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# Effects of dry and wet ageing on culled goat meat quality

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**ABSTRACT**

This study aims to evaluate the effects of ageing time (0, 1, 2, 3, 4 and 5 weeks) and of two different ageing techniques (dry and wet ageing) on the rheological, colorimetric, oxidative, volatile, and sensory attributes of meat (hind limbs) sourced from culled Rossa Mediterranea breed goats. Twenty-four goats were involved in the trial. The hind limbs were divided in the two experimental groups: the right ones were subjected to dry ageing and the left ones to wet ageing. Dry-aged (DA) meat showed higher water-holding capacity (WHC) and lower cooking loss (CL) after ageing compared to wet aged (WA) meat ($p < 0.05$). Among the colorimetric parameters, only lightness showed to be affected by ageing time, decreasing at week 4 ($p < 0.05$), with lower values in DA then WA ($p < 0.05$). Warner Bratzler shear force (WBSF) decreased at week 1 of DA and at week 2 of WA ($p < 0.05$), with no further changes probably due to the water loss during ageing. Hexanal was the most produced volatile compound, with higher amount in DA meat from 1 to 3 weeks of ageing ($p < 0.01$) The first two weeks of dry ageing led to an enhancement in sensory and instrumental tenderness, along with an improvement in flavour, characterised by a heightened release of aldehydes and ketones. However, it is noteworthy that beyond this initial phase, dry ageing has led to a substantial decline in the overall quality.

**HIGHLIGHTS**

- Meat sourced from culled animals is less appreciated by consumers.
- Goat meat offers numerous advantages in terms of animal husbandry and its nutritional value.
- Dry and wet ageing can improve some meat quality parameters.
- Dry ageing can enhance some quality features of culled goat meat if not extended beyond two weeks.

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Goat meat; meat quality; culled animals; oxidation; volatile compounds

## Introduction

In recent years, there has been a growing interest in goat meat, a type of meat that merges intriguing nutritional attributes, setting it apart from other sources of animal proteins, along with advantageous features related to husbandry practices (Mandolesi et al. 2020; Maggiolino et al. 2022). Goat meat contains lower levels of saturated fats and cholesterol (Madruga and Bressan 2011), while boasting higher levels of polyunsaturated fatty acids (PUFA), the beneficial effects of which on human health are widely acknowledged (Aghwan et al. 2014). Moreover, it provides a rich supply of micronutrients, such as iron, which is considerably more abundant compared to pork, chicken, lamb, and beef (Mazhangara et al. 2019), potassium, and $B_{12}$ vitamin. Goat meat serves as a source of essential amino acids like arginine, isoleucine, lysine, methionine, threonine, and tryptophan. Consequently, goat meat effectively caters to the growing demand for lean and wholesome meats among increasingly health-conscious consumers (Pophiwa et al. 2020). A significant consideration that should not be overlooked is that goat meat is not subject to religious dietary restrictions (Abhijith et al. 2023). Beyond the favourable attributes that define meat, a multitude of advantages are linked to goat farming, primarily stemming from their remarkable adaptability, enabling them to thrive in marginal environments, where conventional crops and livestock

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would falter, and this holds significant implications for meat production also. Goats possess a distinctive mobile upper lip that empowers them to meticulously select nutrient-rich vegetation (Elias and Tischew 2016). Furthermore, their unique ability to produce proline-rich proteins, which form complexes with tannins, thereby mitigating their detrimental effects, allows goats to efficiently consume and digest tannin-laden browse, effectively extracting essential nutrients (Schmitt et al. 2020). Noteworthy is the goat's capacity to endure extended periods of water scarcity and withstand heightened thermal stresses, setting them apart from their ovine and bovine counterparts (Nair et al. 2021). These traits reduce maintenance demands, making goat farming a preferred choice in semi-arid regions, characterised by limited agricultural potential (Simela and Merkel 2008). Moreover, goat farming entails lower methane production compared to the rearing of other ruminants, a factor of paramount significance considering the imperative to mitigate the environmental impact associated with red meat production (Pragna et al. 2018). The remarkable prolificacy of goats bestows a twofold advantage: an increased production capacity and the potential for rapid genetic advancement (Plakkot et al. 2020). This heightened prolificacy can be harnessed strategically to ensure a consistent market supply of goat meat to consumers. Despite the mounting interest and the array of potential benefits associated with goat meat consumption and production, this meat remains a niche product in many countries, and the goat meat industry is not as developed as its bovine or swine counterparts (Ngomane et al. 2022). The reasons for this disparity are mainfold and primarily linked to consumer perceptions, associating goat meat with unpleasant odours and flavours, unappealing colour, and perceived toughness (Mandolesi et al. 2020). Additionally, the widespread belief that goat meat is regarded as an inferior product for low-income populations discourages its commercialisation (Ngwako et al. 2021). Such perceptions are exacerbated when considering meat derived from adult goats (Paulos et al. 2015). Although there is a wealth of scientific evidence attesting to the perceived higher quality of meat derived from young animals, compared to that from older animals (Webb et al. 2005; Rodrigues and Teixeira 2009; Karthik et al. 2017), the effects of the age at slaughter on goat meat quality have not been thoroughly explored. Pophiwa et al. (2020) argued that the age at slaughter might not be a valid classification criterion for goat carcasses quality. In Europe, goat farming is primarily geared towards milk production and it is on the rise (Miller and Lu 2019). Consequently, the proportion of animals destined to culling is notably significant. The meat derived from these animals holds limited commercial value and is often undervalued by consumers. For this reason, it is typically subjected to a variety of processes in order to obtain transformed products. Numerous studies have examined various transformational prospects for this meat, concurrently assessing consumer acceptability (Stajić et al. 2020; Teixeira et al. 2020; Pisinov et al. 2021). The capacity of both wet and dry ageing to enhance tenderness, flavour, and overall acceptability through different biochemical and biophysical changes in the muscle tissue is well-documented. Tenderisation is mainly due to the enzymatic degradation of key myofibrillar and cytoskeletal proteins (Della Malva et al. 2019), while the improvement in flavour is due to the action of enzymes which break down proteins and lipids into smaller and more flavourful fragments (Sgarro et al. 2022). Specifically, dry ageing imparts superior value to meat, rendering it a premium product (Stenström et al. 2014; Park et al. 2018). However, the effects of these two ageing techniques on the quality of meat obtained from culled goats have not yet been investigated. The composition of the goat's hind limbs seems favourable to producing high-value items, characterised by low fat content and high leanness. With the aim of enhancing the value of meat obtained from culled goats for human consumption, this study seeks to assess the impact of ageing time (from 0 to 5 weeks) and two distinct ageing techniques (dry and wet ageing) on the rheologic, colorimetric, oxidative, volatolomic and sensory profile of goat meat (hind limbs).

## Materials and methods

### *Animal management, slaughtering and sampling procedures*

Twenty-four culled Rossa Mediterranea goats were comprised in the study. The animals were sourced from the same farm and were slaughtered at the end of their productive cycle, as determined by the farmer, at an average age of 7 years ± 8 months (mean ± standard deviation) and an average live weight of 82.5 kg ± 3.75 (mean ± SD). Before slaughtering, the goats were subjected to a 60-day fattening regimen, during which they received *ad libitum* alfalfa hay (containing 195 g/kg crude protein DM and 348 g/kg crude fibre DM) and a commercial pelleted concentrated mixture composed of barley, corn, and faba beans (with 21.3% crude protein, 11.4% crude fibre, 2.9% crude fat, and

6.9% ash; on a DM basis). The determination of dry matter AOAC (2005) (method 930.15) and ash (AOAC 2005) (method 942.05) content in the feed was carried out following standard procedures. Fat content was assessed using the Soxhlet extraction procedure (AOAC 2005) (method 991.36), while crude protein was determined using the Kjeldahl $N \times 6.25$ procedure (AOAC 2005) (method 968.06) as described by De Bellis et al. (2022). For the slaughter, the goats were transported to a European Community-approved abattoir, located 31 km away from the farm, in compliance with the European Community laws on Animal Welfare in transport (1/2005EC) and the European Community regulation on Animal Welfare for the slaughter of commercial animals (1099/2009EC). After slaughter, the hind limbs were excised from each carcass, from the coxofemoral joint to the distal part. Subsequently, they were transported to the laboratory under refrigerated conditions (max 4 °C) and divided into two experimental groups, in a balanced manner: the 24 right hind limbs underwent dry ageing, while the 24 left hind limbs underwent wet ageing. The dry ageing process was carried out in a static cell (Chefline® CFP1540, Padua, Italy) at 2 °C and 62% humidity. On the other hand, the wet ageing involved vacuum-packaging the hind limbs using a slightly permeable film, the Besser Vacuum® film (Besser Vacuum, Dignano, Udine, Italy), which has a thickness of 65 μm, weight of 63 g/m$^2$, and permeability equal to 65 cm$^3$/m$^2$ per day per oxygen atmosphere at a temperature of 23 °C and 85% relative humidity. For each ageing technique, the limbs were randomly assigned to an ageing time, ranging from 0 to 5 weeks (labelled as W0, W1, W2, W3, W4 and W5, respectively). Consequently, four limbs were allocated to each ageing time within each ageing technique considered. For laboratory analyses, meat samples were collected from both DA and WA hind limbs at each ageing time. Samples for rheological, colorimetric, oxidative profile, and volatile compound analyses were collected from the *rectus femoris* muscle, while samples for sensory analysis were taken from the *vastus medialis* muscle.

## Rheological analysis

The pH assessment was carried out using a portable pH metre with a glass electrode, suitable for easy penetration into tissues (Carlo Erba pH 710; Carlo Erba Reagenti, Milan, Italy). Calibration was automatically performed for muscle temperature, and before each measurement, two buffer solutions with pH 4 and 7 were employed (Crison, Lainate, Italy) (De Palo et al. 2017).

As described by De Palo et al. (2014), for the analysis of cooking loss (CL), cubic meat pieces measuring 1.5 cm per side were used. These samples were weighed (Wi) and then cooked inside vacuum-sealed bags in a water bath at 80 °C. The attainment of an internal temperature of 75 °C was verified using a copper constantin fine-wire thermocouple (Model 5SC-TT-T-30–36; Omega Engineering Inc., Stamford, CT, USA) fixed at the geometric centre of the sample. After cooling and fluid removal, the cooked samples were reweighed (Wf), and the CL was calculated as a percentage of weight loss: $[(Wi - Wf)/Wi] \times 100$.

The water-holding capacity (WHC) was estimated as described by De Palo et al. (2016)., utilising the centrifugation method. From each limb, samples weighing 0.3 g were taken, subsequently being centrifuged at $30{,}000 \times g$ for 1 h using an Allegra 64 R centrifuge (Beckman Instruments Inc., Brea, CA, USA). Prior to (Wi) and following centrifugation (Wf), the samples were weighed, and the centrifugation loss was calculated: $\{100 - [(Wi - Wf)/Wi]\} \times 100$. Two technical replicates were carried out for each sample.

Warner Bratzler shear force (WBSF) was measured on parallelepiped-shaped samples of $3 \times 6 \times 6$ cm, sectioned so that the longitudinal axes was parallel to the orientation of muscle fibres. The samples were cooked in a plastic bag in a water bath at 85 °C until an internal temperature of 75 °C was reached (measured using a fine constantan-copper thermocouple wire, model 5SC-TT-T-30–36, Omega Engineering Inc., fixed at the geometric centre of the sample). Subsequently, instrumental measurement was performed using an Instron 1140 device (Instron, High Wycombe, UK) equipped with a computer, at a crosshead speed of 50 mm/min and a load cell of 50 N. Each sample was cut three times, and the average of these three values was calculated. The results were expressed in kg (Gálvez et al. 2019).

## Colorimetric analysis

The instrumental measurement of colour was achieved using a Minolta CR-300 colorimeter (D65 illuminant; Minolta Camera Co. Ltd., Osaka, Japan) following the CIE L*, a*, b* colour model (CIE, 1976). The calibration was performed using the Hunter-lab colour space system with a white tile ($L^* = 99.2$, $a^* = 1.0$, $b^* = 1.9$). Readings were taken at a 0° viewing angle with a pulsed xenon arc lamp A, utilising an 8 mm diameter measurement area, always on a fresh cut surface. Following the procedure described by De Palo et al. (2012), measurements were taken at three different

points on the sample, and at each point, rotating the colorimeter for 90°, three measurements were collected. Hence, 9 measurements corresponded to each sample.

### Oxidative profile analysis

Lipid oxidation analysis was conducted using the TBARS method, following the protocol outlined by Buege and Aust (1978). The quantification was expressed in terms of malondialdehyde (MDA) content per kilogram of meat. Briefly, minced muscle samples (5 g) were placed in a 50-mL test tube, followed by homogenisation with 15 mL of deionised distilled water (DDW). For TBARS determination, a 1 mL aliquot of the homogenate was carefully transferred into a glass tube. Subsequently, 0.05 mL of butylated hydroxytoluene (72 μL/mL in ethanol) was introduced, along with 1950 mL of TBA/trichloroacetic acid (TCA)/HCl solution (composed of 3.75 μL/mL TBA, 150 μL/mL TCA, and 0.25 N HCl). This sample solution underwent agitation and was subjected to incubation at a temperature of 90 °C for a duration of 15 min within a thermostatic bath. Following this incubation period, the samples were allowed to cool to room temperature (15–30 °C) and subsequently centrifuged at a speed of 2000 × g for 15 min. The supernatant's absorbance at 531 nm was measured, referencing it against a blank containing 2 mL of TBA/TCA/HCl solution within 1 mL of distilled water. The quantification of TBARS was conducted by comparison with a standard curve established using 1,1,3,3-tetramethoxypropane (Maggiolino et al. 2020).

For protein oxidation assessment, two aliquots of homogenate (50 μL each), previously prepared for TBARS determination, were subjected to the addition of 1 mL of 10% TCA. Subsequent centrifugation at 1,200 × g for 3 min at 4 °C facilitated protein oxidation measurement. One aliquot, serving as the standard, was treated with 1 mL of 2 M HCl solution. The other aliquot was treated with 1 mL of 2 M HCl containing 10 mM 2,4-dinitrophenyl hydrazine (DNPH). Following an hour of incubation at room temperature (15–30 °C) with intermittent shaking every 20 min, 1 mL of 10% TCA was added. The samples underwent vortexing for 30 s, followed by triple centrifugation at 1,200 × g for 3 min at 4 °C. The resulting supernatant was meticulously removed, taking care not to disrupt the pellet. The pellet was subjected to washing with 1 mL of ethanol:ethyl acetate (1:1), followed by three rounds of centrifugation at 1,200 × g for 3 min at 4 °C. The pellet was then dissolved in 1 mL of 20 mM sodium phosphate 6 M guanidine hydrochloride buffer. Carbonyl concentration was determined on the DNPH treated sample at 360 nm using a spectrophotometric method with a Beckman Coulter DU800 and was expressed as nanomoles carbonyl per milligram of protein. Protein concentration was determined through the Biuret assay, following the protocol by Tokur and Korkmaz (2007). To assess hydroperoxides (HP), 2 mL of homogenate, previously prepared for TBARS determination, were mixed with 4 mL of CH3OH and 2 mL of CHCl3. After vigorous vortexing for 30 s, 2 mL of CHCl3 and 1.6 mL of 0.9% NaCl were added. The samples were shaken for 1 min, followed by centrifugation at 3,500 × g for 10 min at 4 °C. The lower chloroform phase was sampled, and 1 mL of CH3COOH/CHCl3 and 50 μL of KI (1.2 g/1 mL distilled water) were added. After 5 min of storage in a dark room, 3 mL of 0.5% CH3COOCd were introduced, followed by vortexing and centrifugation at 4,500 × g for 10 min at 40 °C. Absorbance at 353 nm was measured against a blank comprising 2 mL of distilled water. The results were quantified in micromoles per gram, in accordance with the method of Buege and Aust (1978).

### Volatile compound analysis

At each experimental time, five-gram samples were collected from each leg for volatile compound analysis. Cooking was carried out using an electric griddle (model CG660; Delonghi, Treviso, Italy) set at 130–150 °C for 5 min. Each sample achieved an internal temperature of 70 °C, monitored using a thin copper constantan thermocouple wire (Model 5SCTT-T-30-36; Omega Engineering Inc., Norwalk, CT, USA) positioned at the geometric centre of the sample, following the procedure detailed by Maggiolino et al. (2019). Post-cooking, the samples were ground using a commercial grinder (Moulinex/Swan Holding Ltd., Birmingham, United Kingdom). Subsequently, the ground meat (1 ± 0.05 g) was weighed and placed in 20 mL vials (Agilent Technologies, Santa Clara, CA, USA), supplemented with an internal standard (82 ng of 2-octanol), and sealed with a Teflon-coated rubber septum. The extraction of volatile organic compounds (VOCs) was performed using the headspace solid-phase microextraction gas chromatography-mass spectrometry (SPME-GC-MS) method, as described by Maggiolino et al. (2021). After a 15-minute equilibration period at the same temperature in a Triplus RSH Autosampler (Thermo Fisher Scientific, Rodano, Italy) to ensure uniform temperature for both the sample and headspace, extractions were conducted at 35 °C for 30 min using a divinylbenzene/carboxen/polydimethylsiloxane SPME fibre assembly (50/30 μm; Supelco, Bellefonte, PA,

USA). Subsequently, the fibres were injected into a Trace 1300 gas chromatograph (Thermo Fisher Scientific, Rodano, Italy) operating in splitless mode. The gas chromatograph was equipped with an ISQ Series 3.2 SP1 mass spectrometer (Thermo Fisher Scientific, Rodano, Italy). Compound separation occurred on a VF-WAX MS capillary column (60 m, 0.25 mm i.d., 0.25 μm film thickness; Agilent, Santa Clara, CA, USA) under the following conditions: injection port temperature, 250 °C; oven temperature, 35 °C for 5 min, followed by a ramp of 1.5 °C/min to 45 °C, then 4 °C/min to 160 °C, and a final increase to 210 °C at 20 °C/min; the final temperature was maintained for 7 min. Mass spectrometer settings were as follows: detector voltage, 1700 V; source temperature, 250 °C; ionisation energy, 70 eV; scan range, 40–300 amu. Peak identification was conducted using Xcalibur V2.0 software (Thermo Fisher Scientific, Rodano, Italy), specifically Qual Browse, by comparing spectra with reference mass spectra from the NIST library (National Institute of Standards and Technology, Gaithersburg, USA). Semi-quantification of compounds was performed using the internal standard method, and quantities were expressed in μg/kg.

### Sensory analysis

The sensory analysis was carried out by a panel consisting of eight individuals, selected based on their sensory acuity and the methods outlined by the British Standards Institution (1993). At each experimental time point, samples were collected from the limbs and cooked as previously described for VOCs. Connective tissue and fat were removed, and the muscle was cut into approximately 2 $cm^3$ blocks, which were wrapped in pre-labelled film and placed in a heated incubator until the tasting. The samples were evaluated following the tasting order designed by MacFie et al. (1989) to balance carryover effects across the samples. The panel test was organised into two separate sitting sessions for each panellist, for each ageing time. During each session, each panel member received four samples for each ageing method, totalling eight samples. At the conclusion of the two sessions, each panel member double-tested all four samples for each ageing method, resulting in a total of sixteen tastings. The samples administration order was randomised by the sensory panel software, in a different order for each panel member. The tested samples were evaluated on a scale of 1 to 10 points for tenderness (from 1 = extremely tough to 10 = extremely tender), juiciness (from 1 = extremely dry to 10 = extremely juicy), overall liking (from 1 = extremely unlikeable to 10 = extremely likable), sweetness, off-odours, meaty flavour, and off-flavours (from 1 = extremely weak to 10 = extremely strong) (Sgarro et al. 2024).

### Statistical analysis

The dataset was assessed for normal distribution and variance homogeneity using the Shapiro-Wilk test. Subsequently, an analysis of variance (ANOVA) was conducted using the General Linear Model (GLM) software by SAS (2018) (version 9.3, SAS Institute Inc., Cary, NC, USA), following the following model:

$$y_{ijk} = \mu + \alpha_i + A_j + T_k + (A \times T)_{jk} + \varepsilon_{ijkl},$$

where $y_{ijk}$ represents all parameters as dependent variables; $\mu$ is the mean; $\alpha_i$ is the single limb random effect, A represents the effect of the $j^{th}$ method of ageing ($j = 1, 2$), T represents the effect of the $k^{th}$ ageing time ($k = 1, \ldots, 6$), A × T represents the effect of the binary interaction between the two independent variables (jk = 1, … , 12) and $\varepsilon_{ijkl}$ is the error. Subsequently, a Tukey test for repeated measures was carried out to evaluate the differences between the means during the ageing time.

All means were expressed as square means and mean standard error. The significance level was set to $p < 0.05$.

## Results

### Rheological, colorimetric and oxidative parameters

Results of rheological and colorimetric parameters are presented in Table 1. Only ageing time affected pH, resulting in a drop from W0 to W1 in both ageing techniques ($p < 0.01$). The WHC was influenced by the ageing technique, with higher values observed in dry-aged (DA) meat than those reported in the wet-aged (WA) one, both at W3 and W5 ($p < 0.05$). The CL decreased in DA meat from W0 to W4 ($p < 0.01$) and from W4 to W5 in WA ($p < 0.05$). Ageing technique also influenced CL, with lower values observed in DA meat, compared to the WA meat, at W3 ($p < 0.05$) and W4 ($p < 0.01$). The WBSF was not affected by ageing technique. However, ageing time reduced WBSF values at W1 in DA meat ($p < 0.05$) and at W2 in WA meat ($p < 0.05$). Except for lightness, none of the colorimetric parameters displayed differences based on ageing time and ageing technique ($p > 0.05$). Lightness values decreased from W2 to W4 in DA meat ($p < 0.05$), and, at W4, they were lower than those recorded in WA meat ($p < 0.05$). All the oxidative

**Table 1.** Effect of ageing time, ageing technique, and their binary interaction on rheological, colorimetric and oxidative parameters of meat from culled goats (*rectus femoris* from the entire hind limb) handled for 5 weeks in dry and wet ageing ($n = 4$ samples for each ageing time in each ageing method).

| | | Aging time | | | | | | | Analysis of variance | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aging technique | W0 | W1 | W2 | W3 | W4 | W5 | SEM[d] | A[e] | T[f] | A × T |
| Rheological parameters | | | | | | | | | | | |
| pH | DA[g] | $6.81^{A}$ | $5.58^{B}$ | $5.48^{B}$ | $5.61^{B}$ | $5.52^{B}$ | $5.33^{B}$ | 0.05 | 0.5225 | <0.0001 | 0.2268 |
| | WA[h] | $6.97^{A}$ | $5.64^{B}$ | $5.59^{B}$ | $5.58^{B}$ | $5.70^{B}$ | $5.74^{B}$ | | | | |
| Water holding capacity (%) | DA | 84.50 | 84.66 | 84.71 | $89.08^{x}$ | 86.97 | $88.36^{x}$ | 1.15 | 0.0121 | 0.9943 | 0.4747 |
| | WA | 83.42 | 83.76 | 82.53 | $80.91^{y}$ | 81.13 | $79.03^{y}$ | | | | |
| Cooking loss (%) | DA | $44.73^{Aa}$ | $42.06^{A}$ | $39.23^{ab}$ | $36.43^{bx}$ | $31.89^{BXc}$ | 38.48 | 0.98 | 0.0176 | 0.1062 | 0.1303 |
| | WA | 44.83 | 40.7 | 41.83 | $43.77^{y}$ | $42.96^{Ya}$ | $40.31^{b}$ | | | | |
| Warner Bratzler shear force (kg) | DA | $5.65^{a}$ | $5.05^{b}$ | $4.85^{b}$ | $5.02^{b}$ | $5.12^{b}$ | $5.09^{b}$ | 0.44 | 0.5973 | 0.0161 | 0.0825 |
| | WA | $5.59^{a}$ | $5.44^{a}$ | $5.15^{b}$ | $5.11^{b}$ | $5.22^{b}$ | $5.12^{b}$ | | | | |
| Colorimetric parameters | | | | | | | | | | | |
| $L^*$ | DA | 38.39 | 38.14 | $40.62^{a}$ | $35.34^{b}$ | $35.50^{bx}$ | $34.69^{b}$ | 0.68 | 0.1652 | 0.2423 | 0.2648 |
| | WA | 38.39 | 35.96 | 39.93 | 37.95 | $40.52^{y}$ | 38.25 | | | | |
| $a^*$ | DA | 17.04 | 18.71 | 18.53 | 17.32 | 17.23 | 18.12 | 0.25 | 0.7016 | 0.2185 | 0.6709 |
| | WA | 17.02 | 18.41 | 18.03 | 18.76 | 17.81 | 17.85 | | | | |
| $b^*$ | DA | 1.05 | 1.65 | 1.37 | 0.78 | 0.85 | 0.05 | 0.31 | 0.5622 | 0.8162 | 0.6775 |
| | WA | 1.10 | 0.24 | 0.34 | 0.28 | 1.73 | 0.45 | | | | |
| Chroma | DA | 17.15 | 18.85 | 18.60 | 17.35 | 17.27 | 18.12 | 0.26 | 0.7325 | 0.2651 | 0.6653 |
| | WA | 17.12 | 18.42 | 18.06 | 18.71 | 17.91 | 17.90 | | | | |
| Hue (°) | DA | 0.46 | 0.43 | 1.49 | 0.48 | 0.47 | 0 | 0.36 | 0.8893 | 0.7752 | 0.5282 |
| | WA | 0.46 | 0.51 | −0.54 | 1.55 | 1.47 | −0.54 | | | | |
| Oxidative parameters | | | | | | | | | | | |
| TBARS[i] (mg MDA/kg of meat) | DA | $0.33^{A}$ | $0.86^{BX}$ | $1.04^{BCX}$ | $0.93^{BCaX}$ | $0.91^{BCa}$ | $1.16^{CbX}$ | 0.02 | <0.0001 | <0.0001 | 0.0014 |
| | WA | $0.43^{Aa}$ | $0.45^{AaY}$ | $0.51^{abY}$ | $0.66^{bcY}$ | $0.75^{Bc}$ | $0.76^{BcY}$ | | | | |
| Hydroperoxides (mmol/g of meat) | DA | $0.56^{A}$ | $0.89^{BX}$ | $1.10^{CX}$ | $0.94^{Bx}$ | $0.92^{B}$ | $0.91^{BX}$ | 0.01 | <0.0001 | <0.0001 | <0.0001 |
| | WA | $0.55^{A}$ | $0.56^{ABY}$ | $0.57^{AY}$ | $0.81^{Cy}$ | $0.84^{C}$ | $0.84^{BCY}$ | | | | |
| Protein carbonyls (mmol DNPH/mg protein) | DA | $1.77^{AX}$ | $1.80^{A}$ | $1.82^{A}$ | $1.86^{A}$ | $2.89^{BaX}$ | $3.17^{BbX}$ | 0.02 | <0.0001 | <0.0001 | <0.0001 |
| | WA | $1.82^{aY}$ | $1.76^{A}$ | $1.77^{A}$ | $1.76^{A}$ | $1.94^{Y}$ | $2.06^{BbY}$ | | | | |

Different superscript letters in the same line show statistical differences (A, B, C: $p < 0.01$; a, b: $p < 0.05$).
Different superscript letters in the same column, for each investigated pattern, show statistical differences (X, Y: $p < 0.01$; x, y: $p < 0.05$).
[d]SEM: standard error of mean; [e]A: ageing technique; [f]T: time; [g]DA: dry ageing; [h]WA: wet ageing; [i]TBARS: thiobarbituric acid reactive substances.

parameters analysed showed to be affected by both ageing time and ageing technique. TBARS levels increased constantly in DA during the experimental trial the trial ($p < 0.01$), reaching the highest amount at W5 ($p < 0.01$). Conversely, in WA meat, TBARS increased up to W4 ($p < 0.01$). Furthermore, from W1 to the end of the trial, TBARS levels were significantly higher in DA meat compared to WA one ($p < 0.01$). In DA meat, HP raised from W0 to W1 ($p < 0.01$) and reached the highest values at W2 ($p < 0.01$). On the other hand, in WA meat, an increase at W3 was detected ($p < 0.01$). Moreover, the DA meat had higher HP levels than WA meat at W1, W2 ($p < 0.01$) and W3 ($p < 0.05$). Protein carbonyls (PC) increased at W4 in DA meat ($p < 0.01$) and at W5 in WA meat ($p < 0.01$), and their levels were higher in DA meat, than in WA meat, at both W4 and W5 ($p < 0.01$).

## *Volatile organic compounds*

Table 2 summarises the impact of ageing time and ageing technique on the chemical profile of VOCs. While in WA meat, ageing time did not affect alcohols content, in DA meat it peaked at W2 ($p < 0.01$), with higher quantities compared to those detected in WA meat ($p < 0.01$). The aldehydes production in DA meat progressively increased from W0 to W2 ($p < 0.01$), then decreased from W2 to W4 ($p < 0.01$). Conversely, in WA meat, an increase at W3 was recorded ($p < 0.01$), followed by a reduction at W4 ($p < 0.01$). However, from W1 to W4, DA meat showed higher aldehydes' content compared to WA ($p < 0.01$). In DA meat, aromatic hydrocarbons reached their highest content at W2 and dropped at W3 ($p < 0.01$), remaining constant in subsequent experimental times ($p < 0.01$). In WA meat, on the other hand, they increased up to W4, with lower amounts than those recorded in DA meat at W2 ($p < 0.01$) and W4 ($p < 0.05$). Hydrocarbons increased from W0 to W2 ($p < 0.01$) and again from W2 to W5 ($p < 0.01$) in DA meat, while in WA meat, they increased only at W5, compared to W0 ($p < 0.01$). Ageing technique affected their synthesis, which was higher in DA meat compared to WA meat at W4 ($p < 0.01$) and W5 ($p < 0.05$).

The total amount of ketones, in DA meat, increased at W2 compared to W0 and W1 ($p < 0.01$), then decreased until the end of the experimental trial ($p < 0.01$). On the other hand, in WA meat, it increased up to W3 ($p < 0.05$). Furthermore, at W1 and W2, ketones values were higher in DA meat compared to

WA meat ($p < 0.01$). Sulphur compounds increased at W3 and W5 in DA meat ($p < 0.01$), and at W4 and W5 in WA meat ($p < 0.01$). Besides, the level of sulphur compounds was higher in DA meat at W1 ($p < 0.05$), W3, W4, and W5 ($p < 0.01$), compared to WA one.

Table 3 shows the effect of ageing time and ageing technique on the content of the main compounds detected in larger quantities. Butanal increased in DA meat at W2 ($p < 0.01$) and in WA meat at W3 ($p < 0.05$), displaying at W4 higher concentrations in WA meat than in DA one ($p < 0.01$). The presence of 2-methyl-butanal raised week by week from W0 to W2 ($p < 0.01$), reaching higher concentrations than those detected in WA meat ($p < 0.01$). Then, it declined from W2 to W3 ($p < 0.01$). Conversely, in WA meat, it surged from W1 to W3 ($p < 0.05$) before diminishing at W4 ($p < 0.05$). The content of 3-methyl-butanal increased in DA meat from W0 and W1 to W2 ($p < 0.01$), demonstrating a higher content compared to that found in WA meat ($p < 0.01$). A further increase occurred from W2 to W3 ($p < 0.01$). Hexanal in DA meat increased from W0 to W1 ($p < 0.01$) and further from W1 to W2 ($p < 0.01$), while it progressively decreased from W3 to W4 ($p < 0.01$). In WA meat it increased at W3 ($p < 0.01$), remaining constant at W4

**Table 2.** Effect of ageing time, ageing technique, and their binary interaction on the content of the main VOC families in meat from culled goats (*rectus femoris* from the entire hind limb) handled for 5 weeks in dry and wet ageing, expressed in μg/kg ($n = 4$ samples for each ageing time in each ageing method).

| | | Aging time | | | | | | | Analysis of variance | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aging technique | W0 | W1 | W2 | W3 | W4 | W5 | SEMe | A[f] | T[g] | A × T |
| Alcohols | DA[h] | 15.44$^{A}$ | 47.36$^{A}$ | 150.52$^{BX}$ | 53.51$^{A}$ | 49.76$^{A}$ | 52.87$^{A}$ | 6.79 | 0.0001 | 0.0007 | 0.0001 |
| | WA[i] | 15.44 | 16.38 | 15.80$^{Y}$ | 49.77 | 21.62 | 17.93 | | | | |
| Aldehydes | DA | 177.92$^{A}$ | 378.27$^{BX}$ | 885.25$^{CX}$ | 430.57$^{BX}$ | 183.99$^{AX}$ | 174.56$^{Ax}$ | 11.12 | <0.0001 | <0.0001 | <0.0001 |
| | WA | 157.15$^{ABCa}$ | 146.98$^{AaY}$ | 137.34$^{ADaY}$ | 241.28$^{BbY}$ | 50.61$^{DbY}$ | 52.51$^{ACDby}$ | | | | |
| Aromatic hydrocarbons | DA | 10.53$^{A}$ | 45.77$^{A}$ | 195.65$^{BX}$ | 52.51$^{A}$ | 31.31$^{Ax}$ | 17.23$^{A}$ | 13.92 | 0.5566 | 0.0131 | 0.0005 |
| | WA | 10.31$^{Aa}$ | 16.84$^{a}$ | 12.93$^{aY}$ | 113.95$^{b}$ | 121.80$^{Bby}$ | 7.41 | | | | |
| Hydrocarbons | DA | 4.67$^{A}$ | 10.51$^{A}$ | 28.50$^{Ba}$ | 36.07$^{Ba}$ | 70.56$^{BCbX}$ | 111.29$^{Cx}$ | 5.45 | 0.0009 | <0.0001 | 0.0890 |
| | WA | 4.67$^{a}$ | 7.91$^{a}$ | 15.44 | 8.27 | 12.06$^{Y}$ | 53.52$^{by}$ | | | | |
| Ketones | DA | 55.32$^{Aa}$ | 126.48$^{BCbX}$ | 169.20$^{BX}$ | 109.53$^{ACb}$ | 65.38$^{Aa}$ | 54.86$^{ACa}$ | 7.31 | <0.0001 | 0.0030 | 0.0003 |
| | WA | 55.32 | 33.53$^{aY}$ | 33.23$^{aY}$ | 79.55$^{b}$ | 40.56 | 23.18 | | | | |
| Sulfur compounds | DA | 16.65$^{A}$ | 21.06$^{Ax}$ | 23.53$^{A}$ | 69.80$^{BX}$ | 65.19B$^{X}$ | 89.32$^{CX}$ | 1.78 | <0.0001 | <0.0001 | <0.0001 |
| | WA | 16.65$^{AB}$ | 6.65$^{Aay}$ | 21.55$^{ABb}$ | 22.61$^{AbY}$ | 24.86$^{BY}$ | 43.18$^{CY}$ | | | | |

Different superscript letters in the same line show statistical differences (A, B, C, D: $p < 0.01$; a, b: $p < 0.05$).
Different superscript letters in the same row, for each investigated pattern, show statistical differences ($^{X, Y}$: $p < 0.01$).
[e]SEM: standard error of mean; [f]A: ageing technique; [g]T: time; [h]DA: dry ageing; [i]WA: wet ageing.

**Table 3.** Effect of ageing time, ageing technique, and their binary interaction on the content of the most abundant compounds in meat from culled goats (*rectus femoris* from the entire hind limb) handled for 5 weeks in dry and wet ageing, expressed in μg/kg ($n = 4$ samples for each ageing time in each ageing method).

| | | Aging time | | | | | | | Analysis of variance | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aging technique | W0 | W1 | W2 | W3 | W4 | W5 | SEMe | A[f] | T[g] | A × T |
| Aldehydes | | | | | | | | | | | |
| Butanal | DA[h] | 2.17$^{A}$ | 2.39$^{A}$ | 7.12$^{B}$ | 6.51$^{B}$ | 3.96$^{X}$ | 2.85 | 0.51 | 0.2763 | 0.0002 | 0.0230 |
| | WA[i] | 2.57$^{A}$ | 1.50$^{Aa}$ | 4.83$^{A}$ | 5.90$^{b}$ | 9.41B$^{Y}$ | 5.66$^{b}$ | | | | |
| 2-Methyl-butanal | DA | 4.66$^{A}$ | 8.38$^{A}$ | 41.44$^{BX}$ | 14.28$^{A}$ | 16.81$^{A}$ | 6.74$^{A}$ | 2.94 | 0.1672 | 0.0019 | 0.0231 |
| | WA | 6.66 | 4.38$^{a}$ | 13.05$^{Y}$ | 20.33$^{b}$ | 5.60$^{a}$ | 7.19 | | | | |
| 3-Methyl-butanal | DA | 4.62$^{A}$ | 4.51$^{A}$ | 39.10$^{BX}$ | 18.77$^{C}$ | 13.85 | 6.78 | 1.98 | 0.0199 | <0.0001 | <0.0001 |
| | WA | 4.62 | 4.92 | 9.90$^{Y}$ | 13.27 | 8.78 | 5.84 | | | | |
| Hexanal | DA | 134.05$^{A}$ | 298.07$^{BX}$ | 665.03$^{CX}$ | 315.38$^{BX}$ | 32.87$^{D}$ | 27.73$^{D}$ | 6.24 | <0.0001 | <0.0001 | <0.0001 |
| | WA | 111.60$^{A}$ | 103.20$^{AY}$ | 113.75$^{ABaY}$ | 163.09$^{BbY}$ | 11.47$^{B}$ | 24.41$^{B}$ | | | | |
| Nonanal | DA | 17.97$^{A}$ | 36.11$^{ABa}$ | 90.52$^{CX}$ | 59.67$^{Bbx}$ | 7.78$^{Ab}$ | 7.84$^{A}$ | 3.76 | 0.0001 | <0.0001 | <0.0001 |
| | WA | 17.97 | 17.78 | 11.28$^{Y}$ | 31.02$^{y}$ | 9.33 | 3.27 | | | | |
| Pentanal | DA | 16.02$^{A}$ | 19.14$^{A}$ | 32.91$^{A}$ | 28.28$^{A}$ | 195.53$^{BX}$ | 183.69$^{BX}$ | 7.69 | <0.0001 | <0.0001 | <0.0001 |
| | WA | 16.88 | 14.78 | 13.38 | 7.11 | 25.00$^{Y}$ | 9.09$^{Y}$ | | | | |
| Aromatic hydrocarbons | | | | | | | | | | | |
| Ethylbenzene | DA | 3.16$^{Aa}$ | 8.33$^{A}$ | 67.11$^{BX}$ | 3.81$^{Ab}$ | 18.48$^{Aa}$ | 4.40$^{A}$ | 4.95 | 0.0067 | <0.0001 | <0.0001 |
| | WA | 3.16$^{A}$ | 3.86$^{A}$ | 3.67$^{AY}$ | 13.63$^{A}$ | 29.97$^{B}$ | 1.86$^{A}$ | | | | |
| 1,4-Dimethyl-benzene | DA | 4.02$^{Aa}$ | 18.55$^{Ab}$ | 50.51$^{BX}$ | 15.49$^{A}$ | 19.76$^{Ab}$ | 9.19$^{A}$ | 5.92 | 0.1163 | <0.0001 | 0.0001 |
| | WA | 4.02$^{A}$ | 13.38 | 9.31$^{aY}$ | 24.87$^{Bb}$ | 28.46$^{Bb}$ | 4.11$^{a}$ | | | | |
| Ketones | | | | | | | | | | | |
| 2-Propanone | DA | 11.92$^{Aa}$ | 29.17$^{bx}$ | 42.99$^{BaX}$ | 40.00$^{BaX}$ | 20.06$^{A}$ | 19.50$^{b}$ | 2.23 | 0.0002 | 0.0059 | 0.0102 |
| | WA | 11.92 | 14.24$^{y}$ | 14.43$^{Y}$ | 17.12$^{Y}$ | 21.98 | 9.97 | | | | |

Different superscript letters in the same line show statistical differences (A, B, C, D: $p < 0.01$; a, b: $p < 0.05$).
Different superscript letters in the same column, for each investigated pattern, show statistical differences (X, Y: $p < 0.01$; x, y: $p < 0.05$).
[e]SEM: standard error of mean; [f]A: ageing; [g]T: time; [h]DA: dry ageing; [i]WA: wet ageing.

and W5 ($p < 0.01$). The hexanal content was higher in DA meat than in WA meat from W1 to W3 ($p < 0.01$). The levels of nonanal in DA meat increased progressively from W0 to W2 ($p < 0.01$), reaching higher quantities at W2 than in WA meat at the same time ($p < 0.01$). Although the quantity of nonanal reduced at W3 ($p < 0.01$), it was still greater than that detected in WA meat at the same time ($p < 0.05$). Pentanal displayed a different trend in DA meat, increasing at W4 compared to earlier times ($p < 0.01$) and reaching higher concentrations than those observed in WA meat at W4 and W5 ($p < 0.01$). In DA meat, ethylbenzene and 1,4-dimethyl benzene had a similar trend increasing at W2 ($p < 0.01$). Furthermore, the quantities detected at W2 were higher in DA meat compared to those found in WA meat ($p < 0.01$). In the latter, 1,4-dimethyl benzene reached its maximum amount at W3 ($p < 0.01$), while ethylbenzene recorded greater concentrations at W4 than in the previous weeks ($p < 0.01$). In DA meat 2-propanone raised up to W2 ($p < 0.01$), then dropped at W4 ($p < 0.01$). Moreover, the amounts recorded in DA meat were higher than those in WA meat at W2 and W3 ($p < 0.01$).

## Sensory evaluation

In Table 4 is shown the impact of ageing time and ageing technique on sensory evaluation. In DA meat, juiciness dropped from W0 to W3 ($p < 0.01$) and further to W4 ($p < 0.01$), while WA meat was not affected by ageing time ($p > 0.05$). Moreover, juiciness was higher in WA meat compared to DA meat, from W3 to W5 ($p < 0.01$). Tenderness increased in DA meat from W0 to W1 ($p < 0.01$), decreased from W2 to W3 ($p < 0.01$), remaining constant until W5 ($p < 0.01$). However, in WA meat, tenderness was greater at W2, W3, and W4 compared to W0 ($p < 0.01$). Furthermore, tenderness of DA meat was higher at W1 ($p < 0.01$) and lower at W4, if compared to WA meat ($p < 0.01$). Sweetness showed to be not affected by ageing time and ageing technique ($p > 0.05$), while the assessment of meaty flavour in DA meat increased from W0 to W1 and even more from W1 to W2 ($p < 0.01$), while they progressively decreased from W2 to W4 ($p < 0.01$). In DA meat, this descriptor was more strongly perceived at W4 compared to W0 ($p < 0.01$), and less perceived at W5 compared to W4 ($p < 0.01$). DA meat exhibited a higher meaty flavour at W1 and W2 compared to WA meat ($p < 0.01$); whereas at W4 and W5, meaty flavour was more prominently perceived in WA meat, than in DA meat ($p < 0.01$). Off-odours scores increased in DA meat from W0 to W3 ($p < 0.01$), and, further, increased at W4 and W5 ($p < 0.01$). In WA meat, off-odours were more pronounced at W5, compared to W0 ($p < 0.01$). While off-flavours were not affected by ageing time in WA meat ($p > 0.05$), in DA meat they were highly perceived at W3, then at W0, as well as at W4, compared to W3 ($p < 0.01$). Both off-odours and off-flavours were influenced by the ageing technique, showing higher scores in DA meat than in WA meat, in the ageing time ranged from W3 to W5 ($p < 0.01$). The overall liking assessment increased from W0 to W2 ($p < 0.01$) and decreased from W2 to W5 ($p < 0.01$) in DA meat, whereas in WA meat, it peaked at W2 than the previous ageing times ($p < 0.01$). Furthermore, DA meat received higher

**Table 4.** Effect of ageing time, ageing technique, and their binary interaction on sensory evaluation of meat (from 1 to 10 scale) from culled goats (*vastus medialis* from the entire hind limb) handled for 5 weeks in dry and wet ageing ($n = 4$ samples for each ageing time in each ageing method).

| | | Aging time | | | | | | | Analysis of variance | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aging technique | W0 | W1 | W2 | W3 | W4 | W5 | SEM[f] | A[g] | T[h] | A × T |
| Juiciness | DA[i] | $7.19^{A}$ | 7.24 | 6.86 | $6.32^{BX}$ | $5.78^{CX}$ | $5.14^{CX}$ | 0.48 | 0.0082 | <0.0001 | 0.0063 |
| | WA[j] | 7.13 | 7.11 | 7.01 | $7.13^{Y}$ | $7.31^{Y}$ | $7.27^{Y}$ | | | | |
| Tenderness | DA | $6.21^{A}$ | $7.65^{BX}$ | $7.72^{B}$ | $5.52^{C}$ | $5.23^{CX}$ | $4.98^{C}$ | 0.32 | 0.0022 | <0.0001 | <0.0001 |
| | WA | $6.17^{A}$ | $6.27^{AY}$ | $7.32^{B}$ | $7.13^{B}$ | $6.61^{BY}$ | 6.98 | | | | |
| Sweetness | DA | 4.63 | 4.89 | 4.81 | 4.72 | 4.98 | 5.12 | 0.41 | 0.4866 | 0.3889 | 0.6228 |
| | WA | 4.58 | 4.69 | 4.81 | 4.89 | 4.82 | 4.61 | | | | |
| Meaty flavor | DA | $6.12^{A}$ | $7.53^{BX}$ | $8.54^{CX}$ | $6.56^{A}$ | $5.53^{DX}$ | $5.71^{DX}$ | 0.52 | 0.0012 | <0.0001 | <0.0001 |
| | WA | $6.21^{A}$ | $6.54^{Y}$ | $6.25^{AY}$ | 7.12 | $6.88^{BY}$ | $6.28^{AY}$ | | | | |
| Off-odors | DA | $3.24^{A}$ | $3.54^{A}$ | $3.52^{A}$ | $4.81^{BX}$ | $5.54^{C}$ | $5.87^{DX}$ | 0.68 | 0.0040 | <0.0001 | <0.0001 |
| | WA | $3.41^{A}$ | $3.5^{A}$ | $3.36^{A}$ | $3.45^{AY}$ | 4.21 | $4.15^{BY}$ | | | | |
| Off-flavors | DA | $3.32^{A}$ | $3.57^{A}$ | $3.47^{A}$ | $4.92^{BX}$ | $5.89^{BX}$ | $6.51^{CX}$ | 0.31 | <0.0001 | <0.0001 | <0.0001 |
| | WA | 3.52 | 3.23 | 3.47 | $3.71^{Y}$ | $4.13^{Y}$ | $4.83^{Y}$ | | | | |
| Overall liking | DA | $6.52^{A}$ | $7.31^{B}$ | $8.91^{CX}$ | $7.28^{B}$ | $5.31^{DX}$ | $4.12^{EX}$ | 0.44 | <0.0001 | 0.0011 | <0.0001 |
| | WA | $6.56^{A}$ | $6.58^{A}$ | $7.08^{B}$ | 6.89 | $6.93^{Y}$ | $6.69^{Y}$ | | | | |

Different superscript letters in the same line show statistical differences (A, B, C, D, E: $p < 0.01$).
Different superscript letters in the same column, for each investigated pattern, show statistical differences (X, Y: $p < 0.01$).
[f]SEM: standard error of mean; [g]A: ageing; [h]T: time; [i]DA: dry ageing; [j]WA: wet ageing.

scores of overall liking at W2 ($p < 0.01$), as well as lower scores at W4 and W5 ($p < 0.01$), than WA meat.

## Discussion

Several meat quality attributes are affected by the pH of the skeletal muscle (Kadim et al. 2014). Higher ultimate pH values negatively impact colour, tenderness and water behaviour in meat (Webb et al. 2005). As muscle undergoes the transition into meat, there is a buildup of lactic acid in the tissue, causing a decline in the pH of meat. Upon reaching the isoelectric point of key proteins, particularly myosin, the protein's net charge becomes neutral, resulting in an equal distribution of positive and negative charges on the proteins. This electrostatic balance leads to a decrease in the water-binding capacity of the protein, limiting the amount of water that can be attracted and retained (Huff-Lonergan and Lonergan 2005). It is widely reported in literature that goats tend to have higher ultimate pH values. The reasons behind this phenomenon are not entirely known, but it is also well-established that goats are more susceptible to *ante-mortem* stress, due to their highly excitable temperament (Casey and Webb 2010). However, in our results, pH values were consistent with the normal pH range reported in literature (Webb et al. 2005). Ageing time and ageing technique affected water behaviour in meat. While the CL in DA meat decreased at W3 and even further at W4, the WHC did not show significant differences over time. However, notable differences emerged between the two ageing techniques concerning these patterns in the last three weeks. The DA meat showed lower CL, but higher WHC, if compared to WA meat. This result has been previously reported and can be attributed to the dehydration process associated with dry ageing (Juárez et al. 2011; Obuz et al. 2014; Kim et al. 2020). In support of this hypothesis, juiciness assessed by panellists decreased over the last three weeks of dry ageing. Conversely, in WA meat, juiciness remained unchanged throughout the whole ageing period. Increasing the relative humidity in the dry ageing room may mitigate dehydration but raises the risk of microbial spoilage. Hence, for dry ageing, at least for beef, a recommended relative humidity range of 61–85% has been suggested (Dashdorj et al. 2016). Additionally, it is essential to consider an important characteristic that qualify goats: most of the fat is deposited in visceral tissues rather than in carcase deposits, resulting in lean carcases with a low percentage of subcutaneous fat. Consequently, the limited presence of subcutaneous fat coverage, combined with the long-legged carcase conformation, make goat carcases prone to significant moisture losses during ageing (Goetsch et al. 2011). However, CL values observed are slightly higher than the most reported in goat meat. Gawat et al. (2022) reported values between 20.7 and 25.2% of cooking losses in longissimus thoracis and semitendinosus muscles sous vide cooked, other authors reported values ranging between 21 and 33% after bath water cooking (Kadim et al. 2004; Liu et al. 2013; Abuelfatah et al. 2016; Akram et al. 2019). Similar to our results, reported values up to 40%, observing differences between breeds. It must be considered that during cooking processes there are differences in water losses. Temperature and time applied can affect meat shrinkage (Vaskoska et al. 2020). Transverse shrinkage starts between 35 and 45 °C (Tornberg 2005) and is completed between 60 and 62° (Palka and Daun 1999). Longitudinal shrinkage starts between 55 and 64 °C and is completed by 90 °C (Vaskoska et al. 2020) These processes are usually related to the denaturation of myofibrillar and connective tissue proteins in the muscle structure during cooking, and it can be influenced by many factors such as ionic strength and pH as well as changes during different ageing processes (Purslow et al. 2016). All these processes can be also linked to different fibre types, collagen content and sarcomere lengths (Vaskoska et al. 2020). and can explain differences in values reported.

The water content on meat's surface influences its colour. Lightness offers an achromatic contribution to the perceived colour of meat, and its value depends on the light scattering by the microstructure (Purslow et al. 2020). This parameter is related to the chemical composition of meat, particularly to water content and intramuscular fat concentration and composition (De Palo et al. 2012). During ageing, the disruption of muscle fibres results in the transfer of water from intracellular to extracellular regions (De Palo et al. 2013). This typically leads to an increase in lightness values (Maggiolino et al. 2021). However, our findings show a drop in lightness from W2 to W3 in DA meat and lower values compared to WA meat at W4. These outcomes are consistent with the hypothesis of dehydration of the thigh muscles during the latter weeks of dry ageing, which, unlike wet ageing, does not involve the use of ageing bags. Colour is one of the most important factors affecting the consumers choice at purchasing, in fact they often link it to meat freshness (della Malva et al. 2022). Generally, meat colour stability is negatively affected by ageing resulting in a decrease in the redness parameter. Among the

colorimetric parameters examined, aside from lightness, redness, yellowness, chroma and hue did not display noteworthy variations in relation to ageing time, technique and their interaction. Nevertheless, it is necessary to consider that colour analysis was always performed on a freshly cut surface and therefore, it can be presumed that the oxidative processes were not so advanced as to yield chromatic changes in the deeper portions of the muscle. High dehydration can also impact meat tenderness. Although a decrease in WBSF values occurred at W1 for DA meat and at W2 for WA meat, there is an upward trend in values during the final three weeks of dry ageing. Dry ageing holds the potential to enhance tenderness through myofibrillar protein proteolysis and structural protein degradation (Kim et al. 2019). However, the dehydration that might have occurred could have led to the upward trend in WBSF values and the consequent reduction in tenderness scores assigned by the panellists during the last three weeks of dry ageing (Pearce et al. 2011; Wang et al. 2020). The oxidation of proteins also frequently leads to an increase in meat's toughness. The reasons for this could be linked to the formation of protein cross-links, as well as reduced proteolysis of structural proteins (Bao and Ertbjerg 2019). The outcomes obtained from the analysis of protein oxidation products seem to validate this hypothesis. Although oxidative processes did not result in significant variations in the colorimetric parameters, notable changes were observed in the oxidative parameters, as they were affected by both ageing time and ageing technique. In goat meat, polyunsaturated fatty acids predominate over saturated ones, making goat meat appealing for human consumption. Nevertheless, this trait also entails an increased susceptibility to oxidation (Cunha et al. 2018). In DA meat, the concentration of TBARS and HP increased more rapidly, reaching higher levels than in WA meat. The absence of a dry ageing bag exposes meat to atmospheric oxygen, the primary oxidising agent (Domínguez et al. 2019). Conversely, wet ageing, facilitated by the presence of a vacuum-sealed bag, shielded the meat, thus attenuating and managing oxidative processes (Maggiolino et al. 2020). The content of protein carbonyls increased later during both ageing methods, particularly in the last two weeks. This observation aligns with the general phenomenon of protein oxidation occurring later than lipid oxidation (Domínguez et al. 2021). Protein oxidation exhibited a similar trend to that observed for lipid oxidation occurring more rapidly and prominently in DA meat compared to WA meat. Oxidative reactions are undesirable as they contribute to the degradation of lipids and proteins, diminish shelf-life, and bear potential toxicological implications for human health (Wu et al. 2017; Huang and Ahn 2019). However, it is through these reactions that the compounds accountable for conferring taste and aroma characteristics are engendered (Pereira and Abreu 2018). The analysis of VOCs revealed the presence of 69 different compounds belonging to the following 10 chemical groups: alcohols, aldehydes, aromatic hydrocarbons, carboxylic acids, esters, furans, hydrocarbons, ketones, pyrazines and sulphur compounds. However, since carboxylic acids, esters, furans, and pyrazines were absent at some time points, they were not reported in the tables. Considering that VOCs arise from oxidation, mainly from lipid autoxidation processes, it was not unexpected that the release of VOCs in our study was generally higher in DA meat, compared to WA meat. Indeed, the greater release, could be attributed to the presence of oxygen and the heightened oxidative phenomena, characteristic of dry ageing (Lee et al. 2021). In meat of both ageing techniques, the most prevalent chemical group is that of aldehydes, followed by ketones and aromatic hydrocarbons. Our results reveal that these three groups of compounds, along with alcohols, exhibited an upward trend during the initial two weeks of dry ageing. They reached significantly higher concentrations compared to those found in the WA meat during the same period. In contrast, hydrocarbons and sulphur compounds reached their production peak later, in the final two weeks of the dry ageing process. This result is consistent with existing literature and aligns with the outcomes observed for oxidative parameters, since aldehydes, aromatic hydrocarbons, alcohols, and ketones are well-known derivatives of lipids, while the majority of sulphur compounds and hydrocarbons are generated subsequently through the Maillard reaction (Khan et al. 2015; Tateo et al. 2020). The contributions that compounds belonging to these groups provide to the final flavour of meat are distinct and depend on their concentration and odour activity value (OAV) (Bleicher et al. 2022). In contrast to alcohols, which, despite their high concentrations generally do not make a substantial contribution to the perceived flavour due to their elevated OAV (Domínguez et al. 2014), aldehydes, ketones, and aromatic hydrocarbons are tipically strongly perceived (Van Ba et al. 2012). Compounds belonging to these families are accountable for positive and esteemed flavour notes (Ba et al. 2014; Maggiolino et al. 2019). Particularly, aldehydes can confer the characteristic meaty flavour, primarily

attributed to hexanal (Frank et al. 2016). Indeed, in our results during the initial two weeks of dry ageing, precisely when the release of these compounds peaked, meaty flavour was strongly perceived by the panellists. Upon surpassing the two-week mark of dry ageing, the scores assigned to the perception of meaty flavour dropped, in parallel with the decrease in levels of volatile compounds that predominated the initial two weeks. Although oxidative processes play a key role in the development of meat flavour, if they progress excessively, they can lead to the synthesis of compounds responsible for unpleasant tastes and aromas (Casaburi et al. 2015; Sun et al. 2022). Hence, starting from the third week of dry ageing there was a gradual increase in the perception of off-odours and off-flavours in the sensory analysis. The increasing perception of off-odours and off-flavours in the final weeks of dry ageing could be attributed to the rise in sulphur compounds or certain compounds belonging to the aldehyde group. For instance, pentanal, the content of which increased in the latter weeks of dry ageing, becomes responsible for rancid and thoroughly displeasing notes when present at elevated concentrations (Stetzer et al. 2008). Undoubtedly, the presumed dehydration and the advanced oxidative processes during the latter stages of dry ageing affected the assessment for overall liking. After the notably high scores of the initial two weeks, DA meat experienced a distinct qualitative deterioration, which was also reflected in the sensory evaluation scores. Conversely, while WA meat did not attain scores as high as those of DA meat (remaining consistently close to adequacy scores), it maintained steady scores throughout all ageing time.

## Conclusions

The findings of this study confirm that both time and ageing technique affected some quality parameters of meat obtained from culled goats. The first two weeks of dry ageing led to an enhancement in sensory and instrumental tenderness, along with an improvement in flavour, characterised by a heightened release of aldehydes and ketones. However, it is noteworthy that beyond this initial phase, dry ageing has led to a substantial decline in the overall quality. The pronounced dehydration observed during extended dry ageing has adversely affected meat's water-retention capacity, resulting in diminished juiciness and tenderness. Furthermore, advanced oxidative processes have led to a reduction in compounds perceived as positive, while giving rise to the synthesis of compounds accountable for off-odours and off-flavours. These were notably more pronounced in the last two weeks of ageing, as perceived by the panellists. Hence, for this specific type of meat, it is advisable to avoid extending the duration of dry ageing in a static room beyond the initial two-week period. Although wet ageing has exhibited less dehydration and better control over oxidative processes, due to vacuum-sealed packaging, the scores achieved at the two-week mark for overall liking were lower compared to those assigned to dry ageing. Therefore, despite wet ageing allows extended ageing times, the overall quality improvements were modest, if compared to dry ageing.

## Ethical approval

All animals and procedures employed in this study received approval from the Ethical Committee for Welfare of Animals employed in scientific research of the Department of Veterinary Medicine of the University of Bari (Approval n. 08/2021).

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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