cooking methods on the colour parameters of the *longissimus thoracis* of suckling calves is presented in Table 3. Irrespective of the cooking method, the meat colour was significantly ($P < 0.05$) lighter (higher L* value), more yellow (higher b* value) and less red (lower a* value) than the raw samples, with a greater hue angle (h° value). Sous vide meat had higher L* (by 0.74, $P > 0.05$ and 2.37, $P < 0.05$, respectively), a* (by 2.69 and 1.83; $P < 0.05$) and b* values (by 2.19 and 1.61; $P < 0.05$) than grilled and steamed samples. Colour saturation (C*) was significantly ($P < 0.05$) lower for grilled (16.80) and steamed (17.38) samples than for raw (18.59) and sous vide meat (18.99). Heat treatment significantly ($P < 0.05$) shifted the hue angle of veal from pinkish-red (h° = 49.63) to yellow between 66.66 (sous vide) and 73.25 (grilling).

The cooking method significantly ($P < 0.05$) influenced cooking loss (Table 4). The sous vide samples had the lowest cooking loss it was on average 6 pp. lower than in the grilled and steamed meat. There were no significant differences in shear force (WBSF) or shear energy depending on the cooking method.

The content of α-tocopherol (vitamin E) varied significantly ($P < 0.05$) between raw (163.88 μg/100 g) and cooked meat (107.69–140.88 μg/100 g), irrespective of the heat treatment (Table 5). The highest content of α-tocopherol in the cooked samples was observed in grilled meat, followed by sous vide and steamed ones. The content of retinol in all samples was below the limit of quantification (LOQ) of the method used, i.e. 2 μg/100 g. While heat treatment significantly ($P < 0.05$) increased the amount of thiobarbituric acid reactive substances (TBARS), on average by 2.24 mg MDA/kg, the TBARS value was twice as high in the steamed samples than in the grilled ones ($P < 0.05$).

The sensory properties of the sous vide and grilled samples were scored higher than the steamed meat, and significant ($P < 0.05$) differences were noted for almost all attributes (except for tenderness), including overall quality (Table 6). The highest scores for all sensory characteristics were obtained in the sous vide samples, i.e. aroma – 8.22, juiciness – 8.44, tenderness – 8.68, flavour – 8.91, and overall quality – 8.93 pts. (out of a maximum of 10 pts).

Table 2
Effect of cooking method on proximate composition, collagen content, and water activity (a_w) of the *longissimus thoracis* of Limousin suckling calves (mean value ± SE).

Cooking method	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Collagen (%)	a_w
Raw	$74.75^c \pm 0.08$	$22.47^a \pm 0.09$	$0.70^a \pm 0.05$	$1.19^a \pm 0.04$	$0.43^a \pm 0.01$	$0.933^a \pm 0.003$
Grilling	$67.18^a \pm 0.14$	$29.51^c \pm 0.09$	$1.01^b \pm 0.04$	$1.38^b \pm 0.03$	$0.71^d \pm 0.03$	$0.930^a \pm 0.004$
Sous vide	$69.97^b \pm 0.39$	$26.80^b \pm 0.42$	$0.89^b \pm 0.02$	$1.26^{ab} \pm 0.04$	$0.55^b \pm 0.01$	$0.920^a \pm 0.004$
Steaming	$67.02^a \pm 0.56$	$28.76^c \pm 0.14$	$1.37^c \pm 0.04$	$1.23^{ab} \pm 0.05$	$0.63^c \pm 0.02$	$0.932^a \pm 0.004$

Means in columns with different letters a, b, c, d differ statistically significantly at $P < 0.05$.

Table 3
Effect of cooking method on colour parameters of the *longissimus thoracis* of Limousin suckling calves (mean value ± SE).

Cooking method	L*	a*	b*	C*	h°
Raw	$41.00^a \pm 0.28$	$12.14^d \pm 0.48$	$14.04^a \pm 0.29$	$18.59^b \pm 0.52$	$49.63^a \pm 0.62$
Grilling	$63.90^{bc} \pm 0.48$	$4.86^a \pm 0.12$	$16.07^b \pm 0.14$	$16.80^a \pm 0.16$	$73.25^d \pm 0.33$
Sous vide	$64.64^c \pm 0.24$	$7.55^c \pm 0.17$	$17.40^c \pm 0.14$	$18.99^b \pm 0.18$	$66.66^b \pm 0.36$
Steaming	$63.01^b \pm 0.47$	$5.72^b \pm 0.24$	$16.36^b \pm 0.17$	$17.38^a \pm 0.23$	$71.06^c \pm 0.59$

Means in columns with different letters a, b, c, d differ statistically significantly at $P < 0.05$.

Table 4
Effect of cooking method on cooking loss, shear force (WBSF) and shear energy of the *longissimus thoracis* of Limousine suckling calves (mean value ± SE).

Cooking method	Cooking loss (%)	WBSF (N)	Shear energy (mJ)
Grilling	$26.61^b \pm 1.68$	$24.36^a \pm 1.14$	$119.50^a \pm 8.68$
Sous vide	$20.62^a \pm 0.81$	$20.75^a \pm 1.58$	$88.52^a \pm 5.76$
Steaming	$26.68^b \pm 1.15$	$20.40^a \pm 1.60$	$93.65^a \pm 6.67$

Means in columns with different letters a, b differ statistically significantly at $P < 0.05$.

Table 5
Effect of cooking method on retinol (vitamin A) and α-tocopherol (vitamin E) content and TBARS value of the *longissimus thoracis* of Limousin suckling calves (mean value ± SE).

Cooking method	Retinol (μg/100 g)	α-Tocopherol (μg/100 g)	TBARS (mg MDA/kg)
Raw	<LOQ = 2	$163.88^d \pm 2.31$	$0.13^a \pm 0.01$
Grilling	<LOQ = 2	$140.88^c \pm 2.60$	$1.60^b \pm 0.02$
Sous vide	<LOQ = 2	$124.06^b \pm 1.45$	$2.24^c \pm 0.02$
Steaming	<LOQ = 2	$107.69^a \pm 1.82$	$3.28^d \pm 0.03$

Means in rows with different letters a, b, c, d differ statistically significantly at $P < 0.05$.

Table 6
Effect of cooking method on sensory properties (rated on a 10-point scale) of the *longissimus thoracis* of Limousin suckling calves (mean value ± SE).

Cooking method	Aroma	Juiciness	Tenderness	Flavour	Overall quality
Grilling	$6.93^b \pm 0.74$	$8.23^b \pm 0.50$	$8.21^a \pm 0.56$	$7.66^{ab} \pm 0.48$	$8.06^b \pm 0.38$
Sous vide	$8.22^b \pm 0.65$	$8.44^b \pm 0.37$	$8.68^a \pm 0.33$	$8.91^b \pm 0.44$	$8.93^b \pm 0.25$
Steaming	$3.71^a \pm 0.31$	$5.55^a \pm 0.42$	$7.08^a \pm 0.45$	$6.84^a \pm 0.50$	$6.15^a \pm 0.35$

Means in columns with different letters a, b differ statistically significantly at $P < 0.05$.

4. Discussion

4.1. Proximate composition

The proximate composition of the raw *longissimus thoracis* muscle in present study is within the ranges obtained by Gerber (2007) in various cuts of veal – breast, chop, loin, braising steak and ground meat (water 63.9–75.3%, protein 18.3–22.8% and ash 0.96–1.25%). Cooking had varied effects on the content of several nutrients in veal, depending on the method used. An expected decrease in the moisture content was observed, on average by 7.70 pp., with a significantly the lower level in steamed and grilled meat. Similar results were previously reported for veal and beef by other authors (Alfaia et al., 2010; Modzelewska-Kapituła, Dąbrowska, Jankowska, Kwiatkowska, & Cierach, 2012; Nikmaram, Yarmand, & Emamjomeh, 2011; Oz et al., 2017). Water losses in cooked meat are caused by three main processes: 1) water can evaporate due to increased temperature and/or reduced pressure; 2) increased temperatures during cooking cause myofibrillar proteins to shrink, resulting in a parallel decrease in the interfibrillar volume, which in turn reduces the ability of myofibrils to hold water; 3) contraction of the perimysium (which takes place at 56–62 °C) causes compression of the muscle fibre bundles, which in turn encourages water to be released from the meat cut (Sánchez del Pulgar, Gázquez, & Ruiz-Carrascal, 2012).

As a consequence of moisture loss through cooking, the concentration of most nutrients increases. Thus the fat and protein contents of cooked meat are usually higher than in the corresponding raw meat (Campo et al., 2013; Modzelewska-Kapituła et al., 2012; Sheard, Wood, Nute, & Ball, 1998). This tendency was also observed in this study, as significant increases in protein (5.56 pp. on average) and fat (0.39 pp. on average) were noted for all cooking methods in comparison to raw meat.

The content of intramuscular fat (IMF) is one of the most important parameters for consumers due to its importance for the quality and nutritional value of meat (Domínguez et al., 2019). In the present study, however, the level of fat was very low (0.7%) – no more than half of that recorded by other authors in veal or beef (Gerber, 2007; Modzelewska-Kapituła et al., 2019), which is generally typical of meat from suckling calves (Domaradzki et al., 2017). According to European Commission Regulation (EC) No 1924/2006 (EC, 2006), the veal used in the study can be considered low-fat, as the lipid content was lower than 3%.

The ash value obtained for raw meat, as an indicator of total mineral content, is in agreement with the results of other authors (Gerber, 2007; Lopes et al., 2015). Cooking did not lead to significant differences in ash content among treatments, but there were some differences between samples cooked by various methods (steaming < sous vide < grilling). Moreover, the content of ash in the grilled samples was significantly higher than in the raw meat. Since grilling takes place in the absence of water (a dry cooking method), it allowed for a higher retention of ash than steaming (a wet cooking method) or sous vide, in which moisture loss can be limited by the use of plastic bags. Similarly, Lopes et al. (2015) observed that microwaving and grilling increased the ash content of Barrosã-PDO veal, while boiling decreased its content compared with the raw meat. Differences between dry-heat and moist-heat cooking methods have also been reported for mutton by Sainsbury, Schönfeldt, and Van Heerden (2011), with greater moisture losses in dry-heat cooking procedures. Van Heerden and Strydom (2017) showed that selection of an appropriate cooking method might increase nutrient retention, as lamb and mutton cuts cooked with moist heat showed a tendency to retain nutrients better than dry-cooked cuts. However, cut-specific characteristics may also have influenced this effect.

Collagen, the main connective tissue protein in animals, comprises 20% to 25% of total body protein (Roy, Das, Aalhus, & Bruce, 2021). It makes up a few per cent of the weight of strong, sinewy muscles and 1–2% of muscle mass (Wiśniewski, Wróbel, Barszczewski, Sakowski, & Kuczyńska, 2021). Christensen et al. (2011) found that among 15 European cattle breeds, slaughtered at the age of 13–16 months, the total collagen percentage of the *longissimus thoracis* in Limousin was one of the lowest (0.29% wet tissue). A slightly higher collagen content (0.89%) in Limousin crossbred calves staying with their mothers in the pasture up to 7–8 months was reported by Florek (2009). In veal of other breeds total collagen content may vary from 0.6% in 'Vitela Tradicional do Montado-PGI' calves slaughtered at 9 months (Monteiro et al., 2013) to 1.8%, in Holstein-Friesian calves slaughtered at about 6 months (Scheeder, Becker, & Kreuzer, 1999). For the latter breed, but milk-fed calves slaughtered at 50–60 days, Domaradzki, Florek, and Litwińczuk (2013) reported total collagen content of 0.9% in the *longissimus lumborum* and 1.4% in the *semitendinosus* muscle.

Collagen plays a vital role during cooking. When collagen fibres are heated, they shrink, causing fluid loss and less tender meat (Wiśniewski et al., 2021). In general, an increase in total collagen content during heating of beef was reported by Modzelewska-Kapituła et al. (2012). While the content of collagen depended on the thermal processing method (in steam and dry air), endpoint internal temperature (75 °C, 85 °C and 95 °C), and muscle type (*infraspinatus* and *semimembranosus*), the collagen content in the cooked samples was as much as twice as high as in the raw meat (Modzelewska-Kapituła et al., 2012). Moreover, the collagen level in the *infraspinatus* muscle heated to 75 °C in dry air was significantly higher than in the case of steaming (3465 vs. 2743 mg/100 g, respectively), which was explained by the lower moisture content in the muscle after heating in dry air. Kołczak, Krzysztoforski, and Palka (2007) reported the greater passing of intramuscular collagen into the water during boiling of bovine muscles than in roasted or fried samples. In the present study, a significant increase in collagen content was observed after cooking, as well as a higher level of collagen in grilled samples compared to steamed ones, which is in agreement with the studies cited above.

Water activity (a_w) is one of the major parameters responsible for food stability, modulation microbial growth, and determination of the type of microorganisms encountered in food (Tapia, Alzamora, & Chirife, 2020). While moisture content is defined as the ratio of water mass to sample mass, water activity is the partial vapour pressure of pure water, which indicates the availability of water for bacterial growth. The a_w of meat and meat products is in the range of 0.99–0.70. Meat products have a lower a_w than fresh meat and therefore a better shelf-life (Leistner & Roedel, 1975). Food with $a_w > 0.90$ can be considered to have a high moisture level (Leistner, 1985). In fresh meat, a_w is high, close to 1, which is confirmed by the results of numerous studies conducted on various meats, including beef (Florek et al., 2019), goat (Teixeira, Pereira, & Rodrigues, 2011), mutton (Sen, Naveena, Muthukumar, & Vaithiyanathan, 2014). Results focusing on quality changes in veal products associated with water activity during processing, storage and cooking are very limited (Li, McKeith, Shen, & McKeith, 2018). Li et al. (2018) reported that the water activity of fresh veal patties was 0.991 and did not change significantly after cooking to various internal temperatures. Sen et al. (2014) evaluated the effect of different endpoint temperatures (51 °C, 65 °C, 71 °C and 79 °C) on the physicochemical stability of mutton chops and reported higher water activity in samples cooked at higher endpoint temperatures, though the differences were minimal and not significant. This is in agreement with our study, where no significant differences in a_w were observed in veal samples cooked by different methods.

4.2. Colour parameters

Colour is an important factor for consumer acceptance of uncooked or cooked meat and meat products (Oz et al., 2017). The colour of meat products is determined by the chemistry of myoglobin, the primary red pigment of muscle tissue. The ligand bound to haem iron, the valence state of iron, and the globin status (native or denatured) determine meat colour through various chemical forms of myoglobin. During heating, the globin protein is denatured, and the oxidation of purplish-red deoxymyoglobin or bright red oxymyoglobin to brown metmyoglobin is accelerated. Therefore, red meat turns brown, due to the formation of ferric haemichromes (Ramírez, Morcuende, Estévez, & Cava, 2004). In addition, cooked samples may undergo different patterns of protein denaturation depending on the final temperature reached at the surfaces (Lorenzo, Cittadini, Munekata, & Domínguez, 2015). Colour analysis performed by García-Segovia, Andrés-Bello, and Martínez-Monzó (2007) found that cooked beef steaks were generally lighter and more yellow, whereas the a* value decreased as temperature and cooking time increased. According to García-Segovia et al. (2007), consumers prefer a lighter colour (a higher L*) of cooked meat. Redness (a* value) is a parameter linked to the freshness of raw meat and the chemical state of myoglobin (Ramírez et al., 2004). In our study a* value of the raw veal meat was decreased by cooking most likely due to the denaturation of myoglobin (Roldan, Antequera, Martin, Mayoral, & Ruiz, 2013). Taking into account the cooking method, grilled samples had a significantly lower a* value than other cooked samples (grilling < steaming < sous vide). The fact that the redness value was highest in sous vide veal might indicate the lowest myoglobin degradation during heating. Moreover, cooking led to a significant increase in yellowness in all samples, which was most likely due to the formation of metmyoglobin and further heat-denaturation of this protein, giving rise to a brownish colour (Roldan et al., 2013). In the present study, the highest b* values of cooked samples were noted after the longest treatment, i.e. sous vide. Similarly, García-Segovia et al. (2007) reported significantly higher b* value for sous vide samples than for steaks cooked at atmospheric pressure and under vacuum (cook-vide). The potential differences in colour resulting from sous vide cooking at moderate temperatures for long periods of time may be due to differences in the degree of myoglobin denaturation and in the development of the Maillard reaction on the meat surface (Sánchez del Pulgar et al., 2012).

As mentioned above, muscle pigments (haemoglobin and myoglobin) are degraded by heat to form greyish-brown pigments (Oz & Celik, 2015). This occurs when the core temperature is around 55–60 °C (AMSA, 2012). However, heating meat to high temperatures, during grilling or pan-frying, also causes browning (Satyanarayan & Honikel, 1992). This is due to the formation of brown melanoidins and the development of heat-induced antioxidants in cooked meat, known as MRP (Maillard reaction products) (Ramírez & Cava, 2005). These products are thought to reduce the development of lipid oxidation and warmed-over-flavour in cooked and chill-stored meats and to have a positive impact on the palatability of meat products. It should be noted that MRPs are considered to have both positive and negative impacts on human health. Various MRPs act as antioxidants, bactericides, antiallergenic agents, anti-browning agents, pro-oxidants, and carcinogens. Most of these properties depend on food processing (Tamanna & Mahmood, 2015).

Chroma, or meat colour saturation (C*), is related to the concentration of myoglobin, but also to its degree of denaturation. This attribute is more predominant at higher concentrations of myoglobin and a lower rate of myoglobin denaturation (Sánchez del Pulgar et al., 2012). This was reflected in present study, as the C* values for raw and sous vide samples were significantly higher than those obtained for grilled and steamed samples.

The hue angle (h°) is affected by the chemical state of myoglobin and is inversely related to the a* value (Sánchez del Pulgar et al., 2012). Thus, sous vide samples showed significantly lower h° values than those cooked by other methods (sous vide < steaming < grilling), most likely due to the lower degree of myoglobin denaturation.

4.3. Cooking loss and shear force

Heat treatments induce water loss in meat, which is an important attribute of meat processing and sensory quality (Lorenzo & Domínguez, 2014). The water is lost due to heat-induced protein denaturation during cooking, which causes less water to be entrapped within the protein structures held by capillary forces (Aaslyng, Bejerholm, Ertbjerg, Bertram, & Andersen, 2003). The amount of cooking loss explains some of the variation in juiciness and influences the appearance of the meat due to the combined loss of liquid and soluble matter (Aaslyng et al., 2003). Laroche (1988) showed that cooking juice lost during heating processes was composed of water containing myofibrillar or sarcoplasmic proteins, collagen, lipids, salt, polyphosphates, flavour compounds, and other substances. Cooking loss from a product depends on the mass transfer process during heat treatment, and therefore different cooking methods can introduce variation into the cooking loss of meat products, thus affecting eating quality traits such as tenderness and juiciness (Cheng & Sun, 2008).

In the present study, cooking loss was significantly affected by the cooking method. Similar results have been reported by other authors (Alfaia et al., 2010; Domínguez, Gomez, Fonseca, & Lorenzo, 2014). As expected, the lowest cooking loss was observed in the sous vide samples (Table 4), which also had the highest moisture content (Table 2), while the highest cooking loss was found in grilled and steamed samples, which had the lowest moisture percentage. This difference was most likely due to different endpoint temperatures; grilled and steamed meat reached a higher temperature (72 °C) than sous vide samples (65 °C). Our results are similar to those obtained by Modzelewska-Kapituła et al. (2019) in beef from Holstein-Friesian bulls, in which sous vide treatment caused lower cooking losses than steaming (30.0% vs. 34.2%). Alfaia et al. (2010) also observed that increasing the final internal temperature (grilling < boiling < microwaving) resulted in greater cooking losses, as more moisture was lost through evaporation during processing. Gerber, Scheeder, and Wenk (2009) obtained lower cooking loss in veal chops grilled to a core temperature of 72 °C than in rolled breasts pan-fried for 1 min per side and then steamed for 45 min. The authors concluded that the long cooking time in combination with moist heating results in a high leaching effect.

According to Destefanis, Brugiapaglia, Barge, and Dal Molin (2008), cooked beef can be considered 'very tender' if the WBSF is below 32.96 N. Taking into account this recommendation, all samples in the present study, irrespective of the cooking method, can be classified as very tender. García-Segovia et al. (2007) suggest that changes in shear force during cooking are closely linked to the denaturation of intramuscular collagen or alterations in the myofibrillar structure. Between 50 °C and 65 °C, shrinkage of collagen fibres reduces the breaking strength of the connective tissue (perimysium). When the temperature is higher, the denaturation of intramuscular connective tissue contributes to meat tenderization, but the structural changes in myofibrils cause toughening. In traditional cooking methods, meat toughening is observed above 60 °C and results from myofibrillar protein denaturation (Modzelewska-Kapituła et al., 2019). In contrast, Vaudagna et al. (2002) reported that sous vide treatment at 60–65 °C resulted in tender beef. In addition, Botinestean, Keenan, Kerry, and Hamill (2016) noted lower shear force values for beef subjected to sous vide at 60 °C than for beef heated in a water bath to 70 °C. According to Modzelewska-Kapituła et al. (2019), the shorter time and higher temperature of steam cooking as compared to sous vide may result in a lower degree of collagen denaturation and a higher extent of denaturation of myofibrillar proteins, causing higher shear values. Lorenzo et al. (2015) noted that shear force values were affected by cooking loss; samples with higher cooking loss percentages also had the highest shear force values. In the present study, the relatively low shear force were most likely linked to type of meat, as veal is generally more tender than other red meats. Moreover, in our study veal was aged under vacuum for 14 days. The decrease in WBSF with ageing is well documented in the literature. In addition, veal not only contains more total collagen than beef, but its collagen is more soluble (Domaradzki et al., 2017). Collagen with a low number of thermo-stable intermolecular cross-links gelatinizes during cooking, which decreases the shear force of meat (Modzelewska-Kapituła, Nogalski, & Kwiatkowska, 2016).

4.4. Retinol, alpha-tocopherol, and TBARS value

Processing and cooking conditions cause variable losses of vitamins. Losses vary widely depending on the food and cooking method. Degradation of vitamins depends on specific conditions during the culinary process, e.g. the temperature, presence of oxygen, light, moisture, pH, and duration of heating. Retinol is considered one of the most labile vitamins during cooking processes (Lešková et al., 2006). Little is known about the effect of cooking methods on the stability of vitamin E in meat (Sobral et al., 2018). However, Chow (2001) reported that natural tocopherols are not highly stable. Gerber et al. (2009) found that the retinol and alpha-tocopherol concentrations in raw veal varied from 1.3 to 2.7 μg/100 g and from 207 to 268 μg/100 g, respectively. Heat treatment reduced the retinol content to between 0.9 and 1.6 μg/100 g and the alpha-tocopherol content to 172–208 μg/100 g. Driskell et al. (2011) reported that beef from steers contained from 469 to 508 μg/100 g of alpha-tocopherol. In the present study, the content of alpha-tocopherol in both in raw and cooked veal was lower than the values observed by the authors cited. The highest losses of this vitamin were observed during steaming, followed by sous vide and grilling. Steinhart and Rathjen (2003) found that the preparation of hot meals (roasting, baking, or stewing) affected the stability of the tocopherols, and in meat nearly 70% can be destroyed during heating. Vitamin A is stable in an inert atmosphere, but rapidly loses its activity when heated in the presence of oxygen, especially at higher temperatures (Lešková et al., 2006). Stepanova et al. (1982) reported that vitamin A was one of the least preserved substances in various meat samples (poultry and rabbit), irrespective of the cooking method. In our study, the retinol content was below the detection limit and therefore has been omitted from the discussion.

Compounds produced by lipid oxidation have a major influence on the flavour of cooked meat (Lorenzo & Domínguez, 2014). It is well known that lipid autoxidation to a certain extent produces an off-flavour of rancidity, sometimes referred to as 'warmed-over flavour'. However, moderate lipid oxidation during the initial cooking of meat contributes to desirable aromas (Song et al., 2011). As mentioned above, heat treatment caused a significant increase in the oxidation processes in veal (Table 5). These outcomes are in agreement with reports by many authors (Domínguez et al., 2014; Lorenzo et al., 2015; Lorenzo & Domínguez, 2014; Oz et al., 2017). Others, however (Alfaia et al., 2010; Nuernberg et al., 2006), have not observed an increase in the TBARS value after cooking.

According to Campo et al. (2006), a TBARS value of about 2 can be considered the threshold for acceptability of raw oxidized beef, whereas the threshold adopted by McKenna et al. (2005) was 1.0 mg MDA/kg. However, the values reported for raw meat may not be comparable with cooked samples, as confirmed research carried out by Hughes, McPhail, Kearney, Clarke, and Warner (2014) which showed that panellists testing cooked beef (*longissimus* muscle) aged for 20 weeks did not perceive any off-flavours, despite TBARS values ranging between 2.60 and 3.11 mg MDA/kg meat.

Among the cooking methods used in the present study, grilling resulted in significantly the lowest TBARS value, followed by sous vide and steaming (Table 5). Our results are similar to those obtained by Domínguez et al. (2014), who found the lowest TBARS level in grilled foal meat. According to the authors, the high temperature used in treatments such as grilling can cause the lipid oxidation compounds generated to react with other molecules such as amino acids and peptides, which may appear due to proteolytic reactions, thereby decreasing the content of oxidation compounds and malonaldehyde.

Factors associated with thermal treatment (cooking method, rate and final temperature), are considered as ones of those, that should be taken into account for the cooking effects on the rate and extent of lipid oxidation (Alfaia et al., 2010). In our study the duration of cooking and therefore exposure to elevated temperatures was different between heat treatments. This variation in total temperature exposure may contribute to the difference in oxidative biomarkers (elevated TBARS value and reduced concentration of alpha-tocopherol). According to Domínguez et al. (2014) the oxidation processes during cooking are more affected by cooking time than temperature. Similarly, Broncano, Petrón, Parra, and Timón (2009) in *latissimus dorsi* of Iberian pigs observed that the application of heat during a long time (20 min) in the roasted method (150 °C) resulted in a higher degree of meat oxidation than in the samples grilled in a shorter time (4 min) at higher temperature (190 °C).

4.5. Sensory quality

The aroma and flavour of cooked meat play a very important role in its eating quality and consumer acceptance and preference. These attributes are associated with volatile components derived from thermally induced reactions occurring during heating via four pathways: lipid oxidation, the Maillard reaction, an interaction between Maillard reaction products and lipid-oxidized products, and vitamin degradation. Flavour and other sensory attributes such as tenderness and juiciness are the most important criteria of acceptability, and the palatability of meat affects consumer's purchasing decisions (Ba, Hwang, Jeong, & Touseef, 2012). However, of all meat traits, tenderness seems to be the most important in terms of eating quality (Destefanis et al., 2008). In this study, tenderness was scored high, with minor and non-significant differences depending on the cooking method (Table 6).

It is widely accepted that most of the volatile aromatic compounds that contribute to the palatability of cooked meat are formed at temperatures above 70 °C, so a pleasant cooked flavour would not be expected to be developed at lower temperatures (between 50 and 60 °C). Therefore, in this case the flavour of meat is a combination of the contribution from fatty acid degradation products and from non-volatile compounds. Cooking time also increases the concentration of Strecker degradation products, such as carbon disulphide, dimethyl disulphide, 2-methylthiophene, 2-pentylthiophene and benzothiazole, which have a low odour threshold and are known to provide the meaty, savoury, roasted and boiled flavours associated with cooked meat (Dominguez-Hernandez, Salaseviciene, & Ertbjerg, 2018). This may explain the more intense aroma of the sous vide samples compared with the other heat treatments used in this study. On the other hand, the temperature profile of the sample was not uniform for all samples (e.g. grilled or steamed), with the exterior exposed to hotter temperatures than the interior. This also may be a potential source of variation in the eating experience and flavour or aroma volatiles generated during the cooking process. Lorenzo and Domínguez (2014) observed that the amounts of total volatile flavour compounds increased with cooking temperature.

Modzelewska-Kapituła et al. (2019) also observed a more intense aroma and taste in sous vide samples in comparison with steam-cooked beef, due to the use of vacuum pouches. This packaging and the longer cooking time of the sous vide treatment prevented the losses of specific volatile compounds, thereby increasing their concentrations, resulting in a more intense aroma and improved taste.

Juiciness is defined as the feeling of moisture in the mouth during chewing (Aaslyng et al., 2003). This sensation results from the combination of moisture chewed out of the meat and saliva mixed into it. Aaslyng et al. (2003) suggested that the initial juiciness experienced at the start of chewing depended only on the water content of the meat, whereas juiciness experienced later during chewing was determined by a combination of the water and intramuscular fat contents and saliva production. Meat treated by the sous vide method had significantly the highest moisture content of all treatments, but the level of fat was lower than in the other samples (Table 2). In beef, juiciness and cooking loss have been shown to be negatively correlated, so that high cooking loss results in low juiciness (Toscas, Shaw, & Beilken, 1999). Increased cooking loss also has a negative effect on the sensorial tenderness of beef (Silva, Patarata, & Martins, 1999). This is in agreement with the results of our study, in which juiciness and tenderness were highest in the sous vide samples, which also displayed the lowest level of cooking loss.

5. Conclusion

The results of this study suggest that the cooking method caused some significant quality changes in veal meat. The heat treatments increased lipid oxidation (TBARS value) and decreased the level of α-tocopherol, especially in the case of steaming. Regarding colour parameters, heat treatments increase lightness and yellowness while decreasing redness. The sous vide samples had the lowest cooking loss, whereas shear force values were similar for all cooking methods, which was consistent with the results of the tenderness assessment by the panellists. The sensory analysis showed a preference for the sous vide and grilled samples. Therefore, it can be concluded that in the case of veal the best cooking method is sous vide, followed by grilling. The least desirable method was steaming, mainly due to the low scores for sensory characteristics. Although veal is assumed to be very nutritious and tasty, its quality can be substantially modified by the cooking method.

Ethical approval

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CRediT authorship contribution statement

Agnieszka Kaliniak-Dziura: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Piotr Domaradzki:** Conceptualization, Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Marek Kowalczyk:** Formal analysis, Investigation. **Mariusz Florek:** Conceptualization, Validation, Writing – review & editing. **Piotr Skałecki:** Investigation, Writing – original draft. **Monika Kędzierska-Matysek:** Resources, Visualization. **Piotr Stanek:** Investigation, Data curation. **Małgorzata Dmoch:** Investigation. **Tomasz Grenda:** Formal analysis. **Edyta Kowalczuk-Vasilev:** Investigation.

Declaration of Competing Interest

All the authors declare that no conflict of interest exits in the submission of this manuscript.

References

Aaslyng, M. D., Bejerholm, C., Ertbjerg, P., Bertram, H. C., & Andersen, H. J. (2003). Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. *Food Quality and Preference, 14*(4), 277–288. https://doi.org/10.1016/S0950-3293(02)00086-1

Alfaia, C. M., Alves, S. P., Lopes, A. F., Fernandes, M. J., Costa, A. S., Fontes, C. M., & Prates, J. A. (2010). Effect of cooking methods on fatty acids, conjugated isomers of linoleic acid and nutritional quality of beef intramuscular fat. *Meat Science, 84*(4), 769–777. https://doi.org/10.1016/j.meatsci.2009.11.014

AMSA (American Meat Science Association). (2012). *Meat Color Measurement Guidelines*. Illinois, USA.

AOAC. (2012). Official methods of analysis of the AOAC international. In W. Horwitz, & G. W. Latimer, Jr. (Eds.), *Gaithersburg, Maryland, USA* (19th ed.).

Ayub, H., & Ahmad, A. (2019). Physiochemical changes in sous-vide and conventionally cooked meat. *International Journal of Gastronomy and Food Science, 17*, Article 100145. https://doi.org/10.1016/j.ijgfs.2019.100145

Ba, H. V., Hwang, I., Jeong, D., & Touseef, A. (2012). Principle of meat aroma flavors and future Prospect. In I. Akyar (Ed.), *Latest research into quality control*. https://doi.org/10.5772/51110. Intech Open.

Baldwin, D. E. (2012). Sous vide cooking: A review. *International Journal of Gastronomy and Food Science, 1*(1), 15–30. https://doi.org/10.1016/j.ijgfs.2011.11.002

Botinestean, C., Keenan, D. F., Kerry, J. P., & Hamill, R. M. (2016). The effect of thermal treatments including sous-vide, blast freezing and their combinations on beef tenderness of *M. semitendinosus* steaks targeted at elderly consumers. *LWT – Food Science and Technology, 74*, 154–159. https://doi.org/10.1016/j.lwt.2016.07.026

Broncano, J. M., Petrón, M. J., Parra, V., & Timón, M. L. (2009). Effect of different cooking methods on lipid oxidation and formation of free cholesterol oxidation products (COPs) in latissimus dorsi muscle of Iberian pigs. *Meat Science, 83*(3), 431–437. https://doi.org/10.1016/j.meatsci.2009.06.021

Campo, M. M., Muela, E., Olleta, J. L., Moreno, L. A., Santaliestra-Pasías, A. M., Mesana, M. I., & Sanudo, C. (2013). Influence of cooking method on the nutrient composition of Spanish light lamb. *Journal of Food Composition and Analysis, 31*, 185–190. https://doi.org/10.1016/j.jfca.2013.05.010

Campo, M. M., Nute, G. R., Hughes, S. I., Enser, M., Wood, J. D., & Richardson, R. I. (2006). Flavour perception of oxidation in beef. *Meat Science, 72*(2), 303–311. https://doi.org/10.1016/j.meatsci.2005.07.015

Cheng, Q., & Sun, D. W. (2008). Factors affecting the water holding capacity of red meat products: A review of recent research advances. *Critical Reviews in Food Science and Nutrition, 48*, 137–159. https://doi.org/10.1080/10408390601177647

Chow, C. K. (2001). Vitamin E. In R. B. Rucker, J. W. Suttie, D. B. McCormick, & L. J. Machlin (Eds.), *Handbook of vitamins* (3rd ed., pp. 165–197). Marcel Dekker.

Christensen, M., Ertbjerg, P., Failla, S., Sañudo, C., Richardson, R. I., Nute, G. R., & Williams, J. L. (2011). Relationship between collagen characteristics, lipid content and raw and cooked texture of meat from young bulls of fifteen European breeds. *Meat Science, 87*, 61–65. https://doi.org/10.1016/j.meatsci.2010.09.003

CIE. (2004). *Colorimetry* (3rd ed., pp. 16–20). Vienna Austria: Commission International de l'Eclairage.

Cui, Z. K., Han, Y., Manoli, T., Mo, H. Z., Bi, J. C., & Zhang, H. (2021). Advantages and challenges of sous vide cooking. *Food Science and Technology Research, 27*, 25–34. https://doi.org/10.3136/fstr.27.25

Destefanis, G., Brugiapaglia, A., Barge, M. T., & Dal Molin, E. (2008). Relationship between beef consumer tenderness perception and Warner-Bratzler shear force. *Meat Science, 78*(3), 153–156. https://doi.org/10.1016/j.meatsci.2007.05.031

Domaradzki, P., Florek, M., & Litwińczuk, A. (2013). Total and soluble collagen contents in skeletal muscles of different cattle categories of polish Holstein-Friesian breed. *EPISTEME: Czasopismo Naukowo-Kulturalne, 21*(2), 177–185.

Domaradzki, P., Stanek, P., Litwińczuk, Z., Skałecki, P., & Florek, M. (2017). Slaughter value and meat quality of suckler calves: A review. *Meat Science, 134*, 135–149. https://doi.org/10.1016/j.meatsci.2017.07.026

Domínguez, R., Gomez, M., Fonseca, S., & Lorenzo, J. M. (2014). Effect of different cooking methods on lipid oxidation and formation of volatile compounds in foal meat. *Meat Science, 97*(2), 223–230. https://doi.org/10.1016/j.meatsci.2014.01.023

Domínguez, R., Pateiro, M., Gagaoua, M., Barba, F. J., Zhang, W., & Lorenzo, J. M. (2019). A comprehensive review on lipid oxidation in meat and meat products. *Antioxidants, 8*(10), 429. https://doi.org/10.3390/antiox8100429

Dominguez-Hernandez, E., Salaseviciene, A., & Ertbjerg, P. (2018). Low-temperature long-time cooking of meat: Eating quality and underlying mechanisms. *Meat Science, 143*, 104–113. https://doi.org/10.1016/j.meatsci.2018.04.032

Driskell, J. A., Kim, Y.-N., Giraud, D. W., Hamouz, F. L., de Mello, A. S., Erickson, G. E., & Calkins, C. R. (2011). Vitamin and mineral content of value cuts from beef steers fed distiller's grains. *Journal of Food Composition and Analysis, 24*(3), 362–367. https://doi.org/10.1016/j.jfca.2010.08.013

EC. (2005). Council regulation (EC) no 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending directives 64/432/EEC and 93/119/EC and regulation (EC) no 1255/97. *Official Journal of the European Union, L, 3*, 1–44.

EC. (2006). Regulation (EC) no 1924/2006 of the European Parliament and of the council of 20 December 2006 on nutrition and health claims made on foods. *Official Journal of the European Union, L, 404*, 9–25.

EC. (2009). Council regulation (EC) no 1099/2009 of 24 September 2009 on the protection of animals at the time of killing. *Official Journal of the European Union, L, 303*, 1–30.

Eitenmiller, R. R., Landen, W. O., Jr., & Ye, L. (2007). *Vitamin analysis for the health and food sciences* (2nd ed.). CRC Press.

Florek, M. (2009). Effect of chosen factors on calf slaughter value, physicochemical parameters of meat and its nutritional quality. In *Dissertations of University of Life Sciences in Lublin, 107 (in polish, Summary in English)*.

Florek, M., Domaradzki, P., Żółkiewski, P., Ruda, B., Litwińczuk, Z., & Kędzierska-Matysek, M. (2019). Physicochemical properties and indices of shelf life stability of dry aged beef with acid whey. *Medycyna Weterynaryjna, 75*(8), 487–492. https://doi.org/10.21521/mw.6214

García-Segovia, P., Andrés-Bello, A., & Martínez-Monzó, J. (2007). Effect of cooking method on mechanical properties, color and structure of beef muscle (*M. pectoralis*). *Journal of Food Engineering, 80*(3), 813–821. https://doi.org/10.1016/j.jfoodeng.2006.07.010

Gerber, N. (2007). *The role of meat in human nutrition for the supply with nutrients, particularly functional long-chain n-3 fatty acids*. Doctoral dissertation. ETH Zurich.

Gerber, N., Scheeder, M. R. L., & Wenk, C. (2009). The influence of cooking and fat trimming on the actual nutrient intake from meat. *Meat Science, 81*(1), 148–154. https://doi.org/10.1016/j.meatsci.2008.07.012

Hughes, J. M., McPhail, N. G., Kearney, G., Clarke, F., & Warner, R. D. (2014). Beef longissimus eating quality increases up to 20 weeks of storage and is unrelated to meat colour at carcass grading. *Animal Production Science, 55*, 174–179. https://doi.org/10.1071/AN14304

IZ PIB. (2014). Feeding Recommendation for Ruminants and Feed Tables. In J. A. Strzetelski, F. Brzóska, Z. M. Kowalski, & S. Osięgłowski (Eds.), *IZ PIB Foundation. (in Polish)*.

Kołczak, T., Krzysztoforski, K., & Palka, K. (2007). The effect of post-mortem ageing and heating on water retention in bovine muscles. *Meat Science, 75*(4), 655–660. https://doi.org/10.1016/j.meatsci.2006.09.014

Laroche, M. (1988). Lacaisson. In J. P. Girard (Ed.), *Technologie de laviandeet des produitscarnés (pp. 33–75)*. Technique & Documentation Lavoisier.

Leistner, L. (1985). Hurdle technology applied to meat products of the shelf-stable product and intermediate moisture food types. In D. Samantos, & J. Multon (Eds.), *Properties of water and food* (pp. 309–329). Dordrecht: Martinus Nijhoff Publishers.

Leistner, L., & Roedel, W. (1975). The significance of water activity for microorganisms in meats. In R. B. Duckworth (Ed.), *Water relation in foods* (pp. 309–323). London: Academic Press.

Lešková, E., Kubíková, J., Kováčiková, E., Košická, M., Porubská, J., & Holčíková, K. (2006). Vitamin losses: Retention during heat treatment and continual changes expressed by mathematical models. *Journal of Food Composition and Analysis, 19*(4), 252–276. https://doi.org/10.1016/j.jfca.2005.04.014

Li, K., McKeith, A. G., Shen, C., & McKeith, R. A. (2018). Comparison study of quality attributes of ground beef and veal patties and thermal inactivation of *Escherichia coli* O157:H7 after double Pan-broiling under dynamic conditions. *Foods, 7*(1), 1. https://doi.org/10.3390/foods7010001

Lopes, A. F., Alfaia, C. M., Partidário, A. M., Lemos, J. P., & Prates, J. A. (2015). Influence of household cooking methods on amino acids and minerals of Barrosã-PDO veal. *Meat Science, 99*, 38–43. https://doi.org/10.1016/j.meatsci.2014.08.012

Lorenzo, J. M., Cittadini, A., Munekata, P. E., & Domínguez, R. (2015). Physicochemical properties of foal meat as affected by cooking methods. *Meat Science, 108*, 50–54. https://doi.org/10.1016/j.meatsci.2015.05.021

Lorenzo, J. M., & Domínguez, R. (2014). Cooking losses, lipid oxidation and formation of volatile compounds in foal meat as affected by cooking procedure. *Flavour and Fragrance Journal, 29*, 240–248. https://doi.org/10.1002/ffj.3201

McAfee, A. J., Emeir, M., McSorley, A., Geraldine, J., Cuskelly, B., Bruce, W., & Fearon, A. M. (2010). Red meat consumption: An overview of the risks and benefits. *Meat Science, 84*(1), 1–13. https://doi.org/10.1016/j.meatsci.2009.08.029

McKenna, D. R., Mies, P. D., Baird, B. E., Pfeiffer, K. D., Ellebracht, J. W., & Savell, J. W. (2005). Biochemical and physical factors affecting discoloration characteristics of 19 bovine muscles. *Meat Science, 70*(4), 665–682. https://doi.org/10.1016/j.meatsci.2005.02.016

Modzelewska-Kapituła, M., Dąbrowska, E., Jankowska, B., Kwiatkowska, A., & Cierach, M. (2012). The effect of muscle, cooking method and final internal temperature on quality parameters of beef roast. *Meat Science, 91*(2), 195–202. https://doi.org/10.1016/j.meatsci.2012.01.021

Modzelewska-Kapituła, M., Nogalski, Z., & Kwiatkowska, A. (2016). The influence of crossbreeding on collagen solubility and tenderness of infraspinatus and semimembranosus muscles of semi-intensively reared young bulls. *Animal Science Journal, 87*(10), 1312–1321. https://doi.org/10.1111/asj.12581

Modzelewska-Kapituła, M., Pietrzak-Fiećko, R., Tkacz, K., Draszanowska, A., & Więk, A. (2019). Influence of sous vide and steam cooking on mineral contents, fatty acid composition and tenderness of semimembranosus muscle from Holstein-Friesian bulls. *Meat Science, 157*, Article 107877. https://doi.org/10.1016/j.meatsci.2019.107877

Monteiro, A. C. G., Gomes, E., Barreto, A. S., Silva, M. F., Fontes, M. A., Bessa, R. J. B., & Lemos, J. P. C. (2013). Eating quality of "Vitela Tradicional do Montado"-PGI veal and Mertolenga-PDO veal and beef. *Meat Science, 94*, 63–68. https://doi.org/10.1016/j.meatsci.2012.12.011

Nikmaram, P., Yarmand, M. S., & Emamjomeh, Z. (2011). Effect of cooking methods on chemical composition, quality and cook loss of camel muscle (*longissimus dorsi*) in comparison with veal. *African Journal of Biotechnology, 10*(51), 10478–10483. https://doi.org/10.5897/AJB10.2534

Nuernberg, K., Kuechenmeister, U., Nuernberg, G., Hartung, M., Dannenberger, D., & Ender, K. (2006). Effect of storage and grilling on fatty acids in muscle pigs fed plant oils. *European Journal of Lipid Science and Technology, 108*, 554–560. https://doi.org/10.1002/ejlt.200600006

Oz, F., Aksu, M. I., & Turan, M. (2017). The effects of different cooking methods on some quality criteria and mineral composition of beefsteaks. *Journal of Food Processing and Preservation, 41*. https://doi.org/10.1111/jfpp.13008. Article e13008.

Oz, F., & Celik, T. (2015). Some properties of goose meat. *Journal of Food Processing and Preservation, 39*, 2442–2454. https://doi.org/10.1111/jfpp.12494

Pereira, P. M., & Vicente, A. F. (2013). Meat nutritional composition and nutritive role in the human diet. *Meat Science, 93*(3), 586–592. https://doi.org/10.1016/j.meatsci.2012.09.018

PN-A-04018/Az3. (2002). *Agricultural food products – Determination of nitrogen by Kjeldahl method and expressing as protein*.

PN-ISO 1442. (2000). *Meat and meat products – Determination of moisture content (reference method)*.

PN-ISO 1444. (2000). *Meat and meat products – Determination of free fat content*.

PN-ISO 3496. (2000). *Meat and meat products – Determination of hydroxyproline content*.

PN-ISO 4121. (1998). *Sensory analysis – Methodology – Evaluation of food products by methods using scales*.

PN-ISO 936. (2000). *Meat and meat products – Determination of total ash*.

Ramírez, M. R., & Cava, R. (2005). Changes in colour, lipid oxidation and fatty acid composition of pork loin chops as affected by the type of culinary frying fat. *LWT - Food Science and Technology, 38*(7), 726–734. https://doi.org/10.1016/j.lwt.2004.09.005

Ramírez, M. R., Morcuende, D., Estévez, M., & Cava, R. (2004). Effects of the type of frying with culinary fat and refrigerated storage on lipid oxidation and colour of fried pork loin chops. *Food Chemistry, 88*, 85–94. https://doi.org/10.1016/j.foodchem.2004.01.024

Roldan, M., Antequera, T., Martin, A., Mayoral, A. I., & Ruiz, J. (2013). Effect of different temperature–time combinations on physicochemical, microbiological, textural and structural features of sous-vide cooked lamb loins. *Meat Science, 93*, 572–578. https://doi.org/10.1016/j.foodchem.2013.10.079

Roy, B. C., Das, C., Aalhus, J. L., & Bruce, H. L. (2021). Relationship between meat quality and intramuscular collagen characteristics of muscles from calf-fed, yearling-fed and mature crossbred beef cattle. *Meat Science, 173*, Article 108375. https://doi.org/10.1016/j.meatsci.2020.108375

Ruiz-Carrascal, J., Roldan, M., Refolio, F., Perez-Palacios, T., & Antequera, T. (2019). Sous-vide cooking of meat: A Maillarized approach. *International Journal of Gastronomy and Food Science, 100138*. https://doi.org/10.1016/j.ijgfs.2019.100138

Sainsbury, J., Schönfeldt, H. C., & Van Heerden, S. M. (2011). The nutrient composition of south African mutton. *Journal of Food Composition and Analysis, 24*, 720–726. https://doi.org/10.1016/j.jfca.2011.01.001

Sánchez del Pulgar, J., Gázquez, A., & Ruiz-Carrascal, J. (2012). Physico-chemical, textural and structural characteristics of sous-vide cooked pork cheeks as affected by vacuum, cooking temperature, and cooking time. *Meat Science, 90*(3), 828–835. https://doi.org/10.1016/j.meatsci.2011.11.024

Satyanarayan, V. T., & Honikel, K. O. (1992). Effect of different cooking methods on warmed-over flavour development in pork. *Zeitschrift für Lebensmittel-Untersuchung und -Forschung, 194*, 422–425. https://doi.org/10.1007/BF01197721

Scheeder, M. R. L., Becker, B., & Kreuzer, M. (1999). Veal colour and other meat quality characteristics in valves fattened on maize silage and concentrate. *Archives Animal Breeding, 42*, 535–554. https://doi.org/10.5194/aab-42-535-1999

Sen, A. R., Naveena, B. M., Muthukumar, M., & Vaithiyanathan, S. (2014). Colour, myoglobin denaturation and storage stability of raw and cooked mutton chops at different end point cooking temperature. *Journal of Food Science and Technology, 51*(5), 970–975. https://doi.org/10.1007/s13197-011-0557-z

Sheard, P. R., Wood, J. D., Nute, G. R., & Ball, R. C. (1998). Effects of grilling to 80 °C on the chemical composition of pork loin chops and some observations on the UK National Food Survey Estimate of fat consumption. *Meat Science, 49*(2), 193–204. https://doi.org/10.1016/s0309-1740(97)00138-1

Silva, J. A., Patarata, L., & Martins, C. (1999). Influence of ultimate pH on bovine meat tenderness during ageing. *Meat Science, 52*, 453–459. https://doi.org/10.1016/S0309-1740(99)00029-7

Sobral, M. M. C., Cunha, S. C., Faria, M. A., & Ferreira, I. M. (2018). Domestic cooking of muscle foods: Impact on composition of nutrients and contaminants. *Comprehensive Reviews in Food Science and Food Safety, 17*, 309–333. https://doi.org/10.1111/1541-4337.12327

Song, S., Zhang, X., Havat, K., Liu, P., Jia, C., Xia, S., & Niu, Y. (2011). Formation of the beef flavour precursors and their correlation with chemical parameters during the controlled thermal oxidation of tallow. *Food Chemistry, 124*, 203–209. https://doi.org/10.1016/j.foodchem.2010.06.010

Steinhart, H., & Rathjen, T. (2003). Dependence of tocopherol stability on different cooking procedures of food. *International Journal for Vitamin and Nutrition Research, 73*, 144–151. https://doi.org/10.1024/0300-9831.73.2.144

Stepanova, E. N., Grigoreva, M. P., Orlova, N. V., Smirnova, E. V., Fomina, L. V., & Chumakova, W. (1982). Effect of cooking on vitamins in poultry and rabbit meat. *Voprosy Pitaniya, 3*, 54–58.

Tamanna, N., & Mahmood, N. (2015). Food processing and Maillard reaction products: Effect on human health and nutrition. *International Journal of Food Science*. https://doi.org/10.1155/2015/526762. Article 526762.

Tapia, M. S., Alzamora, S. M., & Chirife, J. (2020). Effects of water activity (aw) on microbial stability as a hurdle in food preservation. In G. V. Barbosa-Cánovas, A. J. Fontana, S. J. Schmidt, & T. P. Labuza (Eds.), *Water activity in foods*. Inc: John Wiley & Sons. https://doi.org/10.1002/9781118765982.ch14.

Teixeira, A., Pereira, E., & Rodrigues, E. S. (2011). Goat meat quality. Effects of salting, air-drying and ageing processes. *Small Ruminant Research, 98*, 55–58. https://doi.org/10.1016/j.smallrumres.2011.03.018

Toscas, P. J., Shaw, F. D., & Beilken, S. L. (1999). Partial least squares (PLS) regression for the analysis of instrument measurements and sensory meat quality data. *Meat Science, 52*(2), 173–178. https://doi.org/10.1016/S0309-1740(98)00165-X

Van Heerden, S. M., & Strydom, P. E. (2017). Nutrient retention values and cooking yield factors for three south African lamb and mutton cuts. *Journal of the Science of Food and Agriculture, 97*(14), 5037–5042. https://doi.org/10.1002/jsfa.8396

Vaudagna, S. R., Sanchez, G., Neira, M. S., Insani, E. M., Picallo, A. B., Gallinger, M. M., & Lasta, J. A. (2002). Sous vide cooked beef muscles: Effects of low temperature – Long time (LT-LT) treatments on their quality characteristics and storage stability. *International Journal of Food Science and Technology, 37*, 425–441. https://doi.org/10.1046/j.1365-2621.2002.00581.x

Vieira, C., García, M. D., Cerdeño, A., & Mantecón, A. R. (2005). Effect of diet composition and slaughter weight on animal performance, carcass and meat quality, and fatty acid composition in veal calves. *Livestock Production Science, 93*, 263–275. https://doi.org/10.1016/j.livprodsci.2004.11.020

Wiśniewski, K., Wróbel, B., Barszczewski, J., Sakowski, T., & Kuczyńska, B. (2021). Chemical characteristics of limousine beef depending on finishing diets and muscle type of meat. *Acta Universitatis Cibiniensis Series E: Food Technology, 143*(XXV). https://doi.org/10.2478/aucft-2021-0014, 1, 143–154.

Witte, V. C., Krause, G. F., & Bailey, M. E. (1970). A new extraction method for determining 2-thiobarbituric acid values of pork and beef during storage. *Journal of Food Science, 35*, 582–585. https://doi.org/10.1111/j.1365-2621.1970.tb04815.x