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

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4   Katarina Budimir, Maria Federica Trombetta, Matteo Francioni, Marco Toderi, Paride

5   D'Ottavio*

6

7   Dipartimento di Scienze Agrarie, Alimentari ed Ambientali, Università Politecnica delle

8   Marche, Via Brecce Bianche 10, 60131 Ancona, Italy

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16   ***Corresponding author: Paride D'Ottavio**

17   Dipartimento di Scienze Agrarie, Alimentari ed Ambientali

18   Università Politecnica delle Marche

19   Via Brecce Bianche 10

20   60131 Ancona, Italy

21   Tel: +39-071-2204156

22   Email: p.dottavio@univpm.it

23

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Abstract

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

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

1. Introduction

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

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

The age and weight of lambs at slaughter are among the main factors that affect the meat quality at both levels, in terms of the carcass and the meat. A greater weight usually implies an older lamb, except when the feed is manipulated or the lamb has periods of specific alimentary restrictions (Guerrero et al., 2013). Although greater slaughter age of lambs results in heavier carcasses, increased adiposity and better carcass conformation (D'Alessandro et al., 2013; Juárez et al., 2009), this can also result in increased intramuscular fat (Abdullah and Qudsieh, 2009; della Malva et al., 2016; Pérez et al., 2002). Furthermore, lambs slaughtered at a greater age can have a fatty acid (FA) composition of the meat that is 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 Altamurana (della Malva et al., 2016; Marino et al., 2008),

103 Apulian (Cifuni et al., 2000), Leccese (D'Alessandro et al., 2013), Trimeticcio (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.

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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 lomborum* 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 where than 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

2.4. Fatty acid analysis

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

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

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2.5. Statistical analysis

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

3. Results and discussion

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

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

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

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

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

In contrast to D'Alessandro et al. (2013), who observed no effects of slaughter age on any of the meat colour parameters of light lambs, in the present study, some colour differences were recorded (Table 5). Contrary to data reported for other breeds (Abdullah and Qudsieh, 2009; della Malva et al., 2016; Juárez et al., 2009; Santos-Silva et al., 2002a; Sañudo et al., 1996), in the present study, increased age and weight of the lambs did not result in darker meat. Indeed, no differences were found for the lightness (L*), yellowness (b*) and Hue and Chroma between the meat of the lambs slaughtered at 40 and 60 days of age. There was significantly greater (P <0.01) redness (a*) for the meat of the older and heavier lambs, 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 ($\sum$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 lomborum* 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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Table 1

Growth performance of Bergamasca lambs slaughtered at 40 and 60 days of age (means ± 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

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 ± SD).

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

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

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

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

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

573    $\sum$C18:1t: sum of unidentified C18:1 *trans* isomers; $\sum$C18:1c: C18:1Δ9c + Δ11c; $\sum$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 ± SD).

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

584 $\sum$C18:1t: sum of unidentified C18:1 *trans* isomers; $\sum$C18:1c: C18:1Δ9c + Δ11c; $\sum$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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592