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Influence of almond hulls in lamb diets on animal performance and meat quality / Scerra, M., Bognanno, M., Foti, F., Caparra, P., Cilione, C., Mangano, F., Natalello, A., Chies, L.. - In: MEAT SCIENCE. - ISSN 0309-1740. - 108903:(2022). [10.1016/j.meatsci.2022.108903]

*Availability:*

This version is available at: <https://hdl.handle.net/20.500.12318/127586> since: 2022-11-17T15:08:03Z

*Published*

DOI: <http://doi.org/10.1016/j.meatsci.2022.108903>

The final published version is available online at:<https://www.sciencedirect>.

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2 **Scerra M, Bognanno M, Foti F, Caparra P, Cilione C, Mangano F, Natalello A, Chies L, 2022.**

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4 *Meat Science, article 108903. ISSN: 0309-1740*

5 *which has been published in final doi: 10.1016/j.meatsci.2022.108903*

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## **Influence of almond hulls in lamb diets on animal performance and meat quality**

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### **Abstract**

Almond hulls (AH) were fed to lambs to study effects on performance and meat quality. Thirty Sarda lambs were allotted to three experimental groups and fed for 40 days either a cereal-based concentrate diet (control) or diets in which cereals were replaced with 15% (AH15) or 30% (AH30) almond hulls on a DM basis. Diets did not affect final body weight, dry matter intake, average daily gain, feed conversion ratio or carcass weight. Replacing part of the cereal mix (i.e., barley and maize) with AH did not affect meat fatty acid profiles. After 5 and 7 days of refrigerated storage respectively for cooked and raw meat, AH15 and AH30 treatments reduced meat lipid oxidation ( $P < 0.001$ ). Our results suggest feeding almond hulls up to 30% in fattening lamb diets can improve meat oxidative stability without compromising growth performance.

Keywords: by-product, lipid oxidation, fatty acids, phenolic compounds, antioxidants.

## 44 **Introduction**

45 Almond trees (*Prunus dulcis*) are deciduous, broad-leaved, slow growing, long-lived and can reach  
46 5-7 m in height. The seeds of the almond tree, almonds, are oily, rich in vitamins and minerals and  
47 the main nuts produced in subtropical countries (An et al., 2020). Almond production leads to  
48 generation of by-products, such as almond hulls (AH), which is the outer covering that splits open  
49 at maturity. As a byproduct, the almond industry produces 1.5 million tons of AH (Almond Board  
50 of California, 2018), and in California (i.e. the leading producer of almonds), these are commonly  
51 added to dairy cattle diets.

52 Almond hulls are low in protein but high in NDF, with a remarkable concentration of non-structural  
53 carbohydrates. However, AH composition is influenced by factors such as the variety and the  
54 fraction of debris (DePeters, Swanson, Bill, Asmus, & Heguy, 2020). In an early study, Takeoka  
55 and Dao (2003) found extracts from AH had higher antioxidant activity than an equivalent  
56 concentration of  $\alpha$ -tocopherol. Almond hulls are particularly rich (up to 4.5%) in phenolic  
57 compounds, including phenolic acids and flavonol glycosides (An et al., 2020). The biological  
58 activities of AH phenolics are under current investigation (An et al., 2020; Najari, Khodaiyan,  
59 Yarmand, & Hossein, 2022) as numerous studies have demonstrated phenolics can offer beneficial  
60 effects, most importantly their antioxidant capacity (Hussain Tan, Yin, Blachier, Tossou, & Rahu,  
61 2016; Oliveira et al., 2016; Li, Li, & Lin, 2018).

62 Effects of feeding AH to sheep on growth and carcass performance have been reported (Phillips,  
63 Doyle, Harl, Carpenter, & Aschenbrener, 2015), but to the best of our knowledge, no studies have  
64 investigated any effects on meat quality. In addition, effects of AH on lamb fatty acid composition  
65 have not been reported, although studies indicate phenolic compounds can impair ruminal  
66 biohydrogenation of polyunsaturated fatty acids (PUFA) (Vasta & Luciano, 2011; Lanza et al.,  
67 2015; Frutos et al., 2020).

68 The objectives of the present study were, therefore, to assess the effects of feeding AH on lamb  
69 growth performance, meat quality traits, oxidative stability and fatty acid composition.

70

## 71 **2. Materials and methods**

72 The present trial was conducted from May to December 2021 and all procedures were approved  
73 (prot. No. 8937) by the Animal Welfare Committee (O.P.B.A) of the University of Reggio Calabria.

74 The trial included twenty-seven Sarda male lambs born in May. Lambs were weaned at 60 days of  
75 age and then fed a commercial concentrate (30% maize, 30% barley, 20% fava bean, 17% wheat  
76 bran, 3% vitamin mineral premix on a DM basis) for 80 days. When lambs reached an average  
77 initial body weight  $27.79 \pm 0.40$  (SD) kg, they were allocated to individual straw-bedded pens and  
78 randomly assigned to one of three dietary treatments (n = 9) and adapted to diets for 10 days. At the  
79 end of the adaptation period, lambs were fed diets *ad libitum* for 40 days. The control group  
80 received the same commercial concentrate given after weaning whereas the two experimental  
81 groups received the concentrate diet with 15 % (AH15 group) and 30 % (AH30 group) AH  
82 substituted for barley and maize. To maintain a similar crude protein concentration between  
83 treatments, the AH15 and AH30 also had a higher fava bean content (table 1). The ingredients of  
84 each concentrate mixture were ground (5-mm screen) to avoid the selection of ingredients. Hay was  
85 provided *ad libitum* in a separate feeder.

86 The experimental diets were provided twice daily, early morning and late afternoon at a rate of  
87 110% of ad libitum intake calculated by weighing-back refusals daily.

88 Once a week the animals were weighed to assess average daily gain. At the end of the trial, all the  
89 lambs were slaughtered on the same day at a commercial abattoir according to the European Union  
90 welfare guidelines. Experimental diets and water were available to lambs until approximately 4 h

91 before slaughter. Lambs were firstly stunned by a captive bolt and exsanguinated. Each carcass was  
92 immediately weighted and stored at 4° C for 24 h.

93

#### 94 *2.1. Muscle sampling procedures*

95 Samples of *longissimus thoracis et lumborum* muscle (*LTL*) were collected from the left side of  
96 each carcass, vacuum-packed and stored at -30°C in darkness. One sample of *LTL* from each animal  
97 was vacuum-packed and stored at 4 °C in darkness for 24 hours to evaluate lipid oxidation and  
98 colour stability in raw muscle slices.

99

#### 100 *2.2. Analyses of Feedstuffs and meat proximate analysis*

101 Samples of the feeds offered were collected over the duration of the trial and sub-samples of each  
102 feed were pooled, freeze-dried, ground (1 mm screen) and stored at -30 °C pending analyses.

103 Feed samples were analysed for neutral detergent fibre (NDF) (Van Soest, Robertson, & Lewis,  
104 1991), crude protein (AOAC, 1995a; method 984.13; Kjeldahl method), crude fat (AOAC, 1995b;  
105 method 920.39) and ash (AOAC, 1995c; method 942.05). Following the procedure described by  
106 Makkar, Blümmel, Borowy, and Becker (1993) total phenolic compounds and total tannins were  
107 analysed.

108 Fatty acid composition of AH and diets were extracted using chloroform and converted to fatty acid  
109 methyl esters (FAME) with 2 % (v/v) sulfuric acid in methanol (Priolo, Valenti, Natalello, Bella,  
110 Luciano, & Pauselli, 2021), using tridecanoic acid as an internal standard. Gas chromatographic  
111 (GC) analysis was performed as described later for the analysis of intramuscular fatty acid.

112 Tocopherols were extracted from 200 mg of almond hulls and concentrates, as reported by Rufino-  
113 Moya, Joy, Lobón, Bertolín, & Blanco (2020).

114 After thawing *LTL* samples for 24 h at 4 °C, moisture, crude fat, ash and protein (method no.  
115 950.46, 991.36, 920.153 and 984.13 respectively) were assessed according to AOAC procedures  
116 (AOAC, 1995).

117

118 *2.3. Analysis of fatty acids, vitamin E and cholesterol in muscle*

119 Muscle lipids were extracted from 10 g of tissue with chloroform/methanol (2:1, v/v) and 100 mg of  
120 lipids were methylated (15 min at 50 °C) using 1 ml of 0.5 M sodium methoxide in methanol and 2  
121 ml of hexane, which included nonadecanoic acid as internal standard. GC analysis was performed  
122 on a ThermoQuest gas chromatograph (ThermoQuest, Milan, Italy) with a high-polar fused silica  
123 column (100 m, i.d. 0.25 mm, film thickness 0.25 µm; SP 24056; Supelco Inc., Bellefonte, PA) and  
124 flame ionization detector (FID). Gas-chromatography conditions and identification of FAME was  
125 performed as reported by Natalello et al. (2019). Atherogenic and thrombogenic indexes were  
126 evaluated using formulas reported by Ulbricht and Southgate (1991).

127 Tocopherols, retinol, and cholesterol from muscle were extracted and quantified as reported by  
128 Natalello et al. (2022), using an UHPLC system.

129

130 *2.4. Meat oxidative stability measurements*

131 Lipid oxidation was monitored in raw and cooked meat by measuring thiobarbituric acid reactive  
132 substances (TBARS) at each day of storage as reported by Luciano et al. (2019). In brief, three  
133 slices from *LTL* (2 cm thick) were overwrapped with a commercial PVC film, placed in a tray and  
134 kept at 4°C. Using one slice for each day of storage, colour and lipid oxidation measurements were  
135 performed at day 0 (after 2 h of blooming) and after 3, 7 days of storage. Three more slices were  
136 cooked at 75 °C for 30 min in a water bath and used to assess the extent of lipid oxidation at 0, 2  
137 and 5 days in cooked meat. The two slices used to assess lipid oxidation after 2 and 5 days were  
138 stored at +4°C.

139 From each slice, 2.5 g of *LTL* were homogenized with 12.5 ml of distilled water. Then, 12.5 ml of  
140 10% (w/v) trichloroacetic acid were added to precipitate proteins, after which samples were filtered.

141 In a screw-cap glass tubes, 4 ml of clear filtrate was mixed with 1 ml of 0.06 1M aqueous  
142 thiobarbituric acid and samples were incubated in a water bath at 80 °C for 90 min. The absorbance

143 of the samples at 532 nm was measured using a Shimadzu double beam spectrophotometer (model  
144 UV-1800; Shimadzu Corporation, Milan, Italy). The assay was calibrated using solutions of known  
145 concentrations of TEP (1,1,3,3, -tetra-ethoxypropane) in 5% (w/v) trichloroacetic acid ranging from  
146 5 to 65 nmoles/4 ml. Results were expressed as TBARS values (mg of malonaldehyde (MDA)/kg of  
147 meat).

148 Colour stability of raw meat was measured with a Minolta CR300 colour-meter (Minolta Co. Ltd.  
149 Osaka, Japan), set with illuminant A and 10° standard observer. The colour descriptors L\*  
150 (lightness), a\* (redness), b\* (yellowness), C (saturation), and H (hue angle) were measured in the  
151 CIE L\* a\* b\* colour space. To determine changes in muscle colour during storage, the coefficient  
152  $\Delta E$  was calculated using the formula:  $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5}$ , where  $\Delta L^*$ ,  $\Delta a^*$  and  
153  $\Delta b^*$  denote the difference in the values of lightness, redness and yellowness, respectively, in  
154 individual muscles between day 0 and day 3 or 7.

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### 158 *2.5. Statistical analysis*

159 The effect of the dietary treatment (Control, AH15 and AH30) on animal performance, feed intake,  
160 tocopherols and intramuscular FA was analysed using a one-way ANOVA. A GLM procedure for  
161 repeated measures was used to analyse oxidative stability parameters to assess the effect of dietary  
162 treatment (Diet), the time of storage (Time) and their interaction (Diet x Time) as fixed factors,  
163 while individual animal was included as a random factor. Differences between means were assessed  
164 using Tukey's multiple-comparison test. Significance was declared at  $P \leq 0.05$ , whereas trends  
165 toward significance were considered when  $0.05 < P \leq 0.10$ . Data were analysed using the statistical  
166 software Minitab, version 14 (Minitab Inc, State College, PA).

167

## 168 **3. Results**

169 *3.1. Animals Performance and intakes*

170 As shown in Table 2, the replacement of 15 % and 30 % of cereal mix with AH did not affect  
171 animal voluntary dry matter intake (DMI), feed conversion ratio (FCR), final body weight, average  
172 daily gain (ADG) or hot carcass weight. Animals from the three groups ingested the same amount  
173 of total fatty acids ( $P > 0.05$ ). Among the individual fatty acid intakes, no statistical differences  
174 were observed between the experimental groups. However, the lambs from the AH30 group tended  
175 to ingest a higher quantity of steric acid and oleic acid than lambs from the control group.

176

177

178 *3.2. Fatty Acid Composition of Intramuscular fat and antioxidant vitamins*

179 The intramuscular fatty acid composition and the concentration of tocopherols and retinol in meat  
180 are reported in Table 3. Vitamin E (VE) was mainly represented by  $\alpha$ -tocopherol and its  
181 concentration was not affected by supplementing almond hulls in the diet of lambs. Also, the  
182 concentration of retinol (vitamin A) was not affected by the dietary treatment.

183 Feeding with AH did not affect the content of total saturated fatty acids ( $P > 0.05$ ), MUFA ( $P >$   
184  $0.05$ ) and PUFA ( $P > 0.05$ ) in the meat. The contents of  $n-3$  PUFA and  $n-6$  PUFA were also  
185 comparable between groups. As a consequence, the  $n-6/n-3$  ratio was also comparable between  
186 groups. No statistical differences were observed for each fatty acid identified. The atherogenic (AI)  
187 and thrombogenic index (AI) were not affected by the dietary treatment, as well as the  
188 concentrations in meat of the highly peroxidizable (HP) PUFA, with unsaturation degree  $\geq 3$ , and of  
189 the HP-PUFA  $\div$  VE ratio.

190

191 *3.3. Meat colour and oxidative stability*

192 Figure 1 reports effects of dietary treatment and time of storage on lipid oxidation measured in raw  
193 and cooked meat. In both raw and cooked meat during the storage days the TBARS values  
194 increased ( $P < 0.001$ ). Feeding almond hulls positively influenced this parameter. In fact, both AH

195 treatments reduced the extent of the overall lipid oxidation measured over time ( $P < 0.001$ ). A  
196 significant diet  $\times$  time interaction was found in raw and cooked meat ( $P < 0.001$ ).  
197 Specifically, compared to day 0, while the TBARS values already increased after 3 days in raw  
198 meat (Fig. 1a) of the control-fed lambs ( $P < 0.01$ ), lipid oxidation increased after 7 days in raw meat  
199 from animals fed both AH diets ( $P < 0.01$ ). Raw meat from AH15 and AH30 treatments had lower  
200 TBARS values compared to raw meat from control treatment after 7 days of storage ( $P < 0.001$ ;  
201 1.14, 0.59 and 0.55 respectively for control, AH15 and AH30 groups). In cooked meat (Fig. 1 b),  
202 the TBARS values were lower ( $P < 0.001$ ) for each observation day (Day 0, 3 and 5) in meat from  
203 both AH treatments compared to control.  
204 The time of storage influenced some of the colour parameters, with  $L^*$ ,  $b^*$  and  $H^*$  values increasing  
205 ( $P < 0.01$ ) from 0 to 3 days and stabilizing thereafter (table 4). No significant difference was  
206 observed for  $\Delta E$  index ( $P > 0.05$ ).

207

208

#### 209 **4. Discussion**

210 The inclusion of locally available industrial by-products in animal diets to replace conventional  
211 ingredients may contribute to improve the sustainability of livestock industry. This practice could  
212 help farmers to reduce the costs of animal feeding and lead to the reduction of costs related to the  
213 disposal of waste biomass by agro-industries, as well as reducing feed-to-food competition in  
214 livestock production. Moreover, the dietary inclusion of by-products naturally rich in bioactive  
215 compounds could lead to the transfer of these compounds to the animal products, improving their  
216 nutritional and functional properties.

217 Almond hulls have been successfully included in dairy cow (Aguilar, Smith, & Baldwin, 1983;  
218 Swanson, Bill, Asmus, Heguy, & DePeters, 2021) and broilers diets (Wang, Singh, Kong, & Kim,  
219 2021) but data on effects of AH in lamb finishing diets on lamb performance and carcass  
220 characteristics have been limited. In this study, AH diets had no effect relative to control on the

221 final body weight, voluntary DMI, ADG or feed conversion rate. The composition of the three diets  
222 probably influenced these results. The higher NDF/non-structural carbohydrate of AH (Swanson et  
223 al., 2021) compensate for reduced starch from maize and barley, and lower protein of AH was  
224 compensated from by additions of fava beans. Similar results were observed in an experimental trial  
225 with lambs carried out by Phillips et al. (2015), where almond hulls were integrated into the diet at  
226 5% and 10%. Rad, Rouzbehan, and Rezaei (2016) also observed no statistical differences on DMI  
227 and ADG when alfalfa was replaced with urea-almond hulls in a diet for fattening lambs.

228 To the best of our knowledge, this is the first experiment in which the effects of feeding AH on  
229 meat quality in growing lambs has been evaluated. The present trial was planned to replace part of  
230 the cereals, which are commonly used as dietary ingredients for growing ruminants with AH.

231 Replacing part of the cereal mix (i.e., barley and maize) with AH did not affect meat fatty acid  
232 profiles. These results were unexpected, because AH are rich in bioactive compounds that are  
233 believed to be able to modulate the rumen biohydrogenation process. In our experiment, animals  
234 from the three experimental groups had a similar intakes of C18:2 *n-6* and C18:3 *n-3*, as well as  
235 other fatty acids identified. Nonetheless, we expected some changes in the concentration of several  
236 intramuscular fatty acids such as C18:3 *n-3*, C18:1 *trans-11* and C18:2 *cis-9 trans-11* as a result of  
237 supplementing AH. This expectation was linked to the higher amount of phenolic compounds in the  
238 AH compared to concentrate (Frutos et al., 2020; Valenti et al., 2021). In the rumen, rumenic acid is  
239 mainly produced by the isomerization of dietary linoleic acid, while vaccenic acid derives mainly  
240 from the biohydrogenation of both C18:2 *n-6* and C18:3 *n-3* (Shingfield, Bernard, Leroux, &  
241 Chilliard, 2010). Dietary polyphenols may alter the rumen microbial population and metabolism  
242 (Scerra et al., 2018; Salami et al., 2019; Vasta et al., 2019; Scerra et al., 2021). In fact, different  
243 studies reported that some secondary metabolites of plants such as tannins, polyphenolic  
244 compounds, could impair ruminal biohydrogenation of PUFA via modification of the bacterial  
245 population in the rumen and the inhibition of biohydrogenation steps, such as the conversion of  
246 vaccenic acid to stearic acid. In our experiment, the results observed did not suggest an inhibition of

247 the biohydrogenation process due to AH phenols, although the lambs of both AH groups received  
248 diets with 4-5 times more total phenols than the control group lambs.

249 However, although the effect of dietary phenolic compounds on ruminal biohydrogenation has been  
250 long studied (Vasta et al., 2009; Vasta & Luciano, 2011; Vasta et al., 2019; Frutos et al., 2020),  
251 their ability to modulate biohydrogenation is still a controversial issue.

252 The effects of feeding almond hulls on oxidative stability of raw and cooked meat are reported in  
253 fig. 1. The time of storage and dietary treatment affected TBARS values measured in raw *LTL* slices  
254 during 7 days of refrigerated storage (Fig. 1a). In raw meat, diet effects were most strongly noted  
255 after 7 days of refrigerated storage, with a TBARS of control *LTL* being double that of AH.  
256 However, TBARS values in raw meat remained below the value of 2 mg MDA/Kg, which is  
257 considered a threshold for the sensory perception of rancidity (Campo, Nute, Hughes, Enser, Wood  
258 & Richardson, 2006), for the entire monitoring period for all experimental groups.

259 In the present study, to further highlight diet-related differences of meat oxidative stability under  
260 more pro-oxidant conditions, TBARS values in cooked *LTL* during 5 days of storage were  
261 evaluated. The effects of diet on oxidative stability were more evident when the meat was subjected  
262 to more stressful conditions, and already on the first day of studying the oxidative stability in  
263 cooked meat, the TBARS values were significantly lower in both AH treatments compared to the  
264 control treatment.

265 Different authors reported that the increase of antioxidant compounds in the diet is commonly  
266 associated with the improvement of the antioxidant capacity of meat (Descalzo & Sancho, 2008;  
267 Luciano et al., 2017). In this study, the level of vitamin E ( $\alpha$ -Tocopherol and  $\gamma$ -Tocopherol) was  
268 higher in the control diet than in both AH diets. However, differences between treatments in  
269 vitamin E intake probably were not enough to result in differences in meat oxidative stability.

270 In fact, despite the data reported on vitamin E and considering that vitamin E has been extensively  
271 proven to play a major role in protecting animal tissues against lipid peroxidation (Burton & Traber,  
272 1990; Luciano et al., 2017), after 7 and 5 days of storage, respectively for raw and cooked meat,

273 TBARS values of meat from control group were higher than the TBARS values observed in meat  
274 from both almond hull groups.

275 Some authors (Takeoka & Dao, 2003) reported that the extracts from almond hulls presented higher  
276 antioxidant capacity than the equivalent concentration of  $\alpha$ -tocopherol. Safarian et al. (2016)  
277 observed a high content of antioxidants, including flavonoids, terpenoids, and other phenolic  
278 compounds in a powdered extract of almond hulls, indicating that this by-product is a potential  
279 source of dietary antioxidants.

280 Therefore, the protective effects of the diets containing 15 and 30 % of almond hulls against lipid  
281 oxidation observed in our experiment could be attributed to the presence of high levels of  
282 antioxidant compounds (e.g., flavonoids), which were about 5 times higher in the AH30 diet than in  
283 the control diet. Other authors (Luciano et al., 2012; Gravador et al., 2015) have also attributed the  
284 improvement in the oxidative stability of lamb meat to the antioxidant action of the phenolic  
285 compounds present in the studied feed.

286 Colour stability is another important aspect to consider when meat shelf life is studied. Some  
287 authors report as fatty acid oxidation could promote oxidation of myoglobin (Alderton, Faustman,  
288 Liebler, & Hill, 2003; Faustman, Sun, Mancini, & Suman, 2010) and consequently, strategies to  
289 reduce lipid oxidation should bring positive effects in terms of colour stability. In this experimental  
290 trial, while the dietary treatment affected the lipid oxidation in raw and cooked meat, no effect was  
291 observed on colour stability. Moreover, Diet x Time interactions were not significant for any of the  
292 colour stability parameters, indicating that dietary treatment did not affect the trend of variation of  
293 the colour descriptors.

294

295

## 296 **Conclusions**

297 Partial replacement of cereals in concentrate with almond hulls had no effect on lamb meat fatty  
298 acid profiles. Higher oxidative stability was, however, observed in meat from animals fed AH.

299 The inclusion of almond hulls at up to 30% in diets for fattening lamb, therefore, might be an  
300 excellent strategy to reduce cereals feeding without compromising animal growth performances,  
301 while improving meat oxidative stability.

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**Table 1**

Ingredients (% on DM basis) and chemical composition of diets offered

	Control diet	AH15 diet	AH30 diet	Almond hulls	Hay
Barley	30	21	12		
Maize	30	21	12		
Bran	17	17	15		
Fava bean	20	23	28		
Almond hulls	-	15	30		
Vitamin mineral premix <sup>1</sup>	3	3	3		
<i>Chemical composition</i>					
Dry matter (DM) g/kg wet weight	873	863	855	784	902
Crude protein g/kg DM	140	138	136	54.4	53.6
Ether extract g/kg DM	19.3	19.4	20.3	8.70	4.23
Ash g/kg DM	22.1	26.1	32.5	107	87.8
NDF g/kg DM	228	244	294	337	740
Total phenolic (g TAe <sup>2</sup> /kg DM)	3.34	13.5	15.6	64.7	5.81
Total tannins (g TAe <sup>2</sup> /kg DM)	1.16	7.22	7.50	38.1	2.20
<i>Tocopherols, µg/g dry matter</i>					
α-Tocopherol	61.1	35.1	35.6	33.5	5.25
γ-Tocopherol	70.8	58.5	59.3	11.7	12.5
δ-Tocopherol	14.4	8.08	8.03	12.1	9.58
<i>fatty acids (g/100g of total fatty acid)</i>					
C14:0	0.20	0.18	0.30	0.54	2.20
C16:0	16.9	17.0	17.4	18.7	53.6
C18:0	2.10	2.60	3.01	6.30	8.30
C18:1 <i>n</i> -9	21.1	24.7	26.8	45.3	9.70
C18:2 <i>n</i> -6	51.8	49.2	47.5	18.8	12.5
C18:3 <i>n</i> -3	3.50	3.61	4.20	5.80	5.50

<sup>1</sup>Supplied per kilogram: vitamin A=6750 UI; vitamin D3=1000UI; vitamin E 2 mg; vitamin B12 0,01 mg; vitamin B1 1mg; folic acid 0,2 mg; D-pantotenic acid 5 mg; Co 0,05 mg; Mn 12,5 mg; Zn 15 mg; Mo 0,5mg.

<sup>2</sup>tannic acid equivalent.

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**Table 2**Lamb performances and chemical composition of *LTL* muscle (g/100g wet weight).

	Dietary treatments <sup>1</sup>			SEM <sup>6</sup>	<i>P</i> values
	Control	AH15	AH30		
Final BW <sup>2</sup> , kg	36.6	36.1	36.2	0.683	0.445
Hot carcass weight, kg	17.8	17.5	17.4	0.454	0.865
Total DMI <sup>3</sup> , kg/d	1.65	1.57	1.63	34.07	0.465
Concentrate intake, g/d	956	931	963	28.07	0.398
Hay intake, g/d	694	631	667	20.31	0.432
ADG <sup>4</sup> , g/d	220	207	210	4.432	0.612
FCR <sup>5</sup> , g DMI <sup>3</sup> /g ADG <sup>5</sup>	7.50	7.58	7.73	0.362	0.234
Total FA <sup>7</sup> intake, g/d	19.3	18.4	19.2	1.645	0.679
SA <sup>8</sup> intake, g/d	0.41	0.48	0.58	0.087	0.087
OA <sup>9</sup> intake, g/d	4.07	4.54	5.17	0.121	0.071
LA <sup>10</sup> intake, g/d	10.0	9.04	9.14	0.263	0.139
ALA <sup>11</sup> intake, g/d	0.68	0.66	0.81	0.121	0.109
<i>Chemical composition</i>					
Moisture	73.6	73.7	74.0	0.168	0.676
Crude protein	22.1	21.7	21.6	0.220	0.269
Ether extract	3.56	3.65	3.89	0.227	0.579
Ash	1.11	1.06	1.11	0.012	0.133

<sup>1</sup>Treatments were: only concentrate (control), concentrate integrated with almond hulls at the level of 15% (AH15) or at the level of 30% (AH30) of dry matter on the diet fed.

<sup>2</sup>BW=Body weight; <sup>3</sup>DMI=dry matter intake; <sup>4</sup>ADG=average daily gain; <sup>5</sup>FCR=feed conversion ratio; <sup>6</sup>SEM=standard error of means; <sup>7</sup>FA=Fatty acid; <sup>8</sup>SA=Stearic acid; <sup>9</sup>OA=Oleic acid; <sup>10</sup>LA=Linoleic acid; <sup>11</sup>ALA= $\alpha$ -linolenic acid.

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**Table 3**

Effect of the dietary treatments on the antioxidant vitamins ( $\mu\text{g/g}$  meat) and fatty acid composition of *LTL* (mg/100 g of meat)

Item	Dietary Treatment			SEM	<i>P</i> values
	Control	AH15	AH30		
<i>Tocopherols and retinol, <math>\mu\text{g/g}</math> muscle</i>					
$\alpha$ -Tocopherol	1.75	1.70	2.02	0.153	0.690
$\gamma$ -Tocopherol	0.48	0.42	0.52	0.034	0.491
Retinol	0.64	0.36	0.56	0.080	0.369
Cholesterol (mg/g)	1.17	1.13	1.23	0.057	0.836
C10:0	4.08	3.78	4.05	0.205	0.826
C12:0	1.88	1.74	2.51	0.233	0.369
C14:0	48.2	49.21	55.7	2.890	0.535
C14:1 <i>cis</i> -9	2.03	1.63	1.90	0.153	0.585
C15:0 <i>iso</i>	2.09	1.89	2.02	0.156	0.887
C15:0 <i>anteiso</i>	1.81	1.65	2.03	0.144	0.583
C15:0	6.98	5.16	6.06	0.399	0.393
C16:0 <i>iso</i>	3.34	2.97	3.99	0.219	0.157
C16:0	566	606	624	24.10	0.623
C16:1 <i>cis</i> -9	40.6	40.7	39.3	1.700	0.932
C16:1 <i>cis</i> -7	4.83	5.06	5.77	0.303	0.433
C17:0 <i>anteiso</i>	10.9	9.01	10.8	0.586	0.350
C17:0 <i>iso</i>	9.57	7.82	10.5	0.647	0.226
C17:0	26.2	21.4	24.9	1.07	0.169
C17:1 <i>trans</i> -10	4.47	3.82	5.28	0.328	0.197
C17:1 <i>cis</i> -9	17.3	13.6	13.5	0.775	0.097
C18:0	364	394	439	16.90	0.111
C18:1 <i>trans</i> -9	8.05	8.51	9.23	0.465	0.603
C18:1 <i>trans</i> -10	14.1	11.4	17.7	1.910	0.426
C18:1 <i>trans</i> -11 VA <sup>1</sup>	16.0	16.6	19.6	1.880	0.591
C18:1 <i>cis</i> -9	1011	1049	1117	42.90	0.619
C18:1 <i>cis</i> -11	33.5	30.2	30.9	1.320	0.586
C18:1 <i>cis</i> -12	5.49	5.35	5.92	0.262	0.668
C18:1 <i>cis</i> -13	3.03	2.66	3.01	0.120	0.380
C18:1 <i>cis</i> -14	4.37	4.40	5.76	0.311	0.109
C18:2 <i>trans</i> -9 <i>trans</i> -12	0.13	0.17	0.43	0.078	0.252
C18:2 <i>cis</i> -9 <i>cis</i> -12 LA <sup>1</sup>	133	105	116	7.800	0.369
C18:3 <i>n</i> -3 ALA <sup>1</sup>	6.24	4.69	7.92	0.743	0.212
C18:2 <i>cis</i> -9 <i>trans</i> -11	8.76	8.11	10.6	0.749	0.375
C 20:0	3.20	2.82	3.43	0.173	0.369
C 20:1 <i>cis</i> -11	3.00	3.26	3.55	0.159	0.387

C20:2 <i>cis-11 cis-14</i>	1.50	0.99	1.40	0.160	0.416
C20:3 <i>n-6</i>	4.51	3.65	3.47	0.390	0.532
C20:3 <i>n-3</i>	0.03	0.04	0.07	0.022	0.768
C20:4 <i>n-6</i>	35.8	29.7	25.2	3.630	0.459
C20:5 <i>n-3</i> EPA <sup>1</sup>	3.67	2.02	2.27	0.372	0.151
C22:5 <i>n-6</i>	5.99	4.94	4.11	0.585	0.443
C22:5 <i>n-3</i> DPA <sup>1</sup>	1.52	1.05	1.02	0.223	0.610
C22:6 <i>n-3</i> DHA <sup>1</sup>	0.19	0.15	0.21	0.043	0.888
∑ SFA <sup>1</sup>	987	1058	1129	39.70	0.361
∑ MUFA <sup>1</sup>	1186	1218	1303	47.70	0.605
∑ PUFA <sup>1</sup>	203	162	175	12.90	0.437
OBCFA <sup>1</sup>	61.7	50.4	61.0	2.910	0.214
∑ <i>n-3</i>	11.6	7.95	11.5	1.020	0.261
∑ <i>n-6</i>	189	152	159	12.00	0.438
<i>n-6/n-3</i>	17.8	19.3	14.8	1.020	0.208
Thrombogenic index <sup>2</sup>	1.07	1.18	1.24	0.041	0.238
Atherogenic index <sup>3</sup>	0.55	0.59	0.57	0.014	0.426
HP-PUFA <sup>4</sup> (mg/g muscle)	0.60	0.49	0.46	0.050	0.504
HP-PUFA ÷ VE <sup>5</sup>	2.39	2.35	2.26	0.047	0.510

<sup>1</sup>VA: vaaccenic acid; LA: linoleic acid; ALA:  $\alpha$ -linolenic acid; EPA: eicosapentaenoic acid; DPA: docosapentaenoic acid; DHA: docosahexaenoic acid; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; OBCFA: odd and branched chain fatty acids.

<sup>2</sup>Thrombogenic index:  $(C14:0 + C16:0 + C18:0)/(0.5 \text{ MUFA} + 0.5 \text{ PUFA } n-6 + 3 \text{ PUFA } n-3 + \text{PUFA } n-3/\text{PUFA } n-6)$ .

<sup>3</sup>Atherogenic index:  $(C12:0 + 4 * C14:0 + C16:0)/(\text{MUFA} + \text{PUFA } n-6 + \text{PUFA } n-3)$ .

<sup>4</sup>Highly peroxidizable (HP) PUFA: calculated as the sum of PUFA with  $\geq 3$ .

<sup>5</sup>Calculated as the ratio between HP-PUFA and total vitamin E, both expressed as mg/g muscle. Original values obtained were not normally distributed according to the Anderson-Darling test. Therefore, logarithmic transformation was adopted and values in table are presented as LOG10

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**Table 4**

Effect of the dietary treatments and time of refrigerated storage on raw meat colour stability

	Dietary treatment <sup>1</sup>			Time (T) <sup>3</sup>			SEM	P values		
	Control	AH15	AH30	Day 0	Day 3	Day 7		Diet	Time	Diet x Time
L* values <sup>2</sup>	42.0	43.2	42.8	40.7 <sup>b</sup>	43.5 <sup>a</sup>	43.8 <sup>a</sup>	0.399	0.458	0.002	0.846
a* values <sup>2</sup>	16.6	14.6	14.3	16.0	15.3	14.2	0.505	0.126	0.319	0.193
b* values <sup>2</sup>	12.0	12.2	11.4	10.7 <sup>b</sup>	12.2 <sup>a</sup>	12.6 <sup>a</sup>	0.245	0.399	0.004	0.930
C* values <sup>2</sup>	20.7	19.0	18.4	19.3	19.9	19.0	0.480	0.116	0.751	0.226
H* values <sup>2</sup>	37.2	39.8	38.7	33.8 <sup>b</sup>	40.2 <sup>a</sup>	41.6 <sup>a</sup>	0.714	0.160	0.001	0.199
ΔE	4.69	3.99	5.85	-	4.68	5.01	0.306	0.171	0.347	0.674

<sup>a, b</sup> Within row, different superscripts indicate differences between days of storage (P<0.05) tested using the Tukey's adjustment for multiple comparisons.

<sup>1</sup>Treatments were: only concentrate (Control); concentrate and almond hulls at the level of 15% (AH15) or at the level of 30% dry matter on the diet fed (AH30).

<sup>2</sup>L\*=lightness; a\*=redness; b\*=yellowness; C\*=Chrome; h\*=hue angle, measured in degrees.

<sup>3</sup>Time days of storage at 4 °C under aerobic conditions (meat slices).

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