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The heavy suckling lamb of Sarda dairy sheep and its crossbreed with Dorper rams: Performance, meat quality and consumer perceptions

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ABSTRACT

The increase of meat production in dairy sheep farms, has been evaluated by the extension of the suckling period from the traditional 28 days to 75 days to obtain a new product, the heavy suckling lamb. Nineteen single-born Sarda (S) lambs (10 male, 9 female) and 20 single-born Dorper x Sarda (DS) lambs (9 male, 11 female), randomly selected from autumn lambing season, were fed exclusively with maternal milk until slaughtering at 20 ± 0.28 kg of body weight (BW, mean ± standard deviation, SD) and approximately 11 weeks of age. Body weight were recorded at birth and every 15 days until slaughter to estimate average daily gain (ADG). At slaughter, carcass measurements, pH and colour traits were recorded from the left side of the carcass. Proximate composition, fatty acid (FA) profile, cooking and drip losses were evaluated using the *Longissimus thoracis et lumborum* (LTL) muscle. In addition, Visual Panel Test (VPT) and Taste Panel Test (TPT) were performed. Experimental results evidenced that ADG did not differ between pure and crossbreed lambs and between sexes. The S lamb carcasses showed a higher fat content and rib fat thickness compared to that of crossbreed. No significant differences were found between genetic types and sex for colour and pH determinations, cooking and drip losses, whereas LTL fat of DS displayed a higher nutritional FA profile with higher content of 22:5n-3, 22:6n-3, branched-chain FA, and odd- and branched chain FA. No differences emerged during VPT and TPT, demonstrating that both DS and S lamb meats present no distinguishable visual and eating quality characteristics. The production of heavy suckling lambs from Sarda and Dorper crossbreed by the extension of suckling period appeared a promising strategy for producing meat of high quality, well appreciated by the consumers.

1. Introduction

In Mediterranean dairy sheep farms, lambs are usually sold as suckling and slaughtered at about 4–5 weeks of age, with a body weight (BW) of about 10 kg. The early slaughtering age depends mainly on the shepherds' interest for selling milk or turning it into cheese on the farm; indeed, the conversion rates of milk to lamb meat decline beyond this age (Battacone, Lunesu, Rassu, Pulina, and Nudda, 2021; Nudda et al., 2019; Santos, Silva, Mena, and Azevedo, 2007), because the genetic background of dairy breeds, oriented toward milk production, enhance body fat deposition.

In the Mediterranean Europe, lamb's meat consumption is traditionally associated with the Christmas and Easter time and the slaughtering period is concentrated in winter (December–January) and spring (March–April) seasons. Consequently, the economic value of lamb carcasses is strongly affected by the seasonality of market demand, with negative effects for farmers income when ewes give birth when the demand for this product is depressed. For Mediterranean dairy sheep industry, the sale of milk-fed lambs represents a significant amount of the revenue of the farmers (20–30% of the total farm income, Pulina et al., 2018).

The per capita consumption of lamb has been steadily decreasing in recent decades worldwide (FAO, 2022) and this pushes the lamb-meat industry to be competitive. Several studies have demonstrated the growing importance that consumers attribute to the intrinsic and extrinsic characteristics of lamb meat in driving their choices (Bernabéu, Rabadán, El Orche, and Díaz, 2018; Rabadán, Díaz, Brugarolas, and Bernabéu, 2020). Sardinia, with more than tree millions of Sarda dairy sheep, produce about 75% of the Italian suckling lamb meat. Regolamento, (CE) n. 138/2001 – Gazzetta ufficiale Comunità europee L 23, 25.01, 2001 is one of the most relevant quality labels for meat from suckling lambs produced in the Mediterranean dairy sheep farms. In

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addition to the traditional suckling lamb, this PGI protocol provides indications to produce the category of "cutting lambs" by using Sarda purebred or by its crossing with specialised and tested meat breeds to obtain carcasses weighing between 10 and 13 kg. Since "cutting lambs" are fed mostly on mother's milk, this category of lamb is not preferred by Sardinian dairy sheep farmers, which instead choose to maximize the income from milk sales, especially when the market price of sheep milk is high. Furthermore, purebred Sarda lambs, when slaughtered at weight higher than 10 kg, are characterized by an excessive body fat accumulation, which is not appreciated by consumers.

Crossbreeding between dairy and meat sheep is considered worldwide as a valuable opportunity to obtain lambs with a higher commercial value due to the carcasses traits that best meet the expectations of consumers (Ellies-Oury, Papillon, Arranz, and Carpentier, 2022). The crossbreeding of Sarda dairy ewes with rams of meat breeds, such as Ile de France, has been studied to produce suckling lambs slaughtered at 10–13 kg of BW (Acciaro et al., 2020). To date, no information is available on the growth performance and carcass traits of lambs obtained by crossing dairy breed as Sarda ewes with Dorper rams, even though this type of crossbreeding is eligible for the PGI "Agnello di Sardegna", nor on the use of crossbreeding to produce a heavy suckling lamb (around 20 kg of BW at selling 60 days of age). However, the extension of the feeding period in crossbred and purebred lambs has been tested with the aim of finding sustainable approaches to meet the growing international demand for red meat produced in Australia (Ponnampalam, Knight, Moate, and Jacobs, 2020).

This practice would allow a shift of the sale period to place the product at a more commercially favourable time, without compromising the typical features of the dairy lambs.

Dorper is a meat breed of South Africa characterized by high adaptability to hot and arid conditions (like Mediterranean area), early maturity, and fast-growing (Cloete, Snyman, and Herselman, 2000; Gavojdian, Cziszter, Pacala, and Sauer, 2013), and it has been largely used to improve the growth performance and carcass traits in crossbreeding with indigenous breed of tropics and China (Gebreyowhens, Regesa, and Esifanos, 2017; Teklebrhan, Urge, Mekasha, and Baissa, 2014).

The objective of this study was to evaluate the potential of the crossbreed, in terms of growth performance, carcass characteristics, lamb meat quality and consumer perceptions obtained by crossing Sarda dairy ewes with Dorper rams, particularly adapted to harsh Mediterranean climate. This is intended to achieve an improvement in the technical knowledge useful to properly evaluate the use of this crossbreed to improve market conditions of dairy sheep farms by production of the category "heavy suckling lamb".

2. Material and methods

The experiment was conducted from December 2021 to March 2022, and it was compliant with the Animal Research: Reporting of In Vivo Experiments (ARRIVE) guidelines and in accordance with the U.K. Animals (Scientific Procedures) Act, 1986 and associated guidelines, EU Directive 2010/63/EU for animal experiments. Indeed, all procedures were approved by the Ethics committee (O.P.B.A) of the University of Sassari (Prot. n. 58,790 21/05/2021).

2.1. Experimental procedure

A total of 39 single-born lambs were used. Among them, 19 lambs were from Sarda (S) purebred (10 male and 9 females) and 20 lambs were from Dorper x Sarda (DS) crossbreeds (9 male and 11 females). They were randomly selected from a commercial dairy sheep farm located in the centre-east of Sardinia. The S lambs were generated by breeding 5 Sarda rams with 200 Sarda ewes, and the DS lambs were generated by breeding 4 Dorper rams with 80 Sarda ewes.

Both groups of ewe lambs were housed and kept separately in two adjacent paddocks in a common barn. Ewes were fed the same diet consisting of 1 kg of a commercial concentrate (dry matter, DM: 84.77%; crude protein, CP: 21.42%, neutral detergent fibre, NDF: 20.04%, on DM basis) and an ad libitum base ration of mixed field bale wrapped haylage (DM: 48.21%; CP: 11.88%, NDF: 63.21%, on DM basis) with an estimated forage intake of 1.24 kg DM. The diet contained a total of 15.8% CP and 43.9% NDF (DM basis) and was fed twice a day (morning and afternoon). In addition, they were not milked because all the milk was suckled by the lambs.

In accordance with the PGI "Agnello di Sardegna", lambs were housed with the mothers all day and nourished by suckling milk from birth until reaching approximately 20 kg of BW obtained experimentally at 11 weeks, to achieve a carcass weight between 10 and 13 kg, with a slaughter yield of 60%. This new non-traditional product first called here *heavy suckling lamb*.

2.2. Measurements and samples collection

Lamb BW was recorded at birth and every 15 days until slaughter. Ewes and lambs stayed together until the day of slaughter. The lambs were separated in the morning and transported (85 km) to an EU-approved commercial abattoir. Lambs were electrical stunned and then the jugular vein was severed.

Carcass measurements, pH and colour traits were recorded from the left side of the carcass.

The carcasses weight was measured immediately after slaughter (hot carcass weight) and after 48 h of cooling to 4 °C (cold carcass weight). Carcass yields were calculated as the percentages of the hot and cold carcass weights relative to the final BW. The final BW was measured directly prior to slaughter. After 48 h, lamb carcasses were split in different cuts and each portion was weighted. The methods of cutting were in accordance with the indications of the Regolamento, (CE) n. 138/2001 – Gazzetta ufficiale Comunità europee L 23, 25.01, 2001.

Body fat deposition was evaluated separating and weighting perirenal and peritoneal fats. Carcasses were ribbed. In addition, rib fat thickness was measured between the 12th and 13th rib using an electronic caliper (Electronic Digital Caliper, 150 mm, INECO, Italy) accurate to 0.02 mm.

2.2.1. Colour and pH determinations

Colour measurements (L^*, lightness, a^*, redness/greenness and b^* yellowness/blueness, CIE, 1986) were carried out using a Minolta colorimeter (CM-600d Konica Minolta, Japan; 10° observer angle and D65 illumination) approximately at 45 min *post-mortem* at the end of slaughterline on the *Rectus abdominis* muscle, on the superficial fascia without removing the fat, between the 6th and 7th rib. Meat colour was measured at 48 h after slaughter in the *Longissimus thoracis et lumborum* (LTL) muscle on the 12th rib on freshly cut surfaces after about 3 min of blooming. The average of five readings were recorded.

The pH and temperature were measured 45 min after slaughter and after 3, and 48 h of storage at 4 °C using a temperature-compensated pH meter calibrated using pH 4 and 7 reference solutions at regular intervals before use (Thermo Scientific 0250A0 pH/mV/relative mV/temperature meter, model 250A, Orion Research Inc., Boston, MA, USA).

2.2.2. Meat quality analyses

The LTL muscle samples were collected from carcasses after 48 h *post-mortem* and used for the determination of cooking and drip losses, proximate composition, and fatty acid (FA) profile.

2.2.2.1. Water holding capacity. Water holding capacity was determined by measuring drip loss and cooking loss of the samples. Meat samples were used for cooking loss after colour measurements. Cooking loss was performed in two replicates, and it was measured according to

Nudda et al. (2013), by cooking about 25 g of LTL sample (W1) in microwave at 650 W, for about 35 s, until a core temperature of 75 °C was reached. The internal temperature was measured using a digital thermometer (Taylor USA, model 9847 N, Oak Brook, IL, USA), inserted in the centre of the sample, immediately after its removal from the oven. Samples were cooled down to room temperature, dried with filter paper and weighed (W2). Cooking loss (%) was calculated as {(W1-W2)/W1} × 100.

Drip loss was measured without replications by using about 25 g of LTL sample (W1), suspended for 24 h at 4 °C in a plastic bag, avoiding contact with the bag. After 24 h, sample was removed from the plastic bag, blotted dry, and weighed (W2), and the drip loss was calculated as (%) = {(W1-W2)/W1} × 100 according to Honikel (1998).

2.2.2.2. Proximate composition analyses. About 40 g of LTL were used to determinate moisture, total protein, and fat contents. Total fat content was determined in accordance with Folch, Lees, and Stanley (1957), whereas crude protein and total ash according to the Association of Official Analytical Chemists (AOAC) method (2000).

2.2.2.3. Fatty acid analysis. The LTL muscle was stored at −80 °C until the analysis. Moisture content was determined on about 40 g of samples after 72 h of freeze-drying. Lyophilized and finely ground of LTL meat samples was used for fat extraction according to Folch et al. (1957), with some modification. Briefly, 30-mL chloroform:methanol (2:1) were added to one g of sample in a 50-mL tube; the sealed tube, shaken for 30 s, sonicated for 5 min, and then centrifuged at 600 ×*g* for 10 min. The supernatant was filtered under vacuum and 6 mL 1% NaCl (wt/vol) were added, and centrifuged again at 600 ×*g* for 10 min. Then the upper methanol:water layer was then discharged, whereas the chloroform extract layer was evaporated under nitrogen. Twenty mg of extracted lipid fraction were converted to FA methyl esters (FAMEs) using the standard procedure of the International Dairy Federation (IDF, 1999) base-catalyzed methylation procedure. One mL of internal standard (0.5 mg/mL of 19:0 methyl ester; Sigma-Aldrich) was added before methylation. The FAMEs were separated in a capillary column (CP-Sil 88,100 × 0.25 × 0.2, Agilent Technologies, Santa Clara, CA, USA). Single FAMEs were identified using FAMEs standards and considering elution order published in literature, as detailed previously by Nudda et al. (2011). Analytical standard included the Supelco 37 component FAME MIX (Supelco, Bellefonte, PA, USA), the GLC-110 MIX (Matreya Inc. Pleasant Gap, PA, USA). High purity individual isomers of conjugated linoleic acid (CLA; *c*9,*t*11–18:2 and *t*10,*c*12–18:2; Matreya Inc., Pleasant Gap) were used to identify most CLA isomers of interest. Additional standard CLA isomers *c*9,*c*11–18:2, *t*9,*t*11–18:2, *t*11,*t*13–18:2 (77% cis,trans; 2% cis,cis; 6% trans,trans) (Matreya Inc., Pleasant Gap), a CLA mixture standard (Nu-Check-Prep. Inc., Elysian, Minn., U.S.A.) was used. Some individual branched-chain FA (BCFA) were used (Matreya Inc. Pleasant Gap, PA, USA). Polyunsaturated FAn-2 (PUFAn-2), a nonconjugated 18:2 isomer mixture of individual PUFA, all *cis*-5,8,11,14,17–20:5 (eicosapentaenoic acid, EPA), all *cis*-4,7,10,13,16,19–22:6 (docosahexaenoic acid, DHA), all *cis*-5,8,11,14–20:4 (arachidonic acid, ARA), all *cis*-6,9,12–18:3, and all *cis*-9,12,15–18:3 (Matreya Inc., Pleasant Gap, Pa., U.S.A.) were used to identify PUFA. Each FA was expressed as percent of total FAME. The saturated FA (SFA) was calculated as the sum of the individual saturated FA; monounsaturated FA (MUFA) as sum of the monounsaturated FA; PUFA as the sum of polyunsaturated FA; PUFAn-6 as sum of the PUFA belonging to the n-6 family; PUFAn-3 as the sum of the PUFA belonging to the n-3 family; odd- and branched-chain FA (OBCFA) as the sum of odd-chain FA (OCFA) and BCFA. Nutritional indices for assessing nutritional quality of FAs were calculates (Chen and Liu, 2020): the index of atherogenicity (AI), the index of thrombogenicity (TI), and the hypocholesterolemic/hypercholesterolemic ratio (h/H). They were calculated as follow: AI = [12:0 + (4 × 14:0) + 16:0]/[(PUFA) + (MUFA)]; TI = (14:0 + 16:0)/[(0.5 × MUFA) + (0.5 × n-6) + (3 × n-3) + (n-3:n-6)]; h/H = [(sum of *c*9–18:1, *c*11–18:1, 18:2n-6, 18:3n-6,18:3n-3, 20:3n-6, 20:4n-6, 20:5n-3, 22:4n-6, 22:5n-3 and 22:6n-3)/(14:0 + 16:0)].

2.2.3. Visual and Taste Panel Test

For Visual Panel Test (VPT) and Taste Panel Test (TPT), DS and S heavy suckling lamb meats were compared. Eleven trained panellists were involved, in three sessions.

Panel test was performed using all male lambs. The visual attributes rated were appearance, tenderness, consistency, quality, colour, odour, freshness and ranking of acceptability. The eating quality attributes were palatability, tenderness, consistency, odour, freshness, chewiness, juiciness, texture, taste, flavour, aroma, level of yield and the overall acceptability and the preference test has been done. The level of yield refers a lean to fat proportion.

A ten-point (0–10, 0 very bad, 10 excellent) descriptive scale was used as scoring system and the preference test has been carried out, choosing the favourite.

2.2.4. Statistical analysis

Data on birth weight, slaughter weight, hot and cold carcass weights, carcass traits, colour, pH and temperature measurements, drip loss, cooking loss, proximate composition, and FA profile were analysed by the PROC GLM procedure of SAS to test the difference between the genetic type (S and DS) and sex, and their interactions.

Data on ADG were analysed by a PROC MIXED of SAS. The model included genetic type, sex and time as fixed effect with interaction terms for genetic type x sex, genetic type x time and sex x time. Random term for animal was also included.

For VPT and TPT, data were analysed by a PROC MIXED procedure of SAS including the effect of genetic type and session as fixed effects with interaction terms for genetic type and session, and random term for panelist. Means were separated using Tukey's test. Data of the preference test were analysed with a Chi-square test of association. The accepted level of significance was $P \leq 0.05$.

3. Results

3.1. Animal performance and carcass traits

Almost all the production traits, summarized in Table 1, were not significantly different between genetic type and sex, except for the carcass yields (hot and cold) that were highest in the females ($P < 0.01$). For ADG, the effect of genetic type (0.22 kg/d for both DS and S lambs; $P = 0.78$) and sex (0.24 vs. 0.21 ± 0.02; for males and females, respectively; $P = 0.07$; Fig. 1) were not significant while the effect of time was significant ($P = 0.001$). Any significant genetic type x sex interaction was found for growth performance (Table 1).

Regarding carcass traits (Table 2), S lambs had a higher peritoneum weight ($P < 0.05$), perirenal fat content ($P < 0.01$) and rib fat thickness ($P < 0.001$) than DS lambs; the females have a highest kidneys ($P < 0.05$) and peritoneum ($P < 0.05$) weights and perirenal fat content ($P < 0.01$) and rib fat thickness ($P < 0.05$). A significant interaction between genetic type and sex was observed for rib fat thickness ($P < 0.05$), due to higher fat accumulation in female than males in S (results not shown), whereas no differences between the sexes have been observed in the crossbreed.

3.2. Colour, pH, temperature and water holding capacity

The genetic type did not affect the colour parameters (Table 3), either measured 45 min and 48 h after slaughter whereas the effect of sex evidenced higher L^* parameter and lower temperature at 3 h after slaughter, in males than females.

The pH and the temperature measured 45 min after slaughter, were

Table 1
Growth performance of Dorper x Sarda and Sarda heavy suckling lambs.

	Genetic type		Sex		SEM[a]	*P*-value[b]		
Item	Dorper x Sarda	Sarda	Males	Females		GT	Sex	GT x Sex
Birth weight, kg	3.90	3.71	3.82	3.87	0.09	ns	ns	ns
Slaughter weight, kg	19.50	20.46	20.41	19.59	0.290	ns	ns	ns
Hot carcass weight, kg	11.91	12.51	12.23	12.20	0.210	ns	ns	ns
Cold carcass weight, kg	11.67	12.29	11.99	11.99	0.201	ns	ns	ns
Hot carcass yield, %	61.00	61.10	59.87	62.17	0.400	ns	**	ns
Cold carcass yield, %	59.80	60.06	58.69	61.12	0.398	ns	**	ns

[a] SEM = standard error of the mean.
[b] GT = genetic type; GT x Sex = genetic type and sex interaction; * $P \leq 0.05$; ** $P < 0.01$; ns = not significant.

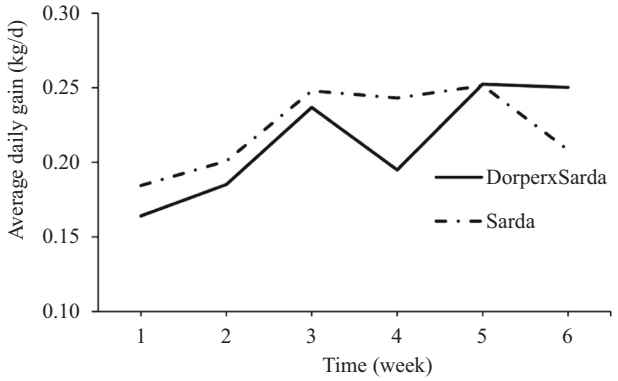

Fig. 1. Evolution of average daily gain (ADG, kg/d) in Dorper x Sarda and Sarda heavy suckling lambs.

higher in S than DS lamb carcasses (Table 3). The temperature measured 3 h after slaughter were highest in S and in female lambs.

The genetic type and sex did not influence both drip and the cooking losses (Table 3). A significant interaction ($P < 0.05$) between genetic type and sex was evidenced for drip loss, being higher in males than females in crossbreed compared to S, most likely related to the fat content of meat S (results not shown).

3.3. Proximate composition and fatty acid profile

The effect of genetic type, sex and their interaction on the proximate composition and the FA profile of lamb meat are presented in Table 4. The DS had a higher moisture ($P < 0.01$) and a lower fat content than S lambs ($P < 0.01$). The sex of lambs did not affect the composition and influenced only few FAs.

Compared to S, DS lambs had a higher 14:0iso, 15:0iso, 15:0ai, 15:0 and 16:0iso, 22:0, 22:4n-6, 22:5n-3, 22:6n-3, SFA, OCFA, BCFA and OBCFA contents. The DS also presented a higher AI value ($P < 0.05$) than S lambs while TI and h/H indices did not differ between the two breeds.

The S lambs showed a greater concentration of *c*9–16:1, *t*9–18:1, *c*12–18:1, *c*13–18:1 and MUFA than DS.

In males there were higher 17:0iso and SFA and lower *c*9–16:1, *c*9–17:1, *c*9–18:1, *c*13–18:1 and MUFA concentrations than females. Males also presented a higher AI value ($P < 0.05$) than S lambs while the TI and h/H indices did not differ between the two sexes.

A significant interaction between genetic type and sex was evidenced for *c*7–16:1 ($P < 0.05$), 18:3n-3 ($P < 0.05$), and for 22:6n-3 ($P = 0.05$), because were significantly higher in female of crossbreed compared to S, whereas no differences in males was found.

The content of FAs in 100 g of meat (Table 5) of DS lamb was significantly lower compared to S lamb for almost all FAs. The sex of the lambs influenced only *c*13–18:1, which was significantly higher ($P < 0.05$) in males than females. The interaction between genetic type and sex was never significant.

3.4. Consumer perception

Results on consumers perception evaluated by VPT and TPT are summarized in Tables 6 and 7. The effect of genetic type was not significant for any quality characteristics evaluated by the VPT and TPT ($P > 0.05$). The session did not affect the results. Any significant genetic type x session interaction was found. The preference test did not evidence significant differences both for VPT ($P = 0.45$) and TPT ($P = 0.17$).

4. Discussions

4.1. Animal performance and carcass traits

The extension of suckling period to produce heavy suckling lambs

Table 2
Carcass traits of Dorper x Sarda and Sarda heavy suckling lambs.

	Genetic type		Sex		SEM[a]	*P*-value[b]		
Item	Dorper x Sarda	Sarda	Males	Females		GT	Sex	GT x Sex
Pluck weight, kg	1.23	1.25	1.26	1.22	0.024	ns	ns	ns
Head weight, kg	0.87	0.86	0.87	0.86	0.015	ns	ns	ns
Tail weight, kg	0.16	0.15	0.23	0.08	0.034	ns	ns	ns
Neck weight, kg	0.54	0.63	0.62	0.56	0.022	*	ns	ns
Legs weight, kg	2.83	2.93	2.91	2.85	0.051	ns	ns	ns
Shoulder weight, kg	1.75	1.82	1.80	1.77	0.033	ns	ns	ns
Rib weight, kg	1.39	1.42	1.43	1.38	0.04	ns	ns	ns
Belly weight, kg	0.96	1.11	0.98	1.10	0.032	ns	ns	ns
Kidneys weight, kg	0.08	0.08	0.08	0.07	0.001	ns	*	ns
Peritoneum weight, kg	0.20	0.28	0.21	0.26	0.016	*	*	ns
Perirenal fat, kg	0.12	0.20	0.13	0.19	0.01	**	**	ns
Rib fat thickness, mm	2.31	4.15	2.76	3.72	0.30	***	*	*

[a] SEM = standard error of the mean.
[b] GT = genetic type; GT x Sex = genetic type and sex interaction; * $P \leq 0.05$; ** $P < 0.01$; *** $P < 0.001$; ns = not significant.

Table 3
Meat colour, pH, temperature, drip loss and cooking loss of Dorper x Sarda and Sarda heavy suckling lamb carcasses.

	Genetic type		Sex		SEM[a]	*P*-value[b]		
Item	Dorper x Sarda	Sarda	Males	Females		GT	Sex	GT x Sex
*L** (brightness) 45 min	60.8	60.5	61.5	59.8	0.46	ns	*	ns
*a** (red–green component) 45 min	5.8	6.0	5.5	6.3	0.33	ns	ns	ns
*b** (yellow-blue component) 45 min	11.9	12.6	12.0	12.5	0.37	ns	ns	ns
*L** 48 h	39.2	38.0	39.1	38.1	0.52	ns	ns	ns
*a** 48 h	15.4	14.7	14.9	15.2	0.32	ns	ns	ns
*b** 48 h	12.6	12.2	12.6	12.2	0.21	ns	ns	ns
pH 45 min	6.13	6.38	6.29	6.22	0.06	*	ns	ns
pH 3 h	5.57	5.86	5.80	5.63	0.07	ns	ns	ns
pH 48 h	5.55	5.55	5.54	5.56	0.01	ns	ns	ns
T 45 min, °C	31.83	34.03	32.37	33.41	0.40	**	ns	ns
T 3 h, °C	17.44	19.29	17.34	19.31	0.49	*	*	ns
T 48 h, °C	4.74	4.99	4.99	4.74	0.17	ns	ns	ns
Drip loss, %	1.06	1.14	1.47	1.02	0.07	ns	ns	*
Cooking loss, %	32.80	33.56	31.60	32.95	0.53	ns	ns	ns

[a] SEM = standard error of the mean.
[b] GT = genetic type; GT x Sex = genetic type and sex interaction; * $P \leq 0.05$; ** $P < 0.01$; ns = not significant.

could be a valid strategy to satisfy the market demand, improving meat quality. The production of heavy suckling lambs by local dairy breeds could lead to production of meat only during specific time of year and with a higher fat content since their genetic background, oriented to milk production, enhance body fat storage. Crossbreeding of dairy ewes, as Sarda breed, with meat breeds such as the Dorper can help to improve the value of meat and increase its accessibility.

In this study, the extension of suckling period probably limited growth performance of DS lambs showing the same BW in the two genetic groups at the time of slaughter. In fact, performance of crossed Dorper lambs tend to be higher in finishing systems based on high energy diets (Schoeman, 2000). In our trial, lambs were fed maternal milk and this type of feeding could probably depress ADG of crossbreed animals. The highest visceral body fat deposition observed in purebred S lambs is justified by the higher tendency of this breed to accumulate body fat because of its selection for milk production. Breeds selected to milk or meat production have a different body fat distribution, with a higher subcutaneous fat deposition in meat than in milk breeds, which, instead, have a higher visceral fat deposition (Kempster, Arnall, Alliston, and Barker, 1982; Ronchi, Bernabucci, and Bertoni, 1993; Wood, MacFie, Pomeroy, and Twinn, 1980). The higher body fat deposition observed in females than males, that justify the higher dressing percentage and carcass yields, was expected and could be due to the early maturity and primary fat deposition that characterized females (Rodríguez et al., 2008). The significant interaction for rib fat thickness could be explained in S by the early maturation of females than males, and the different response in DS could be related to different precocity between breeds.

4.2. Colour, pH, temperature and water holding capacity

Colour is one of the most important meat quality attributes that drive meat consumer preferences, and which depend mostly on animal diet, genotype, and age (Estrada-León et al., 2022; Radzik-Rant et al., 2020; Tomasevic, Djekic, Font-i-Furnols, Terjung, and Lorenzo, 2021). In our study, no relevant differences for colour parameters were observed between genetic types and sex, as both DS and S lambs were milk-fed and reared from the same breed of ewes (Sarda ewes) fed the same diet. *Post-mortem* pH measurements with cooking and drip losses are also considered as the main indicators of the technological quality of meat (Listrat et al., 2016). In this study, no relevant differences were observed between genetic types and between sex for pH, which 48 h after slaughter reached an appropriate value of 5.5 in both groups, indicating that meat colour and meat organoleptic characteristics were not altered by crossbreeding (Estrada-León et al., 2022; Tomasevic et al., 2021).

Cooking and drip losses did not differ between genetic types and sex. These parameters are particularly important to evaluate meat quality: the lower water losses during cooking the higher meat juicier (Estrada-León et al., 2022). Moreover, if the syneresis (Devi, Rasane, Kaur, and Singh, 2019) during carcass storage is limited, decreases the accumulation of a reddish liquid fraction around the packaged product, which negatively affect consumer perception (Devi et al., 2019; Estrada-León et al., 2022).

4.3. Proximate composition and fatty acid profile

Differences between DS and S heavy suckling lambs on meat quality and composition are independent of maternal diet since both groups of ewes, belonging to the Sarda breed, were fed the same diet. The meat of DS exhibited a lower amount of intramuscular fat than S: this could be explained by genotype as meat breeds differ in their capacity for intramuscular fat accumulation compared to dairy breeds (Prache, Schreurs, and Guillier, 2022). The fat content of meat has been commonly associated to the water holding capacity. However, in this experiment, despite differences in the intramuscular fat content, the drip loss and cooking loss did not change in accordance with previous report (Zhang, Liu, Kong, Li, and Yue, 2022), confirming that pH, rather than the fat content, is one of the most important factors influencing the water holding capacity in meat.

The FA profile showed that for both genetic types, the predominant FA was oleic (*c*9–18:1), followed by palmitic (16:0) and stearic acids (18:0) in line to that reported previously for different breeds and lamb production systems (Serra et al., 2009; Nudda et al., 2011; Diaz et al., 2005; Battacone et al., 2021).

Mirystic acid (14:0) was higher and myristoleic was lower in DS than S lambs. Despite 14:0 has been included as one of the main atherogenic and thrombogenic FA, it has several beneficial health properties as contrasting aging-related disorders (Mahmoudi et al., 2019; Ponnappan, Holley, and Lipschitz, 1996; Shang et al., 2022), skin inflammation (Alonso-Castro, Serrano-Vega, Pérez Gutiérrez, Isiordia-Espinoza, and Solorio-Alvarado, 2022), hyperglicemia (Iwata, Sakai, Takahashi, and Sakane, 2019; Sakai, Matsumoto, Urano, and Sakane, 2022; Takato, Iwata, Murakami, Wada, and Sakane, 2017), and potential therapeutic effect on bone aging-related diseases, such as osteoporosis and osteoarthritis (Kwon, Jin, Kim, Kim, and Lee, 2015). Myristic acid has also strong antimicrobial potential (Chen et al., 2019) and it is a new candidate marker of severe inflammation and sepsis, as its concentration decrease in patients with septic shock (Zazula et al., 2021). In view of the higher 14:0 concentration, DS lamb meat evidenced a higher AI value, an indicator used for assessing the nutritional value of foods (Attia, Al-Harthi, Korish, and Shiboob, 2017).

The BCFA 14:0iso, 15:0iso, 15:0ai and 17:0iso and the OCFAs,

Table 4
Proximate and fatty acid composition (% of total fatty acids) in muscle (*Longissimus thoracis et lumborum*, LTL*)* of Dorper x Sarda and Sarda heavy suckling lambs.

	Genetic type		Sex		SEM[b]	*P*-value[c]		
Item[a]	Dorper x Sarda	Sarda	Males	Females		GT	Sex	GT x Sex
Moisture, %	72.98	71.20	72.35	71.79	0.33	**	ns	ns
Protein content, %	18.47	18.22	18.27	18.42	0.44	ns	ns	ns
Fat content, %	6.90	9.32	7.85	8.41	0.12	**	ns	ns
14:0	8.19	7.60	8.15	7.67	0.154	*	ns	ns
*c*9–14:1	0.30	0.34	0.31	0.33	0.010	*	ns	ns
14:0iso	0.08	0.06	0.07	0.07	0.003	***	ns	ns
15:0iso	0.22	0.20	0.21	0.21	0.004	*	ns	ns
15:0ai	0.31	0.25	0.28	0.28	0.009	***	ns	ns
15:0	0.75	0.61	0.68	0.69	0.019	***	ns	ns
16:0iso	0.28	0.25	0.26	0.27	0.006	**	ns	ns
16:0	25.38	25.16	25.40	25.15	0.177	ns	ns	ns
*c*7–16:1	0.49	0.46	0.48	0.47	0.007	*	ns	*
*c*9–16:1	1.99	2.28	2.02	2.23	0.051	**	*	ns
17:0iso	0.56	0.55	0.57	0.54	0.006	ns	*	ns
17:0ai	0.58	0.56	0.55	0.59	0.010	ns	ns	ns
17:0	1.15	1.07	1.11	1.12	0.020	ns	ns	ns
*c*9–17:1	0.71	0.67	0.65	0.73	0.011	*	***	ns
18:0iso	0.15	0.15	0.14	0.15	0.003	ns	ns	ns
18:0	11.06	11.26	11.46	10.87	0.185	ns	ns	ns
*t*9–18:1	0.22	0.27	0.26	0.23	0.008	**	ns	ns
*t*10–18:1	0.59	0.50	0.57	0.51	0.067	ns	ns	ns
*t*11–18:1	0.67	0.65	0.66	0.67	0.025	ns	ns	ns
*t*12–18:1	0.26	0.28	0.28	0.26	0.006	ns	ns	ns
*c*9–18:1	33.57	34.83	33.37	34.96	0.385	ns	*	ns
*c*11–18:1	0.98	0.96	0.94	0.99	0.020	ns	ns	ns
*c*12–18:1	0.25	0.29	0.28	0.26	0.009	*	ns	ns
*c*13–18:1	0.09	0.11	0.09	0.11	0.003	**	**	ns
*t*16,*c*14–18:1	0.20	0.20	0.21	0.20	0.004	ns	ns	ns
18:2n-6	4.17	4.26	4.38	4.05	0.108	ns	ns	ns
18:3n-3	0.59	0.57	0.57	0.59	0.013	ns	ns	*
*c*9,*t*11–18:2 + *t*7,*c*9–18:2	0.48	0.47	0.46	0.48	0.013	ns	ns	ns
*t*9,*t*11–18:2	0.024	0.025	0.024	0.025	0.001	ns	ns	ns
t11,*t*13–18:2	0.010	0.011	0.008	0.012	0.002	ns	ns	ns
20:2n-6	0.02	0.02	0.02	0.02	0.001	ns	ns	ns
20:4n-6	1.06	0.97	1.04	0.99	0.054	ns	ns	ns
20:3n-3	0.01	0.01	0.01	0.01	0.001	ns	ns	ns
20:5n-3	0.11	0.10	0.10	0.11	0.006	ns	ns	ns
22:0	0.022	0.017	0.02	0.02	0.001	*	ns	ns
22:4n-6	0.11	0.08	0.10	0.09	0.004	**	*	ns
22:5n-3	0.33	0.28	0.31	0.30	0.011	*	ns	ns
22:6n-3	0.12	0.10	0.11	0.11	0.005	*	ns	*
SFA	50.43	49.07	50.53	49.05	0.364	*	*	ns
MUFA	41.10	42.61	40.93	42.70	0.359	*	**	ns
PUFAn-3	1.19	1.10	1.13	1.16	0.032	ns	ns	ns
PUFAn-6	5.54	5.51	5.74	5.33	0.165	ns	ns	ns
OCFA	1.96	1.74	1.84	1.86	0.034	**	ns	ns
BCFA	2.17	2.02	2.08	2.11	0.029	**	ns	ns
OBCFA	4.13	3.76	3.92	3.97	0.058	**	ns	ns
n-6/n-3	4.70	5.06	5.10	4.67	0.128	ns	ns	ns
AI	1.20	1.11	1.20	1.12	0.023	*	*	ns
TI	1.24	1.19	1.25	1.19	0.019	ns	ns	ns
h/H	1.23	1.30	1.23	1.29	0.022	ns	ns	ns

[a] *c* = cis; *t* = trans; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFAn-3 = polyunsaturated fatty acids omega3; PUFAn-6 = polyunsaturated fatty acids omega6; OCFA = odd-chain fatty acids; BCFA = branched-chain fatty acids; OBCFA = sum of individual odd- and branched-chain FA; n-6/n-3 = omega6/omega3 ratio; AI = aterogenic index calculated as follow: AI = [12:0 + (4 × 14:0) + 16:0]/[(PUFA) + (MUFA)]; TI = trombogenic index calculated as follow: TI = (14:0 + 16:0)/[(0.5 × MUFA) + (0.5 × n-6) + (3 × n-3) + (n-3:n-6)]; h/H = hypocholesterolemic to hypercholesterolemic ratio calculated as follow: h/H = [(sum of *c*9–18:1, *c*11–18:1, 18:2n-6, 18:3n-6,18:3n-3, 20:3n-6, 20:4n-6, 20:5n-3, 22:4n-6, 22:5n-3 and 22:6n-3)/(14:0 + 16:0)].

[b] SEM = standard error of the mean.

[c] GT = genetic type; GT x Sex = genetic type and sex interaction; * $P \leq 0.05$; ** $P < 0.01$; *** $P < 0.001$; ns = not significant.

pentadecanoic acid (15:0) and heptadecanoic acid (17:0) were significantly higher in crossbreed than S lambs. These FA are of nutritional importance because their beneficial role in gut health (Xin et al., 2021) and cardiovascular diseases (Warensjö et al., 2004), inflammation (Ran-Ressler et al., 2011) and cancer (Ran-Ressler et al., 2011). They are mostly derived from rumen bacteria and then are transferred to ruminant tissues (Nudda, Correddu, Cesarani, Pulina, and Battacone, 2021). For that reason, they could be considered as biomarkers of rumen fermentation (Battacone et al., 2021). However, in our case since maternal diet did not differ between the two groups, differences in FA profile between DS and S lambs could be attributed to animal body composition (van Harten et al., 2016), to genetic basis or to differences on carcass fatness (Nürnberg, Wegner, and Ender, 1998).

For the same motivation, no differences between DS and S lambs were observed for the content of essential FA 18:2n-6, 18:3n-3, *t*11–18:1 and *c*9,*t*11–18:2 + *t7*,*c*9–18:2.

Regarding the long-chain FA, the crossbreeding increased the content of some of them such as 22:0, 22:5n-3 (docosapentaenoic acid, DPA) and 22:6n-3 (DHA). This is likely related to the intramuscular fat content, as lean meat has lower phospholipids/triglycerides ratio; since

Table 5
Fatty acid content (mg/100 g meat) in muscle (*Longissimus thoracis et lumborum*, LTL) of Dorper x Sarda and Sarda heavy suckling lambs.

	Genetic type		Sex		SEM[b]	*P*-value[c]		
Item[a]	Dorper x Sarda	Sarda	Males	Females		GT	Sex	GT x Sex
14:0	573.50	709.40	644.00	635.30	32.80	*	ns	ns
*c*9–14:1	21.21	32.19	28.34	24.70	1.83	**	ns	ns
14:0iso	5.47	5.19	5.64	5.02	0.25	ns	ns	ns
15:0iso	15.13	18.36	17.27	16.10	0.80	*	ns	ns
15:0ai	21.70	23.04	23.17	21.49	1.01	ns	ns	ns
15:0	52.74	56.43	56.20	52.79	2.61	ns	ns	ns
16:0iso	19.48	23.14	22.18	20.30	0.96	*	ns	ns
16:0	1761	2364	2114	1992	109	**	ns	ns
*c*7–16:1	33.70	43.47	38.94	37.95	2.17	*	ns	ns
*c*9–16:1	138.53	215.20	190.20	160.90	11.6	***	ns	ns
17:0iso	38.70	51.07	45.14	44.29	2.19	**	ns	ns
17:0ai	40.20	52.90	49.24	43.38	2.54	**	ns	ns
17:0	80.26	101.29	93.77	87.07	5.01	*	ns	ns
*c*9–17:1	49.11	63.23	60.21	51.54	2.99	*	ns	ns
18:0iso	10.30	14.18	12.98	11.35	0.76	**	ns	ns
18:0	760.30	1063.40	921.90	893.30	54.2	**	ns	ns
*t*9–18:1	15.15	25.24	19.93	20.21	1.38	***	ns	ns
*t*10–18:1	42.53	45.65	43.46	44.67	5.67	ns	ns	ns
*t*11–18:1	45.92	60.54	55.17	50.81	3.08	*	ns	ns
*t*12–18:1	17.81	25.90	21.82	21.68	1.22	**	ns	ns
*c*9–18:1	2329	3322	2962	2656	175	**	ns	ns
*c*11–18:1	67.15	89.67	82.84	73.16	3.93	**	ns	ns
*c*12–18:1	17.11	26.39	21.97	21.28	1.28	***	ns	ns
*c*13–18:1	6.41	10.11	9.02	7.35	0.56	***	*	ns
*t*16,*c*14–18:1	14.07	19.08	16.78	16.23	0.87	**	ns	ns
18:2n-6	284.50	386.10	334.00	334.10	14.6	***	ns	ns
18:3n-3	40.36	53.20	48.82	44.30	2.37	**	ns	ns
*c*9,*t*11–18:2 + *t*7,*c*9–18:2	33.23	43.95	40.28	36.54	2.21	*	ns	ns
20:2n-6	1.66	1.93	1.86	1.72	0.09	ns	ns	ns
20:4n-6	70.15	84.83	76.76	77.87	3.53	*	ns	ns
20:3n-3	0.83	1.20	1.10	0.92	0.09	*	ns	ns
20:5n-3	7.31	8.58	8.31	7.52	0.40	ns	ns	ns
22:0	1.50	1.64	1.63	1.51	0.13	ns	ns	ns
22:4n-6	7.15	7.43	7.05	7.54	0.29	ns	ns	ns
22:5n-3	22.44	24.77	23.93	23.20	0.86	ns	ns	ns
22:6n-3	8.16	8.76	8.48	8.42	0.42	ns	ns	ns
SFA	3500	4607	4125	3949	209	**	ns	ns
MUFA	2852	4051	3615	3248	207	**	ns	ns
PUFAn-3	81.40	99.96	93.61	87.12	3.95	*	ns	ns
PUFAn-6	375.60	496.80	433.90	435.40	18.1	***	ns	ns
OCFA	136.77	163.00	154.80	144.00	7.56	ns	ns	ns
BCFA	150.97	187.90	175.60	161.90	8.07	*	ns	ns
OBCFA	287.70	350.90	330.40	306.00	15.5	*	ns	ns

[a] *c* = cis; *t* = trans; SFA = saturated fatty acids; MUFA = monounsaturated fatty acids; PUFAn-3 = polyunsaturated fatty acids omega3; PUFAn-6 = polyunsaturated fatty acids omega6; OCFA = odd-chain fatty acids; BCFA = branched-chain fatty acids; OBCFA = sum of individual odd- and branched-chain FA.
[b] SEM = standard error of the mean.
[c] GT = genetic type; GT x Sex = genetic type and sex interaction; * $P \leq 0.05$; ** $P < 0.01$; *** $P < 0.001$; ns = not significant.

Table 6
Overall means and standard errors of the means of visual quality characteristics (appearance, tenderness, consistency, quality, colour, smell, and freshness) of lamb meat from the Dorper x Sarda and Sarda genetic types, evaluated by the Visual Panel Test (VPT).

Item[a]	Dorper x Sarda	Sarda	SEM[b]	*P*-values[c]
Appearance	7.29	7.15	0.24	ns
Tenderness	7.60	7.63	0.25	ns
Consistency	7.50	7.41	0.21	ns
Quality	7.83	7.76	0.25	ns
Colour	7.60	7.56	0.24	ns
Odour	7.24	6.88	0.28	ns
Freshness	7.99	7.80	0.27	ns

[a] Ten-point rating scale (1–10; 0 very bed, 10 excellent) was used with higher scores indicating more favourable rating.
[b] SEM = standard error of the mean.
[c] ns = not significant.

long- chain PUFA are incorporated preferentially into membrane phospholipids rather than in the triglycerides fraction (Jerónimo, Alves, Prates, Santos-Silva, and Bessa, 2009), the high content of long-chain PUFA in the meat of DS lambs compared to fatter purebred lambs could be related to a high proportion of the phospholipids fraction in relation to that of triglycerides. The sex of animals is another important factor of variation of FA profile (Nürnberg et al., 1998). The males showed a lower proportion of *c*9–17:1 and *c*9–18:1 than females, in accordance with previous observation in lighter suckling lambs (Nudda et al., 2013). The slight differences observed in the FA profile between males and females could be partially due to the lack of differences in intramuscular fat deposited.

Nutritionally, 100 g of S heavy suckling lamb meat provides 60.54 mg *t*11–18:1, 386.10 mg 18:2n-6, 53.20 mg 18:3n-3 and 43.95 mg *c*9, t11–18:2 + *t*7,*c*9–18:2. No differences were found between DS and S lamb meats for EPA and DHA. On average, 100 g of meat contained 16 g of EPA + DHA, which corresponds to 6% of the recommended daily intake (250 mg/day EPA + DHA) for healthy individuals (EFSA, 2010). Specifically, the DHA content was 8% of the recommended daily intake (100 mg) for visual function in children aged 6–24 months (EFSA,

Table 7
Overall means and standard errors of the means of eating quality characteristics (palatability, tenderness, consistency, odour, freshness, chewiness, juiciness, texture, taste, flavour, aroma, level of yield, and overall acceptability) of lamb meat from the Dorper x Sarda and Sarda genetic types, evaluated by the Taste Panel Test (TPT).

Item[a]	Dorper x Sarda	Sarda	SEM[b]	*P*-values[c]
Palatability	8.03	7.71	0.23	ns
Tenderness	8.30	8.19	0.23	ns
Consistency	8.04	7.72	0.24	ns
Odour	7.37	7.19	0.28	ns
Freshness	8.27	8.08	0.26	ns
Chewiness	8.36	8.15	0.22	ns
Juiciness	7.93	7.71	0.28	ns
Texture	6.37	6.49	0.45	ns
Taste	7.65	7.55	0.28	ns
Flavour	7.59	7.77	0.28	ns
Aroma	7.68	7.42	0.27	ns
Level of yield	7.70	7.47	0.29	ns
Overall acceptability	7.82	7.65	0.24	ns

[a] Ten-point rating scale (1–10; 0 very bed, 10 excellent) was used with higher scores indicating more favourable rating.
[b] SEM = standard error of the mean.
[c] ns = not significant.

2010).

4.4. Consumer perception

No differences emerged during VPT and TPT, demonstrating that both DS and S lamb meats present no distinguishable visual and eating quality characteristics. This is a quite interesting result that suggest that the production of heavy suckling lamb meat could be well appreciated by consumers especially for its taste.

5. Conclusions

The 11 weeks of suckling period to obtain a new product from dairy sheep named *heavy suckling lamb*, increased visceral and intramuscular fat deposition in S purebred lambs. The DS crossbreed showed a lower fat accumulation and better FA profile than purebred lambs. Growth performance did not differ between the genetic types as the Dorper could not unfold the meat breed potential even in crossbreed as it was limited by the ewe milk production, which was not sufficient to sustain higher growth of the crossed lamb beyond one month of age. These higher potentials of the crossbreed were revealed in leaner carcasses and cuts. Visual and taste revealed no significant differences between the samples analysed.

The data obtained confirm the suitability of the Sarda breed for the production of a heavy dairy lamb, but reveal that crosses with Dorper meat rams could provide better performance if fed with a higher amount of milk. The economic viability of producing this new type of lamb remains to be established. This will depend on the consumer selling price, which will certainly have to be higher than the processing value of the milk to make this pastoral activity profitable.

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CRediT authorship contribution statement

Mondina Francesca Lunesu: Conceptualization, Data curation, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. **Gianni Battacone:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Maria Rita Mellino:** Conceptualization, Data curation, Investigation, Writing – review & editing. **Silvia Carta:** Conceptualization, Methodology, Writing-review & editing. **Giuseppe Pulina:** Supervision, Validation, Visualization, Methodology, Writing – review & editing. **Anna Nudda:** Project administration, Supervision, Funding acquisition, Resources, Investigation, Validation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could influence the work reported in this paper.

Data availability

Data will be made available on request.

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