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Effect of farming system on meat traits of native Massese suckling lamb

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ABSTRACT

Growth performance and meat quality traits of 24 Massese suckling lambs reared up to 69 days of age in different farming systems were evaluated. Three groups were considered: stall (S) reared indoors and fed concentrate and hay; pasture (P) reared outdoor and fed pasture and hay; semi free-range (F) reared indoors during the night and at pasture during the day, fed concentrate, hay and herbage. The lambs remained constantly with their dams for the whole period, having thus always access to mothers' milk. Animals weights were recorded, and, after slaughtering, carcass traits were considered. Fatty acids composition and chemical/physical parameters of milk and meat were analysed. Lambs growth was similar in the first 30 days, while afterwards differences emerged: P lambs recorded the worst values reaching slaughter weight of 14.6 kg versus 22.3 and 22.7 of the S and the F group, respectively. Carcass of P lambs resulted less fat and with a lower lean/bone ratio than the other groups (1.8, 2.1 and 2.3 for P, S and F, respectively). Fatty acids composition of ewes' milk had effect on lambs' meat profile, probably because they continued to suck milk until slaughter. Moreover, also farming system affected fatty acids profile of lambs' meat: grazing animals, especially P, showed the highest PUFA and the lowest SFA percentage and P meat showed the best composition for human health. As regards physical traits, F meat was more coloured than P and S meat, while P meat was less tender than others.

HIGHLIGHTS

- Two-month-old Massese lamb is a marketable product.
- Suckled milk affected lambs' meat composition also at later ages.
- Pasture in lambs' diet increases PUFA content in the meat.

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Meat quality; Massese lamb; sustainability; fatty acid

Introduction

Lamb meat produced in Mediterranean region represents a specific and different product respect to northern European countries mainly due to both the livestock system and the slaughter age of the animals (Santos Silva et al. 2002; Kegalj et al. 2011). In Italy, and in particular in Tuscany, lamb meat derives from dairy sheep breeds and lambs are slaughtered at about one month of age, fed exclusively with milk. Consumers are traditionally linked to specific flavour and taste of this kind of lamb characterised by the lack of ruminal system development. In recent years, consumers' attention has focussed on quality products (Verbeke et al. 2010; Hocquette et al. 2012), primarily health and ethical aspects. Moreover, the meat of very young animals is not accepted in moral terms by an

increasing number of people. In this context, animal welfare has become a main topic linked to 'natural management' based on extensive grazing pastures with minimal feed supplements (Boughalmi and Araba 2016). Lambs raised on mountain pastures, without any supplementary feed or treatment, are considered to produce superior quality meat (Ådnøy et al. 2005) perceived by several consumers as cleaner and more organic meat (Cabiddu et al. 2005). In this context, the Italian sheep and goat are well established, and they are often characterised by extensive farming able to use marginal areas (Todaro et al. 2015). Massese sheep is a typical Tuscan local breed, widespread in mountainous and hilly areas and reared according to farming system based on the seasonality of the natural resources during the year. Indeed, Massese breed produces three types of lamb: lambs reared in early

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autumn, in late autumn, and in late spring (Acciaioli et al. 2011). This is possible because the Massese ewe is characterised by a specific reproductive pattern thanks to the capacity of break free from the seasonality of oestrus and carry out 3 lambing in two years (Todaro et al. 2015). Large variety of grazing sources is available for ewes and lambs in spring and summer whereas sheep are almost always raised in stall with supplementary feed during winter and autumn. Lambs remain always with their mothers following them to pasture in which sometimes a small amount of fibre can be ingested (Serra et al. 2009). Those lambs are often slaughtered after a suckling period of 30 days and a live weight between 11 and 14 kg (Serra et al. 2009) in specific periods such as Easter and Christmas (Tocci et al. 2017). Suckling lamb meat is marked by low lipid content and specific fatty acid composition despite the poor carcase yield. Many authors studied the effect of rearing system, in particular, pasture respect to concentrate feeding on meat quality of suckling lamb showing that weaned lamb fed on concentrate had higher intramuscular fat content than animals fed on pasture (Velasco et al. 2001; Valvo et al. 2005; Hajji et al. 2014). An important aspect concerning grazing system effect is the presence of natural antioxidants in green forage which can help to limit meat oxidation (López-Bote et al. 2001; Wood et al. 2004). The influence of forage on sensory proprieties, meat colour and texture has been studied by different authors with contrasting results (French et al. 2001; Priolo et al. 2002). Indeed, lambs reared on pasture, often in the mountains, may walk long distances and their bodies may have a different conformation than lambs confined in stalls or paddocks (Ådnøy et al. 2005). In Italy, information on the extended period of suckling for lambs as well as on the diet effect on carcase and meat quality of autochthonous lambs reared beyond the two months of age with their mothers is scarce or incomplete. The characterisation of Massese lamb meat can represent an opportunity to produce heavier carcasses with greater muscle development, for both increasing the incomes of the farmers and promoting local lamb's meat (Ådnøy et al. 2005). Interesting results on heavier lambs have been related by Spanish Authors (Joy et al. 2008; Ripoll et al. 2019) working on animals slaughtered within 3 months of age with a liveweight of 22 kg and reared at pasture with or without supplementary feed.

Aim of this study was to evaluate growth performances, carcase and meat quality traits of Massese suckling lambs reared under three different farming

systems: (i) stall fed with concentrate and hay, (ii) semi free-range fed with concentrate, hay and grazing pasture, (iii) pasture fed with hay and grazing pasture.

Materials and method

Animals and diets

The trial was carried out at farm level, under the control of the public veterinary service and it complied with the Italian laws on animal experimentation and ethics (LD 04/03/2014, n.26). Meat used in the trial derived from 24 Massese lambs reared in a farm of Pistoia Apennines (Italy). Ewes were chosen randomly from the flock avoiding the primiparous ones and those that had twin or problematic births. Lambs remained together with their own mothers during all life period always having the opportunity to suck milk. After an initial period (10 days) in which lambs and ewes were reared indoors in a separate box ensuring maternal bonding, animals were distributed in three groups based on different farming systems:

- i. group S, stall: 8 lambs (6 males, 2 females) and their respective ewes remained indoors and they were fed with concentrate and hay;
- ii. group F, semi free-range: 8 lambs (5 males, 3 females) and their respective ewes were reared indoors during the night and at pasture during the day, they were fed with concentrate, hay and herbage;
- iii. group P, pasture: 8 lambs (5 males, 3 females) and their respective ewes were reared outdoor and they were fed pasture and hay without any supplementation.

In every system, free access to water was guaranteed, hay was available ad libitum during diurnal time for all groups. For S and F animals, commercial concentrate was available in the evening as dose per capita of 200 g for lambs and 700 g for ewes. Lambs had exclusive access to their concentrate through a creep feeding system. Concentrate was the same for both ewes and lambs and the ingredients were the following: barley, maize, soybean meal, wheat bran, field beans, oatmeal, molasses, alfalfa flour, alfalfa pellets, vitamins and supplement.

The grazing area was changed weekly, so animals rotationally grazed on the plots of land. Each plot measured between 3 and 4 ha. Representative areas of the pastures were sampled using exclusion cages of 1 sqm. The pasture flora was on average composed of 60.2% Graminaceae, 25.5% Leguminoseae and 14.3%

Table 1. Chemical composition of the feeds (%DM).

Parameter	Hay	Concentrate	Pasture herbage
Dry matter (DM)	92.2	93.2	27.74
Crude protein	9.32	15.18	14.79
Ash	6.58	10.40	9.30
Ether extract	1.03	2.61	2.01
Neutral detergent fibre (NDF)	59.22	37.71	54.82
Acid detergent fibre (ADF)	39.21	20.70	34.90
Acid detergent lignin (ADL)	6.52	4.41	5.62

other families. The biomass available was 2500 kg/ha on average.

Hay and concentrate, when included in the diet, were sampled three times during the trial: at start, after 30 days and finally after 60 days.

On hay, concentrate and herbage, moisture (by drying up to constant weight of the sample), fat (as ether extract), protein and ash contents (AOAC 2019), and fibre components (Van Soest et al. 1991) were determined. The results are reported in Table 1. Farmer weighed each lamb three times: at birth, at 30 days of age and before slaughter. Live weights were used to evaluate in vivo performance.

Chemical and fatty acids analysis of milk

Three samples of milk for each ewe were collected by the farmer at the beginning, at 30 days and at the end of the trial. Each milk sample was about 100 mL and was transported, as soon as possible, to the lab under refrigerated conditions. Each sample was divided into two parts: one aliquot was stored at -80°C for fat determination and fatty acid composition and another was stored at -20°C for proximate analysis. Before the analysis milk samples of the three different periods were merged in order to analyse a single sample per ewe. Moisture, total protein, and ash contents were determined following AOAC (2019) methods. Milk lipids extraction was performed according to the AOAC 905.02 Roesse-Gottlieb method.

The fatty acid methyl esters were obtained from saponification (KOH 0.5 N in methanol) and etherification in methanol with H_2SO_4 1% (2 mL at 50°C overnight) as proposed by Christie (1989). Fatty acids were identified and quantified by gas chromatography using a Varian GC 430-GC equipped with autosampler (CP-8400), detector FID and Galaxie Chromatography Data System software (Varian Inc., Mitchell Drive Walnut Creek, CA, USA). Fatty acid separation occurred in a polar fused silica capillary column (Varian CP-Sil-88 Middelburg, Netherland, 50 m, 0.32 mm i.d. film thickness 0.20 μm). FAs were identified by comparing the retention time of the FAME with the standard Supelco FAME mix C4-C24 (18919-1AMP Supelco,

Sigma-Aldrich, corp.) while the identification of isomers of C18:1 was based on commercial standard mix for conjugated methyl ester (O5632 Sigma-Aldrich corp). The quantification of fatty acid was performed thanks to three levels calibration using both FAME Mix C4-C24 and trichosanoic acid (T6543 Sigma-Aldrich, Corp., St. Louis, MO) as internal standard (ISTD). These results were expressed as the percentage of total fatty acids.

Slaughter, carcass measurements and muscle sampling procedures

Lambs were slaughtered at an average age of 69 days \pm 2.8 in an authorised, commercial, EU-licensed abattoir, following the recommendations of the European Council (Council Regulation-EC No 1099/2009) concerning the protection of animals at the time of killing. At slaughter, the hot carcass weight was determined, and the relative yield was calculated as dressing percentage. Carcasses were stored at 4°C for 24 h; then they were weighed, and carcass length and chest depth were measured. Dressing yield was calculated excluding from carcass head, pluck, skin and distal part of legs.

The right side of carcass was dissected in the following cuts as proposed by ASPA (1991) methodology: neck, shoulder, steaks, brisket, loin, abdominal region and hind leg. Each cut was weighed. Shoulder, loin and hind leg were dissected in the different tissues (lean, fat and bone) and weighed; moreover, the main muscles (*Triceps brachii*, *Longissimus dorsi* and *Semimembranosus*) was sampled to represent the overall meat composition.

Analysis on meat

Chemical analyses were carried out on each muscle determining dry matter, crude protein, and ash (AOAC 2019).

Total lipid content was quantified using a modified method of Folch et al. (1957). The total lipid was extracted from 2 g of sample with 37 mL chloroform--methanol, 2:1 (v/v) containing 0.01% of BHT. The lipid extract was washed by adding 10 mL of 0.88% KCl. The supernatant was recovered, and the solvent removed. The purified lipid extract was dissolved in chloroform (5 mL). The lipids quantitative determination was carried out by gravimetric method.

Fatty acid profile of total lipids was determined using the modified technique of Morrison and Smith (1964). The lipids fatty acid profile was performed by

saponification and methylation with BF3-Methanol. Lipid extract (3 mg) added with 0.2 mg of C19:0 (ISTD) was saponified with 3 mL of 0.5 M KOH in methanol at 95 °C for 40 min. A quantity of 1.5 mL of 0.2 N HCl shifted the soaps to free fatty acids. Fatty acids were recovered by double extraction with 2.5 mL of petroleum ether. After removing the solvent by rotavapor, 2 mL of 14% BF3-Methanol were added, and the sample was placed to esterify at 95 °C for 4 min. Fatty acids methyl esters were recovered and dissolved in 2 mL of hexane. Varian 430 apparatus (Varian Inc., Palo Alto, CA) equipped with a flame ionisation detector was used to analyse fatty acid methyl esters. The separation occurred in a Supelco Omegawax TM 320 capillary column (30-m length; 0.32 mm internal diameter; 0.25 µm film thickness; Supelco, Bellefonte, PA). The chromatographic conditions provided an initial temperature of 160 °C, which was then increased by 2 °C/min until the temperature reached 220 °C. Following, sample (1 µL in hexane) was injected with the carrier gas (helium) at a constant flow of 1.5 mL min⁻¹ and at a split ratio of 1:20. The detector temperature was set at 260 °C. The chromatograms were recorded using computing integrator software (Galaxie Chromatography Data System 1.9.302.952; Varian Inc., Palo Alto, CA). The FAs were identified by comparing the retention time of the FAME with a standard with 37-component FAME mix (Supelco, Bellefonte, PA) and were quantified through calibration curves using nonadecanoic acid (C19:0) (Supelco, Bellefonte, PA) as an internal standard. Results were expressed as the percentage of total fatty acids.

After 24 h from carcase dissection, three samples of each muscle were considered for the following physical determinations:

- final pH 24 using pH-meter Delta Ohm HD 8705 (Delta Ohm S.r.L., AOAC, 2000 Caselle di Selvazzano, Padova, Italy) with temperature probe TP870 and pH electrode Hamilton double pore and a calibration performed automatically at pH 4.01 and 6.00;
- the colour parameters CIE L* (lightness), a* (redness) and b* (yellowness), determined using a Minolta colorimeter CR-200 (Minolta Camera Co., Ltd, Osaka, Japan) with white and red calibration plate. The colorimeter was recalibrated with the two standards at the start of each measuring session. Colour was measured on the cut surface of each slice (minimum thickness 2.5 cm) after removing the film protection maintained for the previous 60 min of blooming at 3 °C in order to avoid the surface drying (Honikel 1998, AMSA 2012);

- texture profile analysis (TPA) was performed using a Zwick Roell Z2.5 apparatus (Ulm, Germany texture analyser) with a 1 kN-load cell at the crosshead speed of 1 mm/s and working at room temperature (22 °C). TPA curve-forces were determined by a 100-mm-diameter compression plate on 10 × 10 × 10 mm slices. Hardness (peak force of the first compression cycle), springiness (height of sample recovered between the two compression cycles) and cohesiveness (ratio of positive area of the force during the second compression compared to that obtained during the first compression) were recorded whereas chewiness was calculated as hardness multiplied by cohesiveness multiplied by springiness (Novaković and Tomašević 2017).

Statistical analysis

Data were analysed with the SAS software package (SAS Inc. 2011, Cary, NC) with appropriate models for the different traits.

- For growth traits, MIXED procedure was used with the following model:

$$Y_{ijkl} = \mu + R_i + A_j + G_k + b_1(X_{ijkl}) + E_{ijkl}$$

where *R* is the rearing system; *A* is the animal (random); *G* is the gender; *X* is the age, as covariate, tested up to the second degree; *E* is the error.

- For chemical composition of milk:

$$Y_{ij} = \mu + R_i + E_{ij}$$

where *R* is the rearing system; *E* is the error.

- For slaughter traits:

$$Y_{ijk} = \mu + R_i + G_j + (R \times G)_{ij} + b(X_{ijk}) + E_{ijk}$$

where *R* is the rearing system; *G* is the gender; *X* is the age at slaughter; *E* is the error.

- For physical-chemical parameters of the meat:

$$Y_{ijklm} = \mu + R_i + M_j + G_k + (R \times G)_{ik} + A_l(R \times G)_{ik} + (R \times M)_{ij} + E_{ijklm}$$

where *R* is the rearing system; *M* is the muscle; *G* is the gender; *A* is the Animal; *E* is the error.

Gender, rearing system and relative interactions have been tested against animal variability.

Tukey test was used to test the differences between the least square means. The statistical significance was established at $p < .05$.

Results

Chemical and fatty acid composition of milk

The fatty acid composition of ewes' milk is shown in Table 2. The concentration of both medium chain saturated fatty acids (from C8:0 to C12:0) and C14:0 was lower in ewes' milk of P system respect to other systems. The content of C15:0 was different among systems with the highest value in S ewes and the lowest in P ewes. The C17:0 content was higher in milk of the S group only respect to F one, while no differences were shown for C16:0 and C20:0 fatty acids. Stearic fatty acid (C18:0) showed opposite behaviour with different values among the three groups: higher, intermediate and lower percentage in P, F and S lamb's milk, respectively. Monounsaturated fatty acids C16:1 and C17:1 were always affected by farming system with the highest content in stall ewes' milk, while C18:1 was significantly higher in the milk fat from P ewes.

Table 2. Chemical composition of ewes' milk in the different systems.

Parameter	Rearing system (R)			p-Value	RMSE
	S	F	P		
Fatty acids (%)					
C8:0	1.53 ^a	1.34 ^a	0.32 ^b	.011	0.59
C10:0	11.48 ^a	10.19 ^a	5.57 ^b	.006	2.63
C12:0	7.05 ^a	5.74 ^a	3.18 ^b	.002	1.46
C13:0	0.06 ^a	0.01 ^b	0.00 ^b	.038	0.04
C14:0	13.35 ^a	12.65 ^a	9.62 ^b	.016	1.93
C14:1 n-5	0.24 ^a	0.14 ^b	0.05 ^c	<.001	0.05
C15:0	1.53 ^a	1.22 ^b	0.96 ^c	<.001	0.14
C16:0	25.15	23.57	23.71	.452	2.56
C17:0	1.46 ^a	1.27 ^b	1.35 ^{ab}	.021	0.11
C16:1	1.59 ^a	1.39 ^b	1.22 ^b	.007	0.18
C17:1	0.29 ^a	0.22 ^b	0.19 ^b	.002	0.04
C18:0	8.60 ^c	12.41 ^b	15.85 ^a	<.001	2.39
C18:1	19.85 ^b	21.38 ^b	27.73 ^a	.006	2.96
C18:2 n-6	2.35	2.73	2.62	.371	0.50
C18:3 n-6	0.07	0.03	0.05	.458	0.06
C18:3 n-3	0.87 ^c	1.38 ^b	2.18 ^a	<.001	0.25
C20:0	0.41	0.35	0.46	.295	0.11
C20:1 n-9	0.04	0.03	0.04	.656	0.02
C20:2 n-6	0.12 ^b	0.09 ^b	0.29 ^a	.005	0.09
C20:4 n-6	0.19	0.16	0.24	.082	0.05
C20:5 n-3	0.13 ^b	0.18 ^{ab}	0.23 ^a	.003	0.04
C22:6 n-3	0.09 ^b	0.09 ^b	0.23 ^a	<.001	0.04
C22:0	0.26	0.22	0.33	.290	0.10
C22:2 n-6	0.09 ^b	0.08 ^b	0.21 ^a	.009	0.06
C24:0	0.12	0.10	0.20	.079	0.06
SFA	73.10 ^a	70.94 ^a	63.18 ^b	.007	4.52
MUFA	22.07 ^b	23.19 ^b	29.33 ^a	.010	3.52
PUFA n-3	1.09 ^c	1.65 ^b	2.66 ^a	<.001	0.28
PUFA n-6	2.86	3.13	3.43	.273	0.59
PUFA	3.95 ^b	4.78 ^b	6.09 ^a	.002	0.83

Rearing system: S = stall; F = semi free-range; P = pasture. RMSE: root mean square error. Within row, means with different letters are significantly different ($p < .05$).

Both C18:2 n-6 and C18:3 n-6 acids as well as C20:4 n-6 and PUFA n-6 were unaffected by farming system while C20:2 n-6 and C22:2 n-6 acids were higher in milk intended to P lambs. The content of C18:3 n-3 and PUFA n-3 was significantly different among the three groups with the highest values in P, intermediate in F and the lowest in S milk. The total PUFA and MUFA showed a higher content in P respect to F and S milk, contrariwise, SFA have opposite trend with lower value in P group respect to both F and S.

In vivo performance and carcass traits

The effect of different management systems on the growth rate is reported in Figure 1. Pasture lambs showed worse performance respect to animals of the other systems. The growth differences were evident starting from 30 days of age between S and F versus P lambs and were confirmed until the end of the trial; in fact, the P group presented the lowest average final body weight. Lambs' growth was not affected by the sex of the animals.

Carcass characteristics are shown in Table 3. Farming system significantly affected slaughter weight of P lambs resulting about 8 kg less than other groups. Both carcass length and chest depth showed the lowest values in P lambs, while no differences were observed for dressing yield. As regards the proportions of commercial joints, P lambs presented a greater proportion of both shoulder and hind leg than the S and the F group whereas no differences were shown for the loin portion. Higher growth rate of brisket and abdominal region was achieved by the S group compared to P and F lambs, respectively.

The tissue carcass composition suggested that P lambs were always less fat than other animals. Furthermore, P lambs showed a higher percentage of total bone and a lower lean/bone ratio respect to animals of the other systems. The differences in total tissue composition almost totally reflected the differences among the single cuts analysed: shoulder, loin and hind leg (Table 3). In shoulder and loin, male had more lean tissue compared to female.

pH and physical characteristics of meat

Physical traits of lambs' meat are shown in Table 4. Comparing the rearing systems, pH was lower in S lambs than in grazing animals (F and P). Free water was higher in P than in other groups. As regards colour parameters, F meat was redder (21.38) and more yellow (10.70) compared both to S and P (a*: 19.80–19.34; b*: 8.57–7.85 respectively). As regard

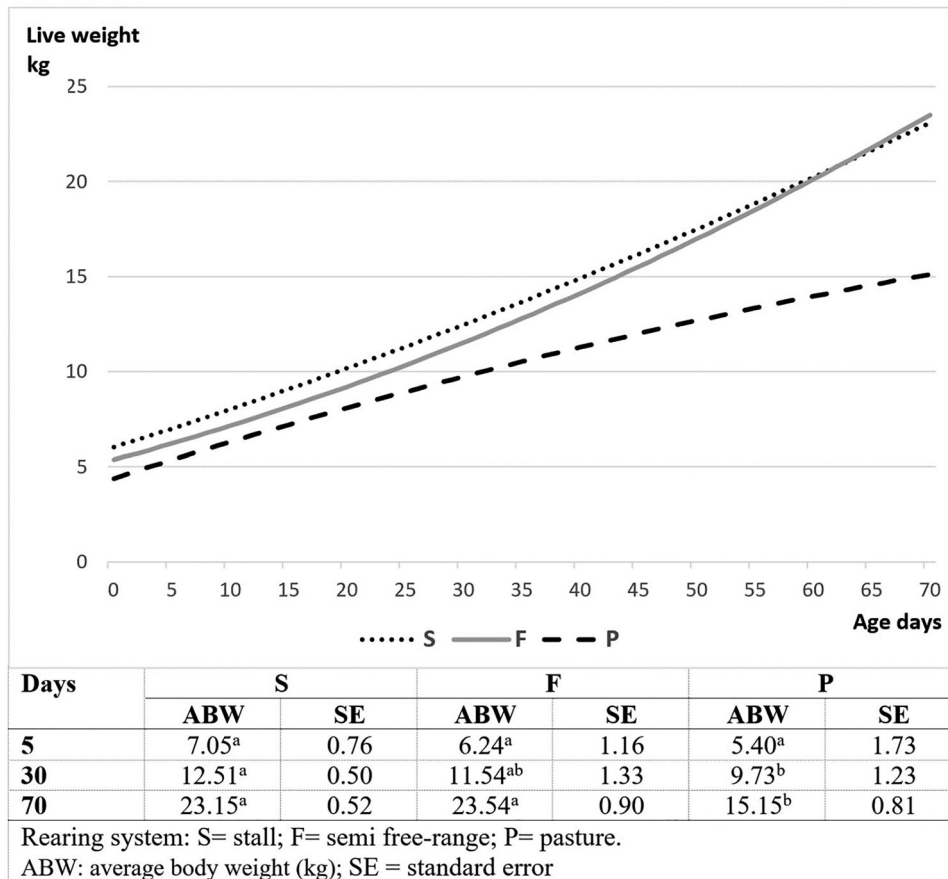


Figure 1. *In vivo* performance during the trial period of the lambs.

Table 3. Effect of different farming system on lambs' carcass traits.

Parameter	Rearing system (R)			Rearing System (R) <i>p</i> -value	Gender (G) <i>p</i> -value	Interaction (R x G) <i>p</i> -value	RMSE
	S	F	P				
Age (d)	69.45	68.6	69.71	.533	.062	.742	2.36
Slaughter weight (kg)	22.30 ^a	22.70 ^a	14.65 ^b	<.001	.867	.196	3.45
Carcass length (cm)	55.71 ^a	54.33 ^a	42.43 ^b	<.001	.660	.812	4.76
Chest depth (cm)	32.29 ^a	33.80 ^a	28.07 ^b	.028	.411	.070	2.02
Dressing yield (%)	48.17	48.48	47.92	.678	.538	.646	0.03
Shoulder tissues (%)							
Neck	10.00	10.21	10.09	.916	.296	.307	0.85
Shoulder	18.42 ^b	19.64 ^b	20.10 ^a	.005	.549	.120	0.86
Steaks	13.39	13.99	13.50	.621	.930	.883	1.07
Brisket	12.63 ^a	12.43 ^a	10.67 ^b	<.001	.190	.351	0.84
Loin	7.27	7.42	7.22	.814	.140	.175	0.53
Abdominal region	4.07 ^a	3.24 ^b	3.54 ^{ab}	.04	.169	.583	0.54
Hind Leg	33.66 ^b	33.17 ^b	34.69 ^a	.04	.934	.597	0.95
Loin tissues (%)							
Lean	59.52 ^b	63.85 ^a	60.90 ^a	<.001	.030	.465	2.12
Fat	10.64 ^a	6.00 ^a	4.56 ^b	<.001	.323	.698	2.61
Bone	29.84 ^b	30.15 ^b	34.57 ^a	.007	.370	.214	2.60
Hind leg tissues (%)							
Lean	60.31 ^b	62.62 ^{ab}	64.35 ^a	.05	.030	.176	3.01
Fat	12.78 ^a	15.29 ^a	2.23 ^b	<.001	.103	.252	3.88
Bone	26.92 ^b	22.09 ^c	33.42 ^a	<.001	.928	.736	3.69
Total tissues (%)							
Lean	60.99 ^b	63.81 ^a	62.72 ^{ab}	.01	.182	.658	1.53
Fat	10.15 ^a	8.13 ^a	2.76 ^b	<.001	.511	.551	2.25
Bone	28.74 ^b	27.86 ^b	34.63 ^a	<.001	.828	.871	2.66
Lean/Bone	2.14 ^a	2.30 ^a	1.85 ^b	.004	.588	.852	0.21

Farming system: S = stall; F = semi free-range; P = pasture. RMSE: root mean square error. SEM: standard error means Within criterion, means with different letters are significantly different ($p < .05$).

Table 4. Quality traits of lamb's meat from different farming systems.

Parameter	Rearing system (R)			Rearing system (R) <i>p</i> -value	Gender (G) <i>p</i> -value	Muscle (M) <i>p</i> -value	Interaction (R × G) <i>p</i> -value	Interaction (R × M) <i>p</i> -value	RMSE
	S	F	P						
pH	5.62 ^b	5.75 ^a	5.80 ^a	.023	.409	<.001	.923	<.001	0.07
Free water	8.97 ^b	8.37 ^b	9.94 ^a	.019	.533	.080	.326	.085	1.07
L*	41.37	42.21	42.72	.646	.877	<.001	.774	.740	3.76
a*	19.80 ^b	21.38 ^a	19.34 ^b	.004	.384	<.001	.462	<.001	1.75
b*	8.57 ^b	10.70 ^a	7.85 ^b	.029	.558	<.001	.702	.004	2.07
Hardness	11.33 ^b	14.85 ^{ab}	20.16 ^a	.027	.794	.040	.322	.222	6.64
Cohesiveness	0.40	0.36	0.35	.097	.916	.386	.251	.664	0.04
Springiness	1.96	1.71	2.16	.136	.650	.343	.988	.057	0.30
Chewiness	9.15 ^b	9.84 ^b	14.71 ^a	.042	.720	.007	.406	.201	4.73

Rearing system (R): S = stall; F = semi free-range; P = pasture. RMSE: root mean square error. Within criterion, means with different letters are significantly different ($p < .05$).

Table 5. Chemical and fatty acid composition of lambs' meat from different farming systems.

Parameter	Rearing system (R)			Rearing system (R) <i>p</i> -value	Gender (G) <i>p</i> -value	Muscle (M) <i>p</i> -value	Interaction (R × G) <i>p</i> -value	Interaction (R × M) <i>p</i> -value	RMSE
	S	F	P						
Moisture (%)	73.35 ^b	72.81 ^b	74.99 ^a	.007	.195	.022	.145	.016	3.58
Crude protein (%)	21.17	21.64	21.48	.533	.174	.004	.860	.011	2.64
Ash (%)	1.24 ^b	1.42 ^a	1.24 ^b	.001	.883	.004	.464	.082	0.19
Lipids (%)	3.40 ^a	3.52 ^a	1.93 ^b	.001	.192	<.001	.070	.522	0.75
Fatty acid (%)									
C12:0	1.10 ^a	0.83 ^{ab}	0.67 ^b	.019	.509	<.001	.272	.057	0.13
C14:0	7.83 ^a	6.70 ^b	4.45 ^c	<.001	.899	<.001	.315	.083	0.69
C14:1	0.56	0.37	0.56	<.001	.329	0.010	.020	.002	0.06
C16:0	24.73 ^a	22.32 ^b	17.80 ^c	<.001	.475	<.001	.525	.021	0.82
C16:1	2.54 ^a	2.53 ^a	1.44 ^b	<.001	.380	<.001	.077	.010	0.18
C18:0	11.20 ^b	11.88 ^b	15.75 ^a	<.001	.684	0.021	.172	<.001	0.45
C18:1 n-9	30.01 ^a	30.67 ^a	24.00 ^b	.001	.252	<.001	.565	.034	1.26
C18:2 n-6	7.76 ^b	8.34 ^b	12.62 ^a	<.001	.050	<.001	.143	.100	1.10
C18:3 n-3	1.69 ^c	2.27 ^b	3.41 ^a	<.001	.170	.006	.905	.379	0.23
C20:1 n-9	0.10 ^b	0.22 ^a	0.20 ^a	<.001	.677	<.001	.005	<.001	0.05
C20:2 n-6	0.02 ^b	0.04 ^a	0.02 ^b	<.001	.002	<.001	.011	.005	0.003
C20:3 n-3	0.02 ^b	0.03 ^a	0.03 ^a	<.001	.170	<.001	.186	.867	0.002
C20:3 n-6	0.20 ^c	0.38 ^b	0.31 ^a	<.001	.184	<.001	.345	.013	0.05
C20:5 n-3	1.00 ^b	1.20 ^b	2.39 ^a	<.001	.625	<.001	.386	<.001	0.25
C22:4 n-6	0.17 ^b	0.17 ^b	0.25 ^a	.011	.122	<.001	.648	.147	0.04
C22:5 n-3	1.03 ^c	1.49 ^b	2.42 ^a	<.001	.534	<.001	.522	.160	0.25
C22:6 n-3	0.58 ^b	0.65 ^{ab}	0.78 ^a	.029	.452	<.001	.334	.087	0.10
SFA	48.11 ^a	44.75 ^b	41.47 ^c	<.001	.583	<.001	.608	.170	1.64
MUFA	35.90 ^a	36.98 ^a	29.59 ^b	<.001	.282	<.001	.463	.040	1.40
PUFA n-3	4.30 ^c	5.63 ^b	9.05 ^a	<.001	.918	<.001	.179	.046	0.78
PUFA n-6	11.33 ^b	12.26 ^b	19.39 ^a	<.001	.073	<.001	.465	.060	1.88
PUFA	15.99 ^c	18.27 ^b	28.94 ^a	<.001	.178	<.001	.407	.060	2.66
PUFA/SFA	0.34 ^b	0.42 ^b	0.70 ^a	<.001	.183	<.001	.516	.042	0.09

Rearing system: S = stall; F = semi free-range; P = pasture. RMSE: root mean square error. Within criterion, means with different letters are significantly different ($p < .05$).

Texture Profile, P meat was the most chewable. Cohesiveness and springiness did not show differences among groups. Lambs did not differ between sex and the interaction between sex and rearing system was not significant for physical parameters.

Meat chemical and fatty acid composition

The effect of farming system and muscle type on chemical and fatty acid composition of meat is reported in Table 5. The results confirmed that the meat of P lambs was less fat compared to the other farming systems. Besides, the highest content of water was reported for the P group, while F lamb had the highest ash value. The interaction between sex and

rearing system suggested that the difference in the meat chemical content was not relative to sex while the diverse muscles seem to be a significant factor (data not reported).

Among farming systems, differences were present in the fatty acids composition. Stall group showed a higher C12:0 level than P lamb and the highest percentage both of C14:0 and C16:0 while the P group had the highest C18:0 level. Pasture lambs showed the lowest percentages of C16:1 and C18:1 n-9 as well as of total MUFA.

As regards the n-6 series, C18:2 n-6 as well as C22:4 n-6 and PUFA n-6 had the highest value in P meat.

Differences for C18:3 n-3 as well as PUFA n-3 were visible between the three groups with the lowest

values for stall followed by increasing value for F and P lambs, respectively. A similar trend was followed by C22:5 n-3 and C22:6 n-3, while the other fatty acids of the n-3 series showed the highest value in P lambs respect to both F and S meat. The concentration of MUFA and PUFA (n-3 and n-6) reflected the trend of the individual fatty acids. PUFA/SFA ratio showed higher value in P lambs than in the other groups.

The fatty acid composition did not show significant interaction between sex and rearing system for most of the parameters.

Discussion

Milk composition

Fatty acid composition of milk suckled by lambs highlighted differences according to the farming system used. The milk of P ewes had lower proportion of medium chain fatty acids (C8:0–C14:0) probably because they are *de novo* synthesised by mammary gland (Chilliard et al. 2003) and the P ewes, that did not receive supplementary feed, had lower metabolisable energy availability than S and F ewes. The lower energy level available to support the lactation leads to a higher mobilisation of these fatty acids from adipose tissue reserves and this transfer in the milk (Palma et al. 2017) can be also the cause of the higher proportions of C18:0 and C18:1 in milk of P ewes.

According to Scerra et al. (2007) and Joy et al. (2012), ewes on pasture produced a milk with lower content of SFAs, a higher levels of MUFAs, PUFA and PUFAs n-3 and also a more favourable n-3/n-6 ratio than ewes fed hay and concentrate. Fresh herbage is an important source of polyunsaturated fatty acids thanks to the high concentration of α -linolenic acid (Nudda et al. 2008) that in the rumen is not completely hydrogenated to C18:0, leading to enrich milk both of α -linolenic and of intermediate fatty acids deriving from it. Also, Manso et al. (2016) reported that with the increasing of pasture intake, the higher concentration of α -linolenic acid allows to rise C18:2 c9- t11, C18:1 t11 and C18:3 n-3 acids in milk fat respect to hay and silage fed ewes. The higher level of C18:1 in ewes' milk on total pasture respect to stall group can be explained by the desaturation in the mammary gland of C18:0. Also, Scerra et al. (2007) reported a higher percentage of C18:0 in milk of pasture group than stall, even if they did not report difference for C18:1.

In vivo performance and carcass traits

The lower growth rate of P lambs observed in our study had been already observed by Karaca et al. (2016) and Priolo et al. (2002) and was probably associated to a higher feed requirement for the movement and the adaptation to climate condition. Furthermore, in our study, both P lambs and ewes did not have concentrates in the diet and the grazing pasture probably did not guarantee the same nutritional level, consequently also the milk suckled was nutritionally poorer than that available for other groups. Álvarez-Rodríguez et al. (2008), studying light lamb raised under different management system in Spain, reported higher growth rate for lambs reared at pasture with concentrate supplement than grazing lamb exclusively fed on natural resources. Nevertheless, Boughalmi and Araba (2016) reported no differences in lambs' growth raised for 3 months exclusively on pasture, pasture or concentrate and concentrate/hay. In our research, the reduced growth of P lambs, appeared mainly in the second part of the trial (from 30 days) when animals were more interested to other feed besides milk (behaviour data not reported). Álvarez-Rodríguez et al. (2007) reported that lambs' growth was affected by milk availability until 45 days of age whereas after this age grazing lambs without supplement feed showed reduced weight gain. So, the rearing system based only on pasture may not cover the needs of lambs, that moreover requires supplementary energy for the increased activity. Furthermore, Álvarez-Rodríguez et al. (2008) suggested that growth of grazing light lambs (without feed supplementation) was more affected by the availability of milk ewes than indoor lambs fed with supplementation which probably balanced the decreased milk intake with concentrate.

The dressing yield did not highlight differences between farming systems, whereas some research (Priolo et al. 2002; Karaca et al. 2016) reported that lower dressing percentage were associated to pasture lambs due to differences in gastrointestinal content and fattening levels.

Carcass characteristics reflected in *vita* performance with reduced weight, body development and size for P lambs. This result, also in this case, can be linked to the greater requirement of energy on pasture and to metabolic modifications due to the exercise (Boughalmi and Araba 2016) not adequately sustained by feed supplementation. The proportion of joints was similar to those obtained in Sarda lambs (Vacca et al. 2008), even if P lambs showed a greater proportional development of shoulder and hind leg. This higher limb development of P lambs could be linked to the

major physical activity due to the extensive farming systems (namely P and F) respect to S lambs. On the other hand, the lower level of the energy in the diet of the P group led to major grazing activity which in turns could be affected limbs proportions when compared to F groups, also grazing on pasture.

The low level of growth of pasture lambs was also confirmed by other aspects: the measures of the carcase, the size of the brisket, the level of fat in tissue composition and the higher percentage of bone respect to animals of the other systems, as previously stated by Karaca et al. (2016).

Fat deposition depends on the nutritional intake and specifically on the diet energy level as well as from the maturity of the animal linked to different stages of tissue growth; it is known in fact that fat is deposited later than lean (Priolo et al. 2002). Also Carrasco, Ripoll, et al. (2009) reported that the major energy intake was reflected in the carcase composition: grazing lambs continuously stocked on a permanent pasture without concentrate had both a lower percentage of fat and an higher percentage of bone than lambs fed with supplementation. In this research, on Churra Tensina lambs, the differences of fat percentage (3%) were not as higher as in our study and the muscle/bone ratio had always higher values than our data. The absence of concentrated feed in P lambs of our trial could have compromised muscle formation as confirmed by lean/bone ratio. As reported by Aguayo-Ulloa et al. (2013) forage-based diets do not satisfy the nutritional requirements of lambs producing leaner carcasses. Lastly, it seems that P lambs maintained the characteristics of young suckling lambs and this behaviour could be explained by the different growth physiology.

Meat quality characteristic

Meat of grazing lambs (P and F) had the lowest glycolytic potential, as also related by Young et al. (1997) that noticed the same behaviour in cattle. In lamb, Hajji et al. (2014) suggested that diets with high-energy content protect against glycogen depleting, allowing to have a lower pH. In our study it seems that the difference was linked principally to grazing treatment (P and F): the low-energy diets compared to the higher requirements of grazing lambs led to less acidification of meat due to lower presence of glycogen reserves. A further factor that may have affected the higher pH in meat of grazing animals might have been the higher stress levels due to both more

difficult and time-consuming gathering at pasture as suggested by Ådnøy et al. (2005).

Free water was different between concentrate supplementation groups (S and F) and P lambs without a specific relation with the other parameters. Boughalmi and Araba (2016) observed higher pH and lower WHC in the stall group, explaining that pH may affect several sensory and instrumental characteristics of meat such as free water and colour.

As regards the colour parameters, usually grazing animals are linked to high yellowness and redness values of meat thanks to the physical activity and the high dietary content of carotenoids, flavonoids and α -tocopherol of pasture as suggested by Lynch et al. (2000) and Carrasco, Panea, et al. (2009). In our study, the high redness of F meat could be associated to physical activity, resulting in a greater concentration of haem pigments (Carrasco, Panea, et al. 2009). The higher yellowness of F lambs was probably due to the higher content of carotenoids in pasture and to the fact that carotenoids are associated to the fat tissue (Ripoll et al. 2008) that is low in meat of the P group. In fact, differences in the fat yellowness of Churra Tensina lambs were also reported by Joy et al. (2008) compared grazing and indoor lambs. P lambs and their ewes had access to fresh herbage and consequently there was the possibility to transfer pigment in the milk for the lambs (Joy et al. 2012) but it seems that this did not affect the meat colour of the P group. The colour differences did not play a direct role in lightness that, instead, could have been related to higher fat content according to Priolo et al. (2002). Khliji et al. (2010) suggested that the redness was more important than lightness for consumers and they proposed the redness limit for acceptability of 9.5, that is lower than the values found in this research.

As regards the meat texture profile, the P group was the hardest and the most chewable; this could be associated with the double action of low lipid levels and of greater physical activity necessary for grazing compared to the stall rearing system. The effect of rearing system and consequently of the lambs' diet on meat tenderness is not clear and many factors seem capable to affect this parameter. Some studies reported higher hardness in meat from concentrate-fed lambs than from pasture animals (Santos Silva et al. 2002; Carrasco, Ripoll, et al. 2009), whereas others did not find significant differences (Panea et al. 2011). However, the level of carcase lipid, the physical activity as well as the level of protein and energy in

the diet of lambs can have influenced the results obtained in our study.

Meat chemical and fatty acid composition

The chemical composition of meat was affected by the feeding system, highlighting a lower intramuscular fat level and a higher moisture content in the P group. Manso et al. (2016) identified feeding and exercise as the principal influencing factors both for chemical composition of muscle and carcass fat level. Also, Priolo et al. (2002) and Cividini et al. (2012) reported that carcasses from stall and concentrate finished fed lambs were fatter than those from grass-fed animals. As showed in the present study, Arousseau et al. (2004) and Hajji et al. (2014) reported that feedlot lambs had more intramuscular fat than P lambs in relationship to higher energy expenditure of pasture fed animals. The higher physical activity of grazing animals causes an increase in the mobilisation of lipids reserve in order to form muscle tissue and reduce fatness. In our study, the key factor seems to be the feeding system because semi free-range group did not show difference respect to the stall group even if they performed diurnal outdoor activities.

The behaviour of meat fatty acids composition in our research could be affected by various factors: (i) lambs suckled during all the trial period, indeed the milk of the ewes could have influenced the tissue composition; (ii) lambs had available solid feed, consequently some rumen biohydrogenation was present and it takes part in the transfer of compounds to the tissue.

The content of SFA of milk and meat of different farming systems seems to have the same behaviour, in particular C18:0 had a similar level in P lambs. Indoor farming system positively affected the content of SFA except for C18:0. On the contrary, lamb meat derived from P lambs had lower value of SFA, in particular for C12:0, C14:0, and C16:0, considered unhealthy. The lower level of SFA, especially C16:0, was already reported by various authors considering both suckling lamb (Velasco et al. 2001; Valvo et al. 2005) and lambs fed with solid feed (Scerra et al. 2007). The higher content of C16:0 in intramuscular fat of lambs fed with supplementation could be linked to its synthesis during the conversion process of acetyl-CoA to malonyl-CoA in de novo fatty acids synthesis of animals' tissues (Boughalmi and Araba 2016).

MUFA did not differ between milk and meat in P animals whereas a different behaviour, in particular for C18:1 of intramuscular fat, was noted for F and S

groups. As suggested by Scerra et al. (2007), the C18:1 content in muscle tissue can be directly related to the fatness level, higher in lambs fed with concentrate. Usually C18:1 increases with the fatness because there is a major activity of enzyme $\Delta 9$ desaturase involved in the synthesis of this fatty acid from C18:0 (Bauman et al. 2000).

A positive relationship between milk and meat were found for total PUFA and C18:3 n-3 in agreement with the results observed in previous studies (Scerra et al. 2007; Joy et al. 2012). These authors considering suckling lambs suggested a major effect of diet on n-3 series fatty acids because they did not have biohydrogenation in the rumen of the milk fatty acids (Nudda et al. 2008). Osorio et al. (2007) suggested that during the first weeks of life of suckling lambs the fatty acids adsorbed in the intestine contributed to the major part of deposited fatty acids, whereas the de-novo synthesis would have contributed only to 6–20%. Also, in our study it seems that the fatty acid content of milk, especially those influenced from ewe's diet, had an effect on acid profile of meat, probably because lambs continued to suck milk up to 69 days of age. In this context, regarding meat quality traits (fatty acid composition included), Lobón et al. (2017) suggested the greater importance of the ewes' diet during suckling period than during the subsequent lambs' fattening period. Regarding n-3 series, the comparison among farming systems showed an increasing trend based on farming systems from lower values of stall group to the higher content of pasture whereas intermediate values were shown by F meat. Diet with a higher content of herbage was rich in C18:3 n-3 whereas other PUFA of n-3 series were higher in young herbage as proposed by Chilliard et al. (2001). This could have affected our study because grazing lambs (P and F) changed the pasture every week in order to make the best use of pasture's resources.

Effect of farming system on fatty acids of lambs' meat was evident on n-6 series, in particular for C18:2 n-6, but for this fatty acid, there was a lack of relationship between milk and meat fatty acids.

Intramuscular fat of P lambs was almost two-fold richer in PUFA compared to the stall-fed lambs: it seems that the increase of herbage availability also rises the content of some PUFA. Wood et al. (2008) suggested that diets based on pasture leads to a high level of PUFA in meat due to the different way in which the feed is processed in the rumen. It is known that type and origin of dietary lipids affect the transfer of fatty acids to the tissues because the metabolism of fat in the rumen includes hydrolysis and subsequent

biohydrogenation (Buccioni et al. 2012; Manso et al. 2016).

Lastly, the PUFA/SFA ratio used as an index of healthiness of meat with a recommended minimum level value for the human diet of 0.40 (Wood et al. 2008) was also affected by farming systems: meat of P lambs had more favourable index for human health. As regards S animals, the value dropped below the threshold value of 0.4. Our results were higher than those reported by Santos Silva et al. (2002) which obtained in Merino Branco lambs a value of 0.29 for concentrate fed and of 0.34 for grazing fed animals.

Conclusions

Rearing of Massese lambs up to 2 months of age can represent a feasible alternative to increase the production of meat and consequently the farmers' income. Moreover, management based on extensive pastures, especially in mountain regions, plays an important role as component of landscape in the maintenance of marginal areas. The results of this study could be used to promote a diversification in the production of lambs' meat, creating a strategic product based on the use of local and mountain resources. Overall, our data suggested that the feeding system based only on pasture besides ewes' milk not fully met the requirements of lambs, providing animals more similar to light lambs fed exclusively with sheep's milk.

The growth of the lambs was similar in the first 30 days, probably because during this period ewes' milk was the main resource of feed. In the following phase, growth differences raised up especially for P lambs. Farming systems affected fatty acids profile of both ewe's milk and lamb's meat, with grazing animals P and F showing the lowest level of SFA and the highest of PUFA, in particular P meat had also the best composition for human health. Fatty acids composition of ewes' milk had effect on lambs' meat profile, probably because they continued to suck milk until 69 days of age. Semi free-range system with pasture during the day plus a supplementation (concentrate and hay) seems to be the best rearing system: (i) for the farmers which can implement this system in the periods when lamb is required or when cheese is not produced; (ii) for the acceptability of consumers which are always more interesting in the 'natural' image of animal product.

Ethical approval

This study was conducted in post-mortem and the in vivo measurements were applied within the regular farm

management practices that did not require any stressful procedures. No ethical approval was therefore requested.

Disclosure statement

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

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