ITALIAN JOURNAL OF ANIMAL SCIENCE
2021, VOL. 20, NO. 01, 1270–1281
https://doi.org/10.1080/1828051X.2021.1954557

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PAPER

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Effects of feeding system and CLA supplementation on animal, carcase and meat characteristics of fattened lambs and ewes

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ABSTRACT

To promote local food products could be a valuable strategy for preserving autochthonous sheep breeds. A total of 115 lambs and ewes of local sheep breeds (Alpagota, Bogna, Foza and Lamon) of the Veneto region were used to evaluate the effect of different feeding systems on the production and quality of lambs and mutton meat. We carried out three fattening trials involving 24 ewes and their 31 suckling lambs, 24 weaned lambs, and 24 heavy lambs, fed indoor diets with or without a rumen-protected conjugated linoleic acids (rp-CLA) supplement (C18:2*c*9,*t*11 and C18:2*t*10,*c*12) to improve the nutritional value of the meat. Controls were a group of 12 pasture-fed weaned lambs. The weaned lambs at pasture had good fattening performances (33 kg live-weight at slaughter, 45% dressing percentage), whereas lambs fattened indoors on hay and some concentrates had lower weight (28 kg) and dressing percentages (41%), and require improvements to their feed. Feeding the animals on total mixed diets resulted in good *in vivo* and *post mortem* performances of culled ewes (64 kg slaughter weight, 48% dressing percentage), suckling lambs (21 kg, 50%) and heavy lambs (61 kg, 48%), showing that valuable supplies of lamb and mutton meat can be obtained across different seasons. Supplementing indoor diets with rp-CLA does not modify the animals' performances nor the organoleptic traits of meat.

HIGHLIGHTS

- Intensive indoor fattening allows to obtain suckling, weaned and heavy lambs and mutton from culled ewes all-year-round beyond the seasonal supplies of traditional feeding system.
- The supplementation of indoor diets with rp-CLA does not modify the animals' performances, slaughter traits or meat organoleptic traits.

ARTICLE HISTORY
Received 11 January 2021
Revised 30 June 2021
Accepted 2 July 2021

KEYWORDS
Indoor feeding; age category; linoleic acid isomers; pasture; Alpine sheep breeds

Introduction

Sheep breeding in the mountains, and particularly in the Alps, has profoundly changed in recent decades. Nomadic transhumance has almost disappeared, whereas small flocks are still reared on some traditional farms in the hills and valleys, and sometimes taken up to highland pastures in the summer (Pastore 2002). These activities provide several ecosystem services, like land protection, landscape preservation, and, in particular, survival of the genetic resources represented by the many autochthonous sheep breeds (Bittante 2011) and also they contribute to the survival of local traditions and culture, in part through local foods and food products. For example, in the Eastern Italian Alps, some breeders milk their Brogna ewes and process the milk into "Pegorin" sheep cheese (Bittante et al. 2014). "Pendole" and "Carne de fea affumegada", strips of meat dried according to a traditional technique, are produced from adult culled ewes of the Lamon and Alpagota breeds, respectively, while "Pitina", a local fermented sausage, is made from meat of the Alpagota breed (Slow Food Foundation for Biodiversity 2000; Bovolenta et al. 2007). However, the major source of revenue for breeders these days is the production of lambs which foster the tourism, especially by high-quality restaurants (Font i Furnols et al. 2011; Hersleth et al. 2012).

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Supplemental data for this article can be accessed here.

Productions from traditional pasture-based systems, like the prestigious Slow Food Praesidium "Agnello Alpagoto", lamb of the Alpagota breed, (Slow Food Foundation for Biodiversity 2000) contribute to the valorisation of local products but found a limit in their strongly seasonal supply.

Meat produced from animals reared at pasture may also be an important source of beneficial fatty acids (FA) (Aurousseau et al. 2004; Nuernberg et al. 2005; Shingfield et al. 2013). Some of these FAs have been reported to have high levels of biological activity (Michas et al. 2014; Hennessy et al. 2016; Lordan and Zabetakis 2017), particularly ω3 FA (Sinclair 2007; Kouba and Mourot 2011; Willems et al. 2014) and some of the conjugated linoleic acid (CLA) isomers (Dhiman et al. 2005; Tanaka et al. 2011; Dilzer and Park 2012), although the effects of FAs and micronutrients on human health remains controversial (Dannenberger et al. 2013; Chowdhury et al. 2014; Binnie et al. 2014).

However, pasture is subject to vegetative cycles, and traditional sheep farming is also seasonal, as it is synchronised with the availability of forage. But tourism and restaurants need all-year-round supplies, so alternatives need to be studied. Fattening lambs over longer periods using indoor diets could increase the value of lamb and mutton meat and extend its period of availability but could not serve the important function of maintaining the favourable FA profile of meat obtained from pasture-raised animals. The supplementation of indoor diets with rumen-protected CLA (rp-CLA) have shown to increase the CLA content of beef meat (Schiavon et al. 2011, 2019). We obtained similar results also in the production of lamb meat and milk from local sheep breeds (Pellattiero et al. 2015a, 2015b). If alternative and more intensive methods of year-around lamb meat production are to be introduced, more information is required about the live and *post-mortem* performances of autochthonous sheep breeds, which have not so far been extensively studied.

The aim of this study was to examine, as a case study, the production and quality of ovine meat from fattened suckling, weaned and heavy lambs, and culled ewes of local Alpine breeds fed indoor diets with or without the CLA supplementation and to compare it with traditional pasture-based feeding of weaned lambs.

Material and methods

This study was carried out in accordance with the "Guide for Care and Use of Agricultural Animals in Research and Teaching" (FASS 2010), and did not involve blood or tissue sampling nor the restraining of animals during the fattening period. It was conducted at the "Lucio Toniolo" Experimental Farm of the University of Padova (via dell'Università 4, 35020 Legnaro, Padua, Italy) as part of a project (BIONET) aimed at conserving and promoting local endangered sheep breeds of the Veneto region. The animals used for this research belonged to two flocks undergoing an *in situ* conservation program: the first was kept on the experimental farm of the University of Padova, the second on the pilot farm of Veneto Agricoltura (the regional government agency for agriculture, forestry and agro-industry).

The breeds involved were Alpagota, Brogna, Foza and Lamon, and their characteristics are described in detail and compared in a parallel study within the same project (Bittante et al. 2021). Given the need for breed conservation and to take ethical issues into account, the number of lambs included in the experiment was kept to the minimum required to obtain adequate statistical power.

Experimental design, animals and measurements

In the Alps, lambing is traditionally concentrated in late winter/early spring, and meat is produced from pasture-reared suckling lambs or weaned light lambs. With the aim of assessing the possibility of extending the period of sheep meat production, we studied the indoor feeding of suckling, weaned and heavy lambs up to one year of age, and the slaughter of fattened ewes at the end of the suckling period. Three trials were carried out on a total of 115 head of sheep:

- Trial 1: 24 ewes and their 31 suckling lambs (Brogna, Foza and Lamon breeds) reared indoors, with or without rp-CLA supplementation, from about 6 to 15 weeks after parturition;
- Trial 2: 24 weaned lambs (Alpagota, Brogna and Foza breeds) reared indoors, with or without rp-CLA supplementation, and 12 weaned lambs reared at pasture from about 15 to 32 weeks of age;
- Trial 3: 24 heavy lambs (Brogna, Foza and Lamon breeds) reared indoors, with or without rp-CLA supplementation, from about 33 to 50 weeks of age.

The numbers of animals in each trial and feeding group, their ages and live weights at the outset, and the length of each trial are shown in Table 1. At the beginning, the end, and every four weeks during the trials, before distribution of the morning meal all

Table 1. Number and initial age and body weight of the animals in the study and length of the trials.

	Trial 1		Trial 2		Trial 3	
	Ewes	Suckling lambs	Weaned lambs	Weaned lambs	Heavy lambs	Total
Environment:	Indoors	Indoors	Pasture	Indoors	Indoors	–
Pens	6	6	1	6	6	25
Animals, *N*.	24	31	12	24	24	115
Sex:						
Males, *N*.	–	17	6	12	12	47
Females, *N*.	24	14	6	12	12	68
CLA groups:						
Control animals, *N*.	12	14	12	12	12	62
CLA addition animals, *N*.	12	17	–	12	12	53
Initial age, d	1293 ± 267	41 ± 24	109 ± 26	106 ± 26	231 ± 14	–
Initial body weight, kg	60.5 ± 13.3	12.8 ± 4.5	21.0 ± 5.1	20.5 ± 5.3	37 ± 6.0	–
Trial length, d	63	63	112	112	111	–

Table 2. Feedstuffs used, total mixed rations (TMR) components and chemical analysis of diets used on the three trials.

	Trial 1		Trial 2		Trial 3
	Ewes	Suckling lambs	Weaned lambs	Weaned lambs	Heavy lambs
Environment:	Indoors	Indoors	Pasture	Indoors	Indoors
Feedstuffs:					
Total mixed diet (TMR):	*ad libitum*	*ad libitum*	–	–	*ad libitum*
Mother's milk	–	*ad libitum*	–	–	–
Meadow grass	–	–	*ad libitum*	–	–
Meadow hay	–	–	–	*ad libitum*	–
Concentrates, g/d	–	–	–	267	–
TMR components:					
Wheat straw, g/kg DM	66		–	–	64
Corn silage, g/kg DM	260		–	–	250
Corn meal, g/kg DM	373		–	–	434
Soybean meal, g/kg DM	110		–	–	47[a]
Wheat bran, g/kg DM	64		–	–	61
Sugar-beet pulp, g/kg DM	111		–	–	105
Supplement, g/kg DM	16		–	–[b]	39
Diet composition:					
CP, g/kg DM	130		163	198	107
NDF, g/kg DM	293		393	255	295
ADF, g/kg DM	146		230	101	165
rp-CLA supplement[c], g/d	0 or 12	0 or 4	0	0 or 8	0 or 8

[a]Whole soybeans;
[b]Data refer to concentrates, the meadow hay contained 99, 630 and 355 g/kg DM of crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF), respectively.
[c]Rumen-protected conjugated linoleic acid (rp-CLA) supplementation was top dressed and mixed into the diet fed to the animals in half the pens, according to breed and sex.

animals were weighed, measured (withers height and heart girth), and scored by a trained technician for body score condition (5 classes, from emaciated to severely obese, with subclasses at intervals of 0.25).

Feeding systems and diet composition

The animals kept indoors were housed in 6 pens (containing 4 weaned lambs, or 4 heavy lambs, or 4 ewes with their suckling lambs) in an open barn with permanent wheat straw bedding. The various diets, which were administered *ad libitum* to the animals, are summarised in Table 2. The animals were fed two different total mixed rations (TMR) in trials 1 and 3. In trial 2, the indoor weaned lambs were fed meadow hay produced during the trial (first cut from a permanent meadow contiguous to the pasture destined to outdoor lambs) plus 267 g/d of a concentrate, while the outdoor weaned lambs were grazed together on a permanent meadow (412 m^2/lamb, 18 botanical species identified, 98% of forage from grass species, Italian Ryegrass largely dominant). The concentrate was a commercial compound feed based on cereals meals and brans, oilseed meals, dried beet pulps, minerals and vitamins. The daily amount was calculated to compensate for the expected difference between the value of grass and hay. However, the chemical analyses of hay and grass carried out at the end of the trial revealed a difference larger than expected in favour of fresh grass and the indoor and outdoor diets could not be considered isoenergetic. The TMR (Trial 1 and 3) and the grass, hay and concentrate (trial 2) have been sampled at the beginning, and every 4 weeks during the trials, and the samples soon transferred to the laboratory of the

DAFNAE department of University of Padova for the following chemical analyses: dry matter, (# 934.01; AOAC 2000) and crude protein "CP" (# 976.05; AOAC 2000). Neutral detergent fibre (NDF), expressed inclusive of residual ash, was determined with amylase and sodium sulphite in a neutral detergent solution (Mertens 2002) using an Ankom220 Fibre Analyser (Ankom Technology® Corporation, Macedon, NY). Acid detergent fibre, expressed inclusive of residual ash (ADF), was determined sequentially after NDF analysis (Robertson and Van Soest 1981). Table 2 also reports the compositions of the diets.

A supplement containing rp-CLA was top dressed to the rations of half the indoor pens in quantities of 8 g/d for each weaned or heavy lamb, 12 g/d for each ewe, and 4 g/d for each suckling lamb. The composition of the lipid-coated rp-CLA (Sila, Noale, Italy) was 800 g of lipids, 178 g of ash, 22 g of moisture, 655 g of palmitic, stearic and linoleic acids, 99 g of C18:2*c*9,*t*11, 96 g of C18:2*t*10,*c*12, and 150 g of other FAs and glycerol per kg of commercial product. A detailed description of the chemical composition of the rp-CLA is given in Schiavon et al. (2015).

Slaughter of animals, and measurement and dissection of carcases

All animals were slaughtered in a commercial abattoir having been fasted since the previous evening. The live weight before slaughter was recorded, and the pelt, feet, head, gastro-intestinal tract, offal (trachea, lungs, heart and spleen), liver, and genitals of the carcase were weighed. Carcase measurements and carcase conformation indices were never significantly affected by diet (Bittante et al. 2021), so these data are not presented and discussed here.

The carcases were divided in two halves, then weighed before cooling and again about 24 h after slaughter. The right carcase side was sectioned into the six major carcase cuts: shoulder/fore shank, neck and square cut, breast and flap, whole leg, loin, and rack. The six cuts were weighed and expressed as % of their total weight.

Each of the major cuts was then dissected into muscle, separable fat and bone. These three tissues were then individually weighed and expressed as a % of their sum.

Meat quality analyses

Meat quality analyses were carried out on the whole *Longissimus lumborum* muscle of the loin from the right side of each carcase. After being dissected from the loin, the muscle was vacuum-packed, cooled in a portable refrigerator at 4 °C, then transported to the Meat Laboratory of DAFNAE (Department of Agriculture, Food, Natural resources, Animals and Environment) at the University of Padova (Italy), where it was aged for 6 days at the same temperature. After ageing, the meat was removed from the package and weighed, and the sample joint was divided into two thick slices. The first slice was used to measure pH with a Delta Ohm HI-8314 pH-meter (Delta Ohm, Padua, Italy), and to determine the colour parameters with a Minolta CM-508c (illuminate: D65, Observer: 10°). Meat colour was assessed at 3 anatomical positions on the freshly-cut cross-sectional surface of the muscle after 1 h of exposure to the air, and was expressed in the CIE-Lab colour space terms L*, a*, b*, C* and H*; the three values obtained from each sample were averaged before statistical analyses. The same subsample was used for proximate analysis of the meat (trial 1 and trial 3), which was carried out on homogenised samples, in accordance with Horwitz and Latimer (2005). Moisture was assessed after drying at 102 °C for 16 h, ash was analysed after mineralisation (#981.46B; AOAC 2000), lipids after extraction with petroleum ether (# 991.36; AOAC 2000), and protein was estimated by difference.

A 2 cm-thick segment was taken from the second slice of each muscle sample, closed in individual polyethylene bags, and heated in a water bath to an internal temperature of 70 °C for 40 min in order to measure the percentage cooking loss, calculated as the weight before cooking minus the weight after cooking, divided by the weight before cooking then multiplied by 100. Shear force (SF) was then measured on three 1.13 cm-diameter cylindrical cores (1.00 cm^2 cross-sectional area) taken from the cooked samples parallel to the muscle fibres using a TA-HDi Texture Analyser (Stable Macro System, London, Great Britain) fitted with a Warner-Bratzler shear attachment (10 N load cell, crosshead speed of 2 mm/s) (Joseph 1979).

Statistical analyses

The data obtained in the three trials were not analysed together because of the heteroscedasticity of the residual variance characterising groups of animals that are very different in age and size, and because the three trials were not carried out simultaneously.

All traits were analysed, trial by trial, with the following linear model, using SAS PROC GLM (SAS Institute Inc., Cary, NC):

$$y_{ijklmn} = \mu + breed_i + sex_j + birth_k + age_l + diet_m + e_{ijklmn} \quad (1)$$

where y is the experimental observation; μ is the overall mean; $breed_i$ is the effect of breed (i = Alpagota, Brogna, Foza or Lamon); sex_j is the effect of sex (j = females or males); $birth_k$ is the effect of type of birth (k = single or multiple); age_l is the linear covariate of age at the beginning of the trial; $diet_m$ is the effect of feeding treatment (m = indoor control or indoor rp-CLA or pasture); e_{ijklmn} is the random residual term ∼ N (0, σ2 e). The significance of the effect of CLA addition was tested through a contrast between the indoor diets without and with CLA addition (in all trials), whereas the effect of pasture was tested through the contrast between the pasture group and both the indoor groups (trial 2). These two contrasts are orthogonal.

The main objective of the parallel study (Bittante et al. 2021) was to compare the four local breeds. In the current study, the effect of breed was included in the model to reduce the residual variance and avoid possible bias, but it is not reported or discussed here. Preliminary analyses showed that none of the interactions with breed of animal reached statistical significance and they were therefore not included in the model. Sex, birth type and initial age of fattening animals were also included in the statistical model with the aim of reducing residual variance and avoid possible biases on the estimation of the effect of feeding treatment due to the not perfectly balanced distributions of that factors. Not being objectives of this study and not being illustrated in other studies, the effects of sex, birth type and age at beginning of the fattening trials are made available in Supplementary Tables S1, S2, S3, and S4, but they are not presented and discussed here.

Results

Table 3 summarises the effects of feeding system on the animals' live weight, growth rate, stature and BCS. CLA addition was never significant on *in vivo* traits, except two negligible effects observed on birth weight in trial 1 and on increase in stature of weaned lambs in trial 2. In trial 2, weaned lambs kept on pasture had a greater live weight, withers height and BCS at the end of the fattening period, and correspondingly higher gains in these traits than indoor-reared lambs.

The data collected at the abattoir (carcase weight and weight loss, dressing percentage, and proportions of non-carcase components) are summarised in Table 4. On these traits we found no differences between the two indoor diets (control *vs.* rp-CLA supplementation) in any of the three trials. On the contrary, in trial 2 we found that lambs reared outdoors at pasture had greater carcase weight because of their greater slaughter weight, but also because of a higher dressing percentage than those reared indoors on preserved feedstuffs. This is due to smaller proportions of head, full gastro-intestinal tract, and liver, although the genitals were heavier in lambs raised at pasture.

The results regarding the major carcase cuts and the carcase tissues (muscle, separable fat and bone) are summarised in Table 5. The only difference found between indoor lambs given the CLA supplement and the controls was a lower proportion of shoulder/fore shank in weaned lambs. There were no significant differences due to CLA addition in the proportions of lean meat, separable fat and bone. Compared with weaned lambs reared indoors, lambs reared outdoors at pasture had a lower proportion of shoulder/fore shank in the carcase, and greater proportions of loin and rack, resulting in a lower proportion of separable bone.

Lastly, the data obtained from analysis of the *Longissimus lumborum* muscle (chemical composition, meat colour, pH, cooking losses and meat shear force) are summarised in Table 6. The addition of CLA reduced the ash content and the yellowness and chroma colour indices of the meat of suckling lambs. The only effect of outdoor pasture rearing of weaned lambs on meat quality was an increase in the loin weight and a reduction in meat cooking losses.

Discussion

The effects of pasture versus indoor feeding

The lambing season is traditionally concentrated at the end of winter, and weaned lambs are typically reared outdoors at pasture. We therefore included in trial 2 a group of weaned lambs fattened at pasture as control. The vegetative season of the grasses of natural meadows is relatively short, especially in the mountains, so conserved feedstuffs are needed if lambs are to be produced in early spring (suckling lambs) or in autumn and winter (heavy lambs). Although the various rations were initially calculated to have similar energy concentrations, the weaned lambs reared on pasture outperformed better than those kept indoors in terms of growth, stature, and condition scores (Table 3), and also in terms of dressing percentage (Table 4) due to the lower proportions of head and gastro-intestinal tract. This was due in part to differences in the chemical composition of fresh herbage and hay larger than that expected *a priori* and, probably, also in forage intake. Willems et al. (2013) found the performance of

Table 3. Effects of feeding system on the traits measured on live ewes and lambs at the beginning and end of the fattening trials.

	Feeding system effect			*p* Value		
	Indoor control (Con)	Indoor CLA (CLA)	Outdoor Pasture (Pas)	Con vs CLA	Pas vs Indoor	RMSE
Live weight (LW) and ADG						
Ewes (Trial 1)						
LW_i, kg	64.2	61.1	–	*.57*	–	*11.8*
LW_f, kg	65.4	63.5	–	*.72*	–	*11.6*
ADG, g/d	20	40	–	*.44*	–	*56*
Suckling lambs (Trial 1)						
Birth weight, kg	4.26	4.88	–	***.04***	–	*0.72*
LW_i, kg	12.9	13.7	–	*.51*	–	*3.0*
LW_f, kg	20.9	21.5	–	*.72*	–	*4.0*
ADG, g/d	134	130	–	*.76*	–	*33*
Weaned lambs (Trial 2)						
LW_i, kg	20.7	21.2	20.9	*.73*	*.82*	*3.6*
LW_f, kg	27.4	28.8	33.4	*.45*	***.018***	*4.4*
ADG, g/d	62	71	117	*.47*	***<.001***	*27*
Heavy lambs (Trial 3)						
LW_i, kg	39.8	39.7	–	*.97*	–	*6.7*
LW_f, kg	60.6	61.1	–	*.87*	–	*7.6*
ADG, g/d	241	248	–	*.54*	–	*28*
Height at withers (HW, cm):						
Ewes (Trial 1)						
HW_i	73.7	72.4	–	*.44*	–	*3.7*
HW_f	76.8	75.8	–	*.48*	–	*3.2*
Δ_{HW}	3.1	3.4	–	*.78*	–	*2.1*
Suckling lambs (Trial 1)						
HW_i	49.5	50.9	–	*.25*	–	*2.9*
HW_f	57.7	58.9	–	*.43*	–	*3.5*
Δ_{HW}	8.2	8.0	–	*.79*	–	*2.2*
Weaned lambs (Trial 2)						
HW_i	53.4	54.6	55.0	*.34*	*.32*	*2.9*
HW_f	61.2	60.6	65.1	*.69*	***<.001***	*3.1*
Δ_{HW}	7.8	6.1	10.1	***.002***	*.12*	*2.5*
Heavy lambs (Trial 3)						
HW_i	66.1	65.7	–	*.77*	–	*3.2*
HW_f	75.4	73.9	–	*.36*	–	*3.6*
Δ_{HW}	9.2	8.2	–	*.20*	–	*1.9*
Body condition score:						
Ewes (Trial 1)						
BCS_i	2.77	2.79	–	*.89*	–	*0.28*
BCS_f	3.15	3.04	–	*.43*	–	*0.32*
Δ_{BCS}	0.39	0.24	–	*.23*	–	*0.25*
Suckling lambs (Trial 1)						
BCS_i	3.01	3.16	–	*.14*	–	*0.23*
BCS_f	3.22	3.27	–	*.70*	–	*0.28*
Δ_{BCS}	0.21	0.11	–	*.10*	–	*0.15*
Weaned lambs (Trial 2)						
BCS_i	3.04	3.04	3.03	*.99*	*.95*	*0.29*
BCS_f	3.06	2.95	3.38	*.35*	***<.001***	*0.23*
Δ_{BCS}	0.02	−0.08	0.35	*.41*	***<.001***	*0.27*
Heavy lambs (Trial 1)						
BCS_i	3.32	3.26	–	*.47*	–	*0.22*
BCS_f	3.82	3.73	–	*.41*	–	*0.25*
Δ_{BCS}	0.49	0.47	–	*.88*	–	*0.31*

LWi: initial live weight; LWf: final live weight; ADG: average daily gain; HWi: Initial height at withers; HWf: Final height at withers; ΔHW: variation of height at withers; BCSi: initial body condition score; BCSf: Final body condition score; ΔBCS: Variation of body condition score.

lambs of local Alpine breeds to be dependent on the altitude, steepness and floral composition of natural meadows, and it should be pointed out that our control group was grazed on a lowland, nutrient-rich, species-poor pasture (18 species, 98% of biomass represented by grasses and particularly Italian Ryegrass). The lambs reared at pasture had higher proportions of genitals and liver (Table 3), which indicates earlier sexual development and greater metabolic activity. The testicles of ram lambs kept at pasture were twice the weight of those kept indoors (346 g *vs* 170 g, $p < .001$), even though their live weight was only 17% greater. It should be noted that pasture affected not only the body condition scores of the live animals, but,

Table 4. Effects of feeding system on the traits measured on ewes and lambs at slaughter.

	Feeding system effect			*p* Value		
	Indoor control (Con)	Indoor CLA (CLA)	Outdoor Pasture (Pas)	Con vs CLA	Pas vs Indoor	*RMSE*
Warm carcase weight, kg:						
Ewes	31.1	30.9	–	*.94*	–	*5.6*
Suckling lambs	11.8	12.4	–	*.51*	–	*2.4*
Weaned lambs	11.4	12.0	15.3	*.52*	***<.001***	*2.1*
Heavy lambs	29.6	29.5	–	*.94*	–	*3.8*
Carcase weight loss, %:						
Ewes	2.87	2.98	–	*.44*	–	*0.29*
Suckling lambs	2.95	2.86	–	*.77*	–	*0.74*
Weaned lambs	2.65	2.55	3.15	*.80*	*.07*	*1.58*
Heavy lambs	1.46	1.18	–	*.23*	–	*0.50*
Dressing percentage, %:						
Ewes	47.8	47.8	–	*.99*	–	*1.63*
Suckling lambs	49.9	49.0	–	*.99*	–	*2.72*
Weaned lambs	41.1	40.6	45.3	*.50*	***<.001***	*1.75*
Heavy lambs	48.7	48.1	–	*.37*	–	*1.47*
Pelt, %:						
Ewes	10.6	9.8	–	*.14*	–	*1.12*
Suckling lambs	13.4	13.1	–	*.44*	–	*1.09*
Weaned lambs	12.4	13.2	12.1	*.26*	*.25*	*1.65*
Heavy lambs	13.4	13.9	–	*.43*	–	*1.54*
Head, %:						
Ewes	5.0	4.9	–	*.74*	–	*0.50*
Suckling lambs	6.9	6.6	–	*.14*	–	*0.48*
Weaned lambs	6.4	6.1	5.7	*.14*	***.003***	*0.46*
Heavy lambs	4.7	4.8	–	*.45*	–	*0.30*
Distal legs, %						
Ewes	2.01	2.08	–	*.54*	–	*0.23*
Suckling lambs	3.44	3.60	–	*.48*	–	*0.27*
Weaned lambs	2.39	2.34	2.31	*.46*	*.36*	*0.16*
Heavy lambs	2.31	2.28	–	*.61*	–	*0.11*
Genitals, %						
Ewes	0.16	0.15	–	*.64*	–	*0.03*
Suckling lambs	0.19	0.18	–	*.86*	–	*0.20*
Weaned lambs	0.33	0.35	0.54	*.85*	***.021***	*0.23*
Heavy lambs	0.51	0.51	–	*.94*	–	*0.11*
Gastro-intestinal tract, %:						
Ewes	27.6	27.8	–	*.86*	–	*2.12*
Suckling lambs	23.8	24.0	–	*.85*	–	*2.72*
Weaned lambs	30.9	31.2	26.7	*.73*	***<.001***	*2.25*
Heavy lambs	21.2	20.5	–	*.31*	–	*1.37*
Liver, %:						
Ewes	1.66	1.84	–	*.22*	–	*0.29*
Suckling lambs	1.58	1.64	–	*.40*	–	*0.19*
Weaned lambs	1.31	1.33	1.50	*.57*	***<.001***	*0.08*
Heavy lambs	1.50	1.54	–	*.63*	–	*0.20*
Lungs, heart, spleen, %:						
Ewes	3.46	3.70	–	*.26*	–	*0.43*
Suckling lambs	2.58	2.62	–	*.67*	–	*0.24*
Weaned lambs	2.52	2.29	2.50	*.054*	*.068*	*0.27*
Heavy lambs	2.32	2.35	–	*.75*	–	*0.24*
Kidney fat, %:						
Ewes	0.74	0.79	–	*.75*	–	*0.29*
Suckling lambs	0.25	0.29	–	*.47*	–	*0.15*
Heavy lambs	0.88	0.86	–	*.83*	–	*0.22*

as found in a previous study, also the fatty acid profiles of the subcutaneous and kidney fats, the three muscles and the liver (Pellattiero et al. 2015a). The differences in the major carcase cuts (lower proportions of shoulder/fore shank, greater proportions of loin and rack in pasture-fed weaned lambs), and the small differences in the proportions of carcase tissues (Table 5) confirms that the differences between the pasture-fed and indoor-fed animals is not merely a question of energy availability and weight gain, but also stage of development (puberty), which in turn could have been affected by nutrients availability.

The effects of supplementing indoor diets with and without rp-CLA

Indoor total mixed diets resulted in valuable meat production from culled ewes (64 kg slaughter weight, 48%

Table 5. Effects of feeding system on the proportions of the major carcase cuts and carcase tissues of ewes and lambs.

	Feeding system effect			*p* Value		
	Indoor control (Con)	Indoor CLA (CLA)	Outdoor Pasture (Pas)	Con vs CLA	Pas vs Indoor	RMSE
Major carcase cuts:						
Shoulder/fore shank, %:						
Ewes	15.0	14.3	–	*.97*	–	*1.0*
Suckling lambs	17.6	17.1	–	*.31*	–	*1.2*
Weaned lambs	19.0	18.2	17.5	***.031***	***<.001***	*0.7*
Heavy lambs	16.9	16.8	–	*.81*	–	*0.5*
Neck and square cut, %:						
Ewes	22.6	22.3	–	*.57*	–	*1.3*
Suckling lambs	20.6	21.6	–	*.29*	–	*2.1*
Weaned lambs	20.9	21.7	20.9	*.53*	*.24*	*1.6*
Heavy lambs	22.6	22.6	–	*.97*	–	*1.1*
Breast and flap, %:						
Ewes	14.1	13.3	–	*.13*	–	*1.2*
Suckling lambs	9.9	10.2	–	*.45*	–	*0.8*
Weaned lambs	10.8	11.2	10.8	*.25*	*.44*	*0.7*
Heavy lambs	12.1	12.1	–	*.90*	–	*1.2*
Whole leg, %:						
Ewes	33.1	32.8	–	*.71*	–	*1.7*
Suckling lambs	35.5	35.7	–	*.73*	–	*1.5*
Weaned lambs	35.1	34.4	34.8	*.15*	*.89*	*1.1*
Heavy lambs	33.6	33.8	–	*.82*	–	*1.8*
Loin, %:						
Ewes	5.1	5.4	–	*.31*	–	*0.7*
Suckling lambs	6.1	5.9	–	*.58*	–	*0.8*
Weaned lambs	8.0	8.1	8.6	*.81*	***.032***	*0.7*
Heavy lambs	7.9	7.6	–	*.46*		*1.1*
Rack, %:						
Ewes	5.9	6.3	–	*.15*	–	*0.5*
Suckling lambs	6.4	6.5	–	*.62*	–	*0.5*
Weaned lambs	5.7	5.7	6.3	*.87*	***.005***	*0.5*
Heavy lambs	6.5	6.9	–	*.47*	–	*1.1*
Carcase tissue proportions:						
Muscle, %:						
Ewes	47.8	49.4	–	*.45*	–	*4.3*
Suckling lambs	58.7	58.6	–	*.93*	–	*3.6*
Weaned lambs	47.2	47.0	49.9	*.93*	*.18*	*5.7*
Heavy lambs	47.4	45.9	–	*.55*	–	*5.6*
Separable fat, %:						
Ewes	25.3	24.2	–	*.67*	–	*5.6*
Suckling lambs	10.1	11.4	–	*.32*	–	*3.1*
Weaned lambs	14.0	17.7	18.9	*.27*	*.29*	*8.0*
Heavy lambs	30.0	30.0	–	*.99*	–	*5.3*
Bone, %:						
Ewes	26.2	25.1	–	*.46*	–	*3.1*
Suckling lambs	29.5	29.0	–	*.74*	–	*3.6*
Weaned lambs	33.7	31.8	29.2	*.27*	***.027***	*4.2*
Heavy lambs	23.0	24.2	–	*.37*	–	*3.0*

dressing percentage), suckling lambs (21 kg, 50%) and heavy lambs (61 kg, 48%). The slaughter weight of suckling lambs was also much greater than typically found in lamb production from dairy breeds (Scerra et al. 2007; Vacca et al. 2008) that are slaughtered often very young to destine ewe's milk to cheese-production, while heavy lambs reached slaughter weights typical of meat breeds.

There were two reasons for including rp-CLA in the diets of indoor-reared ewes and lambs. Firstly, conjugated linoleic acids have sometimes had positive effects on protein metabolism (Schiavon et al. 2012), so they could be beneficial if added to moderate-protein diets formulated to reduce the environmental impact of ruminants (Schiavon et al. 2018). Secondly, it is well-known that CLA isomers are particularly abundant in animal products obtained from grazing ruminants, so the move to indoor feeding is expected to reduce the health-promoting properties of lamb meat if some rumen-protected CLA is not added to animals' diet (Gong et al. 2019).

Regarding the first reason, the results obtained from all 4 categories of animal examined in the study showed very small effects of rp-CLA supplementation on both *in vivo* and *post-mortem* traits (Tables 3–6). In monogastric, numerous studies have shown the metabolic effects of CLA supplementation on the increase

Table 6. Effects of feeding system on the meat quality traits measured on ewes and lambs.

	Feeding system			*p* Value		
	Indoor control (Con)	Indoor CLA (CLA)	Outdoor Pasture (Pas)	Con vs CLA	Pas vs Indoor	RMSE
Longissimus lumborum, g:						
Ewes	293	302	–	*.77*	–	*63*
Suckling lambs	133	147	–	*.30*	–	*32*
Weaned lambs	147	162	228	*.36*	***<.001***	*37*
Heavy lambs	396	373	–	*.31*	–	*49*
Protein, %:						
Ewes	20.2	20.2	–	*.87*	–	*0.5*
Suckling lambs	21.1	20.8	–	*.06*	–	*0.4*
Heavy lambs	20.1	20.4	–	*.45*	–	*0.9*
Lipids, %:						
Ewes	4.9	4.2	–	*.31*	–	*1.5*
Suckling lambs	2.4	2.6	–	*.45*	–	*0.6*
Heavy lambs	7.4	6.3	–	*.28*	–	*2.2*
Moisture, %:						
Ewes	73.3	74.2	–	*.26*	–	*1.6*
Suckling lambs	76.3	76.2	–	*.71*	–	*0.8*
Heavy lambs	71.6	72.2	–	*.48*	–	*1.8*
Ash, %:						
Ewes	1.48	1.52	–	*.61*	–	*0.16*
Suckling lambs	1.85	1.79	–	***.029***	–	*0.06*
Heavy lambs	1.63	1.64	–	*.92*	–	*0.21*
Collagen, %:						
Ewes	1.35	1.42	–	*.52*	–	*0.21*
Suckling lambs	1.54	1.32	–	*.002*	–	*0.15*
Heavy lambs	1.58	1.62	–	*.68*	–	*0.23*
Lightness, L*:						
Ewes	32.5	31.9	–	*.67*	–	*2.4*
Suckling lambs	41.9	40.8	–	*.39*	–	*3.1*
Weaned lambs	39.5	37.9	39.7	*.44*	*.27*	*3.53*
Heavy lambs	31.5	33.3	–	*.07*	–	*2.1*
Redness, a*:						
Ewes	9.9	9.6	–	*.75*	–	*1.7*
Suckling lambs	5.4	4.9	–	*.47*	–	*1.5*
Weaned lambs	6.6	7.6	6.7	*.63*	*.26*	*2.1*
Heavy lambs	9.6	9.4	–	*.73*	–	*1.4*
Yellowness, b*:						
Ewes	9.0	9.3	–	*.70*	–	*1.5*
Suckling lambs	9.7	8.2	–	***.021***	–	*1.5*
Weaned lambs	9.8	10.3	10.2	*.86*	*.45*	*1.6*
Heavy lambs	8.5	8.7	–	*.85*	–	*1.7*
Chroma, C*:						
Ewes	13.4	13.4	–	*.99*	–	*2.1*
Suckling lambs	11.2	9.7	–	***.047***	–	*1.7*
Weaned lambs	12.0	13.0	12.4	*.88*	*.24*	*1.9*
Heavy lambs	12.9	12.9	–	*.95*	–	*2.0*
Hue, H*:						
Ewes	41.9	43.7	–	*.31*	–	*3.6*
Suckling lambs	61.5	59.4	–	*.52*	–	*7.7*
Weaned lambs	55.7	53.6	56.8	*.50*	*.55*	*8.5*
Heavy lambs	41.6	42.4	–	*.69*	–	*4.1*
Acidity, pH:						
Ewes	5.51	5.51		*.92*	–	*0.08*
Suckling lambs	5.59	5.64	–	*.23*	–	*0.10*
Weaned lambs	5.61	5.69	5.58	*.16*	*.15*	*0.12*
Heavy lambs	5.92	5.83	–	*.20*	–	*0.16*
Cooking losses, %:						
Ewes	29.3	30.7	–	*.09*	–	*1.8*
Suckling lambs	32.6	31.6	–	*.31*	–	*2.2*
Weaned lambs	26.4	27.1	20.8	*.51*	***<.001***	*2.5*
Heavy lambs	23.2	24.0	–	*.47*	–	*2.6*
Shear force, N/cm^2:						
Ewes	24.7	22.9	–	*.47*	–	*5.0*
Suckling lambs	26.0	25.9	–	*.98*	–	*7.2*
Heavy lambs	24.2	21.0	–	*.11*	–	*4.2*

The symbols (*) are part of the acronyms as described in Material and Methods.

in lean growth, on the reduction of lipid deposition and on the consequent improvement of feed conversion (Pinelli-Saavedra 2019). These effects on performance but also on carcase traits appear to be much more limited in beef (Schlegel et al. 2012; Albertí et al. 2013) and lamb (Serra, Macciotta, et al. 2009; Serra, Mele, et al. 2009; Terré et al. 2011) confirming the modest differences observed in the present work. It worth noting that CLA affect the lipid metabolism, the hormonal secretion, and the timing of puberty in ruminants (Garcia et al. 2003). As the trial 2 on weaned lambs was carried out in the pre-pubertal and early pubertal phases of life of lambs, the effects observed on the increase in stature of live animals, on the incidence of shoulder/fore shank region of the carcase and on the mineral deposition in meat could be interpreted as signals of a modification of the body shape and composition connected with sexual maturity.

Regarding the second reason, in a previous study, we found that rp-CLA addition fulfilled the objective of improving the health-promoting properties of lamb meat, as the sum of the CLA isomers in meat from CLA-supplemented lambs was greater (+67%) than in the meat of non-CLA-supplemented lambs, and very similar to that of pasture-fed lambs (Pellattiero et al. 2015a), consistent with results obtained for beef (Raes et al. 2004; Schiavon et al. 2019). Note that CLA supplementation in the previous study had a very small effect on the deposition of the other fatty acids, which, combined with the results of this study on the BCS of live animals, the incidence of kidney fat and separable fats in the carcase, and of lipids in the muscles indicates a modest effect of CLA addition on the lipid metabolism of growing ruminants.

Conclusions

The results of this study outlined the possibility extending the meat production of autochthonous sheep of the Veneto region beyond the traditional farming season. Weaned lambs fattened indoors on hay and concentrates theoretically similar to fresh grass had lower growth rates than those fattened on pastures indicating a lower actual nutritional value of indoor diet respect to outdoor diet which limited the growth potential of indoor-fed lambs. Therefore, a better knowledge on the quality and palatability of forages is required with the aim of improving indoor feeding regimes. Feeding total mixed diets to ewes, suckling lambs and heavy lambs of Alpine breeds evidenced their potential for producing different valuable sources of lamb and mutton meat with good quality characteristics in seasons of the year different from that in which meat from weaned lambs is available. Supplementing indoor diets with rp-CLA, beyond their possible effects on the fatty acid profile of meat produced indoors, has shown to have no detrimental effects on the animals' performances, slaughter traits or meat quality traits.

Ethical approval

As reported in M&M the research involved the use of animals reared according to the conventional farm and slaughtering techniques and following the international guidelines for animal welfare. Therefore, the research did not require the collection of biological samples or the implementation of other practices that go beyond the conventional farming techniques.

Acknowledgments

The Authors thank Dr. Alberto Simonetto and Luca Carraro for technical assistance.

Disclosure statement

The authors declare no conflict of interest.

Funding

Bionet Project (misura 214 – pagamenti agroambientali – sottomisura H – Rete regionale della biodiversità) financed by Veneto Region.

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Data availability statement

The Raw Data Supporting The Conclusions Of This Article Will Be Made Available By The Authors, Without Undue Reservation

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