PAPER

Influence of outdoor and indoor rearing system of suckling lambs on fatty acid profile and lipid oxidation of raw and cooked meat

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Abstract

Effect of outdoor (OUT) or indoor (IND) rearing systems (RS) of 48 male and female Sarda suckling lambs on fatty acid (FA) composition and lipid oxidation of raw and cooked meat was studied. Ewes grazed daily on natural pasture for 6 h. During grazing time of ewes, IND lambs were kept indoors whereas OUT lambs followed the mother. Slaughter age was 28 days. RS did not affect meat chemical composition, pH, cooking loss and FA profile. Microwave cooking changed markedly the concentrations of almost all meat FAs and FA classes: short (-28%) and medium chain fatty acids (-11%), saturated fatty acids (-7.6%), odd-number carbon and branched-chain FA (-11.8%), proportion of long chain fatty acids (+5.3%) and PUFAn3 (+37.3%) and PUFAn6 (+26.1%) class. Sex influenced significantly the concentration of the main odd-number carbon and branched chain fatty acid. OUT rearing system increased MDA concentration ($P<0.01$). RS × cooking interaction affected PUFA and MDA, which were higher in cooked samples of OUT than IND lambs. The results evidenced that the meat composition of suckling lambs is affected by the feeding system of the mother rather than the management system of lambs.

Introduction

The consumption of meat from suckling lambs is typical in Mediterranean countries, where lambs are traditionally slaughtered as early as possible, so that sheep milk can be transformed into cheese. In the region Sardegna, there is the production of the Sardinian Lamb (*Agnello di Sardegna*) with Protected Geographic Indication (PGI) created in 2001 (CE N° 138/01). These lambs are raised with their dams and fed almost exclusively maternal milk, being slaughtered at 25-30 days of age and a body weight of 9-11 kg.

The suckling lamb meat has a considerable content of fatty acids of nutritional interest (Nudda *et al*., 2011). Recently, great attention has focused on conjugated linoleic acid (CLA), PUFAn3 and long chain FA, which have several benefits to human health. Biochemical studies showed beneficial effects of the *cis*9, *trans*11 CLA, against neoplastic and atherosclerotic processes (Bhattacharya *et al*., 2006; Sofi *et al*., 2009) as well as a cholesterol lowering effect (Pintus *et al*., 2012). Epidemiological studies evidenced that, among PUFAn3, C18:3n3 is associated with a reduced risk of cardiovascular diseases (Roth and Harris, 2010), whereas its elongation products, EPA and DHA, has beneficial effects on proper brain and visual development in the fetus, and maintenance of neural and visual tissues throughout life (Ruxton *et al*., 2004).

Maternal feeding systems have influenced intramuscular fatty acids composition of suckling lambs in Italian (Scerra *et al*., 2007; Valvo *et al*., 2005) and European sheep breeds (Joy *et al*., 2012), with an increased content of CLA c9t11 and PUFAn3, and thus a decreased PUFAn6/PUFAn3 ratio, in the meat of suckling lambs from ewes grazing on pasture or fed dietary linseed, rich in C18:3n3. However, under the same maternal feeding system, different rearing systems of suckling lambs can also be applied. Outdoor or indoor rearing system may influence behavior and physiological response of animals. For example, the suckling lambs that follow their dams on pasture are intuitively subjected to a higher physical activity, spent more time with the mother and can start to graze grass compared to suckling lambs that are raised exclusively indoors. Therefore, the management system of the animals can affect muscle lipid content and fatty acid composition, with important consequences on meat lipid oxidation both in raw and cooked meat. Usually, the increase of PUFA in meat of lambs fed a concentrate-based diet enhances its susceptibility to oxidation (Luciano *et al*., 2013). Differently, the natural anti-oxidants present in grass partially counteract the oxidation susceptibility of meat with high levels of PUFA when lambs are fed a pasture-based diet (Luciano *et al*., 2012). In addition, even though most antioxidant defenses can remain active in fresh meat, some processes such as mincing (O'Grady *et al*., 2000) or cooking (Alfaia *et al*., 2010) can reduce meat oxidative stability. The present study aimed to investigate if raw or cooked meat from suckling lambs that stay outdoor with their mother during their grazing time differed in fatty acid profile and lipid oxidation from that from suckling lambs which stay indoor during the grazing time of their mother. The effects of sex on FA profile and FA oxidation were also investigated.

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Materials and methods

Animals and diets

Forty-eight lambs born from 36 Sarda dairy sheep were randomly distributed to 4 collective pens. At birth, all newborn lambs, covered by the Protected Geographical Indication (PGI) *Agnello di Sardegna*, were housed with their respective mothers for 24 hours and then were divided into two groups (24 lambs each): one remaining with their mother all day long and followed them outdoors during the grazing time (group OUT) and one was housed indoors in the pens (group IND) and therefore their mothers grazed without their lambs. Both groups were balanced for males and females

and for twins. The fresh water was always available for IND lambs. Ewes grazed daily on natural pasture for 6 hours (from 9:30 to 15:30), and were supplemented with concentrate (500 g/d per head), individually administered during the two daily milkings (8:00 and 16:00), and with hay *ad libitum*, when kept indoors with their lambs. During the experiment, the available concentrate was completely eaten by the animals. After evening milking the ewes were kept with IND lambs until the morning milking. All lambs were fed by suckling until slaughter at 28 days of age.

Feed samples of the ewes' diet were collected at the beginning and at the end of the trial for subsequent chemical analysis. A representative pasture sample was collected by clipping ten squares of 0.25 m^2 each, in the selected areas of the pasture.

Diets were formulated to satisfy sheep energy and protein requirements using the Small Ruminant Nutrition Model (Tedeschi *et al.*, 2010). Pasture intake was estimated to be equal to 650 g of DM per head, based on animal energy requirements and diet characteristics, and the average daily consumption of hay was about 800 g of DM per head. Protein and fat content of the diet was 143 g/kg and 18.8 g/kg of DM, respectively. The estimated nutritive value of the diet was 2.22 Mcal of metabolizable energy (ME)/kg of DM.

Individual milk yield was measured the two consecutive days after slaughter as estimation of the milk produced by the ewes that stay continuously or not with their lambs. Individual milk samples were collected and stored at –20°C for subsequent fatty acid analysis.

Muscles samples collection

At 28 days of age, the lambs were weighed and then slaughtered. The cold carcass weight (CCW; *i.e.* body weight minus blood, skin, viscera, feet, tail) and meat pH were determined after 24 h of storage at 4°C. The thigh muscles (*Semitendinosus*, *Semimembranosus* and *Femoral biceps*) were excised from the right side of each carcass. After removing the visible intermuscular fat and connective tissue, the remaining was split into 2 portions (proximal and distal) of about 50 g each. Proximal and distal portions of each lamb were assigned alternatively to raw or cooked treatment, in order to ensure a balanced distribution of the three muscles between treatments. Each portion included the three muscles, because their separation in lambs slaughtered at 28 days of age would not have allowed a sufficient amount of each muscle to perform the cooking treatment. The raw and cooked samples were freeze-dried for 72 h (–55°C and 2.0 hPa). The freeze-dried samples were finely ground and analyzed for chemical composition and fatty acid profile.

Cooking method

Microwave cooking was performed using a polypropylene (PP) pan suitable for microwave placed inside a Samsung GE82W microwave oven equipped with a revolving plate. A sample of 50 g of each animal was cooked at 650 W, for about 35 s, to reach a final core temperature of 75°C, required to achieve a constant degree of doneness (medium, according to Matthews and Garrison, 1975). The meat internal temperature was measured with a common digital thermometer (Taylor USA, model 9847N, Oak Brook, IL, USA), inserted in the centre of the sample, immediately after its removal from the oven. Samples were cooled down to room temperature, dried with filter paper and weighed. Cooking loss was expressed as a percentage of the pre-cooking weight. Samples were then split into two pieces (~25 g): one was used for chemical analysis, whereas the other was used for evaluating the lipid oxidation.

Laboratory analyses

Feed analysis

The DM content of the feed used in the ewes diet was determined by oven-drying at 105°C for 24 h. Dried feed samples were analyzed for NDF, ADF and ADL with the procedure of Van Soest *et al*. (1991) by using the filter bag equipment of Ankom (Ankom Technology Corp., Fairport, NY, USA), for ash (AOAC, 2000; method 942.05), for CP (AOAC, 2000; method 988.05) and for lipid extract (Folch *et al*., 1957). Feed chemical composition was expressed as percentage of DM.

Chemical composition and energy value of raw and cooked samples

The raw and cooked meat samples were analyzed for moisture, total protein, ash and lipid. Crude protein content (N × 6.25) was determined by the Kjeldahl method (AOAC, 1997; method 928.08). Moisture content was determined on about 50 g of samples after 72 h of freeze-drying. Total ash content was determined at 550°C for 24 h according to method 920.153 of AOAC (1997). The energy value (kcal) was calculated by multiplying the amount of protein and fat by the general conversion factors of 4 and 9, respectively (European Commission, 1990).

Fatty acid analysis

Fatty acids composition of fat from feed, milk and muscle samples was determined by gas chromatography (GC Turbo 3400 CX, Varian Inc., Palo Alto, CA, USA). Fat was extracted from milk using the method described by Nudda *et al*. (2006) and from meat using the method described by Nudda *et al*. (2011). The meat samples were lyophilized and finely ground before fat extraction. About 20 mg of extracted lipids 0.5 mg were added with nonadecanoic acid (C19:0) methyl ester (Sigma-Aldrich, St. Louis, MO, USA) as internal standard. The mixture was esterified for 15 min at room temperature by cool base-catalyzed methylation using 0.5 M methanolic solution of sodium methoxide (Sigma-Aldrich) according to the standard procedure of the International Dairy Federation (1999).

The fatty acid methyl esters (FAME) of feed, milk and meat lipids were separated in a capillary column (CP-select CB for FAME; 100 m × 0.32 mm i.d., 0.25- m film thickness; Varian Inc.). The injector and FID temperatures were 255°C. The programmed temperature was 75°C for 1 min. It was then raised to 165°C at a rate of 8°C/min, maintained at 165°C for 35 min, increased to 210°C at a rate of 5.5°C/min, and finally increased to 240°C at a rate of 15°C/min. The split ratio was 1:100 with He at a pressure of 37 psi as the carrier gas. Individual FAME were identified by comparing them to known standards of FAME and published isomeric profiles as detailed in Nudda *et al*. (2011).

The concentration of PUFA and of monounsaturated fatty acids (MUFA), saturated fatty acids (SFA) and odd-branched chain fatty acids (OBCFA) were calculated. The following nutritional indices were calculated: PUFA/SA, n6/n3, atherogenic index (AI), thrombogenic index (TI) and hypocholesterolemic/hypercholesterolemic ratio (h/H). The AI and TI were calculated according to Ulbricht and Southgate (1991) as follows: AI = [C12:0 + (4 × C14:0) + C16:0]/[(ΣPUFA) + (ΣMUFA)], and TI = [C14:0 + C16:0] / [(0.5 × ΣMUFA) + (0.5 × n6) + (3 × n3) + (n3/n6)], without the inclusion of C18:0, which is considered to be neutral on serum cholesterol. The h/H was calculated according to Fernández *et al*. (2007) as follows: h/H = [(sum of C18:1c9, C18:1c11, C18:2n6, C18:3n6, C18:3n3, C20:3n6,C20:4n6, C20:5n3, C22:4n6, C22:5n3 and C22:6n3)/(sum of C14:0 and C16:0)].

Fatty acids were expressed as a proportion of total FAME (% of total FAME) or in gravimetric concentration (mg/100 g of edible portion).

Fatty acids oxidation of raw and cooked samples

Fatty acids oxidation was assessed in raw and cooked chopped meat samples by determination of secondary products of fatty acids oxidation as 2-thiobarbituric acid reactive substances (TBARS), using a modification of the aqueous acid-extraction method described by Raharjo *et al*. (1992). Briefly, 10 g of sample were added with butylated hydroxytoluene, at a level of 0.15% based on lipid content. The sample was then homogenized by using a solution of trichloroacetic acid (TCA; 40 mL, 5% w/v), centrifuged at 5000 g 45 min at 5°C, filtered and volume with TCA (5% aqueous). Two mL of the filtrate were mixed with 2-thiobarbituric acid (TBA, 40 mM), heated at 93°C for 20 min to develop a rose-pink colour. The absorbance was measured at 525 nm, using a spectrophotometer, against a blank containing TCA (2 mL, 5% w/v) and TBA (2 mL 40 mM). The TBARS values were calculated using an external standard technique from a standard curve (0.2-20 M) of 1,1,3,3-tetraethoxypropane (TEP) and expressed as mg of MDA per kg of muscle. The final conversion of TEP concentration to MDA concentration was done using the formula of Pikul *et al*. (1989):

$$TBARS_{(mg\ MDA/Kg\ meat)} = ((A \times m \times 72.063 \times 10^{-6})/E) \times 1000$$

where
A, absorbance of the sample;
m, slope of the calibration curve;
72.063, molecular weight of malondialdehyde;
E, sample weight equivalent.
Two replicates were run per sample.

Statistical analysis

The meat pH and cooking loss were analyzed by ANOVA using lamb rearing system and sex as main effects and their interaction. The differences in milk fatty acid profile were tested by one-way ANOVA, with the rearing system as fixed effect.

Data of meat fatty acids and chemical components were analyzed with the following repeated measures linear mixed model:

$$Y_{ijk} = \mu + RS_i + C_j + S_k + (RS \times C)_{ij} + (RS \times S)_{ik} + (S \times C)_{jk} + A_l(j) + \varepsilon_{ijk}$$

where
Y_{ijk}, observation of FA, fat, protein and ash;
μ, overall mean;
RS_i, fixed effect of lamb rearing system (i, outdoors and indoors);
C_j, fixed effect of cooking (j, raw and cooked);
S_k, fixed effect of sex;
RS x C, RS x S and S x C, first-order interactions;
A_l, random effect of animal l nested within cooking treatment;
ε_{ijk}, residual error.

Statistical analysis was performed using SAS version 9.2 (SAS Inst. Inc., Cary, USA), with differences being declared significant for $P \leq 0.05$ and tendencies for $P \leq 0.10$.

Results and discussion

The chemical composition and the fatty acid profile of the ewe's dietary ingredients are reported in Table 1. The pasture was characterized by grass at the vegetative phase as evidenced by its high protein and low fiber contents and by the high proportion of C18:3 n3 in the lipid extract. The milk yield of ewes that grazed alone or with their lambs was similar (1296 *vs* 1277±52.9 g/d; P=0.80) both at the morning (822 *vs* 807±33.3 g/d; P=0.76) and evening milking (474 *vs* 470±23.9 g/d; P=0.90).

The body weight (mean ±SD) at slaughtering was 9.64±1.97 kg for OUT lambs and 9.47±1.65 kg for IND lambs (P>0.10), whereas the CCW was 4.33±0.98 kg for OUT lambs and 4.37±0.83 kg for IND lambs (P>0.10).

Composition and nutritive value of lamb meat

The chemical characteristics of raw and cooked meat samples for both genders and the two rearing systems evaluated are reported in Table 2. The chemical composition and energy value of the raw meat were within the range values reported for lamb rib loin or other generic cuts of lean lamb meat in food composition databases or surveys carried out in different EU countries (Berge *et al*., 2003; INRAN, 2000) and non-EU countries (USDA, 2013; Hoke *et al*., 1999; Williams, 2007). Based on this information, the meat samples from Sarda lambs analyzed in the present study can be classified as extra-lean meat as defined by FDA (1999), with less than 5 g of fat and 2 g of saturated fatty acid in 100 g of meat.

The rearing system did not affect the meat chemical composition (Table 2), pH (5.7 on average, data not shown) and cooking loss (26.6 and 27.3 in IND and OUT samples), in accordance with other experiments where the type of lamb diet have not influenced meat cooking loss (Vincenti *et al*., 2004; Osorio *et al*., 2008) or pH (Lanza *et al*., 2006; Napolitano *et al*., 2006). The cooking loss observed in our trial was similar to that observed for microwaved lamb rib-loins by Maranesi *et al*. (2005). As expected, the cooking process reduced the meat moisture, with a consequent increase in fat and protein concentration thus determining an increase in energy value. On the basis of our data, the consumption of 100 g of cooked leg muscles from this lamb would provide approximately 5% of the daily energy of 2500 Kcal, 40% of the protein and about 4% of the fat, respectively, recommended as daily allowance for an adult involved in moderate

Table 1. Chemical composition and fatty acid profile of concentrate, hay and pasture of the diet of the ewes.

	Concentrate°	Hay	Pasture
Dry matter, g/kg	872	910	223
Chemical composition, g/kg DM			
Crude protein	170	95	183
Neutral detergent fibre	415	610	425
Acid detergent fibre	207	500	252
Acid detergent lignin	53	50	30
Ash	98	79	104
Lipid extract	24	19	15
Fatty acid, mg/100 mg total FA			
C14:0	1.20	0.39	0.46
C16:0	31.7	18.83	12.82
C18:0	27.3	2.37	0.89
C18:1 c9	10.6	16.5	1.35
C18:2 n6	22.6	40.55	10.79
C18:3 n3	2.00	19.24	69.12

°Commercial concentrate with the following ingredients: wheat bran, soybean hulls (from genetically modified soybean), alfalfa meal, wheat distilled dried grains, wheat bran, sunflower extraction meal, maize germ cake, dried sugar beet pulp, hydrogenated vegetable fatty acid, corn gluten meal, molasses sugar beet, calcium carbonate from limestone rocks, soybean cake, maize. Vitamin supplement: A, 15,000 U/kg; D_3 2923, U/kg; E, 30 mg/kg; B_{12}, 0.06 mg/kg; minerals supplement: Fe ($FeSO_4$), 35 mg/kg; iodine ($Ca(IO_3)_2$), 1.1 mg/kg; MnO, 70 mg/kg; Se (Na_2SeO_3), 0.51 mg/kg; ZnO, 70 mg/kg; Mo (Na_2MoO_4), 1.0 mg/kg.

activity (Società Italiana di Nutrizione Umana, 2012). Ash content differed between genders. Gender did not influence the chemical composition, values of pH and cooking loss of the lamb meat.

Fatty acid composition of milk and lamb meat

The fatty acid composition of ewes milk is reported in Table 3. No differences were observed for any fatty acid for milk suckled by IND and OUT lambs, because there were no differences in the feeding system of the mother. The majority of fatty acids of milk were C18:1 c9, C16:0 and C18:0, and the fatty acid composition is in line with those of animals grazing on lush pasture as evidenced by the values of vaccenic acid (VA), CLA c9t11 and C18:3n3 (Nudda *et al*., 2005; Biondi *et al*., 2008).

The fatty acid profile of lamb meat is reported in Table 4. The fatty acid patterns of lamb muscle were similar to those of the milk from the suckled ewes, being C18:1 c9, C16:0 and C18:0 the main fatty acids found in lambs as well.

Effect of sex

There were differences between males and females (Table 4) for C12:0, for several odd-number carbon, such as C13:0, C15:0, C17:1 c8 and C17:1 c9, and for the branched-chain fatty acids iso C15:0, anteiso C15:0 and iso C17:0. A significant RS × sex interaction was observed for iso C17:0, anteiso C17:0, C17:0, C17:1 c9, and C18:2 c9t12. In particular, females had a higher proportion of anteiso C17:0 than males in the IND system, whereas males had higher value of this FA in the OUT system. On the other hand, the differences between males and females were evident only in the IND system for C17:0 and only in the OUT system for iso C17:0.

Effect of rearing system

The RS did not have a relevant effect on meat individual fatty acids (Table 4) and FA classes (Table 5). In fact, only some minor fatty acids (C16:1 t8, C18:1 t4, C18:1 t6-8, C18:1 c10, C18:1 c12, C18:2 t9t12, C18:2 t8c13, C18:1 c15, C22:0, C22:1), and some minor isomers of CLA (t10c12, t11c13, c9c11) were influenced by rearing system. The C18:0 proportion was not influenced by rearing system. In general, the lack of differences in the fatty acid profile of meat between IND and OUT lambs could be mainly explained by the absence of differences in the feeding system of all mothers, which lead to a similar composition of the milk suckled by the two groups of lambs. In addition, the lack of differences between IND and OUT lambs could also be partly related to the early age of slaughter. In this trial, a visual inspection of the colour of the abomasums content evidenced grass intake by OUT lambs. However, grass ingestion usually starts in the last week before weaning; therefore, the time was likely not long enough to affect rumen function. This is supported by the absence of differences in the meat concentration of odd chain fatty acid (OCFA) between IND and OUT lambs. Indeed, since these fatty acids are useful indicators of an incipient rumen activity, the observed results suggest that rumen activity did not start in OUT and IND lambs during the trial.

In both rearing systems, the VA (C18:1 t11) in meat represented 64% of the total C18:1 *cis* FA. The value of CLA c9t11 is in line with those ones reported in other studies on suckling lambs (Serra *et al*., 2009) and no suckling lambs (Jeronimo *et al.*, 2009). The proportion of PUFAn3, including long chain PUFA (LC-PUFA, C > 20), was not affected by the rearing systems of lambs. However, it is noteworthy to highlight that the DHA value found in the studied lambs is higher than that found in meat from lambs fed concentrate (Terre *et al*., 2011) and from heavier animals fed a grass-based diet (Demirel *et al*., 2008). This could be explained by differences in anatomical depot location (Juárez *et al*., 2008), weight of slaughter (Serra *et al*., 2009) and phospholipids/triglycerides ratio between the samples analyzed in our trial and those from other studies. Since LC-PUFA are incorporated preferentially into membrane phospholipids rather than in the triglycerides fraction (Jerónimo *et al.*, 2009), the high content of LC-PUFA in the meat of young animals compared to fatter or heavier animals could be related to a high proportion of the phospholipids fraction in relation to the triglycerides fraction. This is confirmed by previous observations in which the content of LC-PUFAn3 was very low in adult Sarda sheep (Nudda *et al*., 2007).

Cooking effect

As expected, the cooking process changed markedly the concentrations of almost all FA and FA classes of meat samples (Tables 4 and 5). Cooking decreased significantly the amounts of short (-28%) and medium chain fatty acids (-11%), saturated fatty acids (-7.6%), and odd-number carbon and branched-chain (with iso- or anteiso structure) fatty acids (-11.8%). Cooked meat had, instead, a greater proportion of long chain fatty acids (LCFA; +5.3%) and polyunsaturated fatty acids of the omega3 (PUFAn3; +37.3%) and omega6 (PUFAn6; +26.1%) families. The lower SFA and medium chain fatty acid concentrations observed in the cooked meat are explained by the decrease of C12:0, C14:0 and C16:0. This represents an improvement in the FA profile of meat considering that these fatty acids have potential cholesterol-raising activities (Kris-Etherton and Yu, 1997). Among the C18 FA family, the proportions of C18:0 and C18:1 c9 were not influenced by cooking, whereas the

Table 2. Chemical composition and energy value of raw and cooked leg muscle (semitendinosus, semimembranosus and femoral biceps) from female and male Sarda suckling lambs from different rearing systems.

	Rearing systems		Sex		Cooking			P		
	Indoor	Outdoor	Female	Male	Raw	Cooked	SEM	RS	Sex	Cook
Moisture, %	71.46	71.75	71.24	71.96	74.33	68.90	0.368	ns	ns	**
Protein, %	22.94	22.74	23.05	22.69	20.45	25.23	0.196	ns	ns	**
Lipids, %	2.50	2.78	2.69	2.59	2.12	3.10	0.155	ns	ns	**
Ash, %	1.22	1.23	1.19	1.25	1.22	1.24	0.014	ns	*	ns
Energy value, kcal/100 g	114.0	115.8	115.5	114.4	101.4	128.4	1.404	ns	ns	**

RS, rearing system. **P≤0.01; *P≤0.05; ns, not significant.

proportions of CLA c9t11, VA and other trans isomers were reduced in cooked meat. The decrease in CLA c9t11 and VA by cooking was expected, because their concentration is generally higher in fat tissues than in lean muscles (Jiang *et al*., 2010).

The increase of PUFA content in cooked meat is related partly to the increase of C18:3n3 (+25.4%) and mainly to the increase in concentration of very long chain PUFA, especially EPA and DHA (+51.0%). This is probably because PUFA are incorporated in the membrane structure to a greater extent than SFA, which are more concentrated in the triglycerides fraction. Thus, the proportional change in fatty acid composition may be explained by the fat loss during cooking, which regards mainly triglycerides of adipose tissue with relatively more SFA than unsaturated fatty acids. In the present study, the MUFA was not influenced by cooking, in accordance to previous observations in cooked lamb rib loin (Maranesi *et al*., 2005).

The nutritional value of intramuscular fat

The nutritional indexes of meat quality PUFA/SFA and n6/n3 ratios were increased during the cooking process. In general, a ratio of PUFA to SFA above 0.45 and a ratio of n6/n3 below 4.0 are required in the diet (Simopoulos, 2002; 2008). The values of such indexes observed in the present trial are below the reference level and in line with previous observations in suckling lamb meat (Serra *et al*., 2009; Oriani *et al*., 2005).

Table 6 summarizes the content (mg/100 g of meat) of the FA groups and the most nutritionally important fatty acid. As expected, cooking caused significant increases in the contents of almost all fatty acids reported. Regarding the PUFAn3, the EFSA (2010) has proposed an intake of 250 mg/day of EPA+DHA for primary prevention of cardiovascular diseases in healthy subjects. In this experiment, 100 g of our cooked lamb meat provide about 38 mg of EPA+DHA, which represent 15% of the recommended daily intake for adults. Scientific experts in the area of infant nutrition (Institute of Medicine, 2002) reported that the adequate intake of total PUFAn3 is 0.5 g/d in 6-12 month-old children. Considering that 100 g of a cooked lamb meat contain about 80 mg of PUFAn3 (Table 6), it can be estimated that this portion can satisfy 16% of the recommended daily allowance for PUFAn3 in infants. This is interesting, if we consider that lamb meat is the first meat usually recommended at weaning by Italian pediatricians, because of its presumed lower allergenicity compared with other types of meat (Cardi *et al*., 1998a; 1998b; Martino *et al*., 1998).

Regarding the CLA, no reference values have been established yet. However, it is believed that about 1.33 g/d of CLA from dairy origin, with 90% of the c9t11 isomer, can help to prevent cancer in humans (Baer *et al*., 2001). The cooked lamb meat samples had about 30 mg/100 g of cooked meat. Assuming a 20% conversion rate in the human body of VA to CLA (Turpeinen *et al*., 2002), the measured VA would provide 10 mg of CLA. By adding the CLA and the VA converted into CLA, the lamb meat would provide about 40 mg of CLA/100 g of cooked meat. Therefore, 100 g of this lamb meat would provide only 3.0% of the daily recommended dose of CLA c9t11, which might be considered too low for a potentially beneficial effect on humans. However, this source should not be neglected, because ruminant products are one of the main natural sources of CLA c9t11 in human diet.

Lipid oxidation

The fatty acids oxidation (Table 5), expressed as mg MDA/kg muscle, was higher for OUT than IND lambs, for female than male lambs, and for cooked than raw meat ($P<0.01$). Furthermore, significant interactions RS sex ($P<0.05$) and RS cooking ($P<0.01$) were observed.

The higher MDA value in OUT than in IND lambs was unexpected, because the FA profile, including PUFA and highly peroxidable PUFA (HP-PUFA), did not differ between these two groups. Therefore, it can be hypothesized that the higher MDA levels in meat from OUT lambs was due to a presumably higher physical activity, which could have increased the fat oxidation. The significant interaction RS sex was due to higher MDA content in females than males in the OUT system likely related to the FA composition of the meat, because females showed a numerically higher concentration of highly-oxidable PUFA in the OUT system than in IND system (data not showed). The interaction RS cooking evidenced that

Table 3. Fatty acid profile of sheep milk suckled by Sarda lambs from different rearing systems.

	Rearing system		P
	Indoors	Outdoors	
Fatty acid, g/100g of FAME			
<C14:0	15.93	16.58	ns
C14:0 Myristic	9.35	9.14	ns
C16:0 Palmitic	21.99	21.16	ns
C18:0 Stearic	10.55	10.32	ns
C18:1 c9 Oleic	21.18	23.03	ns
C18:1 t11 Vaccenic	5.55	4.39	ns
CLA c9t11 Rumenic	1.50	1.50	ns
C18:2n6 Linoleic	2.77	3.02	ns
C18:3n3 α-linolenic	0.95	0.93	ns
C20:4n6 Arachidonic	0.14	0.19	ns
C22:1n9	0.00	0.00	ns
C20:5n3 (EPA)	0.06	0.05	ns
C24:1c15 Nervonic	0.00	0.00	ns
C22:5n3 (DPA)	0.12	0.15	ns
C22:6n3 (DHA)	0.04	0.04	ns
Sums and ratios			
SFA	61.96	61.07	ns
MUFA	31.11	32.04	ns
PUFA	6.92	6.89	ns
BCFA	2.30	2.19	ns
PUFAn3	1.23	1.21	ns
PUFAn6	3.09	3.42	ns
PUFA/SFA	0.11	0.11	ns
n6/n3	2.51	2.81	ns

FAME, fatty acid methyl esters; SFA, saturated fatty acids; MUFA, monounsatured fatty acids; PUFA, polyunsatured fatty acids; BCFA, branched fatty acids; ns, not significant.

Table 4. Fatty acid profile (g/100 g of FAME) of raw and cooked leg muscle (*semitendinosus, semimembranosus* and *femoral biceps*) from female and male Sarda suckling lambs from different rearing systems.

	Rearing system		Sex		Cooking			P				
	Indoor	Outdoor	Female	Male	Raw	Cooked	SEM	RS	Sex	C	RS x Sex	RS x C
C12:0	0.48	0.54	0.45	0.57	0.59	0.43	0.028	ns	**	**	ns	ns
C13:0	0.02	0.02	0.02	0.03	0.03	0.02	0.001	ns	**	**	ns	ns
C14:0 iso	0.03	0.03	0.03	0.03	0.04	0.03	0.002	ns	ns	ns	ns	ns
C14:0	4.88	4.75	4.61	5.02	5.45	4.18	0.178	ns	ns	**	ns	ns
C14:1c9	0.15	0.14	0.15	0.14	0.16	0.13	0.008	ns	ns	**	ns	ns
C15:0 iso	0.09	0.09	0.09	0.10	0.11	0.08	0.004	ns	***	**	ns	ns
C15:0 *anteiso*	0.16	0.16	0.15	0.17	0.18	0.14	0.006	ns	*	**	ns	ns
C15:0	0.47	0.46	0.43	0.50	0.51	0.42	0.016	ns	**	**	ns	ns
C16:0 iso	0.17	0.16	0.16	0.17	0.18	0.15	0.004	ns	ns	**	ns	ns
C16:0	20.33	19.75	19.88	20.21	20.87	19.22	0.289	ns	ns	**	ns	ns
C16:1 t6-7	0.02	0.02	0.02	0.02	0.02	0.02	0.001	ns	ns	***	ns	ns
C16:1 t8	0.04	0.02	0.03	0.04	0.03	0.03	0.006	*	ns	ns	ns	ns
C16:1 t9	0.16	0.15	0.14	0.16	0.14	0.16	0.004	ns	*	*	ns	ns
C16:1 t10	0.01	0.01	0.01	0.01	0.01	0.01	0.001	ns	ns	ns	ns	ns
C16:1 c7	0.45	0.46	0.45	0.47	0.46	0.45	0.013	ns	ns	ns	ns	ns
C16:1 c9	1.42	1.35	1.43	1.35	1.48	1.30	0.046	ns	ns	**	ns	ns
C16:1 c10	0.04	0.04	0.04	0.04	0.04	0.04	0.003	ns	ns	ns	ns	ns
C17:0 iso	0.45	0.46	0.44	0.47	0.47	0.45	0.009	ns	*	ns	*	ns
C17:0 *anteiso*	0.50	0.48	0.49	0.49	0.51	0.47	0.012	ns	ns	*	**	ns
C17:0	0.88	0.90	0.91	0.87	0.94	0.85	0.022	ns	ns	**	*	ns
C16:2 n-4	0.03	0.00	0.00	0.03	0.00	0.03	0.016	ns	ns	ns	ns	ns
C17:1 c8	0.11	0.10	0.10	0.11	0.10	0.11	0.003	ns	*	*	ns	ns
C17:1 c9	0.49	0.47	0.51	0.46	0.49	0.48	0.011	ns	**	ns	*	*
C18:0	12.72	13.32	13.08	12.96	12.92	13.12	0.233	ns	ns	ns	ns	ns
C18:1 t4	0.06	0.08	0.07	0.07	0.07	0.07	0.004	**	ns	ns	ns	ns
C18:1 t6-8	0.16	0.19	0.17	0.18	0.19	0.16	0.008	*	ns	**	***	ns
C18:1 t9	0.23	0.26	0.25	0.24	0.26	0.23	0.014	ns	ns	***	ns	n
C18:1 t10	0.88	0.60	0.65	0.82	0.78	0.69	0.138	ns	ns	ns	ns	ns
C18:1 t11	2.16	2.19	2.12	2.22	2.26	2.09	0.055	ns	ns	*	ns	ns
C18:1 c9	33.44	33.99	34.30	33.12	33.66	33.76	0.511	ns	ns	ns	ns	ns
C18:1 c10	0.75	0.47	0.67	0. 56	0.62	0.61	0.060	*	ns	ns	ns	ns
C18:1 c11	1.10	1.13	1.10	1.12	1.03	1.20	0.024	ns	ns	**	ns	ns
C18:1 c12	0.30	0.35	0.33	0.32	0.30	0.36	0.010	*	ns	**	ns	ns
C18:1 c13	0.11	0.12	0.11	0.12	0.11	0.12	0.007	ns	ns	ns	ns	ns
C18:1 c14	0.21	0.23	0.22	0.22	0.24	0.20	0.010	ns	ns	**	ns	ns
C18:2 t9t12	1.05	1.15	1.11	1.09	1.10	1.10	0.025	**	ns	ns	ns	ns
C18:1 c15	0.14	0.16	0.16	0.15	0.16	0.15	0.007	*	ns	ns	ns	ns
C18:2 t8c13	0.34	0.38	0.36	0.36	0.37	0.35	0.012	*	ns	ns	ns	ns
C18:2 c9t12	0.12	0.12	0.13	0.11	0.11	0.13	0.008	ns	ns	***	*	ns
C18:2 t9c12	0.07	0.07	0.07	0.07	0.08	0.07	0.006	ns	ns	ns	ns	ns
C18:2 n6	5.77	5.75	5.78	5.75	5.09	6.44	0.296	ns	ns	**	ns	ns
C18:3 n6	0.05	0.05	0.05	0.05	0.04	0.05	0.003	ns	ns	**	ns	ns
C18:3 n3	1.34	1.31	1.33	1.32	1.18	1.48	0.048	ns	ns	**	ns	ns
CLA c9t11	1.44	1.43	1.40	1.47	1.48	1.40	0.040	ns	ns	**	ns	ns
C18:4 n3	0.04	0.03	0.03	0.04	0.03	0.04	0.003	ns	ns	ns	ns	ns
CLA t9c11 + C20	0.11	0.11	0.11	0.11	0.11	0.11	0.004	ns	ns	ns	ns	ns
CLA t10c12	0.04	0.03	0.03	0.04	0.04	0.03	0.001	*	*	ns	ns	ns
CLA t11c13	0.11	0.09	0.10	0.10	0.10	0.10	0.004	**	ns	ns	ns	ns
CLA c9c11	0.07	0.05	0.06	0.06	0.06	0.06	0.002	**	ns	ns	ns	ns
CLA t9t11 + C20:1	0.14	0.14	0.14	0.14	0.13	0.15	0.004	ns	ns	*	ns	ns
C20:2 n6	0.06	0.05	0.05	0.06	0.05	0.06	0.004	ns	ns	**	ns	ns
C20:3 n-9	0.56	0.55	0.55	0.56	0.46	0.65	0.004	ns	ns	**	ns	ns
C20:3 n6	0.21	0.21	0.22	0.21	0.18	0.25	0.01	ns	ns	**	ns	ns
C20:4 n6	1.86	1.89	1.85	1.90	1.55	2.20	0.149	ns	ns	**	ns	ns
C20:3 n3	0.03	0.03	0.03	0.03	0.03	0.04	0.002	ns	ns	**	ns	ns
C22:0	0.02	0.03	0.02	0.03	0.02	0.03	0.001	*	ns	**	ns	ns
C20:4 n3	0.04	0.03	0.04	0.03	0.03	0.04	0.002	ns	ns	**	ns	ns
C22:1	0.02	0.00	0.00	0.00	0.00	0.01	0.001	**	ns	**	ns	*
C20:5 n3 (EPA)	0.78	0.75	0.78	0.75	0.61	0.92	0.058	ns	ns	**	ns	***
C22:4 n6	0.11	0.10	0.10	0.12	0.09	0.13	0.007	ns	ns	**	***	ns
C24:0	0.04	0.04	0.03	0.04	0.03	0.04	0.004	ns	*	**	***	ns
C22:5 n3 (DPA)	1.06	1.01	1.01	1.06	0.87	1.20	0.068	ns	ns	**	ns	*
C22:6 n3 (DHA)	0.65	0.64	0.61	0.68	0.51	0.77	0.037	ns	ns	**	ns	*

FAME, fatty acid methyl esters; C, cooking; RS, rearing system. **P≤0.01; *P≤0.05; ***P≤0.10; ns, not significant.

Table 5. Fatty acid groups (g/100 g of FAME), lipid oxidation and nutritional indexes of raw and cooked leg muscle (*semitendinosus, semimembranosus* and *femoral biceps*) from female and male Sarda suckling lambs from different rearing systems.

	RS		Sex		Cooking			P				
	IND	OUT	Female	Male	Raw	Cooked	SEM	RS	Sex	Cooking	RS x Sex	RS x Cooking
SFA	41.41	41.39	40.96	41.84	43.03	39.77	0.517	ns	ns	**	ns	ns
MUFA	42.45	42.55	43.04	41.96	42.63	42.37	0.435	ns	ns	ns	ns	*
PUFA	15.55	15.47	15.43	15.59	13.76	17.26	0.675	ns	ns	**	ns	ns
PUFAn3	3.94	3.82	3.84	3.92	3.27	4.49	0.202	ns	ns	**	ns	ns
PUFAn6	9.30	9.40	9.36	9.35	8.27	10.43	0.446	ns	ns	**	ns	ns
OBCFA	2.79	2.79	2.74	2.84	2.97	2.62	0.049	ns	ns	**	ns	ns
TFA	5.28	5.23	5.12	5.39	5.42	5.10	0.179	ns	ns	ns	ns	ns
HP-PUFA	6.79	6.69	6.66	6.81	5.63	7.84	0.406	ns	ns	**	ns	***
SCFA	0.62	0.71	0.59	0.74	0.78	0.56	0.036	ns	ns	**	ns	***
MCFA	29.41	28.59	28.57	29.43	30.70	27.31	0.533	ns	ns	**	ns	ns
LCFA	69.96	70.70	70.84	69.83	68.53	72.14	0.559	ns	ns	**	ns	ns
MDA, mg/kg°	1.25	1.84	1.70	1.40	0.43	2.66	0.074	**	**	**	*	**
Ratios and indexes												
n6/n3	2.44	2.56	2.54	2.46	2.60	2.40	0.062	ns	ns	**	ns	ns
PUFA/SFA	0.39	0.39	0.39	0.38	0.33	0.45	0.023	ns	ns	**	ns	ns
MUFA/SFA	1.03	1.04	1.06	1.01	1.00	1.07	0.017	ns	ns	**	ns	ns
AI	0.73	0.72	0.70	0.75	0.81	0.64	0.024	ns	ns	**	ns	ns
TI	1.02	1.03	1.02	1.03	1.12	0.93	0.028	ns	ns	**	ns	ns
h/H	1.89	1.98	1.99	1.88	1.74	2.13	0.063	ns	ns	**	ns	ns

FAME, fatty acid methyl esters; RS, rearing system; SFA, saturated fatty acids (sum of C10:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C22:0, C24:0 and odd-branched fatty acids); MUFA, monounsatured fatty acids (sum of C14:1, ΣC16:1, Σ C17:1 and Σ C18:1); PUFA, polyunsatured fatty acids (sum of total n6 and total n3); PUFA n3, sum of C18:3n3, C18:4n3, C20:3n3, C20:4n3, C20:5n3, C22:5n3, C22:6n3); PUFA n6, sum of C18:3n6, C20:2n6, C20:3n6, C20:4n6, C22:2n6, C22:4n6; OBCFA, odd and branched fatty acids (sum of C13:0, C13:0 *i*, C13:0 *ai*, C14:0 *i*. C15:0 *i*, C15:0 *ai*, C16:0 *i*, C17:0, C17:0 *i*, C17:0 *ai* and Σ C17:1, where *i* is an *iso*-isomer and *ai* is an *ante-iso*-isomer); TFA, trans fatty acids (sum of C16:1 t6-7, C16:1 t8, C16:1 t9, C16:1 t10, C18:1t4, C18:1t6+t8, C18:1t9, C18:1t10, C18:1t11, C18:2t,t + c/t, C18:2t8,c13); HP-PUFA, sum of PUFA with three or more double bonds; SCFA, short chain fatty acid (C8-C10); MCFA, medium chain FA (C12-C17); LCFA, long chain FA (≥C18). °Lipid oxidation expressed as malondialdehyde (MDA) concentration in the muscle. AI, atherogenic index; TI, thrombogenic index; h/H, hypocholesterolemic/hypercholesterolemic ratio. **P≤0.01; *P≤0.05; ***P≤0.10; ns, not significant.

Table 6. Fatty acid groups and nutritionally important fatty acid content (mg/100 g of meat) of raw and cooked meat samples.

	Cooking			P
	Raw	Cooked	SEM	Cooking
SFA	702.9	860.7	62.24	*
MUFA	700.3	916.6	65.77	*
PUFA	219.6	325.8	13.43	**
PUFAn3	52.0	82.4	3.27	**
PUFAn6	131.9	195.9	8.24	**
OBCFA	48.6	57.3	4.42	ns
HP-PUFA	88.6	141.8	5.35	**
VA	36.9	45.1	3.31	*
CLA	23.9	29.7	2.07	*
ALA	19.1	28.3	1.37	**
ARA	23.8	38.7	1.56	**
EPA	9.5	16.1	0.70	**
DPA	13.7	21.6	0.88	**
DHA	8.1	14.1	0.61	**
n6/n3	2.59	2.39	0.06	*

SFA, saturated fatty acids (sum of C10:0, C12:0, C14:0, C15:0, C16:0, C17:0, C18:0, C22:0, C24:0 and odd-branched fatty acids); MUFA, monounsatured fatty acids (sum of C14:1, ΣC16:1, ΣC17:1 and ΣC18:1); PUFA, polyunsatured fatty acids (sum of total n6 and total n3); PUFA n3, sum of C18:3n3, C18:4n3, C20:3n3, C20:4n3, C20:5n3, C22:5n3, C22:6n3); PUFA n6, sum of C18:3n6, C20:2n6, C20:3n6, C20:4n6, C22:2n6, C22:4n6; OBCFA, odd and branched fatty acids (sum of C13:0, C13:0 *i*, C13:0 *ai*, C14:0 *i*. C15:0 *i*, C15:0 *ai*, C16:0 *i*, C17:0, C17:0 *i*, C17:0 *ai* and ΣC17:1, where *i* is an *iso*-isomer and *ai* is an *ante-iso*-isomer); HP-PUFA, sum of PUFA with three or more double bonds; VA, vaccenic acid; CLA, conjugated linoleic acid; ALA, alpha-linolenic acid; ARA, arachidonic acid; EPA, eicosapentaenoic acid; DPA, docosapentaenoic acid; DHA, docosahexaenoic acid.**P≤0.01; *P≤0.05; ns, not significant.

the TBAR increased with cooking but in higher proportion in OUT than in IND meat samples. However, the amounts of TBARS formed with the microwave cooking were below the critical value of 3 mg/kg at which rancidity is virtually detected (Wong *et al*., 1995).

Conclusions

This study has shown that the indoor and outdoor rearing systems did not change the meat fatty acid profile of suckling lambs. Cooking enhanced the fatty acid profile of meat from suckling lambs, because of a higher concentration of very long chain fatty acids of the omega 3 family, such as EPA and DHA. Sex influenced significantly the concentration of the main odd and branched chain fatty acids. Fatty acid oxidation increased in OUT lambs, suggesting a higher physical activity in the animals that followed the mother on pasture.

References

Alfaia, C.M.M., Alves, S.P., Lopes, A.F., Fernandes, M.J.E., Costa, A.S.H., Fontes, C.M.G.A., Castro, M.L., Bessa, R.J., Prates, J.A., 2010. Effect of cooking methods on fatty acids, conjugated isomers of linoleic acid and nutritional quality of beef intramuscular fat. Meat Sci. 84:769-777.

AOAC, 1997. Official Methods of Analysis, 16th ed. Association of Official Analytical Chemists, Washington, DC, USA.

AOAC, 2000. Meat and meat products: Official Methods of Analysis, 17th ed. Association of Official Analytical Chemists, Gaithersburg, MD, USA.

Baer, R.J., Ryali, J., Schingoethe, D.J., Kasperson, K.M., Donovan, D.C., Hippen, A.R., Franklin, S.T., 2001. Composition and properties of milk and butter from cows fed fish oil. J. Dairy Sci. 84:345-353.

Berge, P., Sañudo, C., Sanchez, A., Alfonso, M., Stamataris, C., Thorkelsson, C., Piasentier, E., Fisher, A.V., 2003. Comparison of muscle composition and meat quality traits in diverse commercial lamb types. J. Muscle Foods 14:281-300.

Bhattacharya, A., Banu, J., Rahman, M., Causey, J., Fernandes, G., 2006. Biological effects of conjugated linoleic acids in health and disease. J. Nutr. Biochem. 17:789-810.

Biondi, L., Valvo, M.A., Di Gloria, M., Scinardo Tenghi, E., Galofaro, V., Priolo, A., 2008. Changes in ewe milk fatty acids following turning out to pasture. Small Ruminant Res. 75:17-23.

Cardi, E., Corrado, G., Cavaliere, M., Grandina, G., Pacchiarotti, C., Rea, P., Mazza, M.L., Nardelli, F., Agazie, E., 1998a. Rezza-Cardi's diet as dietary treatment of short bowel syndrome. Gastroenterology 114(Suppl.1):A869 No. G3565.

Cardi, E., Corrado, G., D'Eufemia, P., Cavaliere, M., Celli, M., Rea, P., Pacchiarotti, C., Frandina, G., Villatico Campbell, A., Gianni, D., 1998b. Rezza-Cardi's diet as treatment of sandifer syndrome. Gastroenterology 114(Suppl.1):A869 No. G3566.

Demirel, G., Ozpinar, H., Nazli, B., Keser, O., 2006. Fatty acids of lamb meat from two breeds fed different forage: concentrate ratio. Meat Sci. 72:229-235.

EFSA, 2010. Scientific opinion on dietary reference values for fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans fatty acids, and cholesterol. EFSA Journal 8:1461-1568.

European Commission, 1990. Council Directive of 24 September 1990 on nutrition labeling for foodstuff, 496/90/EEC. In: Official Journal, L 276, 06/10/1190, pp 40-44.

FDA, 1999. FDA Backgrounder, The Food Label, B99-5. Available from: http://www.fda.gov

Fernández, M., Ordonez, J.A., Cambero, I., Santos, C., Pin, C., Hoz, L., 2007. Fatty acid compositions of selected varieties of Spanish dry ham related to their nutritional implications. Food Chem. 11:107-112.

Folch, J., Lees, M., Stanley, G.H.S., 1957. A simple method for the isolation and purification of total lipids from animal tissue. J. Biol. Chem. 226:497-509.

Hoke, I.M., Buege, D.R., Ellefson, W., Maly, E., 1999. Nutrient and related food composition of exported Australian lamb cuts. J. Food Comp. Anal. 12:97-109.

INRAN, 2000. Tabelle di composizione degli alimenti, aggiornamento 2000. Available from: http://www.inran.it/Documentazione/tabelle.htm

Institute of Medicine, 2002. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids macronutrients. National Academies Press, Washington, DC, USA.

International Dairy Federation, 1999. Milk fat. Preparation of fatty acid methyl esters, Standard N. 182. IDF Publ., Brussels, Belgium.

Jerónimo, E., Alves, S.P., Prates, J.A.M., Santos-Silva, J., Bessa, R.J.B., 2009. Effect of dietary replacement of sunflower oil with linseed oil on intramuscular fatty acids of lamb meat. Meat Sci. 83:499-505.

Jiang T., Busboom, J.R., Nelson, M.L., O'Fallon, J., Ringkob, T.P., Joos, D., Piper, K., 2010. Effect of sampling fat location and cooking on fatty acid composition of beef steaks. Meat Sci. 4:86-92.

Joy, M., Ripoll, G., Molino, F., Dervishi, E., Alvarez-Rodriguez, J., 2012. Influence of the type of forage supplied to ewes in pre- and post-partum periods on the meat fatty acids of suckling lambs. Meat Sci. 90:775-782.

Juárez, M., Horcada, A., Alcalde, M.J., Valera, M., Mullen, A.M., Molina, A., 2008. Estimation of factors influencing fatty acid profiles in light lambs. Meat Sci. 79:203-210.

Kris-Etherton, P.M., Yu, S., 1997. Individual fatty acid effects on plasma lipids and lipoproteins: human studies. Am. J. Clin. Nutr. 65:1628-1644.

Lanza, M., Bella, M., Priolo, A., Barbagallo, D., Galofaro, V., Landi, C., 2006. Lamb meat quality as affected by natural or artificial milk feeding regimen. Meat Sci. 73:313-318.

Luciano, G., Biondi, L., Pagano, R.I., Scerra, M., Vasta, V., López-Andrés, P., Valenti, B., Lanza, M., Priolo, A., Avondo, M., 2012. The restriction of grazing duration does not compromise lamb meat colour and oxidative stability. Meat Sci. 92:30-35.

Luciano, G., Biondi, L., Scerra, M., Serra, A., Mele, M., Lanza, M., Priolo, A., 2013. The effect of the change from a herbage to a concentrate-based diet on the oxidative stability of raw and cooked lamb meat. Meat Sci. 95:212-218.

Maranesi, M., Bochicchio, D., Mantellato, L., Zaghini, A., Pagliuca, G., Badiani, A., 2005. Effect of microwave cooking or broiling on selected nutrients contents, fatty acid patterns and true retention values in separable lean from lamb rib-loins, with emphasis on conjugated linoleic acid. Food Chem. 90:207-218.

Martino, F., Bruno, G., Aprigliano, D., Agolini, D., Guido, F., Giardini, O., Businco, L., 1998. Effectiveness of a home-made meat based formula (the Rezza-Cardi diet) as a diagnostic tool in children with food-induced atopic dermatitis. Pediatr. Allergy Immu. 9:192-196.

Matthews, R.H., Garrison, Y.J., 1975. Food yield summarized by different stages of preparation. Agriculture handbook N. 102. US Department of Agriculture Publ., Washington, DC, USA.

Napolitano, F., Caroprese, M., Girolami, A., Marino, R., Muscio, A., Sevi, A., 2006. Effects of early maternal separation of lambs and rearing with minimal and maximal human contact on meat quality. Meat Sci. 72:635-640.

Nudda, A., Battacone, G., Usai, M.G., Fancellu, S., Pulina, G., 2006. Supplementation with extruded linseed cake affects concentrations of conjugated linoleic acid and vaccenic acid in goat milk. J. Dairy Sci. 89:277-282.

Nudda, A., Castanares, N., Mazzette, A., Canu, G., Carboni, G. A., Pulina, G., 2007. Maternal and fetal fatty acid composition in ovine muscle tissues. Proc. 17th Nat. Congr. ASPA, Alghero, Italy. Ital. J. Anim. Sci. 6(Suppl.1):573 (abstr.).

Nudda, A., McGuire, M.A., Battacone, G., Pulina, G., 2005. Seasonal variation in conjugated linoleic acid and vaccenic acid in milk fat of sheep and its transfer to cheese and ricotta. J. Dairy Sci. 88:1311-1319.

Nudda, A., McGuire, M.K., Battacone, G., Manca, M.G., Boe, R., Pulina, G., 2011. Documentation of fatty acid profile in lamb meat and lamb-based infant food. J. Food Sci. 76:43-47.

O'Grady, M.N., Monahan, F.J., Burke, R.M.,

Allen, P., 2000. The effect of oxygen level and exogenous α-tocopherol on the oxidative stability of minced beef in modified atmosphere packs. Meat Sci. 55:39-45.

Oriani, G., Maiorano, G., Filetti, F., Di Cesare, C., Manchisi, A., Salvatori, G., 2005. Effect of age on fatty acid composition of Italian Merino suckling lambs. Meat Sci. 71:557-562.

Osorio, M.T., Zumalacárregui, J.M., Figueira, A., Cabeza, E.A., Mateo, J., 2008. Effect of rearing system on some meat quality traits and volatile compounds of suckling lamb meat. Small Ruminant Res. 78:1-12.

Pikul, J., Leszczynski, D.E., Kummerow, F.A., 1989. Evaluation of three modified TBA method for measuring lipid oxidation in chicken meat. J. Agr. Food Chem. 37:1309-1313.

Pintus, S., Murru, E., Carta, G., Cordeddu, L., Batetta, B., Accossu, S., Pistis, D., Uda, S., Ghiani, E.M., Mele, M., Secchiari, P., Almerighi, G., Pintus, P., Banni, S., 2012. Sheep cheese naturally enriched in α-linolenic, conjugated linoleic and vaccenic acids improves the lipid profile and reduces anandamide in the plasma of hypercholesterolaemic subjects. Brit. J. Nutr. 24:1-10.

Raharjo, S., Sofos, J.N., Schimdt, G.R., 1992. Improved speed, specificity, and limit of determination of an aqueous acid extraction thiobarbituric acid-C18 method for measuring lipid peroxidation in beef. J. Agr. Food Chem. 40:2182-2185.

Roth, E.M., Harris, W.S., 2010. Fish oil for primary and secondary prevention of coronary heart disease. Curr. Atheroscler. Rep. 12:66-72.

Ruxton, C.H.S, Reed, S.C., Simpson, M.J.A., Millington, K.J., 2004. The health benefits of omega-3 polyunsaturated fatty acids: a review of the evidence. J. Hum. Nutr. Diet. 17:449-459.

Scerra, M., Caparra, P., Foti, F., Galofaro, V., Sinatra, M.C., Scerra, V., 2007. Influence of ewe feeding systems on fatty acid composition of suckling lambs. Meat Sci. 76:390-394.

Serra, A., Mele, M., La Comba, F., Conte, G., Buccioni, A., Secchiari, P., 2009. Conjugated Linoleic Acid (CLA) content of meat from three muscles of Massese suckling lambs slaughtered at different weights. Meat Sci. 81:396-404.

Simopoulos, A.P., 2002. The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomed. Pharmacother. 56:365-379.

Simopoulos, A.P., 2008. The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. Exp. Biol. Med. 233:674-688.

Società Italiana di Nutrizione Umana, 2012. Livelli di assunzione di riferimento di nutrienti ed energia per la popolazione italiana (LARN), rev. 2012. Available from: http://www.sinu.it/pubblicazioni.asp

Tedeschi, L.O., Cannas, A., Fox, D.G., 2010. A nutrition mathematical model to account for dietary supply and requirements of energy and other nutrients for domesticated small ruminants: the development and evaluation of the small ruminant nutrition system. Small Ruminant Res. 89:174-184.

Turpeinen, A. M., Mutanen, M., Aro, A., Salminen, I, Basu, S., Palmquist, D. L., 2002. Bioconversion of vaccenic acid to conjugated linoleic acid in humans. Am. J. Clin. Nutr. 76:504-510.

Ulbricht, T.L.V., Southgate, D.A.T., 1991. Coronary heart disease: seven dietary factors. Lancet 338:985-992.

USDA, 2013. U.S. Department of Agriculture, Agricultural Research Service. 2013. USDA National Nutrient Database for Standard Reference, Release 26. Nutrient Data Laboratory. Available from: https://www.ars.usda.gov/SP2UserFiles/Place/12354500/Data/SR26/reports/sr26fg17.pdf

Valvo, M.A., Lanza, M., Bella, M., Fasone, V., Scerra, M., Biondi, L., 2005. Effect of ewe feeding system (grass vs. concentrate) on intramuscular fatty acids of lambs raised exclusively on maternal milk. Anim. Sci. 81:431-436.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-3597.

Vincenti, A., Colonna, M.A., Ragni, M., Toteda, F., 2004. Effect of type of suckling and polyunsaturated fatty acid use on lamb production. 2. Chemical and fatty composition of raw and cooked meat. Ital. J. Anim. Sci. 3:81-91.

Williams, P. G., 2007. Nutritional composition of red meat. Nutr. Diet. 64:113-119.

Wong, J.W., Hashimoto, K., Shibamoto, T., 1995. Antioxidant activities of rosemary and sage extracts and vitamin E in a model meat system. J. Agr. Food Chem. 43:2707-2712.