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To cite this article: Giovanni Bittante, Erika Pellattiero, Alessio Cecchinato, Franco Tagliapietra, Enrico Sturaro, Maurizio Ramanzin, Michele Pazzola, Giuseppe Massimo Vacca & Stefano Schiavon (2021) Performance, carcass conformation and meat quality of suckling, weaned and heavy lambs, and culled fattened ewes of autochthonous alpine sheep breeds, Italian Journal of Animal Science, 20:1, 970-984, DOI: [10.1080/1828051X.2021.1920484](https://doi.org/10.1080/1828051X.2021.1920484)

To link to this article: <https://doi.org/10.1080/1828051X.2021.1920484>



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Published online: 02 Jul 2021.



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Performance, carcass conformation and meat quality of suckling, weaned and heavy lambs, and culled fattened ewes of autochthonous alpine sheep breeds

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ABSTRACT

Several local sheep breeds of the Alpine regions are in danger of extinction as a result of mountain farms being abandoned. Three fattening trials were carried out on 4 breeds of the Veneto region (Foza, Lamon, Alpagota, and Brogna) on a total of 115 ewes and suckling lambs, weaned lambs and heavy lambs slaughtered at 1356 ± 267 , 104 ± 24 , 219 ± 26 , and 342 ± 14 d of age, respectively. The results confirmed that the adoption of 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%), weaned lambs (30 kg, 42%) and heavy lambs (61 kg, 48%). Carcass compactness and fatness increased with the age of the lambs, whereas the proportions of lean meat and bone decreased. Meat lightness and cooking losses decreased with age, whereas redness and chroma increased. The meat quality of culled ewes was like that of heavy lambs. Carcass conformation and composition (aside from size traits), and the quality of the meat differed little among the four Alpine breeds. These results show that local breeds are potentially valuable sources of lamb and mutton meat across different seasons, paving the way for strategies to develop and promote the meat with the involvement of high-quality restaurants and meat retailers.

HIGHLIGHTS

- Compared to outdoor grazing, the adoption of indoor diets resulted in good *in vivo* and *post-mortem* performances of ewes, suckling lambs and heavy lambs.
- Autochthonous Alpine breeds are potentially valuable sources of high-quality lamb and mutton across different seasons of the year.
- This potential could be exploited in developing a prestigious product aimed at high quality restaurants and butchers. The subsequent demand for the product would, in turn, contribute to the survival of the local sheep breeds of Alpine regions.

ARTICLE HISTORY

Received 11 January 2021
Revised 16 March 2021
Accepted 5 April 2021

KEYWORDS

Mutton meat; meat promotion; sheep biodiversity; local sheep breeds; endangered genetic resources

Introduction

In the valleys of the Alps, sheep have been reared for centuries according to two different systems: in large transhumant flocks destined for meat production, grazing on the plains and coastal areas during winter and on highland pastures during the summer; or in small flocks on several traditional mountain farms, with the function of producing meat (lambs, and culled ewes and rams), as well as some wool for the family's needs, and in some cases also milk, which is processed together with cows' and goats' milk to

make cheese (Pastore 2002). In each system, local breeds with different characteristics were reared: large, long-legged sheep for transhumance, medium-sized and stockier for farm rearing.

In the last decades the evolution of livestock systems in mountain areas was characterised by two trends: specialization/intensification in the most favourable valleys, and abandonment of traditional farms in marginal areas (Cocca et al. 2012). In the Italian Alps, from 1990 to 2010 the number of sheep farms decreased (−44%) whereas the number of animals increased (+9%), with a strong increase of the

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number of heads per farm (Battaglini et al. 2014). This caused a strong reduction of local sheep breeds, with many breeds disappearing or currently threatened with extinction (Bittante 2011).

The autochthonous breeds of the Veneto region (north-eastern Italy) represent a good case study of the situation regarding local sheep breeds reared in Alpine areas. These native breeds are the Alpagota, Brogna, Foza, and Lamon. The former two representing the medium-size farm-reared breeds, and the latter two the large and long-legged, originally used for transhumance, breeds, these latter particularly at risk of extinction (Pastore and Fabbris 1999; Pastore 2002; Bittante 2011).

Sheep farming in the Alpine regions has become a means of conserving landscapes and biodiversity, and represents the concept of multi-functionality, a key principle in EU agricultural policy (EEA 2010; Gazzarin and El Benni 2020).

Effective strategies for conserving endangered genetic resources can be supported in two ways: (i) development of agricultural policies focussing on multifunctionality of farms and breeds (e.g. CAP subsidies become payments or rewards for the provision of public goods); (ii) development of value chains and promotion of quality products able to meet the final consumers' preferences for traditional products and local genetic resources.

The traditional management of Alpine sheep is strictly seasonal (Willems et al. 2013), with lambing concentrated at the end of winter, and lamb consumed during the Easter period (suckling lambs) and late spring to early summer (lambs weaned at pasture). Lamb meat from local breeds, especially if produced sustainably, is preferred by many European consumers (Font i Furnols et al. 2011; Hersleth et al. 2012; Montossi et al. 2013), but raising the profile of local sheep breeds relies in particular on extending meat production to all-year-round and engaging the interest of high-quality restaurants.

Given that pasture is subject to seasonal availability, alternative rearing methods need to be studied. Fattening lambs indoors on appropriate diets over longer periods could be a means of extending the period in which lamb can be produced thereby increasing the economic sustainability of mountain sheep farms (Bhatti et al. 2019; Gazzarin and El Benni 2020). However, animals of these native breeds have not been selected for this type of production, so their growth rates and carcass characteristics, and the quality of their meat need to be evaluated. In addition, the capacity of culled fattened ewes to yield valuable mutton meat also needs to be evaluated.

The general aim of this study was to analyse the production of lamb meat and mutton from different local breeds of the Alpine Veneto region over extended periods using indoor diets. The specific aims of the current paper were to compare the growth rates, live animal and carcass conformations, carcass compositions, and meat quality characteristics of suckling, weaned and heavy lambs, and culled fattened ewes of the two medium-size Alpagota and Brogna, and the two large size Foza and Lamon breeds.

Materials and methods

The present study was carried out in accordance with the 'Guide for Care and Use of Agricultural Animals in Research and Teaching' (FASS 2010). It did not involve any blood or tissue sampling, nor were the animals restrained during the fattening period. Given the need for breed conservation and in consideration of ethical issues, the number of lambs included in the experiment was kept to the minimum required to obtain adequate statistical power. Our study was conducted at the 'Lucio Toniolo' Experimental Farm of the University of Padova as part of the BIONET Project, which is aimed at characterising endangered genetic resources local to the Veneto region. The lambs 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 (via dell'Università 4, 35020 Legnaro, Padova, Italy), the second on the pilot farm of Veneto Agricoltura (the regional agency for agriculture, forestry and agro-industry; via Villiago 5, 32036 Sedico, Belluno, Italy).

Experimental design, animals, and measurements

In traditional sheep farming in the Alps, lambing is concentrated in late winter/early spring in indoor barns. Lamb is normally produced from suckling lambs ('agnello da latte') or weaned light lambs kept at pasture ('agnellone leggero'). To investigate the possibility of extending lamb meat availability to all-year-round, our study also examined meat production from heavy lambs ('agnellone pesante') and mutton from adult fattened ewes. Three trials were carried out, each one consisting of a fattening period followed by the slaughter of all animals (115 head):

- Trial 1: 24 ewes and their 31 suckling lambs reared indoors from 6 to 15 weeks after parturition;
- Trial 2: 24 weaned lambs reared indoors, and 12 reared at pasture from 15 to 32 weeks of age;

Table 1. Sex, breed, initial age and live weight, and experimental diets of the animals involved in the three trials.

	Trial 1		Trial 2		Trial 3	Total
	Ewes	Suckling lambs	Weaned lambs	Weaned lambs	Heavy lambs	
Environment:	Indoors	Indoors	Pasture	Indoors	Indoors	–
Pens	6	6	1	6	6	25
Animals, <i>N.</i>	24	31	12	24	24	115
Males, <i>N.</i>	–	17	6	12	12	47
Females, <i>N.</i>	24	14	6	12	12	68
Breed:						
Alpagota, <i>N.</i>	–	–	4	8	–	12
Brogna, <i>N.</i>	10	15	4	8	11	48
Foza, <i>N.</i>	9	10	4	8	8	39
Lamon, <i>N.</i>	5	6	–	–	5	16
Twins, <i>N.</i>	–	16	8	17	16	57
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	–
Trial length, d	63	63	112	112	111	–
Experimental diet						
Feedstuff ad lib	TMR ^a	TMR ^a	Grass	Hay	TMR ^b	–
Ewes' milk fed	–	Ad lib	–	–	–	–
Concentrates	–	–	–	267 g/d	–	–

^aTMR: total mixed ration (corn meal, corn silage, sugar beet pulp, soybean meal, wheat straw, wheat bran, supplement) with CP 130 g/kg DM, NDF 293 g/kg DM, ADF 146 g/kg DM.

^bTMR: total mixed ration (corn meal, corn silage, sugar beet pulp, wheat straw, wheat bran, soybean meal, supplement) with CP 107 g/kg DM, NDF 295 g/kg DM, ADF 165 g/kg DM.

- Trial 3: 24 heavy lambs reared indoors from 33 to 50 weeks of age.

The numbers of animals used in the trials according to their breed, sex, age, type of birth, and initial live weight, and the types of diet they were fed are given in Table 1. The number of lambs were balanced overall for gender, but the number of individuals of each breed and type of birth varied according to the availability of surplus animals on the two conservation farms. The minimum number of experimental animals per group was quantified, as described by Lerman (1996), as the minimal number to detect significant differences ($p = .05$; power = 85%) in ADG among treatments of 20 g/d, with an anticipated within-group SD for ADG of 30 g/d.

The animals kept indoors were housed in 6 pens (each of 4 weaned lambs, or 4 heavy lambs, or 4 ewes with their suckling lambs) in an open barn with permanent bedding. The feeds, which were administered *ad libitum* to the animals, consisted of two different total mixed rations in trials 1 and 3, and meadow hay plus an average of 267 g/d of a compound feed for the indoor weaned lambs in trial 2, while the outdoor weaned lambs in trial 2 were grazed all together on an Italian permanent ryegrass meadow. The compositions of the diets are reported in the footnotes to Table 1.

In order to improve the fatty acid profile and the nutritional value of the meat from the indoor-fed animals, making it more similar to the meat from grass-fed animals (Pellattiero et al. 2015), a supplement

containing rumen-protected conjugated linoleic acid (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 effects of rp-CLA supplementation and comparison of the indoor feeds with pasture feeding are the object of a parallel study (Bittante et al. 2021), where details of the diets can be found, while a detailed description of the chemical composition of the rp-CLA is given in Schiavon et al. (2015).

At the beginning, the end, and every four weeks during the trials, before distribution of the morning meal all animals were weighed, measured (withers height and heart girth), and scored by a trained technician for body condition (5 classes, from emaciated to severely obese, with subclasses at score intervals of 0.25).

Slaughter of animals, and measurement and dissection of carcasses

At the end of each trial, all animals were fasted for 12 h then slaughtered in a commercial slaughterhouse approved by the European Union and under the control of the Italian national veterinary authority. Live weight before slaughter, and the weights of the pelt, feet, head, gastro-intestinal tract, offal (trachea, lungs, heart and spleen), liver, and genitals were recorded. The following carcass measurements were taken in accordance with the EAAP manual (De Boer et al. 1974):

- Length of carcass (LoC), cm;
- Depth of chest (DoC), cm;

- Length of leg (LoL), cm;
- Width of leg (WoL), cm;

The following conformation indices were also calculated:

- Lateral carcass conformation (DoC/LoC × 100);
- Round conformation (WoL/LoL × 100);
- Carcass thickness index (WoL/LoC × 100);
- Carcass volume (LoC × DoC × WoL/1,000), L;
- Compactness index (Carcass weight/Carcass volume × 100), kg/L.

Dressing percentage was calculated by dividing the carcass weight by the pre-slaughter live weight and multiplying by 100. The carcasses were divided into two halves, then weighed before cooling, and again about 24 h after slaughter. The right carcass side was sectioned into the six major carcass cuts according to local market requirements: shoulder/fore shank, neck and square cut, breast and flap, whole leg, loin, and rack. Respect to the procedure described by Vacca et al. (2008), the flank was not separated from breast. 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 in % of their sum.

Meat quality analyses

The whole *Longissimus lumborum* muscle of the loin cut from the right carcass side was used to conduct the meat quality analyses. The muscle was dissected from the loin, vacuum packed, cooled to 4 °C in a portable refrigerator, transported to the Meat Laboratory of DAFNAE (Department of Agriculture, Food, Natural resources, Animals and Environment) at the University of Padova (Italy), and aged for 6 days at the same temperature.

After aging, the meat sample was removed from the packaging, dried and weighed, and divided into two thick slices. One of the slices was used to measure pH using a Delta Ohm HI-8314 pH-meter (Delta Ohm, Padua, Italy), and to determine the colour parameters using 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 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 analysis. The same subsample was used for proximate analysis of the meat, 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 determined after mineralisation, lipids after extraction with petroleum ether, and protein was estimated by difference. On the same samples also hydroxyproline content was analysed with HPLC method (European Pharmacopoeia, 2010) and total collagen content was computed as Hydroxyproline × 8 (Ignat'eva et al. 2007).

A 2-cm-thick segment was taken from the other slice of the muscle, sealed 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 cooked weight divided by the uncooked weight, and multiplied by 100. Shear force (SF) was then measured on three 1.13 cm-diameter cylindrical cores of the cooked sample taken parallel to the muscle fibres using a TA-HDi Texture Analyser (Stable Macro System, London, Great Britain) with a Warner-Bratzler shear attachment (10 N load cell, crosshead speed of 2 mm/s) (Joseph 1979).

Statistical analysis

The data obtained in the three trials were not analysed together because of the evident heteroscedasticity of the residual variance characterising groups of animals that differ 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, 2008):

$$y_{ijklmn} = \mu + \text{breed}_i + \text{sex}_j + \text{birth}_k + \text{age}_l + \text{diet}_m + e_{ijklmn} \quad (1)$$

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; diet_m is the effect of feeding regime (m = indoor control or indoor rp-CLA or pasture); e_{ijklmn} is the random residual term $\sim N(0, \sigma^2 e)$. The residuals from this model were used for testing the normality of distributions of the traits and for possible outliers ($> \pm 3$ RSD).

As the four local breeds were represented by two large-sized breeds (Foza and Lamon) and two

medium-sized breeds (Alpagota and Brogna), orthogonal contrasts were done to compare first the large with the medium-sized breeds, and lastly the two breeds within each size group. Given the different distributions of the breeds in the three trials (Table 1) and the two degrees of freedom available, we used in each trial one orthogonal contrast to compare the medium-sized and the large sized breeds:

- Foza vs. (Alpagota + Brogna) in trial 2;
- Brogna vs. (Foza + Lamon) in trials 1 and 3;

And we used in each trial one orthogonal contrast to compare the two breeds within the medium-sized or within the large-sized breeds:

- Alpagota vs. Brogna in trial 2;
- Foza vs. Lamon in trials 1 and 3.

Results

The statistical model included the effects of sex, birth type, initial age, and feeding regime so that the least square means for the various traits of the four breeds could be considered unbiased. As the effects of these factors are not among the specific objectives of this study, the results are not shown nor discussed here, except in a few cases where they prove useful for interpreting the results from the different breeds. In any case, preliminary analyses did not reveal any appreciable interactions with the effect of breed. Greater detail regarding these factors can be found in the parallel study (Bittante et al. 2021). As we analysed the results for each trial separately (see *Statistical analyses*), the differences in the average values of the animals of the four categories (suckling lambs, weaned lambs, heavy lambs and culled fattened ewes) were considered relevant when they were greater than the average root mean square errors of the trait analysed.

Live animal performance

Table 2 summarises the live weight (LW), average daily growth rate (ADG), withers height, and BCS of the suckling, weaned and heavy lambs, and culled fattened ewes of the four breeds (Alpagota, Brogna, Foza and Lamon). The final live weights attained by the suckling, weaned and heavy lambs, and culled fattened ewes at the end of the fattening period were 21, 30, 61, and 64 kg, respectively, at the corresponding ages of 104 ± 24 , 219 ± 26 , 342 ± 14 , and

1356 ± 267 d. Growth rates were moderate for suckling (132 g/d) and weaned (84 g/d) lambs, much greater for heavy lambs (245 g/d), and negligible for culled ewes (31 g/d). Average withers height of suckling, weaned and heavy lambs, and ewes was 58, 62, 75 and 76 cm, respectively, and average BCS scores were 3.2, 3.1, 3.8, and 3.1, respectively.

Live weight (LW) at the beginning and end of the fattening trials was affected by breed (the large-sized breeds Foza and Lamon were heavier in all three trials, $p < .01$). LW was also, as expected, affected by sex (ram lambs were heavier than ewe lambs at the end of trials 2 and 3; $p < .01$), type of birth (singlets were heavier than multiple suckling lambs; $p < .01$), age at beginning of the trial (older lambs in trials 1 and 2 were heavier; $p < .01$), and diet (lambs reared on pasture were heavier than indoor-fed lambs at the end of trial 2; $p < .01$) (data not shown). Unlike LW, ADG almost never reached the threshold of statistical significance, except for the greater ADG of lambs of the large-sized breeds ($p < .01$; Table 2), ram lambs over ewe lambs (only in trial 3), and lambs reared at pasture (in trial 2, $p = .027$).

The results for heart girth measures were at similar levels of significance to those for live weight and are therefore not shown in the table. Withers height (WH) was found to be affected by the same factors of variation affecting live weight but was also found to differ in the two medium-sized breeds (Alpagota and Brogna; $p < .01$). The WH of lambs tended to be affected by birth type only at a very early stage (beginning of trial 1, $p < .01$), and by sex only at a very late stage (end of trial 3, $p < .01$).

There were fewer statistical differences in the animals' BCS than in their LW and WH. Lamon suckling lambs were fatter than Foza lambs at slaughter (trial 1, $p = .019$), and Foza lambs were fatter than the lambs of the two medium-sized breeds at the beginning of trial 2 ($p < .01$), but their BCS did not increase further during the trial. Lastly, within the medium-sized breeds, Brogna lambs were fatter than the Alpagota at the beginning of trial 2 ($p < .01$), but not at the end ($p = .08$).

Performance at slaughter

The data collected at the slaughterhouse are summarised in Table 3 (dressing percentages and proportions of pelt, head, legs, genitals, full gastrointestinal tract, liver, lung-heart-spleen, and kidney fat). Carcass weight was, on average, slightly less than 50% of the live weight at slaughter for all age categories, except the weaned lambs (42%),

Table 2. Effects of breed on traits measured on live ewes and lambs at the beginning and end of the fattening trials.

	Breed (LSMs):				Orthogonal contrasts				RMSE
	Alpagota (A)	Brogna (B)	Foza (F)	Lamon (L)	F vs. (A + B)	A vs B	B vs (F + L)	F vs L	
Live weight and ADG									
Ewes (Trial 1)									
LW _i , kg	–	50.10	67.60	70.30	–	–	.006	.692	11.80
LW _f , kg	–	53.10	69.40	70.90	–	–	.01	.832	11.60
ADG, g/d	–	51	29	10	–	–	.293	.563	560
Suckling lambs (Trial 1)									
Birth weight, kg	–	3.94	4.71	5.05	–	–	.002	.394	0.72
LW _i , kg	–	11.60	13.40	14.90	–	–	.09	.396	3.00
LW _f , kg	–	18.20	21.30	24.20	–	–	.025	.198	4.00
ADG, g/d	–	110	130	155	–	–	.044	.175	33
Weaned lambs (Trial 2)									
LW _i , kg	17.20	20.50	25.20	–	<.001	.082	–	–	3.60
LW _f , kg	25.30	28.30	36.00	–	<.001	.203	–	–	4.40
ADG, g/d	76	72	102	–	.027	.804	–	–	270
Heavy lambs (Trial 3)									
LW _i , kg	–	35.80	37.90	45.70	–	–	.09	.265	6.70
LW _f , kg	–	53.80	59.80	69.00	–	–	.013	.247	7.60
ADG, g/d	–	209	254	271	–	–	.002	.567	28
Height at withers (HW), cm									
Ewes (Trial 1)									
HW _i	–	68.30	76.60	74.30	–	–	.001	.287	3.70
HW _f	–	70.90	80.20	77.80	–	–	<.001	.189	3.20
Δ _{HW}	–	2.60	3.60	3.50	–	–	.37	.928	2.10
Suckling lambs (Trial 1)									
HW _i	–	46.50	52.20	51.90	–	–	<.001	.868	2.90
HW _f	–	54.10	60.10	60.70	–	–	<.001	.731	3.50
Δ _{HW}	–	7.60	7.90	9.30	–	–	.47	.446	2.20
Weaned lambs (Trial 2)									
HW _i	49.60	53.80	59.50	–	<.001	.009	–	–	2.90
HW _f	57.00	60.80	69.20	–	<.001	.023	–	–	3.10
Variation Δ _{HW}	7.30	7	9.60	–	.033	.803	–	–	2.50
Heavy lambs (Trial 3)									
HW _i	–	62.10	67.10	68.50	–	–	.002	.663	3.20
HW _f	–	69.70	75.40	78.80	–	–	<.001	.343	3.60
Δ _{HW}	–	7.60	8.20	10.30	–	–	.09	.284	1.90
Body condition score:									
Ewes (Trial 1)									
BCS _i	–	2.72	2.74	2.88	–	–	.525	.375	0.28
BCS _f	–	3.03	3.00	3.24	–	–	.589	.208	0.32
Δ _{BCS}	–	0.32	0.27	0.36	–	–	.980	.510	0.25
Suckling lambs (Trial 1)									
BCS _i	–	3.08	2.96	3.21	–	–	.975	.054	0.23
BCS _f	–	3.21	3.07	3.45	–	–	.707	.019	0.28
Δ _{BCS}	–	0.13	0.11	0.24	–	–	.514	.131	0.15
Weaned lambs (Trial 2)									
BCS _i	2.65	3.14	3.33	–	.002	.002	–	–	0.29
BCS _f	2.96	3.19	3.25	–	.096	.057	–	–	0.23
Δ _{BCS}	0.31	0.06	–0.08	–	.033	.080	–	–	0.27
Heavy lambs (Trial 1)									
BCS _i	–	3.33	3.23	3.32	–	–	.613	.661	0.22
BCS _f	–	3.74	3.71	3.88	–	–	.675	.504	0.25
Δ _{BCS}	–	0.41	0.48	0.55	–	–	.498	.828	0.31

LW_i: initial live weight; LW_f: final live weight; ADG: average daily gain; HW_i: initial height at withers; HW_f: final height at withers; Δ_{HW}: variation of height at withers; BCS_i: initial body condition score; BCS_f: final body condition score; Δ_{BCS}: variation of body condition score. In bold *P* values < 0.05.

especially those fed the indoor diet (Bittante et al. 2021). The proportions of non-carcass components showed a greater variation with the age of the animals. The proportions of head and distal legs decreased with age, while the proportions of genitals and kidney fat increased; ewes had a lower proportion of pelt, and a higher proportion of lung-heart-spleen than lambs; the proportion of gastrointestinal tract was higher in weaned lambs, lower

in heavy lambs; the proportion of liver did not differ much across the different age categories.

Breed did not affect the slaughter traits of the ewes, despite the large differences in their LW at slaughter (Table 3), except for the greater proportion of kidney fat in Lamon than in Foza (*p* = .022). The dressing percentages of suckling lambs did not differ across the breeds, due to similar proportions of wastes and offal. Brogna lambs had smaller proportions of

Table 3. Effects of breed on the slaughter traits of ewes and lambs.

	Breed (LSMs):				Orthogonal contrasts (<i>p</i> -value):				RMSE
	Alpagota (A)	Brogna (B)	Foza (F)	Lamon (L)	F vs. (A + B)	A vs. B	B vs. (F + L)	F vs. L	
Dressing %:									
Ewes (Trial 1)	–	46.80	48.40	48.20	–	–	.093	.823	1.63
Suckling lambs (Trial 1)	–	48.00	48.40	50.60	–	–	.254	.167	2.72
Weaned lambs (Trial 2)	40.90	42.40	43.70	–	.010	.106	–	–	1.75
Heavy lambs (Trial 3)	–	49.90	47.60	47.70	–	–	.006	.918	1.47
Pelt, %:									
Ewes (Trial 1)	–	9.50	10.90	10.1	–	–	.092	.227	1.12
Suckling lambs (Trial 1)	–	12.40	13.40	14.0	–	–	.018	.277	1.09
Weaned lambs (Trial 2)	13.70	11.30	12.70	–	.751	.007	–	–	1.65
Heavy lambs (Trial 3)	–	12.30	13.90	14.8	–	–	.017	.576	1.54
Head, %:									
Ewes (Trial 1)	–	5.20	5.00	4.8	–	–	.272	.515	0.50
Suckling lambs (Trial 1)	–	6.90	6.70	6.60	–	–	.236	.515	0.48
Weaned lambs (Trial 2)	6.20	6.20	5.90	–	.222	.935	–	–	0.46
Heavy lambs (Trial 3)	–	4.60	5.10	4.60	–	–	.145	.104	0.30
Distal legs, %									
Ewes (Trial 1)	–	1.95	2.19	2.00	–	–	.225	.173	0.23
Suckling lambs (Trial 1)	–	3.19	3.73	3.29	–	–	.019	.007	0.27
Weaned lambs (Trial 2)	2.24	2.19	2.62	–	<.001	.597	–	–	0.16
Heavy lambs (Trial 3)	–	2.08	2.56	2.25	–	–	<.001	.010	0.11
Genitals, %									
Ewes (Trial 1)	–	0.17	0.16	0.14	–	–	.227	.092	0.03
Suckling lambs (Trial 1)	–	0.28	0.14	0.14	–	–	.147	.976	0.20
Weaned lambs (Trial 2)	0.39	0.47	0.36	–	.537	.532	–	–	0.23
Heavy lambs (Trial 3)	–	0.52	0.53	0.48	–	–	.776	.636	0.11
Gastro-intestinal tract, %:									
Ewes (Trial 1)	–	28.20	27.60	27.40	–	–	.549	.847	2.12
Suckling lambs (Trial 1)	–	25.20	24.70	21.70	–	–	.137	.050	2.72
Weaned lambs (Trial 2)	30.90	30.40	27.50	–	.003	.654	–	–	2.25
Heavy lambs (Trial 3)	–	20.80	20.50	21.30	–	–	.906	.554	1.37
Liver, %:									
Ewes (Trial 1)	–	1.71	1.84	1.70	–	–	.695	.424	0.29
Suckling lambs (Trial 1)	–	1.59	1.47	1.76	–	–	.791	.008	0.19
Weaned lambs (Trial 2)	1.43	1.38	1.34	–	.060	.243	–	–	0.08
Heavy lambs (Trial 3)	–	1.60	1.47	1.49	–	–	.231	.925	0.20
Lungs, heart, spleen, %:									
Ewes (Trial 1)	–	3.60	3.60	3.53	–	–	.890	.798	0.43
Suckling lambs (Trial 1)	–	2.61	2.51	2.69	–	–	.920	.197	0.24
Weaned lambs (Trial 2)	2.54	2.50	2.27	–	.038	.753	–	–	0.27
Heavy lambs (Trial 3)	–	2.41	2.27	2.33	–	–	.358	.79	0.24
Kidney fat, %:									
Ewes (Trial 1)	–	0.80	0.54	0.96	–	–	.739	.022	0.29
Suckling lambs (Trial 1)	–	0.34	0.19	0.16	–	–	.122	.292	0.15
Heavy lambs (Trial 3)	–	1.38	0.55	0.68	–	–	<.001	.558	0.22

In bold *P* values < 0.05.

pelt and distal hind- and fore-legs than Foza and Lamon ($p < .02$); Foza lambs had heavier distal legs ($p < .01$) and gastro-intestinal tract ($p = .05$), but lighter liver than Lamon lambs ($p < .01$). Foza weaned lambs had a greater dressing percentage than weaned lambs of the medium-sized breeds ($p = .01$) due to lower proportions of the major internal organs, but heavier distal legs ($p < .01$). The only difference between the two medium-sized breeds was that the Brogna had a smaller proportion of pelt than the Alpagota ($p < .01$). Brogna heavy lambs had a greater dressing percentage than heavy lambs of the two large-sized breeds ($p < .01$), due to their lighter pelt ($p = .02$) and distal legs ($p < .01$), but heavier kidney fat ($p < .01$). The only difference between the two large-sized breeds was that Foza lambs had heavier legs than Lamon lambs ($p = .01$).

Carcass weight and conformation

Table 4 summarises the carcass traits (weight, weight loss, measurements, and conformation indices). As expected, the average carcass weight, linear measures and carcass volume index increased with increasing age categories, corresponding to the increase in live weight, but these differences were not strictly proportional for the various traits due to changes in the conformation of the carcass. The average lateral conformation (depth of chest divided by length of carcass, multiplied by 100), round conformation (width of leg divided by length of carcass, multiplied by 100) and carcass thickness index (width of leg divided by length of carcass, multiplied by 100) did not differ much among the age categories (except for the greater lateral conformation of the carcasses of weaned

Table 4. Effects of breed on carcass weight, measurements and conformation indices of ewes and lambs.

	Breed (LSMs):				Orthogonal contrasts (<i>p</i> -value):				RMSE
	Alpagota (A)	Brogna (B)	Foza (F)	Lamon (L)	F vs (A + B)	A vs B	B vs (F + L)	F vs L	
Warm carcass weight, kg:									
Ewes (Trial 1)	–	24.50	34.10	34.30	–	–	.003	.953	5.60
Suckling lambs (Trial 1)	–	10.30	12.20	13.80	–	–	.024	.223	2.40
Weaned lambs (Trial 2)	10.60	12.20	15.90	–	<.001	.138	–	–	2.10
Heavy lambs (Trial 3)	–	26.70	29.10	32.80	–	–	.037	.336	3.80
Carcass weight loss, %:									
Ewes (Trial 1)	–	2.93	2.88	2.96	–	–	.938	.676	0.29
Suckling lambs (Trial 1)	–	2.80	3.10	2.82	–	–	.656	.496	0.74
Weaned lambs (Trial 2)	1.66	3.22	3.47	–	.488	.014	–	–	1.58
Heavy lambs (Trial 3)	–	1.45	1.04	1.46	–	–	.437	.407	0.50
Length of carcass, cm:									
Ewes (Trial 1)	–	72.10	80.30	79.10	–	–	<.001	.573	3.70
Suckling lambs (Trial 1)	–	53.30	57.60	58.30	–	–	<.001	.663	3.10
Weaned lambs (Trial 2)	55.20	57.90	63.40	–	<.001	.145	–	–	3.40
Heavy lambs (Trial 3)	–	66.90	71.30	73.50	–	–	.003	.497	3.20
Depth of chest, cm:									
Ewes (Trial 1)	–	24.60	26.60	26.30	–	–	.009	.667	1.20
Suckling lambs (Trial 1)	–	17.90	18.50	19.10	–	–	.10	.321	1.00
Weaned lambs (Trial 2)	23.00	25.50	25.00	–	.336	.020	–	–	2.00
Heavy lambs (Trial 3)	–	21.30	22.20	24.00	–	–	.008	.153	1.20
Lateral carcass conform, %:									
Ewes (Trial 1)	–	34.20	33.10	33.30	–	–	.227	.902	1.50
Suckling lambs (Trial 1)	–	33.70	32.00	32.70	–	–	.077	.454	1.50
Weaned lambs (Trial 2)	–	37.70	38.80	38.80	.472	.181	–	–	1.60
Heavy lambs (Trial 3)	–	31.90	31.20	32.60	–	–	.960	.334	1.40
Length of leg, cm:									
Ewes (Trial 1)	–	44.00	50.00	48.50	–	–	<.001	.311	2.60
Suckling lambs (Trial 1)	–	35.90	39.60	40.70	–	–	<.001	.300	2.00
Weaned lambs (Trial 2)	32.50	34.00	38.90	–	<.001	.106	–	–	1.80
Heavy lambs (Trial 3)	–	44.60	49.40	49.50	–	–	<.001	.964	1.80
Width of leg, cm:									
Ewes (Trial 1)	–	11.10	12.10	12.40	–	–	.049	.584	1.10
Suckling lambs (Trial 1)	–	8.40	9.30	9.60	–	–	.038	.592	1.00
Weaned lambs (Trial 2)	8.60	9.10	10.20	–	<.001	.176	–	–	0.70
Heavy lambs (Trial 3)	–	11.30	10.70	12.40	–	–	.504	.067	0.80
Round conformation, %:									
Ewes (Trial 1)	–	25.20	24.20	25.70	–	–	.810	.243	2.00
Suckling lambs (Trial 1)	–	23.50	23.60	23.60	–	–	.92	.987	2.40
Weaned lambs (Trial 2)	26.60	26.60	26.10	–	.493	.984	–	–	1.70
Heavy lambs (Trial 3)	–	25.20	21.60	24.90	–	–	.054	.086	1.80
Carcass thickness index, %:									
Ewes (Trial 1)	–	15.40	15.00	15.70	–	–	.972	.271	1.10
Suckling lambs (Trial 1)	–	15.80	16.20	16.50	–	–	.471	.752	1.50
Weaned lambs (Trial 2)	15.60	15.70	16.00	–	.437	.939	–	–	1.00
Heavy lambs (Trial 3)	–	16.80	15.00	16.80	–	–	.180	.196	1.30
Carcass volume, dm ³ :									
Ewes (Trial 1)	–	39.50	52.00	51.60	–	–	.003	.926	6.80
Suckling lambs (Trial 1)	–	16.40	19.70	21.30	–	–	.011	.360	3.20
Weaned lambs (Trial 2)	14.20	17.90	23.20	–	<.001	.010	–	–	2.60
Heavy lambs (Trial 3)	–	32.50	34.10	43.70	–	–	.014	.057	4.70
Compactness index, g/100cm ³ :									
Ewes (Trial 1)	–	62.20	65.60	66.50	–	–	.250	.817	6.30
Suckling lambs (Trial 1)	–	62.30	61.30	64.90	–	–	.810	.352	6.80
Weaned lambs (Trial 2)	71.90	68.00	68.90	–	.261	.734	–	–	6.70
Heavy lambs (Trial 3)	–	83.60	86.40	74.10	–	–	.453	.154	8.20

In bold *P* values < 0.05.

lambs). However, the compactness index, calculated by dividing the carcass weight by the carcass volume (i.e. the volume of a rectangular cuboid with the dimensions length of carcass x depth of chest x width of leg), differed profoundly among the categories. As it is calculated from the dimensions of the bones, it represents, in some way, the ratio between the soft tissues (lean and fat) and the skeleton of the carcass. The index was around 60–65% for the carcasses of

ewes and suckling lambs, about 70% for weaned lambs, and 75–85% for heavy lambs.

The weights, linear measurements and volume indices of the carcasses clearly reflect the differences between the breeds, with the large-sized Foza and Lamon having greater values than the medium-sized Alpagota and Brogna, regardless of animal category ($p < .05$; Table 4). The two large-sized breeds, Foza and Lamon, exhibited no differences in any of the

Table 5. Effects of breed on the proportions of major carcass cuts and carcass tissue of ewes and lambs.

	Breed (LSMs):				Orthogonal contrasts (<i>p</i> -value):				RMSE
	Alpagota (A)	Brogna (B)	Foza (F)	Lamon (L)	F vs (A + B)	A vs B	B vs (F + L)	F vs L	
Major carcass cuts:									
Shoulder/fore shank, %:									
Ewes (Trial 1)	–	14.4	15.3	15.0	–	–	.194	.663	1.0
Suckling lambs (Trial 1)	–	17.2	17.7	17.0	–	–	.752	.287	1.2
Weaned lambs (Trial 2)	18.7	17.7	18.3	–	.654]	.020	–	–	0.7
Heavy lambs (Trial 3)	–	16.3	17.1	17.2	–	–	.006	.94	0.5
Neck and square cut, %:									
Ewes (Trial 1)	–	21.7	23.5	22.1	–	–	.132	.098	1.3
Suckling lambs (Trial 1)	–	22.3	20.1	21.0	–	–	.092	.432	2.1
Weaned lambs (Trial 2)	20.4	21.5	21.8	–	.221	.202	–	–	1.6
Heavy lambs (Trial 3)	–	23.0	23.0	21.7	–	–	.346	.278	1.1
Breast and flap, %:									
Ewes (Trial 1)	–	13.8	13.4	13.9	–	–	.803	.488	1.2
Suckling lambs (Trial 1)	–	10.9	9.7	9.6	–	–	.004	.873	0.8
Weaned lambs (Trial 2)	11.5	11.2	10.3	–	.003	.454	–	–	0.7
Heavy lambs (Trial 3)	–	13.2	10.5	12.7	–	–	.016	.08	1.2
Whole leg, %:									
Ewes (Trial 1)	–	33.2	33.3	32.4	–	–	.710	.405	1.7
Suckling lambs (Trial 1)	–	35.2	36.0	35.7	–	–	.332	.759	1.5
Weaned lambs (Trial 2)	35.0	34.3	35.0	–	.595	.275	–	–	1.1
Heavy lambs (Trial 3)	–	32.9	34.9	33.5	–	–	.152	.449	1.8
Loin, %:									
Ewes (Trial 1)	–	5.4	5.1	5.4	–	–	.581	.523	0.7
Suckling lambs (Trial 1)	–	6.3	5.7	5.9	–	–	.196	.657	0.8
Weaned lambs (Trial 2)	8.2	8.5	8.0	–	.314	.483	–	–	0.7
Heavy lambs (Trial 3)	–	6.7	6.9	9.8	–	–	.006	.014	1.1
Rack, %:									
Ewes (Trial 1)	–	6.0	6.3	6.0	–	–	.638	.385	0.5
Suckling lambs (Trial 1)	–	6.6	6.1	6.7	–	–	.484	.086	0.5
Weaned lambs (Trial 2)	5.8	6.0	5.9	–	.982	.453	–	–	0.5
Heavy lambs (Trial 3)	–	6.0	6.8	7.4	–	–	.085	.561	1.1
Carcass tissue proportions:									
Muscle, %:									
Ewes (Trial 1)	–	49.8	49.5	46.6	–	–	.468	.26	4.3
Suckling lambs (Trial 1)	–	59.0	57.3	59.8	–	–	.807	.23	3.6
Weaned lambs (Trial 2)	45.6	46.0	52.4	–	.013	.912	–	–	5.7
Heavy lambs (Trial 3)	–	49.6	43.5	46.8	–	–	.125	.56	5.6
Separable fat, %:									
Ewes (Trial 1)	–	24.3	22.5	27.4	–	–	.823	.15	5.6
Suckling lambs (Trial 1)	–	12.3	7.9	12.0	–	–	.114	.020	3.1
Weaned lambs (Trial 2)	17.6	19.2	13.8	–	.201	.695	–	–	8.0
Heavy lambs (Trial 3)	–	29.9	31.9	28.1	–	–	.961	.482	5.3
Bone, %:									
Ewes (Trial 1)	–	25.2	27.2	24.6	–	–	.644	.167	3.1
Suckling lambs (Trial 1)	–	26.9	33.4	27.2	–	–	.056	.004	3.6
Weaned lambs (Trial 2)	34.0	29.7	31.0	–	.655	.052	–	–	4.2
Heavy lambs (Trial 3)	–	21.1	25.0	24.7	–	–	.025	.922	3.0

In bold *P* values < 0.05.

measures. Within the medium-sized breeds, however, Alpagota weaned lambs had a lower carcass volume index than Brogna ($p = .01$), due to a smaller depth of chest ($p = .02$), and a much lower carcass weight loss ($p = .01$). There were no differences in the round conformation and compactness indices between the breeds regardless of animal category.

Carcass cuts and dissected tissues

The results regarding the six major carcass cuts and the carcass tissues (lean, separable fat, and bone) are summarised in Table 5. There were a few differences in the proportions of the major carcass cuts among the different age categories: the shoulder/fore shank was

proportionally lighter in ewes, the breast and flap heavier in heavy lambs and ewes, the whole leg heavier in suckling and weaned lambs, and the loin heavier in weaned lambs; the neck and square cut, and the rack did not differ much across the various age categories. Carcass lean represented almost 60% of the carcass weight of suckling lambs, but 50% in all the other age categories. Separable fat represented about 10% of the carcass of suckling lambs, 15% of weaned lambs, 30% of heavy lambs, and 25% of fattened ewes. Lastly, bone represented about 30% of the weight of the carcasses of suckling and weaned lambs, 20–25% of heavy lambs, and 25–30% of fattened ewes.

The effect of sex was significant only in heavy lambs after sexual maturation (data not shown). Males

Table 6. Effects of breed on the meat quality traits of ewes and lambs.

	Breed (LSMs):				Orthogonal contrasts (<i>p</i> -value):				RMSE
	Alpagota (A)	Brogna (B)	Foza (F)	Lamon (L)	F vs (A + B)	A vs B	B vs (F + L)	F vs L	
<i>Longissimus lumborum</i> , g:									
Ewes (Trial 1)	–	243	325	325	–	–	.021	.996	63
Suckling lambs (Trial 1)	–	118	138	164	–	–	.041	.155	32
Weaned lambs (Trial 2)	128	173	237	–	<.001	.024	–	–	37
Heavy lambs (Trial 3)	–	325	356	473	–	–	.002	.027	49
Protein, %:									
Ewes (Trial 1)	–	20.10	20.00	20.50	–	–	.552	.094	0.50
Suckling lambs (Trial 1)	–	20.60	21.00	21.20	–	–	.007	.286	0.40
Heavy lambs (Trial 3)	–	20.60	19.90	20.40	–	–	.376	.597	0.90
Lipids, %:									
Ewes (Trial 1)	–	3.90	5.10	4.80	–	–	.199	.753	1.50
Suckling lambs (Trial 1)	–	2.40	2.50	2.60	–	–	.595	.857	0.60
Heavy lambs (Trial 3)	–	7.30	6.60	6.70	–	–	.572	.948	2.20
Moisture, %:									
Ewes (Trial 1)	–	74.60	73.40	73.30	–	–	.168	.941	1.60
Suckling lambs (Trial 1)	–	76.40	76.50	75.80	–	–	.683	.165	0.80
Heavy lambs (Trial 3)	–	71.20	73.30	71.30	–	–	.205	.289	1.80
Ash, %:									
Ewes (Trial 1)	–	1.45	1.45	1.58	–	–	.474	.191	0.16
Suckling lambs (Trial 1)	–	1.80	1.85	1.79	–	–	.526	.089	0.06
Heavy lambs (Trial 3)	–	1.71	1.63	1.56	–	–	.282	.743	0.21
Collagen, %:									
Ewes (Trial 1)	–	1.35	1.49	1.32	–	–	.656	.202	0.21
Suckling lambs (Trial 1)	–	1.40	1.85	1.79	–	–	.470	.095	0.15
Heavy lambs (Trial 3)	–	1.67	1.31	1.83	–	–	.401	.038	0.23
Lightness, L*:									
Ewes (Trial 1)	–	32.40	33.60	30.70	–	–	.836	.055	2.40
Suckling lambs (Trial 1)	–	42.10	42.30	39.70	–	–	.462	.156	3.10
Weaned lambs (Trial 2)	40.0	40.00	37.200	–	.081	.957	–	–	3.50
Heavy lambs (Trial 3)	–	34.90	31.5	31.00	–	–	.003	.792	2.10
Redness, a*:									
Ewes (Trial 1)	–	9.70	9.90	9.80	–	–	.927	.922	1.70
Suckling lambs (Trial 1)	–	5.70	4.30	5.50	–	–	.303	.177	1.50
Weaned lambs (Trial 2)	6.6	6.80	7.70	–	.286	.841	–	–	2.10
Heavy lambs (Trial 3)	–	10.90	8.10	9.60	–	–	.011	.294	1.40
Yellowness, b*:									
Ewes (Trial 1)	–	8.70	9.70	9.00	–	–	.412	.388	1.50
Suckling lambs (Trial 1)	–	8.40	9.40	9.10	–	–	.236	.653	1.50
Weaned lambs (Trial 2)	9.8	10.4	10.10	–	.992	.456	–	–	1.60
Heavy lambs (Trial 3)	–	9.0	8.90	7.90	–	–	.483	.581	1.70
Chroma, C*:									
Ewes (Trial 1)	–	13.10	13.90	13.30	–	–	.637	.610	2.10
Suckling lambs (Trial 1)	–	10.30	10.50	10.70	–	–	.714	.879	1.70
Weaned lambs (Trial 2)	12.0	12.50	12.90	–	.467	.615	–	–	1.90
Heavy lambs (Trial 3)	–	14.10	12.00	12.50	–	–	.081	.806	2.00
Hue, H*:									
Ewes (Trial 1)	–	42.00	44.70	41.80	–	–	.508	.187	3.60
Suckling lambs (Trial 1)	–	55.40	67.00	59.00	–	–	.046	.074	7.70
Weaned lambs (Trial 2)	56.2	57.00	53.00	–	.353	.856	–	–	8.50
Heavy lambs (Trial 3)	–	38.70	48.10	39.10	–	–	.027	.038	4.10
Acidity, pH:									
Ewes (Trial 1)	–	5.54	5.54	5.45	–	–	.332	.070	0.08
Suckling lambs (Trial 1)	–	5.59	5.67	5.57	–	–	.536	.081	0.10
Weaned lambs (Trial 2)	5.6	5.64	5.63	–	.703	.991	–	–	0.12
Heavy lambs (Trial 3)	–	5.73	6.01	5.88	–	–	.018	.442	0.16
Cooking losses, %:									
Ewes (Trial 1)	–	30.90	30.10	29.00	–	–	.165	.283	1.80
Suckling lambs (Trial 1)	–	32.80	31.90	31.70	–	–	.345	.915	2.20
Weaned lambs (Trial 2)	26.9	23.50	23.90	–	.011	.263	–	–	2.50
Heavy lambs (Trial 3)	–	24.80	23.80	22.10	–	–	.151	.526	2.60
Shear force, N/cm ² :									
Ewes (Trial 1)	–	24.00	25.10	22.30	–	–	.916	.352	5.00
Suckling lambs (Trial 1)	–	22.20	29.50	26.10	–	–	.112	.404	7.20
Heavy lambs (Trial 3)	–	19.60	23.50	24.70	–	–	.049	.766	4.20

In bold *P* values < 0.05.

had greater proportions of shoulder and fore shank, neck and square cut, and rack ($p < .01$), confirmed by the greater proportion of bone ($p < .01$) and much

lower proportion of fat ($p < .01$) that was significant also in suckling lambs ($p < .01$) and in weaned lambs ($p = .05$).

A few differences in the relative proportions of the major cuts were observed among the breeds (Table 5), although not in the carcasses of ewes. The proportion of breast and flap was greater in Brogna and Alpagota than in Foza weaned lambs ($p < .01$), and the proportion of shoulder/fore shank was greater in Alpagota than Brogna weaned lambs ($p = .02$). Brogna suckling and heavy lambs had a greater proportion of breast and flap cut than Foza and Lamon ($p = .01$), compensated for by lower proportions of shoulder/fore shank and loin (heavy lambs only, $p < .01$).

The dissected tissues also showed a few differences among the breeds (Table 5). Foza weaned lambs had a greater proportion of lean meat than Alpagota and Brogna ($p = .01$); Brogna heavy lambs had a lower proportion of bone than Foza and Lamon ($p = .02$), whereas Foza suckling lambs had a greater proportion of bone ($p = .02$), and a lower proportion of separable fat ($p < .01$) than Lamon.

Meat quality traits

Table 6 summarises the results of the analyses carried out on the *Longissimus lumborum* muscle samples. As expected, this muscle increased in weight with the age of the lambs, but was lighter in ewes than in heavy lambs, even though their carcass weights were similar. The chemical composition of the muscle samples from weaned lambs was not analysed. Average protein, collagen and ash contents were similar across age categories; lipid content was much greater in heavy lambs than in suckling lambs, and was intermediate in ewes, while the reverse was found for moisture content. Lightness and hue colour traits of the cross-sectional surface of the muscle decreased with increasing age category, whereas redness and chroma increased, and yellowness was not much influenced. Cooking losses were greater in the meat samples from the carcasses of ewes and suckling lambs than in those of weaned and heavy lambs, whereas pH and shear force differed little across age categories.

Leaving aside the weight of the *Longissimus lumborum* muscle samples used for meat quality analyses, which, being quantitative data, reflect the differences in size among the breeds, the qualitative data did not reveal many differences among the breeds (Table 6). The meat proximate analysis showed only that the meat of Brogna suckling lambs had a slightly lower protein content than that of the Foza and Lamon ($p < .01$), and that Foza heavy lambs had a higher collagen content than the Lamon ($p = .04$). Differences in

meat colour were found only in Brogna heavy lambs, which had greater lightness ($p < .01$) and redness ($p = .01$), and a lower hue angle ($p = .03$) (the latter also in suckling lambs, $p = .05$) than Foza and Lamon. Brogna heavy lambs also had lower pH ($p = .02$) and shear force ($p = .05$) in the raw meat than in the cooked meat.

Discussion

The autochthonous sheep breeds of the Veneto region

The autochthonous sheep breeds of the Veneto region are the object of conservation programs funded by the European Union and the Veneto Regional Government. The results of this study confirmed the differences between the two large-sized breeds (Foza and Lamon) and the two medium-sized breeds (Alpagota and Brogna).

The Foza and Lamon breeds are typical of the traditional long-distance transhumance system (Pastore 2002), where large flocks are moved down to coastal areas during winter and up to highland pastures in summer. They are closely related to each other both geographically and genetically (Dalvit et al. 2009). They are mainly raised to produce lamb meat (suckling and weaned lambs) and mutton (castrated hogget, and culled ewes and rams), while the fleece, which is very coarse, is used for carpet wool. The ewes are not milked. This system has almost disappeared, and those shepherds that remain have shifted to raising other improved breeds of the same Alpine group, like the Bergamasca and Biellese (Ciani et al. 2014; Dimauro et al. 2015). Only a few breeders and a few hundred animals of these breeds are left, and their risk status is categorised by the FAO as critical (Bittante 2011), even though there are *in situ* and *ex situ* conservation programs in place for them. The Lamon and Foza breeds share the characteristics of Alpine ovine populations used in the past in transhumance systems: large size (see live weight figures, Table 2), long legs (see height at withers, Table 2, proportions of distal fore- and hind-legs on weight at slaughter, Table 3, and length of hind leg in the carcass, Table 4), and the high percentage of pelt (Table 3). The results show there were very few differences between the two large-sized local breeds, and the scientific literature contains no comparisons of these two breeds. It should be noted that the Lamon breed has also been tested in crossbreeding schemes aimed at extending the production of lamb to different seasons and to increase prolificacy (Bittante et al. 1996). In any

case, the population size, 'relics', of these two breeds is so small that marked oriented interventions do not seem feasible and the survival of the breeds seems to depend mainly on public and private subsidies.

The two medium-sized local sheep breeds (Alpagota and Brogna) were in the past and still are reared under a different system where small flocks are kept on permanent farms in the hilly and low mountain areas of the region, with some transfer to highland pastures during summer only (Pastore 2002). They are mainly reared to produce lamb and mutton, while the fleece, which is of intermediate quality, is used for textiles. In places, the ewes, especially of the Brogna breed, are still milked to produce pure sheep's milk cheese or mixed milk cheese (Pegorin). Several small breeders raise around a few thousand head of these breeds, which are classified by the FAO as endangered (Bittante 2011). In addition to the differences between the two large-sized breeds, we also found a few differences between the two medium-sized breeds: Brogna lambs were taller and fatter than the Alpagota, and had a smaller proportion of pelt (Table 3), a characteristic normally associated with 'dairyness', which was thus greater in the Brogna than the Alpagota (Bittante et al. 2014). Large variations among different local sheep breeds have also been found in other Alpine countries (Willems et al. 2013).

The production and quality of meat from lambs of different age categories, and from fattened ewes

The Alpine breeds of the Veneto region were in the past and still are the source of some local meat products, which could bring added value to the farming of them (Oliveira et al. 2014). Lamon ewes are used to produce 'Pendole', strips of meat from culled adult animals dried according to a traditional technique, while a local fermented sausage called 'Pitina' is produced from meat from the Alpagota breed (Bovolenta et al. 2007; Slow Food Foundation for Diversity 2020b). However, the major source of revenue for breeders today is the production of lambs. For example, 'Agnello Alpagoto', meat produced from Alpagota lambs reared in accordance with Slow Food guidelines, is one of this Foundation's prestigious Praesidia (Slow Food Foundation for Diversity 2020a).

The lambing season is normally concentrated at the end of winter, and weaned lambs are typically reared outdoors at pasture. However, the vegetative season of the grasses of natural meadows is relatively short, especially in the mountains, so if lambs are to be

produced in early spring (suckling lambs) or autumn and winter (heavy lambs) they need to be supplied with conserved feedstuffs. The scientific literature contains almost no studies comparing the production of lamb meat from local breeds of different age categories. We found that when lactating ewes and their suckling lambs were kept indoors and fed a total mixed diet till 3–4 months of age the lambs reached an acceptable slaughter weight (18–24 kg, on average, according to breed). This is a much greater slaughter weight than is typical of lambs of dairy breeds (Priolo et al. 2000; Scerra et al. 2007; Vacca et al. 2008), and is more similar to that of grass-reared animals (Fernandez-Turren et al. 2020; Ye et al. 2020). The dressing percentage (about 50%), carcass conformation, carcass composition and meat quality traits of the suckling lambs were also very good for this age category (Lirette et al. 1984).

The indoor feeding regime not only eliminated the weight loss that often affects ewes, especially those lambing twins or triplets, but allowed them to obtain moderate BCS, and, in particular, good dressing percentages (45–50%) and carcass conformations and compositions. It is worth noting that culled fattened ewes did not differ much from heavy lambs in terms of slaughter traits and meat quality (Table 4). It seems, therefore, that such animals could be used in developing gastronomic products from these local breeds, although more information is needed on the sensory properties of their meat (Kirton et al. 1985; Fruet et al. 2016).

The weaned lambs reared indoors and fed on hay and concentrates, as is sometimes done on traditional farms, were not comparable with those reared on rich lowland pasture, even when their diets were supplemented with concentrates to provide theoretically similar nutrient levels (Bittante et al. 2021). For all the breeds, the results from trial 2 confirmed the indoor-raised lambs as having suboptimal growth rates, dressing percentages (40–45%, according to breed), and carcass conformation and composition compared with other breeds and environments (Lirette et al. 1984; Demirel et al. 2004; Ye et al. 2020). Here, too, further knowledge is needed regarding the optimal quantity of concentrate, and on substituting traditional diets with a total mixed diet including silages (Jiménez et al. 2019).

A very good growth rate, for these four types of local sheep breeds, was obtained using total mixed rations to fatten heavy lambs till about one year of age (61 kg slaughter weight, 48% dressing percentage). The high level of carcass fat could be reduced

by moderating the energy concentration of the TMR or by restricting this type of production to ram lambs. Nonetheless, more information is needed on the sensory characteristics of this type of meat (Gkarane et al. 2019; Bhatti et al. 2020). Notwithstanding the high average percentage of separable fat (30%), observed with all the breeds (Table 5), the intramuscular fat content remained within acceptable limits (7%). In general, the meat quality characteristics were acceptable: as expected, the meat had a darker colour than the meat from younger lambs, but lower cooking losses, and the tenderness of the cooked meat was similar for both age categories.

Compared to the Lamon breed, better known for the typical products already mentioned, the heavy lambs of the Foza breed show similar aptitudes for the production of heavy carcass. Moreover, heavy lambs of Foza breed had meat with a lower connective content but a darker colour. It worth noting that in the past both breeds were used for production of castrated hoggets of good reputation. The opportunity to abolish castration should be evaluated, both for animal's welfare motivations and because of excessive fattening when high-energy diets are available. These aspects suggest that further research on the meat quality and palatability of the two breeds is needed.

Between the two medium-sized breeds, the Alpagota breed is famous for the lamb production, which benefit of a Slow Food Praesidium certification and this way of valorisation was confirmed to be fully justified by our study, but also the mutton obtainable from culled ewes could become an additional source of income for farmers.

The Brogna breed showed numerous similarities with Alpagota breed for lamb production, but shows more 'dairy' characteristics, as suggested also by greater accumulations of body fat, but also a slightly greater body dimension and incidence of Longissimus muscle. In this case, it appears that the possibility of valorisation of milk/cheese production could be evaluated because this is not new in the history and in the present time of this breed and could possibly be exploited for enhancing the survival of this breed.

Conclusions

This case study of four sheep breeds from the Veneto region showed these autochthonous Alpine breeds to have a good capacity for producing meat, and confirmed the larger size of the Foza and Lamon breeds over the Alpagota and Brogna, as well as the slightly greater dairyness of the latter. As an alternative to the

traditional Alpine method of fattening weaned lambs at pasture, the adoption of total mixed diets resulted in good *in vivo* and *post mortem* performances of ewes, suckling lambs and heavy lambs, and showed these autochthonous Alpine breeds to be potentially valuable sources of high quality lamb and mutton across different seasons of the year. This potential could be exploited in developing a prestigious product aimed at high quality restaurants and butchers. The subsequent demand for the product would, in turn, contribute to the survival of the local sheep breeds of Alpine regions.

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.

Acknowledgements

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

Disclosure statement

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

Funding

This work was supported by the Veneto Region with the Bionet Project (misura 214 – pagamenti agroambientali – sottomisura H – Rete regionale della biodiversità).

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