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Slaughter performance and carcass and meat quality of Bergamasca light lambs according to slaughter age

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note finali coverage

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1 **Slaughter performance and carcass and meat quality of Bergamasca light lambs**
2 **according to slaughter age**

3

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24

25 **Abstract**

26

27 This study was designed to evaluate the effects of slaughter age (40 vs. 60 days) on slaughter
28 performance, carcass and meat quality, and fatty acid composition of intramuscular and
29 subcutaneous fat of Bergamasca lambs reared according to the traditional transhumant system
30 in central Italy. Lambs slaughtered at 60 days of age had higher carcass weight (12.44 vs.
31 10.36 kg), lower dressing percentage (47.68% vs. 52.16%), and higher proportion of non-
32 carcass components and leg commercial cut (37.82% vs. 35.49%). Furthermore, after 3 and 6
33 days of storage, the meat of older lambs showed lower drip loss (3.69% vs. 6.16%; 5.73% vs.
34 9.36%, respectively). Slaughter age did not influence meat pH, cooking loss, or chemical
35 composition while older lambs had meat with higher a* (19.43 vs. 18.91). The fatty acid
36 composition of intramuscular fat was not affected by slaughter age, except for C:13 and C:14
37 fatty acids, which were higher in older lambs. Subcutaneous fat of lambs slaughtered at 40
38 days of age showed a better fatty acid profile, as lower saturated fatty acids (52.46% vs.
39 55.68%) and higher mono- and polyunsaturated fatty acids (34.06% vs. 30.16%, 6.46% vs.
40 5.79%, respectively), and n-6 and n-3 polyunsaturated fatty acids. Furthermore, subcutaneous
41 fat of lambs slaughtered at 40 days of age had better polyunsaturated/ saturated fatty acid ratio
42 (0.12 vs. 0.11) and hypocholesterolemic/ hypercholesterolemic ratio (1.42 vs. 1.03), and lower
43 atherogenic index (1.32 vs. 1.82) and thrombogenic index (1.98 vs. 2.35). For light lamb
44 production using the traditional rearing systems, slightly heavier lambs can be produced
45 without worsening chemical composition and cooking loss and fatty acid composition of the
46 *longissimus lumborum* muscle. However, these lambs might have lower dressing percentages
47 and a less favourable fatty acid profile of subcutaneous fat for human health.

48

49 **Keywords:** light lamb; slaughter age; carcass traits; meat quality.

50 **1. Introduction**

51

52 Traditional lamb production in Mediterranean countries is based on light lambs that are
53 slaughtered at early ages (i.e., at 30 to 60 days of age), so just after weaning or after a short
54 fattening period (Juárez et al., 2009; Santos-Silva et al., 2002a). These carcasses weigh up to
55 13 kg and are characterised by their pale pink colour, lower amounts of fat, and good flavour
56 (Berriain et al., 2000), compared to heavier carcasses produced in other production systems
57 and countries (Ekiz et al., 2013; Hajji et al., 2016; Jacques et al., 2011; Lind et al., 2009;
58 Piasentier, 2003; Priolo et al., 2002).

59 In recent years, the demand for lean carcasses has grown due to increased awareness
60 of consumers for healthy meat, with a focus on the quantity and quality of fat (Font i Fournols
61 and Guerrero, 2014). Scientific studies and nutritional guidelines recommend not only a
62 reduction in total fat intake in the human diet, but also a focus on saturated fatty acids (SFAs)
63 and increased consumption of polyunsaturated fatty acids (PUFAs), and especially n-3
64 PUFAs (Calder and Yaqoob, 2009; World Health Organisation, 2003).

65 The age and weight of lambs at slaughter are among the main factors that affect the
66 meat quality at both levels, in terms of the carcass and the meat. A greater weight usually
67 implies an older lamb, except when the feed is manipulated or the lamb has periods of
68 specific alimentary restrictions (Guerrero et al., 2013). Although greater slaughter age of
69 lambs results in heavier carcasses, increased adiposity and better carcass conformation
70 (D'Alessandro et al., 2013; Juárez et al., 2009), this can also result in increased intramuscular
71 fat (Abdullah and Qudsieh, 2009; della Malva et al., 2016; Pérez et al., 2002). Furthermore,
72 lambs slaughtered at a greater age can have a fatty acid (FA) composition of the meat that is
73 less favourable for human health. This can arise as a result of increased SFAs, less PUFAs

74 and n-3 PUFAs, and increased atherogenic and thrombogenic indices (Cifuni et al., 2000;
75 Marino et al., 2008; Santos-Silva et al., 2002b).

76 These aspects are of the utmost importance for the definition of strategies to enhance
77 the production of lamb meat while also taking into consideration the market demand. In this
78 sense, there are significant gaps of knowledge for lamb produced under quality labels, such as
79 the Protected Geographical Indication of '*Agnello del Centro Italia*' (Lamb from Central
80 Italy; European Union, Commission Regulation No. 475/2013). This can be produced using
81 Bergamasca sheep, as well as some other sheep breeds.

82 Bergamasca sheep are an autochthonous Italian breed that originated from the
83 Lombardy region (northern Italy) and that are traditionally raised according to the
84 transhumant system (Piasentier, 2003). Nowadays, Bergamasca sheep are raised principally
85 for meat in most parts of continental Italy (Bigi and Zanon, 2008), and they are often used for
86 cross-breeding with other to improve meat yield. Male and female Bergamasca sheep can
87 reach adult weights of 105 kg and 82 kg, respectively. In the Lombardy region, Bergamasca
88 sheep are still the most important breed used to produce castrated, heavy and light lambs, as
89 the traditional products of transhumant management (Piasantier et al., 2003).

90 In the Marche region (central Italy), lamb production is mainly based on extensive
91 grazing and the transhumance is still of major importance. In summer, most of the flocks
92 graze on upland pastures. Starting from autumn, the sheep are progressively transferred to
93 lowlands, where until Spring the main forage resources are lucerne meadows, although green
94 cereals, crop residues, marginal lands, and riverbanks are sometimes also used (Caballero et
95 al., 2009; D'Ottavio and Santilocchi, 2014). Lamb production mainly occurs in the lowlands
96 for the Easter and Christmas markets, which is when lamb meat is traditionally consumed in
97 Italy (Cifuni et al., 2000). Lambs are reared on pastures with their dams until they reach the
98 optimal slaughter weight, which according to local practices starts from 40 days of age. The

99 lambs are not weaned so their diet is mostly based on milk (i.e., to 20 days of age), while later
100 they are supplemented with concentrate and/or hay, as needed.

101 The effects of slaughter age on the quality of light lamb meat has been studied for
102 some Italian breeds, such as the Altamura (della Malva et al., 2016; Marino et al., 2008),
103 Apulian (Cifuni et al., 2000), Leccese (D'Alessandro et al., 2013), Trimeticchio (Marino et al.,
104 2008) and Italian Merino (Oriani et al., 2005) sheep. However, there is little or no such
105 information available for the lamb meat quality of the Bergamasca breed of sheep.

106 The aim of the present study was to evaluate the effects of slaughter age on slaughter
107 performance, carcass traits and meat quality, including FA composition of intramuscular and
108 subcutaneous fat, of Bergamasca light lambs reared under the traditional transhumant system
109 of the Marche region of Italy.

110

111 **2. Materials and methods**

112

113 All animal handling followed the recommendations of European Union Directive
114 2010/63/EU, which are implemented in Italian law according to Legislative Decree No.
115 26/2014.

116

117 *2.1. Experimental design, diet and animal management*

118 This study was carried out from September to October 2015 in the Marche region (central
119 Italy) under the standard conditions for rearing and management of the transhumant sheep
120 system that is characteristic for this region. Twenty-two male, single-born, Bergamasca lambs
121 were included in the study. At birth, the lambs were randomly distributed into two groups that
122 were balanced for body weight. All of these lambs stayed with their dams on grasslands
123 dominated by alfalfa (10.3 MJ metabolisable energy kg⁻¹ dry matter [DM], 15.7% crude

124 protein DM, 28.5% crude fibre DM), and suckled their dams throughout the whole study
125 period. The dams grazed and had free access to alfalfa hay (11.8 MJ metabolisable energy kg⁻¹
126 ¹ DM, 15.2% crude protein DM, 22.3% crude fibre DM) and their diet was supplemented with
127 corn grain (0.5 kg head⁻¹ day⁻¹; 16.5 MJ metabolisable energy kg⁻¹ DM, 7.9% crude protein
128 DM, 5.0% crude fibre DM). The lambs were given corn grain *ad libitum* in creep feeders
129 from 20 days of age, and had access to alfalfa hay. The chemical compositions of collected
130 feed samples were determined according to Martillotti et al. (1987). To calculate the average
131 daily gain (ADG), the individual lamb weights were recorded at birth and after each 20 days,
132 until slaughter. The lambs were slaughtered at two different ages: 11 lambs at an average of
133 40 days, and the other 11 lambs at an average of 60 days.

134

135 2.2. Slaughter procedure and assessment of carcass traits

136 To obtain the pre-slaughter weight, the lambs were weighed on the farm and soon after being
137 transferred to a commercial slaughterhouse, where they were stunned and slaughtered by
138 cutting the jugular vein. After the slaughter, the non-carcass components were removed and
139 weighed (i.e., skin, head, feet, pluck [heart, lungs, liver, spleen], digestive tract). After
140 chilling at 4 °C for 24 h, the cold carcass weights were recorded, and the dressing percentages
141 were calculated. The right side of each carcass was jointed into three main commercial cuts:
142 shoulder, whole loin with flank, and leg. The weights of each commercial cut were recorded
143 and are expressed as proportions of the half carcass weight. For further analyses, the
144 *longissimus lumborum* muscles between the first and sixth lumbar vertebrae were obtained.

145

146 2.3. Meat quality parameters

147 The pH of the *longissimus thoracis* muscle (between the tenth and thirteenth thoracic
148 vertebrae) was measured 45 min and 24 h (final pH) *post-mortem* using a portable pH meter
149 (XS pH 110; Eutech Instruments, Singapore) equipped with a penetrating glass electrode.

150 The drip loss and cooking loss were determined on approximately 80 g of 3-cm-thick
151 *longissimus lumborum* muscle. To measure the drip loss (ASPA, 1996), the meat samples
152 were weighed and wrapped in polyethylene bags. After 24 h storage at 4 °C, the samples were
153 gently dried with paper towels, and reweighed. This procedure was carried out as two
154 replications, and was repeated for the third and the sixth days of storage. For cooking loss
155 determination (ASPA, 1996), the meat samples were initially weighed, and then placed in
156 polyethylene bags and cooked in a water bath until they reached an internal temperature of 75
157 °C. The bags with the cooked meat samples were then cooled under cold running water for
158 30 min, and then they were removed from the bags, dried with paper towels, and reweighed.

159 The meat colour was assessed according to the CIELAB system (CIE, 1986), as the
160 lightness (L^*), redness (a^*) and yellowness (b^*) of the *longissimus lumborum* muscle was
161 recorded for the fresh meat (~24 h *post-mortem*) using Minolta CR 200. A D65 illuminant
162 was used at an observation angle of 10° and with an aperture of 30 mm. The instrument was
163 calibrated using white and black standard coordinates. Chroma (C^* ; square root of [$a^{*2} +$
164 b^{*2}]) and hue angle (H° ; $\tan^{-1} [b^*/a^*]$) were also calculated. For each meat sample, three
165 colour measurements and calculations were performed for each parameter, and the means are
166 reported. After the colour measurements were performed, the meat samples were frozen (-20
167 °C), freeze-dried, ground and analysed for their chemical composition. The procedures
168 outlined by the AOAC (1999) were used to determine the DM (method ID 950.46), Kjeldahl
169 N (crude protein; method ID 981.10), fat (method ID 991.36) and ash (method ID 920.153).
170 Analyses were performed in duplicate for each sample, and the parameters and data are
171 corrected for moisture content.

172

173 *2.4. Fatty acid analysis*

174 The FA composition analysis was performed on freeze-dried samples of *longissimus*
175 *lomborum* muscle (i.e., intramuscular) fat and subcutaneous fat. The fat was extracted using a
176 Soxtec system with petroleum ether (boiling point range, 40-60 °C). The oven temperature for
177 both the pre- and post-extraction drying was within the temperature range suggested by Foss
178 for use with the Soxtec system, as 102 ±3 °C (Soxtec Avanti 2055 instruction manual). The
179 liquefied fat (~0.1 mL) was collected and dissolved in hexane (1.0 mL). The FA methyl esters
180 (FAMES) were prepared by ‘rapid’ KOH-catalysed transesterification, according to method
181 ISO 12966-2:2011. The individual FAMES were analysed on a gas chromatography system
182 (HRGC MEGA 2 series; Fisons Instruments, Milan, Italy) equipped with a Rt-2560 column
183 (length, 100 m, internal diameter, 0.25 mm; df, 0.2 µm; Restek, PA, USA) and a flame-
184 ionisation detector, with He as the carrier gas.

185 The identification of the FAs was based on comparisons of retention times with those
186 of commercial standards (Supelco 37 FAMES Mix; Supelco, Bellefonte, PA, USA). The
187 concentrations of the individual FAMES were expressed as percentages of the total FAMES
188 identified, and also grouped as follows: SFAs, monounsaturated FAs (MUFAs) and PUFAs.
189 The PUFA/SFA and n-6/n-3 PUFA ratios were determined, along with the atherogenic and
190 thrombogenic indices (Ulbricht and Southgate, 1991) and the hypocholesterolemic/
191 hypercholesterolemic ratio (h/H; Fernández et al., 2007).

192

193 *2.5. Statistical analysis*

194 The data were analysed using the JMP software version 10 (SAS Institute Inc., Cary, NC,
195 USA, 1989-2007). Student’s t-tests were used to evaluate effects of the two slaughter ages on
196 all of the parameters.

197

198 3. Results and discussion

199

200 The lamb growth performances are given in Table 1. When grouped per slaughter age,
201 the lambs did not differ in birth weight, weight at 20 and 40 days of age, and ADGs through
202 the different periods calculated. ADGs were higher than those reported by Santos-Silva et al.
203 (2002a) for Merino Branco and crossbred Ile de France x Merino Branco light lambs, reared
204 with dams on grass and with concentrate *ad libitum*. The effects of slaughter age on carcass
205 traits and non-carcass components are given in Table 2. As expected, the older lambs had
206 significantly higher pre-slaughter and carcass weights ($P < 0.001$, $P < 0.05$, respectively).
207 According to the European carcass classification system, and based on their average weights,
208 the carcasses from both of the age categories can be classified as class C for light lambs (10.1-
209 13.0 kg; European Union, 1994).

210 In agreement with previous studies (Cifuni et al., 2000; Morbidini et al., 1987),
211 increased slaughter age significantly decreased the dressing percentages of the light lambs (P
212 < 0.001). This can be attributed to the significantly greater weight of offal of the lambs
213 slaughtered at 60 days of age, which negatively affected their dressing percentages. In
214 contrast, Polidori et al. (2017) reported higher dressing percentages for older lambs. These
215 data might be explained on the basis of the different slaughter weights used in these two
216 studies (Polidori et al., 23.8, 37.4 kg; present study, 19.84, 25.99 kg). In the present study, the
217 younger lambs were not functional as ruminants, whereas the older lambs had started to be,
218 which will thus have reduced their dressing percentages, as also explained by Cifuni et al.
219 (2000). As for the present study, D'Alessandro et al. (2013) reported significant differences in
220 carcass weight between Lecce lambs slaughtered at 45 and 60 days of age, although they
221 did not report any variations in dressing percentages. The dressing percentages of the lambs

222 slaughtered at 60 days of age were similar to those reported for heavy Bergamasca lambs
223 (46.3%; Piasentier et al., 2001). However, the dressing percentages of the lambs from both of
224 these age groups were lower than those reported for Leccese lambs slaughtered at 45 and 60
225 days (D'Alessandro et al., 2013) and for Apulian lambs slaughtered at 45 and 90 days of age
226 (Cifuni et al., 2000).

227 For the non-carcass components, slaughter age influenced all of the parameters
228 investigated (Table 2). The lambs slaughtered at 60 days of age had significantly greater (P
229 <0.001) proportions of head, skin, pluck and full digestive tract, and significantly lower (P
230 <0.01) proportions of feet, than the lambs slaughtered at 40 days of age. All of these
231 differences can be attributed to the older slaughter age and the increased growth of the lambs.

232 As expected, the older lambs had significantly greater (P <0.01) half-carcass weights
233 than the younger lambs (Table 3). Furthermore, the lambs slaughtered at 60 days of age had
234 significantly greater (P <0.01) proportions of leg than the lambs slaughtered at 40 days of age,
235 although the other commercial cuts did not differ between the slaughter ages. In a study by
236 Cifuni et al. (2000), first grade wholesale lamb cuts (i.e., rack, loin, leg) were not significantly
237 affected by slaughter age, while the proportions of second grade cuts (i.e., shoulder, neck,
238 breast) decreased as age of slaughter increased. These data were attributed to the greater
239 shoulder and breast proportions of the younger animals. The proportions of leg in the present
240 study was higher than that reported by Skapetas et al. (2006) for lambs slaughtered at 45 and
241 60 days, while the proportions of shoulder were similar to those reported by Skapetas et al.
242 (2006). Similar proportions of shoulder were reported by D'Alessandro et al. (2013) for lambs
243 slaughtered in spring at a slaughter age of 45 days. However, contrary to the present data,
244 D'Alessandro et al. (2013) obtained higher proportions of leg for Leccese lambs slaughtered
245 at 45 days of age, compared to those slaughtered at 60 days of age. These contrary results

246 might be attributed to different methods used to dissect the carcasses into the main
247 commercial cuts.

248 The age at slaughter did not affect the meat pH at 45 min and 24 h *post-mortem* (Table
249 4). These data are in agreement with other studies where the pHs obtained did not differ
250 between light lambs slaughtered at different ages or weights (D'Alessandro et al., 2013; della
251 Malva et al., 2016; Juárez et al., 2009). The final pHs were within the normal ranges (Tejeda
252 et al., 2008) and were similar to those reported for light lambs of different breeds in other
253 studies (D'Alessandro et al., 2013; della Malva et al., 2016; Juárez et al., 2009; Mazzone et
254 al., 2010).

255 No differences were seen between the lambs slaughtered at 40 and 60 days of age in
256 terms of drip loss measured after 1 day of meat storage (Table 4). The drip losses were lower
257 than those reported for Appenninica light lambs (Mazzone et al., 2010). Differences in drip
258 loss between lambs of the two slaughter ages appeared after the third day, and continued
259 through the sixth day of storage, whereby the meat from the younger lambs had significantly
260 higher ($P < 0.001$) drip loss than that from the older lambs. The results might be attributed to
261 faster weakening of myofibrillar proteins by proteolytic enzymes during the storage of meat
262 of younger lambs, thereby affecting the ability of myofibrillar proteins to hold water (Lawrie
263 and Ledward, 2006). These data are in agreement with Russo et al. (2003), who reported
264 better water-holding capacity for heavier carcasses due to lower drip loss after the second day
265 of storage.

266 The cooking losses did not differ between the lambs slaughtered at 40 and 60 days of
267 age (Table 4), and they were lower than those reported for light Appenninica lambs of similar
268 slaughter age (Mazzone et al., 2010). On the contrary, although another method was used to
269 determine their cooking loss, Russo et al. (2003) reported increased cooking losses with
270 increased carcass weight. The lack of any differences in cooking losses between the lambs of

271 the two slaughter age groups in the present study can be explained on the basis that contrary
272 to Russo et al. (2003), the differences in the carcass weights between the age groups of these
273 light lambs were lower.

274 The meat chemical compositions of lambs slaughtered at 40 and 60 days of age are
275 given in Table 5. These data are comparable with those reported for light lambs of different
276 Italian breeds (D'Alessandro et al., 2013; della Malva et al., 2016; Mazzone et al., 2010).
277 Taking into consideration the intramuscular fat content, the meat analysed in the present study
278 was of good quality, on the basis that 2% to 3% of intramuscular fat ensures the desirable
279 organoleptic properties of the meat (Wood, 1990). No significant differences were recorded
280 for moisture, crude protein, fat and ash of the *longissimus lumborum* muscle in terms of the
281 slaughter ages.

282 These data are in agreement with other studies that have highlighted that the chemical
283 composition of lamb meat is not affected by slaughter age (D'Alessandro et al., 2013; Marino
284 et al., 2008) or carcass weight (Russo et al., 2003). In general, greater intramuscular fat has
285 been reported for older lambs of different breeds (Abdullah and Qudsieh, 2009; della Malva
286 et al., 2016; Juárez et al., 2009; Pérez et al., 2002).

287 In contrast to D'Alessandro et al. (2013), who observed no effects of slaughter age on
288 any of the meat colour parameters of light lambs, in the present study, some colour
289 differences were recorded (Table 5). Contrary to data reported for other breeds (Abdullah and
290 Qudsieh, 2009; della Malva et al., 2016; Juárez et al., 2009; Santos-Silva et al., 2002a;
291 Sañudo et al., 1996), in the present study, increased age and weight of the lambs did not result
292 in darker meat. Indeed, no differences were found for the lightness (L*), yellowness (b*) and
293 Hue and Chroma between the meat of the lambs slaughtered at 40 and 60 days of age. There
294 was significantly greater ($P < 0.01$) redness (a*) for the meat of the older and heavier lambs,
295 which is in agreement with other studies (della Malva et al., 2016; Juárez et al., 2009; Sañudo

296 et al., 1996). This can be explained by the higher myoglobin content in the meat of older
297 lambs (Juárez et al., 2009). Furthermore, the colour differences for the meat from the lambs
298 slaughtered at different ages might be due to the higher consumption of milk by the younger
299 lambs, compared to the older ones that used proportionally more concentrate before their
300 slaughter (Sañudo et al., 1996).

301 The FA compositions of the intramuscular and subcutaneous fat are given in Tables 6
302 and 7, respectively. In general, the intramuscular FA composition in the present study was
303 similar to that reported by others for light lambs with high milk content in the diet
304 (D'Alessandro et al., 2015; Cifuni et al., 2000; Oriani et al., 2005). The total SFAs were the
305 most abundant FAs, followed by MUFAs and PUFAs.

306 Slaughter age had relatively small influences on the FA composition of *longissimus*
307 *lomborum* muscle, whereby lambs slaughtered at 60 days of age had significantly greater (P
308 <0.05) tridecylic (C13:0) and palmitic (C16:0) SFAs than those slaughtered at 40 days of age
309 (Table 6). The saturated palmitic FA has been shown to be hyperlipidemic (Bonamone and
310 Grundy, 1988), and therefore consumption of meat from the younger lambs might reduce the
311 risk of heart disease. This confirms data from other studies, where greater amounts of C16:0
312 were reported for the intramuscular fat of older and heavier lambs (Cifuni et al., 2000;
313 D'Alessandro et al., 2015; della Malva et al., 2016; Santos-Silva et al., 2002b). However, the
314 same studies reported better FA profile for the meat of the younger (less heavy) lambs, due to
315 an increase in the proportion of SFAs with lamb growth. This reported trend for intramuscular
316 fat was not evident in the present study, as the slaughter age did not affect any of the other
317 single SFAs, MUFAs or PUFAs in the lamb intramuscular fat. Consequently, the nutritional
318 indices of the meat, which are defined here as the PUFA/SFA, n-6/n-3 and h/H ratios and the
319 atherogenic and thrombogenic indices, were similar between these Bergamasca lambs
320 slaughtered at 40 and 60 days of age.

321 For the FA composition of the subcutaneous fat, there were much more evident effects
322 of slaughter age (Table 7). Here, the lambs slaughtered at 40 days of age showed a better FA
323 composition, in terms of significantly lower ($P < 0.01$) SFAs, and significantly greater (P
324 < 0.01) MUFAs and PUFAs than the lambs slaughtered at 60 days of age. Unweaned lambs
325 have a rumen that is only partially functional, and therefore their dietary unsaturated FAs are
326 likely to be digested and adsorbed as in non-ruminants (Sañudo et al., 1998). In contrast, the
327 older lambs start to consume a dry diet, which needs a more functional rumen to be digested.
328 Consequently, the greater SFAs in the subcutaneous fat of the older lambs that here used
329 proportionally more concentrate before their slaughter, will be due to the extensive
330 hydrogenation by micro-organisms in the rumen.

331 In contrast to these data, Juárez et al. (2009) reported that for the FA composition of
332 subcutaneous fat of suckling and light lambs, weight and age only influenced some of the
333 individual SFAs, while the total SFAs, MUFAs and PUFAs, and the PUFA/SFA ratio, did not
334 differ between the lambs of their two slaughter weights.

335 In the present study, the slaughter age affected the proportion of almost all of the SFAs
336 investigated. In particular, the subcutaneous fat from the older lambs showed significantly
337 greater proportions of capric (C10:0; $P < 0.01$), lauric (C12:0; $P < 0.05$), tridecylic ($P < 0.01$),
338 myristic (C14:0; $P < 0.01$), pentadecanoic (C15:0; $P < 0.01$) and palmitic ($P < 0.001$) SFAs. It
339 has been reported that short chain SFAs C12:0, C14:0 and C16:0 can increase plasma low-
340 density lipoprotein (LDL)-cholesterol (Siri-Tarino et al., 2010). Therefore, the subcutaneous
341 fat from the Bergamasca lambs slaughtered at 60 days showed less favourable levels of SFAs
342 than that of lambs slaughtered at 40 days of age. On the other hand, the subcutaneous fat of
343 the younger lambs had significantly greater heptadecanoic (C17:0; $P < 0.01$) and stearic
344 (C18:0; $P < 0.001$) SFAs. However, although stearic acid is a saturated FA, it will not elevate

345 plasma LDL-cholesterol (Bonamone and Grundy, 1988) as it is poorly digested and can be
346 easily desaturated to oleic acid.

347 For the MUFAs, the lambs slaughtered at 40 days of age had significantly lower (P
348 <0.01) myristoleic (C14:1) and palmitoleic (C16:1) acids, but significantly higher (P <0.01)
349 sum of oleic and cis-vaccenic acid (Σ C18:1c) in their subcutaneous fat, than the lambs
350 slaughtered at 60 days of age. Oleic acid has been reported to be hypolipidemic, which can
351 thus reduce plasma cholesterol and triglycerides (Mattson and Grundy, 1985). Therefore,
352 oleic acid can be considered as a desirable component of the diet (Baer et al., 2014).

353 The slaughter age also showed significantly greater (P <0.05) proportions of single
354 PUFAs in the subcutaneous fat for the lambs slaughtered at 60 days, in terms of C18:2 trans
355 and C20:2 n-6. In agreement with Juárez et al. (2009), the older lambs showed significantly
356 lower linoleic acid (C18:2 n-6; P <0.001). Furthermore, the essential linolenic acid (C18:3 n-
357 3) that has been shown to have positive health benefits was significantly lower (P <0.05) in
358 the meat of the older lambs.

359 With the increased slaughter age, there were significantly decreased total PUFAs for
360 both the n-6 (P <0.001) and n-3 (P <0.05) PUFAs. However, the ratios between these (i.e., n-
361 6/n-3) did not differ for Bergamasca lambs between the two slaughter ages, and they both
362 remained within the recommended value for inclusion in a human diet (i.e., <4) (Wood et al.,
363 2003).

364 The lambs slaughtered at 40 days had subcutaneous fat that showed an improved
365 PUFA/SFA ratio, as this was significantly greater (P <0.01) compared to the lambs
366 slaughtered at 60 days of age. However, the PUFA/SFA ratios of these slaughter age groups
367 were both low, and they did not reach the recommended value for human health (i.e., >0.4)
368 (Wood et al., 2003).

369 The overall changes in the FA compositions of the subcutaneous fat according to
370 increased slaughter age showed significantly lower h/H ($P < 0.01$), which has a negative effect
371 on the nutritional value of the meat. The subcutaneous fat of lambs slaughtered at 40 days of
372 age also had significantly lower, and thus more favourable, atherogenic and thrombogenic
373 indices ($P < 0.01$, $P < 0.001$, respectively), compared to the lambs slaughtered at 60 days of
374 age.

375

376 **4. Conclusions**

377 The increase in the slaughter age for these Bergamasca lambs from 40 days to 60 days
378 resulted in improved carcass weight, a greater proportion of leg commercial cut, and a lower
379 drip loss after meat storage. For light lamb production using the traditional rearing systems,
380 slightly heavier lambs can be produced without worsening chemical composition, cooking
381 loss and fatty acid composition of the *longissimus lumborum* muscle. However, it is important
382 to take in consideration that these heavier lambs might have lower dressing percentages and
383 less favourable FA profile of their subcutaneous fat for human health.

384 For a more complete understanding of the effects of slaughter age on carcass and meat
385 quality, additional studies are needed. These can be designed to evaluate more specifically the
386 meat yield (i.e., from carcass or leg dissection), the effects of lamb nutrition (i.e., FA
387 composition of feed and dams' milk), and the feed intake of the lambs.

388

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540 **Table 1**

541 Growth performance of Bergamasca lambs slaughtered at 40 and 60 days of age (means ±
542 SD).

	Slaughter age (days)		Significance
	40	60	
Live Weight (kg)			
Birth	5.37 ± 1.05	5.11 ± 0.83	NS
20 days	11.79 ± 2.25	11.77 ± 1.22	NS
40 days	19.84 ± 3.07	19.59 ± 2.35	NS
60 days		25.95 ± 3.34	
Average Daily Gain (g d ⁻¹)			
birth to 20 days	318 ± 73.19	337 ± 72.57	NS
20 to 40 days	383 ± 56.82	373 ± 63.01	NS
total rearing period	351 ± 60.23	337 ± 61.93	NS

543 NS: not significant, P > 0.05

544

545 **Table 2**

546 Carcass traits and non-carcass components of Bergamasca lambs slaughtered at 40 and 60
 547 days of age (means \pm SD).

	Slaughter age (days)		Significance
	40	60	
Pre-slaughter weight (kg)	19.84 \pm 3.07	25.95 \pm 3.34	***
Cold carcass weight (kg)	10.36 \pm 1.75	12.44 \pm 2.14	*
Cold dressing (%)	52.16 \pm 2.50	47.68 \pm 2.65	***
Proportion (%) on PSW			
Head	2.63 \pm 0.23	3.92 \pm 0.32	***
Skin	9.09 \pm 0.60	11.54 \pm 0.85	***
Feet	1.01 \pm 0.11	0.83 \pm 0.10	**
Pluck	5.39 \pm 0.93	7.69 \pm 0.44	***
Full digestive tract	13.86 \pm 2.30	17.96 \pm 2.94	***

548 PSW: pre-slaughter weight.

549 * P < 0.05.

550 ** P < 0.01.

551 *** P < 0.001.

552

553 **Table 3**

554 Half carcass weight and proportions of commercial cuts of Bergamasca lambs slaughtered at
 555 40 and 60 days of age (means \pm SD).

	Slaughter age (days)		Significance
	40	60	
Half carcass weight (kg)	4.80 \pm 0.85	6.06 \pm 1.07	**
Proportions of commercial cuts (%)			
Shoulder	19.81 \pm 0.88	19.53 \pm 1.36	NS
Whole loin with flank	44.69 \pm 1.71	42.65 \pm 2.84	NS
Leg	35.49 \pm 1.06	37.82 \pm 1.85	**

556 NS: not significant, $P > 0.05$.

557 ** $P < 0.01$.

558

559 **Table 4**

560 pH, drip loss and cooking loss of Bergamasca lambs slaughtered at 40 and 60 days of age
 561 (means \pm SD).

	Slaughter age (days)		Significance
	40	60	
pH			
45 min	6.41 \pm 0.14	6.54 \pm 0.35	NS
24 h	5.71 \pm 0.11	5.69 \pm 0.14	NS
Drip loss (%)			
1 day	0.77 \pm 0.17	1.01 \pm 0.53	NS
3 days	6.16 \pm 1.41	3.69 \pm 0.97	***
6 days	9.36 \pm 1.45	5.73 \pm 1.16	***
Cooking loss (%)	12.22 \pm 3.85	10.53 \pm 4.94	NS

562 NS: not significant, $P > 0.05$.

563 *** $P < 0.001$.

564 **Table 5**

565 Chemical composition and colour of *longissimus lomborum* muscle of Bergamasca lambs
 566 slaughtered at 40 and 60 days of age (means \pm SD).

	Slaughter age (days)		Significance
	40	60	
Chemical composition (%)			
Moisture	73.45 \pm 1.35	74.55 \pm 1.56	NS
Crude Protein	19.98 \pm 0.50	19.68 \pm 0.62	NS
Fat	2.70 \pm 1.11	2.15 \pm 0.91	NS
Ash	1.31 \pm 0.07	1.39 \pm 0.25	NS
Colour parameters			
L*	41.52 \pm 2.13	41.11 \pm 3.07	NS
a*	18.91 \pm 1.59	19.43 \pm 1.21	*
b*	3.3 \pm 0.55	3.43 \pm 0.93	NS
Hue	0.17 \pm 0.03	0.18 \pm 0.05	NS
Chroma	30.2 \pm 4.61	32.13 \pm 8.19	NS

567 NS: not significant, $P > 0.05$.

568 ** $P < 0.01$.

569

570 **Table 6**

571 Fatty acid composition (% of total fatty acids) of *longissimus lomborum* muscle of
 572 Bergamasca lambs slaughtered at 40 and 60 days of age (means \pm SD).

	Slaughter age (days)		Significance
	40	60	
C10:0	0.64 \pm 0.24	0.75 \pm 0.18	NS
C11:0	0.04 \pm 0.01	0.04 \pm 0.01	NS
C12:0	1.53 \pm 0.57	1.84 \pm 0.50	NS
C13:0	0.10 \pm 0.03	0.12 \pm 0.02	**
C14:0	9.78 \pm 1.90	10.77 \pm 2.05	NS
C15:0	0.97 \pm 0.17	1.01 \pm 0.15	NS
C16:0	24.43 \pm 1.84	26.09 \pm 0.90	**
C17:0	1.20 \pm 0.17	1.12 \pm 0.10	NS
C18:0	11.98 \pm 1.72	11.18 \pm 1.79	NS
C20:0	0.10 \pm 0.04	0.08 \pm 0.03	NS
C21:0	0.15 \pm 0.07	0.16 \pm 0.03	NS
C14:1	0.29 \pm 0.11	0.34 \pm 0.11	NS
C16:1 n-7	1.78 \pm 0.40	1.90 \pm 0.32	NS
C17:1	0.55 \pm 0.14	0.55 \pm 0.10	NS
Σ 18:1t ¹	3.31 \pm 1.59	3.05 \pm 1.21	NS
Σ 18:1c ¹	30.14 \pm 3.68	28.12 \pm 3.29	NS
Σ 18:2t ¹	1.58 \pm 0.26	1.65 \pm 0.27	NS
C18:2 n-6	4.2 \pm 1.36	3.56 \pm 0.83	NS
C18:2 <i>cis</i> -9, <i>trans</i> -11(CLA)	1.50 \pm 0.30	1.64 \pm 0.40	NS
C18:3 n-3	1.57 \pm 0.32	1.53 \pm 0.24	NS
C20:2 n-6	0.09 \pm 0.03	0.07 \pm 0.01	NS
C20:4 n-6	0.53 \pm 0.39	0.63 \pm 0.29	NS
C20:5 n-3	0.26 \pm 0.19	0.29 \pm 0.12	NS
C22:5 n-3	0.34 \pm 0.23	0.36 \pm 0.14	NS
C22:6 n-3	0.14 \pm 0.10	0.14 \pm 0.07	NS
Other fatty acids	2.79 \pm 0.26	2.99 \pm 0.19	NS
SFA	50.91 \pm 3.89	53.17 \pm 2.35	NS
MUFA	32.76 \pm 3.97	30.91 \pm 3.49	NS
PUFA	8.64 \pm 2.46	8.23 \pm 1.32	NS
n-6 PUFA	4.82 \pm 1.67	4.27 \pm 1.01	NS
n-3 PUFA	2.32 \pm 0.82	2.33 \pm 0.50	NS
n-6/n-3 PUFA	2.13 \pm 0.59	1.88 \pm 0.53	NS
PUFA/SFA	0.17 \pm 0.06	0.16 \pm 0.02	NS
h/H	1.11 \pm 0.21	0.95 \pm 0.15	NS
AI	1.66 \pm 0.40	1.92 \pm 0.35	NS
TI	1.79 \pm 0.31	1.92 \pm 0.17	NS

573 Σ C18:1t: sum of unidentified C18:1 *trans* isomers; Σ C18:1c: C18:1 Δ 9c + Δ 11c; Σ C18:2t,

574 18:2 n-6 c,t + t,c + t,t; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids;

575 PUFA: polyunsaturated fatty acids; n-6 PUFA: omega 6 fatty acids; n-3 PUFA: omega 3 fatty

576 acids; PUFA/SFA: polyunsaturated/ saturated fatty acid ratio; h/H: hypocholesterolemic/
577 hypercholesterolemic ratio (Fernández et al., 2007); AI: atherogenic index (Ulbricht and
578 Southgate, 1991); TI: thrombogenic index (Ulbricht and Southgate, 1991); NS: not
579 significant, $P > 0.05$; ** $P < 0.01$.

580

581 **Table 7**

582 Fatty acid composition (% of total fatty acids) of subcutaneous adipose tissue of Bergamasca
 583 lambs slaughtered at 40 and 60 days of age (means \pm SD).

	Slaughter age (days)		Significance
	40	60	
C10:0	0.63 \pm 0.18	0.86 \pm 0.11	**
C11:0	0.03 \pm 0.01	0.04 \pm 0.01	**
C12:0	1.09 \pm 0.39	1.50 \pm 0.30	*
C13:0	0.06 \pm 0.02	0.08 \pm 0.02	**
C14:0	7.42 \pm 1.55	9.28 \pm 1.24	**
C15:0	0.72 \pm 0.18	0.90 \pm 0.09	**
C16:0	19.58 \pm 2.13	22.99 \pm 1.51	***
C17:0	1.73 \pm 0.17	1.51 \pm 0.06	**
C18:0	20.94 \pm 2.23	18.23 \pm 1.68	**
C20:0	0.17 \pm 0.03	0.17 \pm 0.05	NS
C21:0	0.09 \pm 0.03	0.10 \pm 0.01	NS
C14:1	0.10 \pm 0.02	0.14 \pm 0.02	**
C16:1 n-7	0.80 \pm 0.09	0.94 \pm 0.12	**
C17:1	0.42 \pm 0.06	0.39 \pm 0.06	NS
Σ 18:1t ¹	2.84 \pm 2.14	3.82 \pm 1.79	NS
Σ 18:1c ¹	32.74 \pm 2.93	28.69 \pm 2.51	**
Σ 18:2t ¹	1.59 \pm 0.15	1.72 \pm 0.14	*
C18:2 n-6	2.92 \pm 0.33	2.44 \pm 0.14	***
C18:2 <i>cis</i> -9, <i>trans</i> -11(CLA)	1.71 \pm 0.29	1.71 \pm 0.20	NS
C18:3 n-3	1.57 \pm 0.26	1.37 \pm 0.11	*
C20:2 n-6	0.03 \pm 0.01	0.04 \pm 0.01	*
C20:4 n-6	0.05 \pm 0.01	0.05 \pm 0.02	NS
C20:5 n-3	0.02 \pm 0.01	0.02 \pm 0.01	NS
C22:5 n-3	0.12 \pm 0.02	0.13 \pm 0.03	NS
C22:6 n-3	0.04 \pm 0.01	0.03 \pm 0.02	NS
Other fatty acids	2.59 \pm 0.26	2.83 \pm 0.10	*
SFA	52.46 \pm 2.60	55.68 \pm 2.33	**
MUFA	34.06 \pm 2.93	30.16 \pm 2.53	**
PUFA	6.46 \pm 0.62	5.79 \pm 0.34	**
n-6 PUFA	3.00 \pm 0.33	2.52 \pm 0.13	***
n-3 PUFA	1.75 \pm 0.27	1.56 \pm 0.09	*
n-6/n-3 PUFA	1.73 \pm 0.15	1.62 \pm 0.09	NS
PUFA/SFA	0.12 \pm 0.01	0.11 \pm 0.01	**
h/H	1.42 \pm 0.29	1.03 \pm 0.15	**
AI	1.32 \pm 0.31	1.82 \pm 0.30	**
TI	1.98 \pm 0.06	2.35 \pm 0.07	***

584 Σ C18:1t: sum of unidentified C18:1 *trans* isomers; Σ C18:1c: C18:1 Δ 9c + Δ 11c; Σ C18:2t,

585 18:2 n-6 c,t + t,c + t,t; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids;

586 PUFA: polyunsaturated fatty acids; n-6 PUFA: omega 6 fatty acids; n-3 PUFA: omega 3 fatty

587 acids; PUFA/SFA: polyunsaturated/ saturated fatty acid ratio; h/H: hypocholesterolemic/
588 hypercholesterolemic ratio (Fernández et al., 2007); AI: atherogenic index (Ulbricht and
589 Southgate, 1991); TI: thrombogenic index (Ulbricht and Southgate, 1991); NS: not
590 significant, $P > 0.05$.; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

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