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The quality of meat in milk fed lambs is affected by the ewe diet: A review

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ABSTRACT

Several scientific publications have highlighted the importance of feeding management practices in improving the nutritional properties of milk from dairy ewes. Meat production quality from suckling lambs is based on the use of milk as exclusive or near exclusive dietary component. There is considerable evidence that lamb meat contains many important nutrients and bioactive compounds that play an important role in consumer health. This paper examines the different quality characteristics of lamb meat from ewes fed different diets to improve milk quality. To conduct this research, we consulted different scientific databases and acquired relevant documents that studied the relationships between the dietary treatment of lactating ewes and the performance of their suckling lambs (growth and carcass traits) as well as the meat quality in terms of nutrient content (fat and protein in particular), bioactive compounds content (fatty acids, vitamins, and antioxidant molecules), color, odor and flavor. The extent of change in meat carcass traits and meat quality of suckling lambs due to different feeding strategies applied to ewes was evaluated and discussed. This overview of the knowledge on the relationship between the milk quality and suckling lamb quality can be useful for production and communication strategies development for the lamb meat industry.

1. Introduction

Meat from suckling lambs is traditionally consumed in some countries, mostly concentrated in the Mediterranean basin, where sheep farming is mainly oriented towards milk production and ewes are selected for this production purpose (Pulina et al., 2018).

The choice of most sheep farmers to produce meat from suckling lambs is largely determined by their primary need to have milk available for cheese production as soon as possible through slaughtering lambs early at the age of 4–6 weeks after they have reached an acceptable weight for meat consumption. However, for dairy ewes' farms, the proportion of income from the sale of suckling lambs compared to the sale of milk is strongly related to milk and meat prices and varies from 17% in specialised dairy ewes' farms in intensive production systems (Milán, Frendi, González-González, & Caja, 2014) to 30% in pasture-based systems (Tolone, Riggio, Maizon, & Portolano, 2011).

The selection of ewes for milk production makes growing lambs to values higher than standard weight (*e.g.* 10 kg) unprofitable. This is due to the early deposition of body fat, with a rapid decline in the feed conversion rate. Therefore, using feeds, usually in the form of concentrates, to produce meat is considered less profitable than using feeds to produce milk.

Dairy ewes' farmers can improve their income through lamb meat production by cross-breeding ewes with meat breed rams to increase offspring growth rate and dressing percentage so as to produce leaner meat, resulting in lambs with a higher commercial potential (Ellies-Oury, Papillon, Arranz, & Carpentier, 2022; Lunesu et al., 2023).

However, the use of this technique is limited by some critical points such as the marketing restrictions based on protected designation of origin certification (PGI or PDO) that does not allow for cross-breeding.

In the absence of official statistics on suckling lambs produced, we assume that approximately 20% of the 1.26 billion sheep reared in the world are dedicated primarily to milk production (Pulina et al., 2018). Our estimation of the number of suckling lambs is around 160 million per year, equivalent to 0.816 million tons of carcasses, or 8.2% of total sheep meat production (FAOSTAT, 2023).

Traditional suckling lamb can be considered as a product of conversion of ewe milk into meat. Studies measuring the feed conversion

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rate (FCR) of mother's milk on lamb growth (kg of milk per kg of body weight gain) are limited. Pulina, Rossi, and Brandano (1986) measured the FCR in lambs of Sarda breed slaughtered at 28 days obtaining a value of 5.37 kg of milk per kg of body weight gain. In suckling lambs fed with mother's milk or milk replacer, the closure of oesophageal groove diverts milk from the esophagus directly into the abomasum. In conventional management, lambs start eating solid feed between 2 and 4 weeks of age; then, between 3 and 5 weeks of age, their anatomy and digestive function gradually evolve from monogastric to ruminant (Lane, Baldwin VI, & Jesse, 2000).

The weight gain and meat quality of lambs that suckled their mothers depends largely on the quantity and quality of nutrients ingested with the milk, which in turn is influenced by the ewe's diet (Nudda et al., 2020; Pulina, Nudda, Battacone, & Cannas, 2006).

In recent decades, an increasing number of studies focused on feeding strategies to improve the quality of milk from dairy animals, both in terms of fat and protein concentrations and also of substances called nutraceuticals (*e.g.* fatty acids; FAs) with potential health-promoting role in human nutrition.

The enhancement of certain nutraceutical and bioactive compounds in milk can be achieved by manipulating the ewe's diet composition or by supplementing the diet with nutraceuticals. The profitable transfer of some important nutrients and nutraceutical compounds from milk to suckling lamb meat has already been demonstrated by several studies (Battacone, Lunesu, Rassu, Pulina, & Nudda, 2021; Gallardo, Manca, Mantecon, Nudda, & Manso, 2015; Nudda et al., 2015; Vieira, Guerra-Rivas, Martínez, Rubio, & Manso, 2022).

Lamb (as well as other red meats) is rich in protein, fat and other nutrients that are important for a well-balanced human diet. In addition, there is solid scientific evidence of the potential in promoting the nutritional value of lamb meat, raising interest through suggesting the inclusion of this food in diets, particularly for elderly (Holman, Fowler, & Hopkins, 2020; Marche et al., 2023) and infants (Nudda et al., 2011).

This paper reviews the current literature to provide an insight of the extent to which the meat quality of suckling lambs can be enhanced through feeding strategies implemented to improve the milk quality of ewes. The core of the review is a systematic analysis of the state of knowledge on animal performance and meat quality traits in suckling lambs. The hypothesis tested is whether diet manipulation of lactating ewes can improve the growth performance and meat quality of suckling lambs, especially in terms of nutritional and oxidative properties.

2. Material and methods

A systematic literature search was carried out in February 2023 in the Scopus® and Google-Scholar® databases using the following keywords "suckling" AND "lamb" AND "ewe" AND "nutrition". Inclusion criteria were lamb growth performance, lamb carcass characteristics, lamb intramuscular FAs profile, lamb proximate composition, oxidative stability, pH and color of suckling lamb meat. The initial search yielded 127 papers, of which only 21 were selected that referred to suckling lambs fed exclusively on mother's milk (Table 1).

The dataset was prepared in excel by including the mean values of the control and experimental groups reported by the papers; the extent of variation was calculated as difference in mean values between the experimental and control groups for each study divided by the mean value of the control group and expressed as a percentage.

Differences that were not statistically significant in the original paper have been also reported, to ensure completeness of information.

A linear regression analysis was applied to predict the relationship between the independent variable (X, FAs content in maternal milk) and the dependent variable (Y, FAs content in lamb muscle).

The intercept and the slope, as well as 95% confidence interval of regression coefficients (CI 95%), and the residual standard error (RSE) of the regression were reported. For all regression analyses, the intercept and the slope were tested for difference from zero. The slope was tested also for difference from one, only when significantly different from zero. Significance was declared for $P < 0.05$.

3. Effect of maternal diet on growth performance and carcass characteristics of suckling lamb

Pasture-based diets, the inclusion in the diet of feeds rich in secondary metabolites such as some by-products, or the addition of oils with particular reference to linseed, appear to be negligible for improving growth performance and carcass characteristics.

The lack of replicates in all experiments (Table 1) may have hidden the effects of the mothers' diet on growth performance and carcass trait quality in suckling lamb. This factor is a common limitation in several studies and affects the robustness of the conclusions, as properly evidenced and discussed by De Brito, Ponnampalam, and Hopkins (2017). The short lamb suckling period (28–45 days) typically occurring in dairy ewes' farms is another factor responsible for the non-significant effect of milk composition on lamb performance and carcass characteristics (Gallardo et al., 2014; Manso, Bodas, Vieira, Mantecón, & Castro, 2011).

Generally, variations in suckling lambs' performance are mainly related to differences in the maternal milk yield and composition, especially in terms of fat and protein content. As a matter of fact, lambs grow slower and weigh less at weaning when milk yield is lower than the theoretical requirement (Kenyon, Roca Fraga, Blumer, & Thompson, 2019). On the other hand, if milk yield and composition do not limit lamb growth and carcass fatness, the effects of ewe diet on lamb performance and carcass characteristics are not significantly appreciable (Fusaro et al., 2019; Manso et al., 2011).

3.1. Effect of maternal forage diet

A pasture-based maternal diet did not change the growth performance and carcass characteristics of suckling lambs compared with hay and concentrate-based rations (Fusaro et al., 2019). However, in Churra Tensina lambs, replacing hay with pasture in the maternal diet after parturition increased average daily gain (ADG; +12.5%) without changing carcass characteristics (Joy et al., 2012). This is probably due to the combined effect of increased milk production owing to higher digestibility of pasture compared to hay and to the beneficial effects of certain bioactive compounds in pasture (*e.g.* FAs, antioxidants) on immune response of lambs and consequently on growth, which can be transferred to milk from fresh pasture herbage (Sanz Sampelayo, Chilliard, Schmidely, & Boza, 2007; Valdivielso et al., 2015). The use of polyethylene glycol to improve digestion of tannin-rich forages in ewes did not affect lamb growth and meat quality (Baila et al., 2022; Table 2).

3.2. Effect of maternal by-product supplementation

Grape seeds (Pascual-Alonso et al., 2018; Resconi et al., 2018) or whole grape pomace (Gómez-Cortés et al., 2018), characterized by a high polyphenol content (Guerra-Rivas et al., 2016; Nudda et al., 2019), have been included in the diet of lactating ewes to evaluate the effect on performance and carcass traits of their lambs fed maternal milk for 30 days (Table 2). At the level of inclusion ranging from 5% to 10% of the total mixed ration, the grape pomace fed ewes did not evidence significant depressive effect on ADG, carcass weight and dressing percentage of suckling lambs. The amount of polyphenols in grape pomace tested ranged from 1.5 (Nudda et al., 2019) to 2.2–4.3 g/100 g of dry matter (DM; Gómez-Cortés et al., 2018). The lack of change in feed intake and milk production in ewes supplemented with grape pomace (Gómez-Cortés et al., 2018; Nudda et al., 2019) appeared to be the main explanation for the lack of effects on ADG and carcass performance of suckling lambs. This is also supported by the fact that supplementation of ewes with grape polyphenol extract increased milk polyphenol concentration only to a limited extent, as most of the phenols were lost *via* urine (Leparmarai et al., 2019).

Table 1
Main experimental conditions of scientific studies considered.

Dietary group[1]	Number of ewes[2]	Parity/age	Number of suckling lambs	Sex of lambs	Age at slaughter	Milk intake[3]	References
Control	10	Multiparous	10	males	28 days	–	Baila et al., 2022
Sainfoin + PEG	10	Multiparous	10	males	28 days	–	
Control (Stall)	–	3 years old	9	Single born males	45 days	–	D'Alessandro et al., 2012
Pasture	–	3 years old	9	Single born males	45 days	–	
Control (hay)	24	Multiparous single bearing	24	12 males and 12 females	5 weeks	–	Dervishi et al., 2012
Pasture	24	Multiparous single bearing	24	12 males and 12 females	5 weeks	–	
Control	18	Multiparous single bearing	18	9 males and 9 females	28 days	–	Fusaro et al., 2019
Pasture	18	Multiparous single bearing	18	9 males and 9 females	28 days	–	
Linseed	18	Multiparous single bearing	18	9 males and 9 females	28 days	–	
Control	12	Multiparous	12	6 males and 6 females	27.8 days	–	Gómez-Cortés et al., 2018
Vit. E	12	Multiparous	12	6 males and 6 females	27.6 days	–	
Grape pomace-5	12	Multiparous	12	6 males and 6 females	24.6 days	–	
Grape pomace-10	12	Multiparous	12	6 males and 6 females	28.6 days	–	
Control	14	Multiparous	10	–	30 days	–	Pascual-Alonso et al., 2018; Resconi et al., 2018
Grape pomace	14	Multiparous	10	–	30 days	–	
Grape seed	14	Multiparous	10	–	30 days	–	
Control	12	–	12	–	27 days	–	Gallardo et al., 2015
Linseed oil	12	–	12	–	27 days	–	
Linseed oil + synthetic Vit. E	12	–	12	–	27 days	–	
Linseed oil + natural Vit. E	12	–	12	–	27 days	–	
Control pre-partum hay	12	Multiparous single bearing	12	male and females	34 days	–	Joy, Sanz, et al., 2012
Pre-partum pasture	12	Multiparous single bearing	12	male and females	34 days	–	
Control post-partum hay	12	Multiparous single bearing	12	male and females	36 days	–	
Post-partum pasture	12	Multiparous single bearing	12	male and females	32 days	–	
Control	25	Multiparous	29	males and females	60 days	3.40 kg milk/kg lamb BW	Titi & Al-Fataftah, 2013
Soybean oil-3	25	Multiparous	32	males and females	60 days	3.62 milk/kg lamb BW	
Soybean oil-5	25	Multiparous	30	males and females	60 days	4.10 milk/kg lamb BW	
Sunflower oil-3	25	Multiparous	29	males and females	60 days	3.76 milk/kg lamb BW	
Sunflower oil-5	25	Multiparous	31	males and females	60 days	4.35 milk/kg lamb BW	
Control	12	–	12	–	27 days	–	Gómez-Cortés et al., 2014
Extruded linseed	12	–	12	–	27 days	–	
Control pre-partum hay	12	Multiparous single bearing	12	males and females	34 days	–	Joy, Ripoll, et al., 2012
Pre-partum pasture	12	Multiparous single bearing	12	males and females	34 days	–	
Control post-partum hay	12	Multiparous single bearing	12	males and females	36 days	–	
Post-partum pasture	12	Multiparous single bearing	12	males and females	32 days	–	
Control	9	Pluriparous	9	4 males and 5 females	28 days	–	Nudda et al., 2015
Linseed offered during pregnancy	9	Pluriparous	9	5 males and 4 females	28 days	–	
Linseed offered during lactation	9	Pluriparous	9	4 males and 5females	28 days	–	
Linseed offered during pregnancy and lactation	9	Pluriparous	9	5 males and 4 females	28 days	–	
Control	12	Multiparous	12	males and females	–	–	Gallardo et al., 2014
Olive oil	12	Multiparous	12	males and females	–	–	
Fish oil	12	Multiparous	12	males and females	–	–	

(*continued on next page*)

Table 1 (*continued*)

Dietary group[1]	Number of ewes[2]	Parity/age	Number of suckling lambs	Sex of lambs	Age at slaughter	Milk intake[3]	References
Control	12	Multiparous and pluriparous	18	9 males and 9 females	28 days	–	Manso et al., 2011
Olive oil	12	Multiparous and pluriparous	18	9 males and 9 females	28 days	–	
Soybean oil	12	Multiparous and pluriparous	18	9 males and 9 females	28 days	–	
Linseed oil	12	Multiparous and pluriparous	18	9 males and 9 females	28 days	–	
Castellana control	–	–	6	Single males	20–25 days	–	Wilches et al., 2011
Castellana pasture	–	–	6	Single males	20–25 days	–	
Churra control	–	–	6	Single males	20–25 days	–	
Churra pasture	–	–	6	Single males	20–25 days	–	
Control (hay)	10	Multiparous single bearing	10	males and females	34 days	–	Lobón et al., 2017
Pasture	10	Multiparous single bearing	10	males and females	34 days	–	
Control (concentrate)	9	Multiparous single bearing	9	males and females	34 days	–	
Quebracho	10	Multiparous single bearing	10	males and females	34 days	–	
Control (Indoor rearing system)	18	Multiparous and pluriparous	24	males and females	28 days	–	Nudda et al., 2013
Outdoor rearing system	18	Multiparous and pluriparous	24	males and females	28 days	–	
Control	12	Multiparous and pluriparous	18	9 males and 9 females	28 days	–	Vieira et al., 2012
Olive oil	12	Multiparous and pluriparous	18	9 males and 9 females	28 days	–	
Soybean oil	12	Multiparous and pluriparous	18	9 males and 9 females	28 days	–	
Linseed oil	12	Multiparous and pluriparous	18	9 males and 9 females	28 days	–	
Dry diet	10	–	10	–	38 days	–	Valvo et al., 2005
Vech Pasture	10	–	10	–	38 days	–	
Control (stall fed)	12	–	–	–	100 days	–	Scerra et al., 2007
Pasture	12	–	–	–	100 days	–	

The dash indicates that data were not reported in the publication.

[1] PEG = Polyethylene glycol; Vit E = Vitamin E.

[2] There was no replication at the treatment level in any of the reported studies.

[3] BW = Body weight.

3.3. *Effect of maternal fat supplementation*

The dietary inclusion of vegetable fats in form of seeds (Fusaro et al., 2019; Gómez-Cortés et al., 2014; Nudda et al., 2015), oil (Manso et al., 2011) or associated to vitamin E (Gallardo et al., 2015) did not exert a significant effect on growth performance and carcass characteristics of suckling lambs when supplemented to maternal diet (Table 2). The dietary supplementation of soybean or sunflower oils (Titi & Al-Fataftah, 2013) as well as linseed oil (Gallardo et al., 2015; Manso et al., 2011) as free physical form did not significantly affect the ADG and carcass performance of suckling lambs at doses not exceeding 3%–5%. However, lamb birth weight (+16%; Gómez-Cortés et al., 2014) was significantly affected by the inclusion of linseed (Gómez-Cortés et al., 2014) in the diet of their mother.

Fish oils, which are commonly responsible for reduction in milk fat synthesis in the mammary gland (Toral, Monahan, Hervás, Frutos, & Moloney, 2018), could potentially reduce also the growth rate of suckling lambs. However, fats and oils protected from ruminal biohydrogenation could avoid these negative effects. The protection with calcium salts (Ca-salts) of selected FA would reduce the negative effects of fat on ruminal fermentation. Calcium soaps from olive oil and fish oil added to ewe diets did not affect growth and carcass traits of lambs, despite the reduction in milk fat content (Gallardo et al., 2014). This is not surprising considering that also a direct supplementation of vegetable oil to lambs (Miltko, Majewska, Bełżecki, Kula, & Kowalik, 2019) did not affect animal performance and carcass traits. However, when lambs are fed exclusively on dam's milk and milk production does not limit lamb growth, the performance and carcass characteristic of suckling lambs are not altered by adding fats to their dam's rations.

4. Effect of maternal diet on proximate composition and fatty acid profile of suckling lamb meat

The effect of maternal diet appears to be negligible for protein content whereas the effect on suckling lamb meat fat content seems to be stronger (Table 3) mainly because fat is the milk component far more influenced by feeding techniques than milk protein content (Nudda et al., 2020).

Animal nutrition is the main factor influencing the FAs profile in ewe milk and meat. The most significant effects on milk FAs composition have been obtained by modifying the quantity and quality of forage, especially pasture, or by adding vegetable or marine oils to the diet of ewes (Battacone et al., 2021). Maternal diet strongly influences the FAs profile of intramuscular fat in suckling lambs (Table 4), particularly with respect to *t*11–18:1 (vaccenic acid, VA), *c*9,*t*11–18:2 (rumenic acid, RA or conjugated linoleic acid, CLA), 18:3n-3 (alpha-linolenic acid, ALA), 20:5n-3 (eicosapentaenoic acid, EPA) and 22:6n-3 (docosahexaenoic acid, DHA). In general, the FAs profile of intramuscular fat in suckling lambs fed exclusively with mother's milk reflects the FAs profile of mother's milk (Battacone et al., 2021; Fusaro et al., 2019; Manso et al., 2011).

It is evident that the fat content and the FAs profile of meat depend not only on the composition of milk, but also on other factors, among which the consumption of milk plays an important role. The few studies

Table 2
Effect of maternal diet on growth performance and carcass characteristics of suckling lambs. Data of the control group are reported as the mean value and in italics whereas data of the extent of variation are reported as the proportional difference (%) between the treatment group, at the respective level of inclusion, and the control group.

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Lamb performance[4]			Carcass characteristics[5]			References
				BW at birth	ADG	BW at slaughter	HCW	CCW	DP	
Aragonesa	*Control*	*Sainfoin*	*Sainfoin (ad libitum) + 200 g/d barley*	*4.0 kg*	*272 g/d*	*11.6 kg*	*7.78 kg*	*6.19 kg*	*55.6%*	Baila et al., 2022
	FOR	Sainfoin + PEG	Sainfoin (*ad libitum*) + 200 g/d barley +100 g/d PEG	+5.0%	+4.0%	−4.3%	−1.8%	−0.7%	+2.9%	
Leccese	*Control*	*Stall*	*0.5 kg/d concentrate+1.6 kg/d hay*	–	–	*9.25 kg*	*6.54 kg*	*6.44 kg*	–	D'Alessandro et al., 2012
	FOR	Pasture	Access for 10 h/d	–	–	+0.11%	+13.6%	+13.0%	–	
Churra Tensina	*Control*	*Hay*	*Ad libitum*	*3.76 kg*	–	*10.65 kg*	–	–	–	Dervishi et al., 2012
	FOR	Pasture	–	−3.6%	–	−0.5%	–	–	–	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	*4.87 kg*	*221 g/d*	*10.72 kg*	–	*6.74 kg*	*51.94%*	Fusaro et al., 2019
	FOR	Pasture	Access for 22 h/d	+2.1%	+3.6%	+0.6%	–	+0.4%	−3.2%	
Churra Tensina	*Control*	*Pre-partum hay*	*Ad libitum*	*3.6 kg*	*224 g/d*	*11.2 kg*	*5.98 kg*	*5.88 kg*	*52.37%*	Joy, Sanz, et al., 2012
	FOR	Pre-partum pasture	*Ad libitum* access	+2.8%	−2.7%	−0.9%	−1.5%	−1.9%	−0.5%	
	Control	Post-partum hay	*Ad libitum*	*3.7 kg*	*208 g/d*	*11.2 kg*	*5.89 kg*	*5.77 kg*	*51.69%*	
	FOR	Post-partum pasture	*Ad libitum* access	−2.7%	**+12.5%**	−0.9%	+1.5%	+1.9%	+2.1%	
Churra	*Control*	*LO*	*TMR with 2.7% LO*	*4.19 kg*	*295 g/d*	*11.8 kg*	–	*6.23 kg*	–	Gómez-Cortés et al., 2018
	BP	Vit. E	500 mg/kg TMR, on DM	+6.2%	−13.2%	−2.5%	–	−1.4%	–	
	BP	GP-5	5% of TMR, on DM (2.14 g of PFs/kg DM)	+8.1%	−4.1%	−1.7%	–	−2.2%	–	
	BP	GP-10	10% of TMR, on DM (4.28 g of PFs/kg DM)	+4.3%	−12.5%	−4.2%	–	−5.1%	–	
Chamarita	*Control*	*Concentrate without added wine by-product*	*1 kg/d concentrate + ad libitum access to Medicago sativa*	*3.56 kg*	*290 g/d*	*12.25 kg*	–	*5.65 kg*	–	Pascual-Alonso et al., 2018 Resconi et al., 2018
	BP	GP	10% of GP on 1 kg of concentrate/d, on DM + *ad libitum* access to *Medicago sativa*	+3.4%	−14.5%	−9.2%	–	−0.4%	–	
	BP	GS	5% of GS on 1 kg of concentrate/d, on DM + *ad libitum* access to *Medicago sativa*	+4.2%	−7.6%	−4.0%	–	−0.4%	–	
Churra	*Control*	*PO*	*3% of Ca soap of palm oil*	*4.01 kg*	*249 g/d*	*10.8 kg*	–	–	*54.1%*	Gallardo et al., 2014
	Fat	MO	3% of Ca soap of MO	+14.5%	−9.6%	−2.8%	–	–	−3.0%	
	Fat	OLI	3% of Ca soap of OLI	+7.7%	−6.8%	−4.6%	–	–	−3.0%	
Churra	*Control*	*PO*	*3% of TMR, as fed*	*4.14 kg*	*274 g/d*	*11.6 kg*	*6.11 kg*	*5.95 kg*	*51.1%*	Manso et al., 2011
	Fat	OLI	3% of TMR, as fed	+14.5%	+2.2%	−0.9%	−0.2%	−0.2%	+1.4%	
	Fat	SO	3% of TMR, as fed	+2.7%	−5.5%	−1.7%	−1.0%	−0.8%	+0.8%	
	Fat	LO	3% of TMR, as fed	−2.2%	−5.8%	−3.4%	−3.3%	−2.4%	+1.4%	
Awassi	*Control*	*No oils*	*TMR without added oils*	*4.30 kg*	*250 g/d*	–	–	–	–	Titi & Al-Fataftah, 2013.
	Fat	SO-3	3% of TMR	+7.0%	+4.0%	–	–	–	–	
	Fat	SO-5	5% of TMR	−11.2%	−4.0%	–	–	–	–	
	Fat	SF-3	3% of TMR	−0.7%	−4.0%	–	–	–	–	
	Fat	SF-5	5% of TMR	−9.1%	0%	–	–	–	–	
Churra	*Control*	*Without LO and vit E*	*Ad libitum access to TMR*	*4.22 kg*	*310 g/d*	*12.81 kg*	*7.04 kg*	*6.88 kg*	*46.23%*	Gallardo et al., 2015
	Fat	LO	3% LO	−0.7%	−5.5%	−3.4%	−3.6%	−3.3%	0%	
	Fat	LO+ synthetic Vit. E	LO + 400 mg/kg TMR of synthetic Vit. E	+3.8%	+1.3%	+0.2%	+1.1%	+1.3%	−1.1%	
	Fat	LO + natural Vit. E	LO + 400 g/kg TMR of natural Vit. E	−2.1%	−7.7%	−4.8%	−6.4%	−6.3%	+2.1%	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	*4.87 kg*	*221 g/d*	*10.72 kg*	–	*6.74 kg*	*51.94%*	Fusaro et al., 2019
	Fat	LIN	190 g/d	+3.7%	+11.3%	+1.9%	–	+2.4%	+2.2%	
Churra	*Control*	*PO*	*70 g/d FA from calcium soap of PO*	*3.91 kg*	*248 g/d*	*10.84 kg*	*5.99 kg*	*5.84 kg*	*46.1%*	Gómez-Cortés et al., 2014
	Fat	LIN	128 g/d	**+16.1%**	+12.5%	+4.2%	+3.7%	+3.9%	+0.4%	
Sarda	*Control*	*CON-PREG and LACT*	*1 kg/d concentrate + ad libitum access to hay*	*3.86 kg*	*233.8 g/d*	*10.40 kg*	*4.96 kg/d*	–	*47.18%*	Nudda et al., 2015
	Fat	LIN-PREG	150 g/kg of concentrate + *ad libitum* access to hay	−6.5%	−29.9%	−21.2%	−23.0%	–	−1.0%	
	Fat	LIN-LACT	150 g/kg of concentrate + *ad libitum* access to hay	−12.7%	−7.0%	−9.0%	−11.3%	–	−1.2%	
	Fat	LIN-PREG and LACT	150 g/kg of concentrate + *ad libitum* access to hay	−12.4%	−5.1%	−7.8%	−4.4%	–	+4.8%	

Bold and underlined values indicate significant differences ($P < 0.05$) compared to the control group as reported in the original paper. The dash indicates that the data were not reported in the publication.

[1] FOR = Forage; BP = By-product.

[2] PEG = Polyethylene glycol; LO = Linseed oil; Vit E = Vitamin E; GP = Grape pomace; GS = Grape seed; PO = palm oil; MO = Marine oil; OLI = Olive oil; SO; soybean oil; SF = sunflower; LIN = extruded linseed; PREG = Linseed offered during pregnancy; LACT = Linseed offered during lactation.

[3] TMR = Total mixed ration; DM = Dry matter; PFs = polyphenols; FA = Fatty acids.

[4] BW = Body weight; ADG = Average daily gain.

[5] HCW = Hot carcass weight; CCW = Cold carcass weight; DP = Dressing percentage.

in the literature where it has been measured do not report on the quality of the lamb meat. However, on the one hand this lack of information is understandable, given that the measurement of milk intake in lambs can be carried out using the double-weighing method, which could influence the result due to the natural feeding pattern of the lamb with several feedings per day and the stress induced in the animal; on the other hand, this information gap needs to be filled as soon as possible for different rearing conditions and breeds, perhaps by using milk tracing techniques with suitable markers.

4.1. Effect of maternal forage diet

The effect of grazing on the proximate composition of lamb meat seems to be effective on meat fat and protein content (Table 3), although not univocal results have been observed, with a decrease (−20.7%; Lobón, Sanz, Blanco, Ripoll, & Joy, 2017) or an increase (+39.3%; Wilches et al., 2011) in intramuscular fat content, and a decrease (−12%; D'Alessandro, Maiorano, Kowaliszyn, Loiudice, & Martemucci, 2012) or an increase, although negligible, in protein content (+4.0%; Joy, Sanz, et al., 2012). These variations may be related to differences in experimental conditions, breeds (Leccese *vs.* Castellana and Churra breeds), as well as in relation to the botanical composition of pasture (fresh oats *vs.* alfalfa) grazed by lactating ewes (Table 3).

The role of pasture in maternal diet has been extensively studied to enrich meat with FAs, which may have human health benefits (Table 4). In general, lamb meat from ewes fed pasture has a more favourable FAs profile than lamb meat from ewes fed indoors, increasing significantly the content of RA (D'Alessandro et al., 2012; Fusaro et al., 2019; Joy, Ripoll, Molino, Dervishi, & Álvarez-Rodriguez, 2012; Valvo et al., 2005), 18:2n-6 (linoleic acid, LA; Wilches et al., 2011) and ALA (D'Alessandro et al., 2012; Joy, Ripoll, et al., 2012; Valvo et al., 2005; Wilches et al., 2011) in lamb intramuscular fat. The positive effect of pasture-based maternal diet is also evident in the reduction of total saturated fatty acids (SFA) content and n-6/n-3 ratio and in the increase of total polyunsaturated fatty acids (PUFA; Scerra et al., 2007; Wilches et al., 2011; D'Alessandro et al., 2012; Fusaro et al., 2019) and long chain PUFAn-3 (LC-PUFAn-3) such as EPA (Joy, Ripoll, et al., 2012; Scerra et al., 2007; Valvo et al., 2005) and DHA (Valvo et al., 2005) contents. This is mainly attributed to the transfer of beneficial compounds from pasture herbage to milk and then to the meat of the suckling lamb (Battacone et al., 2021). For example, grazing on green forage compared to indoor fed enhances the deposition of beneficial FAs as CLA (Dervishi, Joy, Alvarez-Rodriguez, Serrano, & Calvo, 2012; Joy, Ripoll, et al., 2012; Valvo et al., 2005) and PUFAn-3 (Dervishi et al., 2012; Joy, Ripoll, et al., 2012; Scerra et al., 2007; Valvo et al., 2005) in suckling lamb muscles. No change of CLA concentration in milk (1.33 *vs* 1.0 g/100 g of fat) and in intramuscular fat in suckling lambs (0.87 *vs* 0.77 g/100 g of fat), and an increase in SFA content (+17%) was observed by Scerra et al. (2007), probably because the lambs were slaughtered at 100 days of age and especially in the final part of the trial (last 30 days) they ingested also solid feeds from the mother diet in addition to milk.

The use of pasture before lambing increased the RA content of intramuscular fat in lamb meat (Joy, Ripoll, et al., 2012), probably due to a transplacental passage of FAs to foetal tissues or a desaturation activity on VA in the placental or in the foetal tissue (Nudda et al., 2007). However, maternal diet during lactation has a larger impact than maternal diet during gestation for what concerns CLA, ALA and LC-PUFAn-3 contents in suckling lamb meat (Joy, Ripoll, et al., 2012). The lush pasture is characterized by high content of ALA, which is first isomerized to rumelenic acid (*c*9, *t*11, *c*15–18:3 (RLnA)) and then reduced to VA (Destaillats, Trottier, Galvez, & Angers, 2005; Gómez-Cortés et al., 2014) *via* biohydrogenation pathways in the rumen of ewes. The VA in the mammary gland is mainly converted to *c*9,*t*11–18:2 by the action of stearoyl-CoA desaturase. Similarly, in the intramuscular fat of suckling lambs an amount of CLA is originated by conversion of VA to CLA in lamb tissue (Nudda et al., 2022). Moreover, different expression of lipogenic enzyme in suckling lambs whose dams grazed compared with lambs whose dams were dry-fed has been suggested as a further possible explanation of the greater VA, CLA, and total PUFAn-3 amounts (Dervishi et al., 2012). The effect of pasture diet on milk FAs profile is also modulated by the botanical composition and the seasonal variation in forage quality (Addis et al., 2005; Battacone et al., 2021; Cabiddu et al., 2005). A mixed pasture in the ewes' diet (Cabiddu et al., 2005) consisting of annual ryegrass (*Lolium rigidum* Gaudin) and different legumes as burr medic (*Medicago polymorpha* L.), sulla (*Hedysarum coronarium* L.), and subterranean clover (*Trifolium subterraneum* L.) increased markedly the CLA content in milk fat (Cabiddu et al., 2005). The presence in the forage diet of a daisy plant (*Chrysanthemum coronarium*) resulted in the highest concentrations of CLA in milk (Addis et al., 2005). Moreover, the best effect of pasture herbage can be obtained during the vegetative phase (Battacone et al., 2021; Cabiddu et al., 2005; Nudda, Mele, Battacone, Usai, & Macciotta, 2003). For this reason, in the Mediterranean area the lambing season takes place between late autumn and early winter, when the availability and the quality of pasture herbage is high, with the positive side effect of enriching ewe's milk and the lamb meat with FAs that are beneficial to human health (Battacone et al., 2021).

4.2. Effect of maternal by-product supplementation

Agro-industrial by-products supplementation to lactating ewes can modulate ruminal fat metabolism and subsequently the FAs profile of milk and meat. These by-products may also contain vitamins, unsaturated FAs, phenolic compounds, tannins and flavonoids, that can improve the nutritional attributes and shelf life of animal products. By-product inclusion in maternal diet did not exert a significant effect on the proximate composition and intramuscular fat composition of lambs, probably because of the moderate or low level of inclusion in the diet (Tables 3, 4).

Increasing the inclusion of grape by-product in mother diet from 5% to 10% of the total mixed ration reduced meat fat content from −3.7% to −11.6%, although the differences were not statistically significant (Gómez-Cortés et al., 2018; Table 3). The passage of polyphenols or their metabolites from milk to meat might have occurred, interfering in the expression or activities of lipogenic enzymes in the adipose tissue of lambs. However, in the same study, milk fat concentration did not differ between supplemented and unsupplemented groups (Gómez-Cortés et al., 2018). As recently highlighted by Correddu et al. (2023), the effect of grape by-products on milk yield and its main components is negligible. The grape by-products positively influenced the content of VA, RA, and LA in ewe milk at a level of inclusion ranging from 41 to 196 g/kg DM intake (Correddu et al., 2023). This was reflected in the lamb meat as evidenced by increased VA, RA, LA, and ALA contents, although the extent of variation compared to unsupplemented groups did not reach the level of significance in almost all studies (Table 4).

A significant decrease in cooking losses has been demonstrated as a consequence of increased grape inclusion (Table 3). This positive effect

Table 3
Effect of maternal diet on lamb proximate composition, Warner-Bratzler shear force, cooking and drip lossess. Data of the control group are reported as the mean value whereas data of the extent of variation are reported as the proportional difference (%) between the treatment group, at the respective level of inclusion, and the control group.

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Muscle[4]	Proximate composition[5]					W-B[6]	Cooking losses	Drip losses	References
					Moisture	DM	Protein	Fat	Ash				
Aragonesa	*Control*	*Sainfoin*	*Sainfoin (ad libitum) + 200 g/d barley*	*LTL*	–	*21.0% FM*	*21.0% FM*	*2.36% FM*	*1.81% FM*	–	–	–	Baila et al., 2022
	FOR	Sainfoin + PEG	Sainfoin (*ad libitum*) + 200 g/d barley +100 g/d PEG	LTL	–	0.0%	+1.4%	−7.2%	−1.7%	–	–	–	
Leccese	*Control*	*Hay + concentrate*	*0.5 kg/d concentrate+1.6 kg/d hay*	*LL*	*76.31%*	*23.69% FM*	*22.75% FM*	*2.47% FM*	*1.10% FM*	–	–	–	D'Alessandro et al., 2012
	FOR	Pasture	Access for 10 h/d	LL	−0.9%	+2.9%	**−12.0%**	−8.5%	+3.6%	–	–	–	
Castellana	*Control*	*Concentrate*	*Ad libitum concentrate*	*LL*	*73.88%*	*26.12% FM*	*17.16% DM*	*6.02% DM*	*1.16% DM*				Wilches et al., 2011
	FOR	Pasture	*Ad libitum* access to pasture +30% of supplementation	LL	−0.3%	+0.8%	0	**+12.0%**	0	–	–	–	
Churra	*Control*	*Concentrate*	*Ad libitum concentrate*	*LL*	*74.21%*	*25.79% FM*	*17.18% DM*	*4.94% DM*	*1.12% DM*	–	–	–	
	FOR	Pasture	*Ad libitum* access to pasture +30% of supplementation	LL	−0.9%	+2.7%	+0.8%	**+39.3%**	−2.7%	–	–	–	
Churra Tensina	*Control*	*Hay*	*Ad libitum*	*LTL*	–	–	–	*2.11% FM*	–	–	–		Dervishi et al., 2012
	FOR	Pasture	–	LTL	–	–	–	−2.6%	–	–	–	–	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	*LL*	*74.79%*	*25.1% FM*	*21.7% FM*	*2.29% FM*	*1.22% FM*	–	*3.38%*	*19.79%*	Fusaro et al., 2019
	FOR	Pasture	Access for 22 h/d	LL	+0.9%	−2.6%	−3.1%	+2.6%	−3.3%	–	+6.5%	+3.8%	
Churra Tensina	*Control*	*Hay*	*Ad libitum*	*LTL*	–	–	–	*2.47% FM*	–	–	–	–	Lobón et al., 2017
	FOR	Pasture	*Ad libitum* access	LTL	–	–	–	**−20.7%**	–	–	–	–	
Churra Tensina	*Control*	*Pre-partum hay*	*Ad libitum*	*LTL*	*75.37%*	*24.63% FM*	*20.36% FM*	*2.04% FM*	–	–	–	–	Joy, Sanz, et al., 2012
	FOR	Pre-partum pasture	*Ad libitum* access	LTL	+0.1%	−0.2%	−0.1%	+1.0%	–	–	–	–	
	Control	*Post-partum hay*	*Ad libitum*	*LTL*	*75.71%*	*24.29% FM*	*19.94% FM*	*2.08% FM*	–	–	–	–	
	FOR	Post-partum pasture	*Ad libitum* access	LTL	−0.8%	**+2.6%**	**+4.0%**	−2.9%	–	–	–	–	
Sarda	*Control*	*Lambs do not follow their mother during the grazing time*	*Pasture access for 6 h/d + 500 g/d concentrate + ad libitum hay*	*S*	*71.46%*	*28.54% FM*	*22.94% FM*	*2.5% FM*	*1.22% FM*				Nudda et al., 2013
	FOR	Lambs follow their mother during the grazing time	Pasture access for 6 h/d + 500 g/d concentrate + *ad libitum* hay	S	+0.4%	−1.0%	−0.9%	+11.2%	+0.8%	–	–	–	
Churra	*Control*	*LO*	*TMR with 2.7% LO*	*LTL*	*74.8%*	*25.2% FM*	*21.37% FM*	*3.10% FM*	–	*6.85 kgF cm^{-2}*	*24.1%*	–	Gómez-Cortés et al., 2018
	BP	Vit. E	500 mg/kg TMR, on DM	LTL	−0.1%	+0.4%	+0.4%	−6.1%	–	−16.6%	**−21.6%**	–	
	BP	GP-5	5% of TMR, on DM	LTL	−0.4%	+1.2%	−0.7%	−3.7%	–	−14.9%	**−11.2%**	–	
	BP	GP-10	10% of TMR, on DM	LTL	+0.4%	−1.2%	−0.6%	−11.6%	–	−21.5%	**−20.7%**	–	
Chamarita	*Control*	*Concentrate without added wine by-product*	*1 kg/d concentrate + ad libitum access to Medicago sativa*	*LTL*	–	–	–	–	–	*2.47 kg cm^{-2}*	*5.25%*	*2.61%*	Pascual-Alonso et al., 2018
	BP	GP	10% of GP on 1 kg of concentrate/d, on DM+ *ad libitum* access to *Medicago sativa*	LTL	–	–	–	–	–	+4.5%	+5.9%	−25.3%	
	BP	GS	5% of GS on 1 kg of concentrate/d, on DM + *ad libitum access* to *Medicago sativa*	LTL	–	–	–	–	–	+20.2%	−4.4%	31.0%	
Churra Tensina	*Control*	*Commercial concentrate without quebracho*	*300 g/head, as fed*	*LTL*	–	–	–	*2.24% FM*	–	–	–	–	Lobón et al., 2017
	BP	Quebracho concentrate	300 g/head, as fed	LTL	–	–	–	−1.8%	–	–	–	–	

(*continued on next page*)

Table 3 (*continued*)

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Muscle[4]	Proximate composition[5]					W-B[6]	Cooking losses	Drip losses	References
					Moisture	DM	Protein	Fat	Ash				
Churra	*Control*	*Without LO and vit E*	*Ad libitum access to TMR*	*LL*	*75.46%*	–	*19.56% FM*	*2.79% FM*	*1.42% FM*	–	–	–	Gallardo et al., 2015
	Fat	LO	3% LO	LL	−0.8%	–	+0.8%	+27.2%	−4.2%	–	–	–	
	Fat	LO + synthetic Vit. E	LO + 400 mg/kg TMR of synthetic Vit. E	LL	+0.6%	–	+4.1%	−14.7%	−9.2%	–	–	–	
	Fat	LO + natural Vit. E	LO + 400 g/kg TMR of natural Vit. E	LL	−0.9%	–	+4.2%	+26.2%	**−31.0**%	–	–	–	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	*LL*	*74.79%*	*25.1% FM*	*21.7% FM*	*2.29% FM*	*1.22% FM*	–	*3.38%*	*19.79%*	Fusaro et al., 2019
	Fat	LIN	190 g/d	LL	+0.9%	−2.5%	−3.0%	+3.1%	−4.9%	–	+5.9%	−14.6%	
Sarda	*Control*	*CON-PREG and LACT*	*1 kg/d concentrate + ad libitum access to hay*	*LTL*	*77.3 g/ 100 g*	*22.7 g/ 100 g FM*	*20.1 g/ 100 g FM*	*1.6 g/100 g FM*	*1.11 g/ 100 g FM*	–	–	–	Nudda et al., 2015
	Fat	LIN-PREG	150 g/kg of concentrate + *ad libitum* access to hay	LTL	−0.9%	+3.1%	+2.5%	+12.5%	+6.3%	–	–	–	
	Fat	LIN-LACT	150 g/kg of concentrate + *ad libitum* access to hay	LTL	−0.6%	+2.2%	+2.5%	0.0%	+8.1%	–	–	–	
	Fat	LIN-PREG and LACT	150 g/kg of concentrate + *ad libitum* access to hay	LTL	−1.2%	+4.0%	+4.5%	+6.2%	+9.0%	–	–	–	

Bold and underlined values indicate significant differences ($P < 0.05$) compared to the control group as reported in the original paper. The dash indicates that the data were not reported in the publication.

[1] FOR = Forage; BP = By-product.

[2] PEG = Polyethylene glycol; LO = Linseed oil; Vit. E = Vitamin E; GP = Grape pomace; GS = Grape seed; LIN = extruded linseed; PREG = Linseed offered during pregnancy; LACT = Linseed offered during lactation.

[3] TMR = Total mixed ration; DM = Dry matter.

[4] LTL = *Longissimus thoracis et lumborum*; LL = *Longissimus lumborum*; S = *Semitendinosus, Semimembranosus and femoral biceps.*

[5] FM = Fresh matter; DM = Dry matter.

[6] W-B = Warner-Bratzler shear force.

Table 4

Effect of maternal diet on fatty acids profile of lamb intramuscular fat. Data of the control group are reported as the mean value whereas data of the extent of variation are reported as the proportional difference (%) between the treatment group, at the respective level of inclusion, and the control group.

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Muscle[4]	Fatty acids composition of intramuscular fat[5]											References
					18:0	*t*11–18:1	*c*9, *t*11–18:2	18:2n-6	18:3n-3	n-6/n-3	20:5n-3	22:6n-3	SFA	MUFA	PUFA	
Castellana	*Control*	*Concentrate*	*Ad libitum concentrate*	*LL*	*69.5 mg/g*	–	–	*66.8 mg/g*	*12.4 mg/g*	–	–	–	*657.4 mg/g*	*266.1 mg/g*	*79.2 mg/g*	Wilches et al., 2011
	FOR	Pasture	*Ad libitum* access to pasture +30% supplement	LL	+12.4%	–	–	**+13.9%**	**+62.1%**	–	–	–	**−3.5%**	**+1.2%**	**+21.6%**	
Churra	*Control*	*Concentrate*	*Ad libitum concentrate*	*LL*	*59.7 mg/g*	–	–	*57.5 mg/g*	*12.9 mg/g*	–	–	–	*716.1 mg/g*	*213.4 mg/g*	*70.4 mg/g*	
	FOR	Pasture	*Ad libitum* access to pasture +30% supplement	LL	−1.2%	–	–	**+28.3%**	**+17.1%**	–	–	–	**−11.5%**	**+18.3%**	**+26.3%**	
Churra Tensina	*Control*	*Hay*	*Ad libitum*	*LTL*	*139.0 mg/g*	–	*13.8 mg/g*	*47.9 mg/g*	*16.2 mg/g*	–	*7.7 mg/g*	*5.2 mg/g*	–	–	–	Dervishi et al., 2012
	FOR	Pasture	–	LTL	**+2.2**%	–	**+23.2%**	+14.8%	+25.3%	–	+40.3%	+34.6%	–	–	–	
Comisana	*Control*	*Dry diet*	*1.0 kg/d concentrate + 1.3 kg/d hay*	*LTL*	*95.2 mg/g*	*11.5 mg/g*	*6.2 mg/g*	*128.8 mg/g*	*42.4 mg/g*	*2.86 mg/g*	*33.9 mg/g*	*41.7 mg/g*	*283.1 mg/g*	*191.8 mg/g*	*525.1 mg/g*	Valvo et al., 2005
	FOR	Vech Pasture	Access for 10 h/d *vs* indoor	LTL	**−14.4%**	**+48.7%**	**+117.7%**	**−35.8%**	**+212.0%**	**−78.0%**	**+117.1%**	**+36%**	**−17.2%**	+0.5%	+9.1%	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	*LL*	–	–	*4.7 mg/g*	–	–	*5.30*	–	–	*441.6 mg/g*	*370.9 mg/g*	*187.5 mg/g*	Fusaro et al., 2019
	FOR	Pasture	Access for 22 h/d	LL	–	–	**+70.2%**	–	–	**−18.9%**	–	–	**−4.7%**	+2.5%	**+6.1%**	
Churra Tensina	*Control*	*Pre-partum hay*	*Ad libitum*	*LT*	*136.7 mg/g*	–	*14.2 mg/g*	*53.0 mg/g*	*18.7 mg/g*	–	*10.2 mg/g*	*6.9 mg/g*	*422.0 mg/g*	*440.6 mg/g*	*137.4 mg/g*	Joy, Ripoll, et al., 2012
	FOR	Pre-partum pasture	*Ad libitum* access	LT	+2.3%	–	**+16.9%**	−4.9%	−1.1%	–	−13.7%	−11.6%	−0.3%	+2.1%	−6.0%	
	Control	*Post-partum hay*	*Ad libitum*	*LT*	*135.4 mg/g*	–	*13.5 mg/g*	*48.9 mg/g*	*16.5 mg/g*	–	*7.9 mg/g*	*5.7 mg/g*	*424.8 mg/g*	*453.1 mg/g*	*122.1 mg/g*	
	FOR	Post-partum pasture	*Ad libitum* access	LT	+4.2%	–	**+28.1%**	+11.5%	**+25.5%**	–	**+40.5**%	+28.1%	−1.6%	−3.4%	+18.4%	
Sarda	*Control*	*Lambs do not follow their mother during the grazing time*	*Pasture access for 6 h/d + 500 g/d concentrate + ad libitum hay*	*S*	*127.2 mg/g*	*21.6 mg/g*	*14.4 mg/g*	*57.7 mg/g*	*13.4 mg/g*	*2.44*	*7.8 mg/g*	*6.5 mg/g*	*414.1 mg/g*	*424.5 mg/g*	*155.5 mg/g*	Nudda et al., 2013
	FOR	Lambs follow their mother during the grazing time	Pasture access for 6 h/d + 500 g/d concentrate + *ad libitum* hay	S	+4.7%	+1.4%	−0.7%	−0.3%	−2.2%	+4.9%	−3.8%	−1.5%	0.0%	+0.2%	−0.5%	
Leccese	*Control*	*Hay + concentrate*	*0.5 kg/d concentrate+1.6 kg/d hay*	*LL*	*122.1 mg/g*	–	*9.7 mg/g*	–	*6.0 mg/g*	*2.03*	*0.7 mg/g*	*1.6 mg/g*	*519.0 mg/g*	*407.4 mg/g*	*73.7 mg/g*	D'Alessandro et al., 2012
	FOR	Pasture	Access for 10 h/d	LL	−1.7%	–	**+77.3%**	–	**+110.0%**	**−28.1%**	+85.7%	+31.3%	**−5.8%**	+3.9%	**+18.0%**	
Italian Merino	*Control*	*Hay + concentrate*	*Ad libitum hay + concentrate*	*LL*	*106.4 mg/g*	*16 mg/g*	*7.7 mg/g*	*130.7 mg/g*	*58.3 mg/g*	*13.2 mg/g*	*40.7 mg/g*	*28.9 mg/g*	*308.3 mg/g*	*238.1 mg/g*	*453.6 mg/g*	Scerra et al., 2007
	FOR	Pasture	Natural pasture	LL	−0.9%	**+13.1%**	+13.0%	+13.8%	**+75.1%**	**−18.9%**	**+30.7%**	−2.4%	**+17.1%**	**−21.1%**	**+18.3%**	

(*continued on next page*)

Table 4 (*continued*)

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Muscle[4]	Fatty acids composition of intramuscular fat[5]											References
					18:0	*t*11–18:1	*c*9, *t*11–18:2	18:2n-6	18:3n-3	n-6/n-3	20:5n-3	22:6n-3	SFA	MUFA	PUFA	
Churra	*Control*	*LO*	*TMR with 2.7% LO*	*LTL*	*115.0 mg/g*	*17.5 mg/g*	*8.7 mg/g*	–	*16.2 mg/g*	*1.29*	*15.1 mg/g*	*13.5 mg/g*	*361.0 mg/g*	*376.0 mg/g*	*263.0 mg/g*	Gómez-Cortés et al., 2018
	BP	Vit. E	500 mg/kg TMR, on DM	LTL	−0.9%	+20.6%	+14.9%	–	+30.2%	−8.5%	+9.9%	+7.4%	+2.8%	**−6.1%**	+4.9%	
	BP	GP-5	5% of TMR, on DM (2.14 g of PFs/kg DM)	LTL	0.0%	+20.0%	+37.9%	–	+16.0%	−3.1%	+9.3%	+11.9%	+1.4%	**−7.2%**	+8.0%	
	BP	GP-10	10% of TMR, on DM (4.28 g of PFs/kg DM)	LTL	−4.3%	+26.3%	+37.9%	–	+2.5%	−2.3%	−7.3%	−3.0%	+5.3%	**−5.9%**	+1.1%	
Chamarita	*Control*	*Concentrate without added wine by-products*	*1 kg/d concentrate + ad libitum access to Medicago sativa*	*LTL*	*135.4 mg/g*	–	–	*52.9 mg/g*	*5.3 mg/g*	*4.53*	*4.1 mg/g*	*3.9 mg/g*	*486.9 mg/g*	*398.9 mg/g*	*114.0 mg/g*	Resconi et al., 2018
	BP	GP	10% of GP on 1 kg of concentrate/d, on DM + *ad libitum access* to *Medicago sativa*	LTL	+6.1%	–	–	**+16.3%**	+15.1%	−0.2%	+12.2%	+12.8%	−1.9%	−1.1%	+12.3%	
	BP	GS	5% of GS on 1 kg of concentrate/d, on DM + *ad libitum* access to *Medicago sativa*	LTL	+7.2%	–	.-	+12.3%	+3.8%	+4.9%	+4.9%	+2.6%	+2.1%	−5.2%	+8.8%	
Churra	*Control*	*PO*	*3% of Ca soap of PO*	*LTL*	*126.9 mg/g*	*5.7 mg/g*	*3.6 mg/g*	*84.1 mg/g*	*4.3 mg/g*	*5.44*	*4.4 mg/g*	*6.2 mg/g*	*422.4 mg/g*	*395.4 mg/g*	*175.4 mg/g*	Gallardo et al., 2014
	Fat	MO	3% of Ca soap of MO	LTL	**−19.9%**	**+557.9%**	**+361.1%**	−7.0%	**+123.3%**	**−66.9%**	**+518.2%**	**+146.8%**	−1.4%	**−14.6%**	**+36.5%**	
Churra	*Control*	*PO*	*3% of TMR, as fed*	*LTL*	*127.2 mg/g*	*2.1 mg/g*	*6.6 mg/g*	*120.6 mg/g*	*10.4 mg/g*	*11.08*	*10.2 mg/g*	–	*409.6 mg/g*	*329.9 mg/g*	*260.5 mg/g*	Manso et al., 2011
	Fat	OLI	3% of TMR, as fed	LTL	**+2.6%**	**+57.1%**	+3.0%	−7.6%	−16.3%	+6.8%	−12.7%	–	**−4.7%**	**+11.3%**	−7.0%	
	Fat	SO	3% of TMR, as fed	LTL	**+2.0%**	**+176.2%**	**+97.0%**	**+7.3%**	−19.2%	**+25.5%**	**−32.4%**	–	**−6.0%**	+7.1%	+0.5%	
	Fat	LO	3% of TMR, as fed	LTL	**+4.4%**	**+190.5%**	**+71.2%**	−1.7%	**+102.9%**	**−43.1%**	**+35.3%**	–	**−3.9%**	+2.4%	+3.1%	
Churra	*Control*	*PO*	*3% of Ca soap of PO*	*LTL*	*126.9 mg/g*	*5.7 mg/g*	*3.6 mg/g*	*84.1 mg/g*	*4.3 mg/g*	*5.44*	*4.4 mg/g*	*6.2 mg/g*	*422.4 mg/g*	*395.4 mg/g*	*175.4 mg/g*	Gallardo et al., 2014
	Fat	OLI	3% of Ca soap of OLI	LTL	−0.6%	+122.8%	+94.4%	−1.1%	+16.3%	−7.4%	+31.8%	+16.1%	−8.5%	+4.5%	+10.1%	
Churra	*Control*	*Without LO and vit E*	*Ad libitum access to TMR*	*LTL*	*135.2 mg/g*	*6.7 mg/g*	*5.0 mg/g*	*59.7 mg/g*	*6.2 mg/g*	*4.32*	*3.0 mg/g*	*4.1 mg/g*	*486.0 mg/g*	*386.2 mg/g*	*127.8 mg/g*	Gallardo et al., 2015
	Fat	LO	3% LO	LTL	−0.9%	**+361.2%**	**+224.0%**	−6.0%	**+56.5%**	**−15.5%**	−10.0%	−39.0%	−6.4%	+9.5%	−4.6%	
	Fat	LO+ synthetic Vit. E	LO + 400 mg/kg TMR of synthetic Vit. E	LTL	−1.5%	**+362.7%**	**+208.0%**	**+21.1**%	**+95.2%**	**−23.4%**	**+90.0%**	+24.4%	**−13.6%**	+7.7%	**+28.6%**	
	Fat	LO + natural Vit. E	LO + 400 g/kg TMR of natural Vit. E	LTL	+5.8%	**+446.3%**	**+226.0%**	−3.9%	**+69.4%**	**−21.3%**	+3.3%	−36.6%	−7.0%	+9.3%	−1.6%	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	*LL*	–	–	*4.7 mg/g*	–	–	*5.30*	–	–	*441.6 mg/g*	*370.9 mg/g*	*187.5 mg/g*	Fusaro et al., 2019

(*continued on next page*)

Table 4 (*continued*)

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Muscle[4]	Fatty acids composition of intramuscular fat[5]											References
					18:0	*t*11–18:1	*c*9, *t*11–18:2	18:2n-6	18:3n-3	n-6/n-3	20:5n-3	22:6n-3	SFA	MUFA	PUFA	
Churra	Fat	LIN	190 g/d	LL	–	–	**+46.8%**	–	–	**−31.1%**	–	–	**−7.3%**	+0.1%	**+16.9%**	Gómez-Cortés et al., 2014
	Control	*PO*	*70 g/d of FA from calcium soap of PO*	*LTL*	*126.9 mg/g*	*5.7 mg/g*	*3.6 mg/g*	*84.1 mg/g*	*4.3 mg/g*	*5.44*	*4.4 mg/g*	*6.2 mg/g*	*422.4 mg/g*	*395.4 mg/g*	*135.4 mg/g*	
	Fat	LIN	128 g/d	LTL	−0.9%	**+321.1%**	**+247.2%**	+8.9%	**+309.3%**	**−55.5%**	**+222.7%**	**+101.6%**	−6.4%	−8.9%	**+75.8%**	
Sarda	*Control*	*CON-PREG and LACT*	*1 kg/d concentrate + ad libitum access to hay*	–	*134.2 mg/g*	*9.3 mg/g*	*7.3 mg/g*	*118.8 mg/g*	*7.5 mg/g*	*5.34*	*6.4 mg/g*	*8.9 mg/g*	*374.6 mg/g*	*360.2 mg/g*	*243.7 mg/g*	Nudda et al., 2015
	Fat	LIN-PREG	150 g/kg of concentrate + *ad libitum* access to hay	–	+1.2%	+29.0%	+20.5%	+9.5%	+32.0%	**−19.7%**	**+87.5%**	**+40.4%**	−1.9%	−2.5%	+9.9%	
	Fat	LIN-LACT	150 g/kg of concentrate + *ad libitum* access to hay	–	+1.6%	**+203.2%**	**+112.3%**	+6.1%	**+138.7%**	**−27.3%**	+40.6%	−5.6%	**−8.6%**	+5.7%	+1.9%	
	Fat	LIN-PREG and LACT	150 g/kg of concentrate + *ad libitum* access to hay	–	−1.3%	**+196.8%**	**+126.0%**	−4.8%	**+165.3%**	**−47.0%**	**+110.9%**	+19.1%	−6.8%	+7.3%	−3.3%	

Bold and underlined values indicate significant differences ($P < 0.05$) compared to the control group as reported in the original paper. The dash indicates that the data were not reported in the publication.

[1] FOR = Forage; BP = By-product.

[2] LO = Linseed oil; Vit. E = Vitamin E; GP = Grape pomace; GS = Grape seed; PO = Palm oil; MO = Marine oil; OLI = Olive oil; SO; soybean oil; LIN = extruded linseed; PREG = Linseed offered during pregnancy; LACT = Linseed offered during lactation.

[3] TMR = Total mixed ration; DM = Dry matter; PFs = polyphenols; FA = Fatty acids.

[4] LL = *Longissimus lumborum*; LTL = *Longissimus thoracis et lumborum*; LT = *Longissimus thoracis;* S = *Semitendinosus, Semimembranosus and femoral biceps.*

[5] SFA = Saturated fatty acids; MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids.

could be related to the presence of polyphenols that may exert beneficial effects on drip loss, as they are involved in the preservation of membrane integrity of lipids. The improvement of water holding capacity of meat that reduce the drip and cooking losses has been previously reported in rabbit (Dal Bosco et al., 2014), chicken (Mazur-Kuśnirek et al., 2019) and goat (Zhong et al., 2009) meat through dietary supplementation of polyphenols or other antioxidants, such as vitamin E (Gómez-Cortés et al., 2018).

4.3. *Effect of maternal fat supplementation*

The dietary inclusion of vegetable oils in maternal diet did not exert a significant effect on the proximate composition of lamb meat; the greatest effect was evident on the FAs profile of lamb meat. In fact, the beneficial effect of vegetable oils on maternal milk FAs profile translates into a beneficial effect in intramuscular FAs profile of suckling lamb meat (Table 4). Linseed supplementation has the greatest effect. On average, it increases the content of VA, RA, and ALA in intramuscular fat, compared to lambs whose dams were not supplemented. Linseed supplementation is also effective in increasing the intramuscular fat content of LC-PUFAn-3 as EPA and DHA, reducing the n-6/n-3 ratio and SFA content (Table 4).

Soybean oil was less effective than linseed oil in increasing the CLA content of intramuscular fat in suckling lambs (Manso et al., 2011). Moreover, soybean oil decreased the EPA content (−32.4%; Manso et al., 2011; Table 4) and enhanced the n-6/n-3 ratio (+25.5%; Manso et al., 2011; Table 4). Olive oil in the mother diet significantly increased the content of monounsaturated fatty acids (MUFA), mainly VA, in suckling lamb meat (Manso et al., 2011). Variability in the response to a fat supplementation should be related to differences between breeds, form of fat, and experimental conditions (Table 4).

The supplementation of marine oils to ewes appeared to be effective in increasing VA, RA, ALA and LC-PUFAn-3, mainly EPA and DHA contents in meat of suckling lambs (Table 4). This is of particular importance for nutritional quality of meat as *de novo* synthesis of LC-PUFA in humans is very low (Bradbury, 2011). In general, the use of vegetable or marine oils appears to be a promising strategy to increase healthier FA in dairy and meat products, especially when pasture availability is limited.

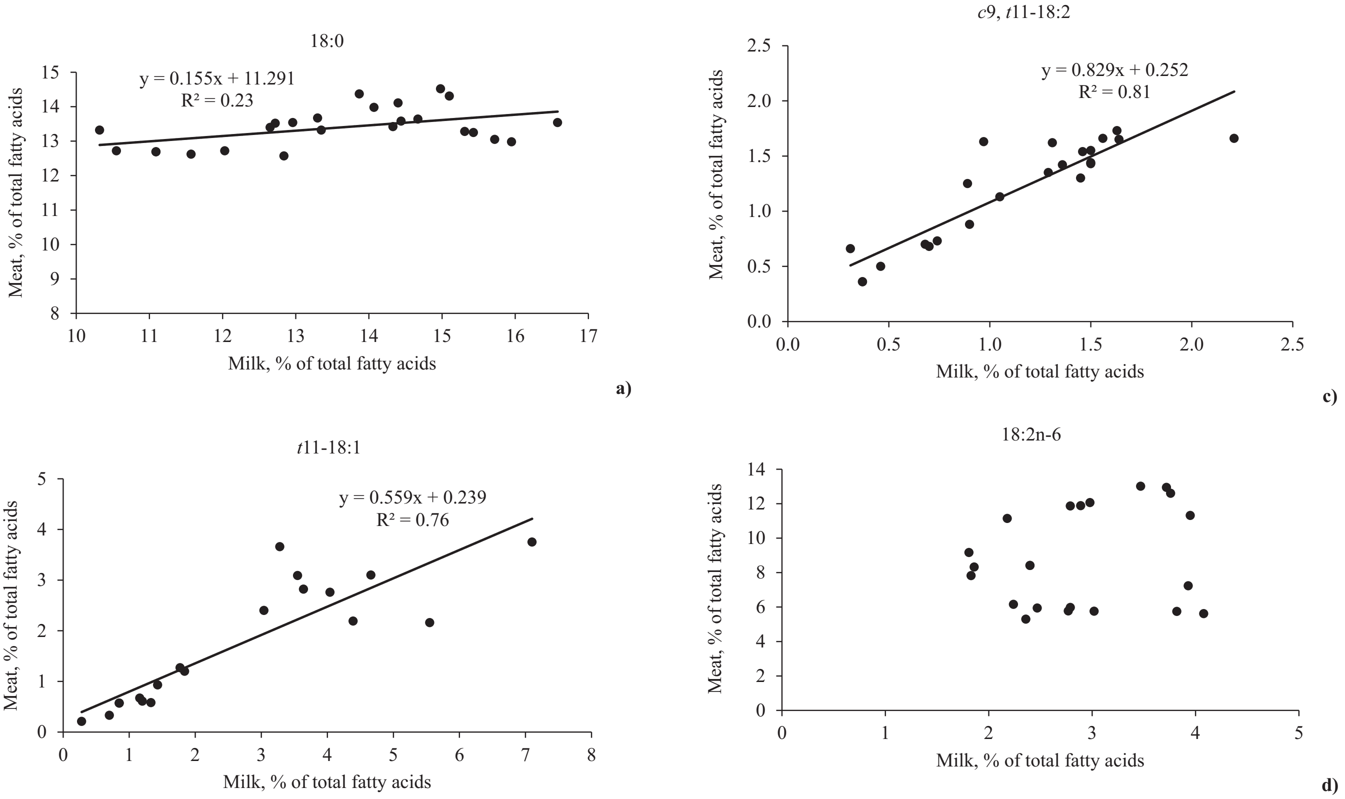

Fig. 1. Relationships between some of the relevant individual fatty acids, saturated fatty acids (SFA), monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) found in the milk of ewes and in the meat of their suckling lambs. Each point refers to a specific study. For Fig. 1e, the back circles refer to the relation between 18:3n-3 in milk of lipid-supplemented ewes and 18:3n-3 in meat of their suckling lambs while the open triangles refer to the relation between 18:3n-3 in milk of non-supplemented ewes and 18:3n-3 in meat of their suckling lambs. In addition, Y1 means 18:3n-3 in lamb meat whose mothers were non supplemented while Y2 means 18:3n-3 in lamb meat whose mothers were lipid-supplemented. References. For 18:0 (Stearic acid, SA, **a**): Manso et al., 2011; Joy, Ripoll, et al., 2012; Nudda et al., 2013; Gallardo et al., 2014; Gómez-Cortés et al., 2014; Gallardo et al., 2015; Nudda et al., 2015; Resconi et al., 2018. For *t*11–18:1 (Vaccenic acid, VA, **b**): Manso et al., 2011; Nudda et al., 2013; Gallardo et al., 2014; Gómez-Cortés et al., 2014; Gallardo et al., 2015; Nudda et al., 2015. For *c*9, *t*11–18:2 (Coniugated linoleic acid, CLA or rumenic acid, RA, **c**): Manso et al., 2011; Joy, Ripoll, et al., 2012; Nudda et al., 2013; Gallardo et al., 2014; Gómez-Cortés et al., 2014; Gallardo et al., 2015; Nudda et al., 2015. For 18:2n-6 (Linoleic acid, LA, **d**): Manso et al., 2011; Nudda et al., 2013; Gallardo et al., 2014; Gómez-Cortés et al., 2014; Gallardo et al., 2015; Nudda et al., 2015; Resconi et al., 2018. For 18:3n-3 (Alpha-linolenic acid, ALA, **e**): Manso et al., 2011; Gallardo et al., 2014; Gómez-Cortés et al., 2014; Gallardo et al., 2015; Nudda et al., 2015 (Lipid source: olive oil, soybean oil, linseed oil, extruded linseed). For 20:5n-3 (Eicosapentaenoic acid, EPA, **f**): Manso et al., 2011; Joy, Ripoll, et al., 2012; Nudda et al., 2013; Gallardo et al., 2014; Gómez-Cortés et al., 2014; Gallardo et al., 2015; Nudda et al., 2015; Resconi et al., 2018. For 22:6n-3 (docosahexaenoic acid, DHA, **g**): Joy, Ripoll, et al., 2012; Nudda et al., 2013; Gallardo et al., 2014; Gómez-Cortés et al., 2014; Gallardo et al., 2015; Nudda et al., 2015; Resconi et al., 2018. For SFA (**h**), MUFA (**i**), and PUFA (**l**): Manso et al., 2011; Joy, Ripoll, et al., 2012; Nudda et al., 2013; Gallardo et al., 2014; Gómez-Cortés et al., 2014; Gallardo et al., 2015; Nudda et al., 2015; Resconi et al., 2018.

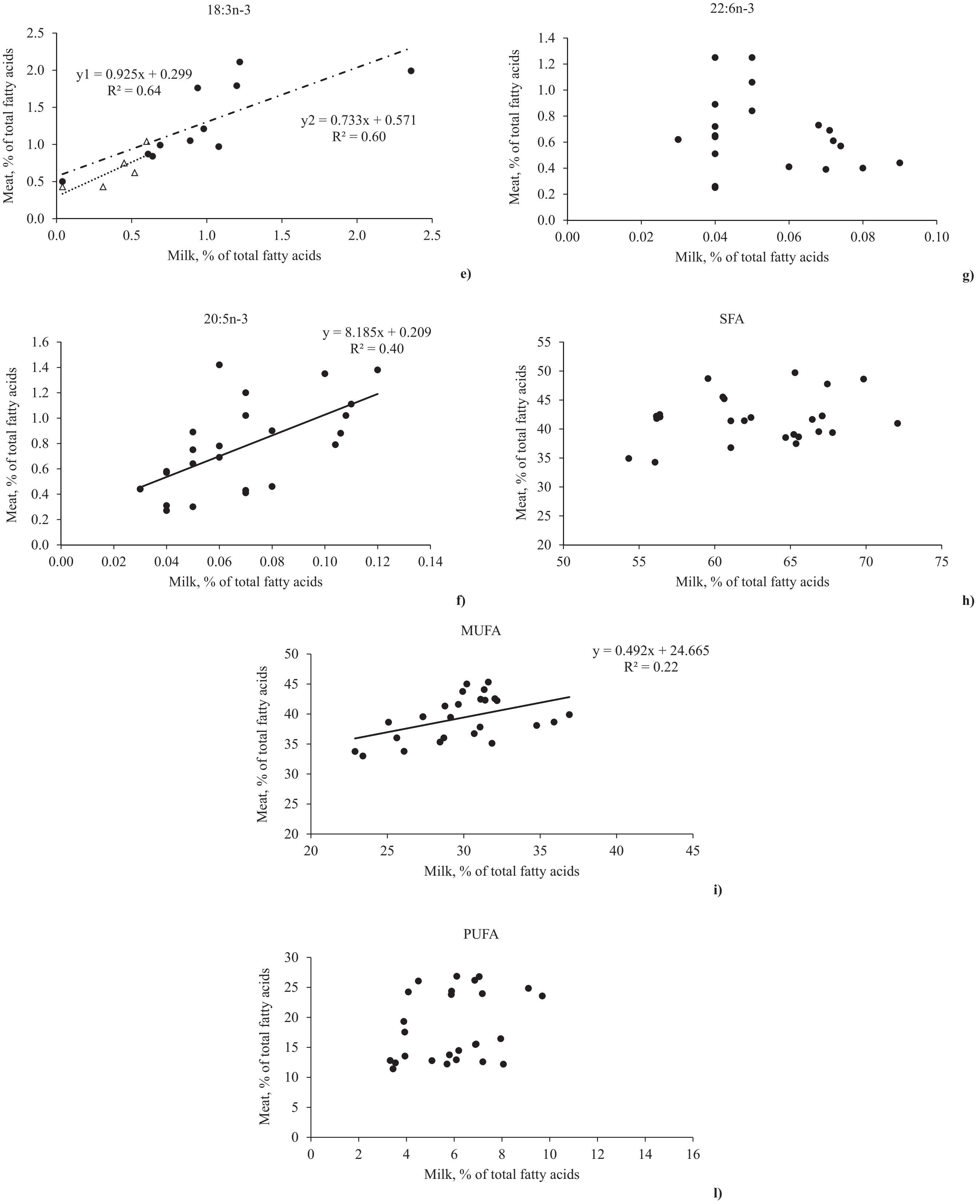

Fig. 1. (*continued*).

4.4. Relationship between milk fatty acid profile and fatty acid profile in suckling lamb meat

Relationship between the proportion of certain individual FAs or groups of FAs in ewe's milk and lamb meat are shown in Fig. 1 and the parameters for the regression analysis (slope, intercept and RSE) are given in Table 5.

The proportion of individual FA in lamb meat was linearly related to the proportion of this FA in milk for stearic acid (SA, 18:0), for EPA, VA, and CLA (Table 5), evidencing an effective transfer from ewe's milk to lamb meat of FAs of nutritional interest in human diet. For VA, the intercept was not different from zero ($P > 0.05$), indicating that milk is the only source of this FA in lamb meat. For CLA, the intercept was greater than zero ($P < 0.05$), probably due to the desaturation of VA to CLA by the activity of the enzyme Delta9-desaturase in the adipose tissue of growing ruminants (Palmquist, Lock, Shingfield, & Bauman, 2005; Serra et al., 2009). The intercept was statistically greater than zero for SA, LA, ALA, DHA, SFA, MUFA and PUFA, suggesting an additional source of these FAs in addition to that transferred from milk, such as a placenta transfer and accumulation of these FAs in pre-partum (Nudda et al., 2022). Slope differed from unity for VA ($b_1 = 0.56$; $P < 0.001$), 18:0 ($b_1 = 0.15$; $P < 0.001$), and 20:5n-3 ($b_1 = 8.18$; $P < 0.01$), indicating different transfer efficiency from milk to meat. Specifically, for SA the low value indicates a threshold of inclusion of FA in lamb tissues; for VA, the $b_1 = 0.56$ suggests an increase of 0.56 units in meat for each unit of VA in milk whereas, for ALA and CLA, it can be assumed that the transfer to meat is almost directly proportional to the proportion in milk. For EPA, its proportion in the intramuscular fat meat is 8.18-fold higher than in milk. Moreover, the regression for ALA separately for lipid-supplemented and non-supplemented ewes showed that was similar as the slope was not significantly different; the intercept value was different from zero for lipid-supplemented ($P = 0.029$) whereas was not different from zero for non-supplemented ewes ($P = 0.184$); however, the number of data sets was low for non-supplemented ewes. A positive relationship between VA ($b_1 = 0.26$; $R^2 = 0.85$), RA ($b_1 = 0.54$; $R^2 = 0.72$), ALA ($b_1 = 0.65$; $R^2 = 0.61$) proportions in milk and meat was also observed by Nudda et al. (2008) in an experimental trial on suckling kids.

5. Effect of maternal diet on oxidative stability of suckling lamb meat

The increase in PUFA, myoglobin with Fe heme and other oxidant components in muscle tissue makes meat susceptible to oxidative processes. In particular, the increase in PUFA in meat could lead to lipid oxidation during processing and storage, reducing the quality of meat products in terms of flavor and color. The dietary supplementation of ewe with vegetable oils, despite the increase in PUFA in intramuscular fat of suckling lambs (Table 4) did not show significant effect on the oxidative stability of the meat assessed by measuring thiobarbituric acid reactive substances (TBARS; Vieira et al., 2012; Nudda et al., 2015). Meat oxidation with high levels of PUFA could be mitigated by the presence of antioxidants compounds, such as vitamin E, carotenoids and polyphenols in dietary ingredients. The inclusion of by-products rich in polyphenols in maternal diet has been found to improve the oxidative stability of lamb meat during storage (Correddu et al., 2020; Salami et al., 2019; Scerra et al., 2021; Vasta & Luciano, 2011; Vasta, Nudda, Cannas, Lanza, & Priolo, 2008). Addition of grape pomace to ewe diet (dose of 5% on DM basis) improved the shelf life of suckling lamb meat packaged and stored in retail conditions, due to the delayed myoglobin and lipid oxidation (Vieira et al., 2022). These positive effects have also been observed by administering synthetic vitamin E (Vieira et al., 2022), probably due to the passage of antioxidant substances from feeds to milk and then to suckling lamb meat. The concentration of vitamin E in the meat of suckling lambs was positively correlated with those in the maternal milk (Gallardo et al., 2015). However, the efficiency of vitamin E deposition at the tissue level decreased with increasing dose of the vitamin in the milk (Gallardo et al., 2015), confirming the previous observation by Kasapidou et al. (2012) with lambs receiving increasing levels of vitamin E. Other antioxidant compounds contained in forage fed to ewes increased the polyphenol content in the meat of their lambs, but meat lipid oxidation level was not significantly related to meat polyphenol content (Baila et al., 2022) probably because the quantification of the oxidative biomarkers (*e.g.*, TABARs) was performed in raw fresh meat samples. In fact, oxidative status of meat is usually significantly altered by chopping, cooking (Nudda et al., 2013), packaging (Ponnampalam et al., 2017) and storage (Kasapidou et al., 2012), and vitamin E and polyphenols may counteract and delay oxidation processes.

6. Effect of maternal diet on color parameters and pH of suckling lamb meat

Visual impression and selection of meat by consumer is affected by the meat color which, in turn, depends on myoglobin concentration, carotenoids (Calnan, Jacob, Pethick, & Gardner, 2016) and unsaturated FAs contents.

6.1. Effect of maternal forage diet

The forage-based maternal diet did not affect meat pH of suckling lamb (Table 6) except in one study in which the *ad libitum* permanent access to pasture compared with ewes stalled indoors, receiving hay *ad libitum,* decreased significantly the pH value (−0.9%) of suckling lamb

Table 5
Linear regression analysis applied to predict the relationship between fatty acids content in lamb muscle (as Y) and fatty acids content in maternal milk (as X).

Fatty acid[1]	b0			b1				RSE	R2
	Value	CI 95%	Different from 0	Value	CI 95%	Different from 0	Different from 1		
18:0	11.29	9.65–12.95	<0.001	0.15	0.03–0.28	<0.05	<0.001	0.54	0.23
*t*11–18:1	0.24	−0.28-0.76	ns	0.56	0.40–0.72	<0.001	<0.001	0.61	0.76
*c*9,*t*11–18:2	0.25	0.03–0.48	<0.05	0.83	0.64–1.01	<0.001	ns	0.21	0.81
18:2n-6	6.63	1.43–11.83	<0.05	0.73	−1.01-2.48	ns		2.85	0.04
18:3n-3	0.44	0.24–0.64	<0.001	0.87	0.67–1.08	<0.001	ns	0.28	0.77
20:5n-3	0.21	−0.081-0.510	ns	8.18	4.00–12.24	<0.001	<0.01	0.27	0.40
22:6n-3	0.85	0.440–1.267	<0.001	−3.69	−11.10-3.72	ns		0.28	0.05
SFA	30.19	8.77–51.61	<0.01	0.18	−0.16-0.52	ns		4.02	0.05
MUFA	24.67	13.04–36.29	<0.001	0.49	0.10–0.88	<0.05	<0.05	3.25	0.22
PUFA	12.68	4.51–20.84	<0.001	0.95	−0.37-2.27	ns		5.63	0.08

b0 = intercept; b1 = slope; CI 95% = the 95% confidence interval of regression coefficients; ns = not significant; RSE = residual standard error; R2 = coefficient of determination. The intercept and the slope were tested for statistical difference from zero ($P < 0.05$).
The slope was tested also for statistical difference from 1 ($P < 0.05$), only when significantly different from zero.
[1] SFA = Saturated fatty acids; MUFA = Monounsaturated fatty acids; PUFA = Polyunsaturated fatty acids.

Table 6

Effect of maternal diet on pH and meat (*Rectus abdominis* and *Longissimus thoracis et lumborum muscles)* color of suckling lambs. Data of the control group are reported as the mean value whereas data of the extent of variation are reported as the proportional difference (%) between the treatment group, at the respective level of inclusion, and the control group.

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Muscle[4]	Muscle pH 24 h post slaughter	Color parameters					Referencea
						Lightness (*L**)	Redness (*a**)	Yellowness (*b**)	Hue angle (*H**)	Chroma (*C**)	
Aragonesa	*Control*	*Sainfoin*	*Sainfoin (ad libitum) + 200 g/d barley*	RECT	*5.5*	–	–	–	–	–	Baila et al., 2022
	FOR	Sainfoin + PEG	Sainfoin *(ad libitum)* + 200 g/d barley +100 g/d PEG		+0.5%	–	–	–	–	–	
Leccese	*Control*	*Stall*	*0.5 kg/d concentrate+1.6 kg/d hay*	RECT	*6.03*	–	–	–	–	–	D'Alessandro et al., 2012
Leccese	FOR	Pasture	Access for 10 h/d		0.5%	–	–	–	–	–	
Churra Tesina	*Control*	*Pre-partum hay*	*Ad libitum*	RECT	*5.64*	*51.78*	*9.12*	*13.14*	–	–	Joy, Sanz, et al., 2012
	FOR	Pre-partum pasture	*Ad libitum* access		+0.5%	**−5.5**%	**+14.7**%	−11.0%	–	–	
	Control	*Post-partum hay*	*Ad libitum*		*5.65*	*52.36*	*8.89*	*13.42*	–	–	
	FOR	Post-partum pasture	*Ad libitum* access		0%	**−7.7**%	**+20.4**%	**−14.9**%	–	–	
Churra Tensina	*Control*	*Hay*	*Ad libitum*	RECT	*5.60*	*47.8*	*10.2*	*10.1*	*44.6*	*14.4*	Lobón et al., 2017
	FOR	Pasture	*Ad libitum* access		**−0.9**%	**−9.0**%	+3.9%	**−25.7**%	**−22.2**%	**−9.0**%	
Churra	*Control*	*LO*	*TMR with 2.7% of LO*	RECT	*5.74*	*47.8*	*4.66*	*5.16*	*49.4*	*7.18*	Gómez-Cortés et al., 2018
	BP	Vit. E	500 mg/kg TMR, on DM		−1.6%	+1.7%	−12.4%	−0.4%	+5.3%	−6.0%	
	BP	GP-5	5% of TMR, on DM (2.14 g of PFs/kg DM)		−1.0%	−2.3%	**+32.6**%	−1.7%	−18.8%	**+12.8**%	
	BP	GP-10	10% of TMR, on DM (4.28 g of PFs/kg DM)		+0.5%	−1.7%	+8.6%	−8.1%	−8.5%	−0.4%	
Churra Tensina	*Control*	*Commercial concentrate without quebracho*	*300 g/head, as fed*	RECT	*5.57*	*45.2*	*10.7*	*8.7*	*38.4*	*14.0*	Lobón et al., 2017
	BP	Quebracho concentrate	300 g/head, as fed		0	+2.0%	−5.6%	+2.3%	+6.5%	−3.6%	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	LTL	*5.56*	*52.43*	*12.29*	*8.08*	–	–	Fusaro et al., 2019
	FOR	Pasture	Access for 22 h/d		−0.4%	−6.2%	**+16.6%**	−20.9%	–	–	
Churra Tensina	*Control*	*Pre-partum hay*	*Ad libitum*	LTL	*5.64*	*48.94*	*8.97*	*9.33*	–	–	Joy, Sanz, et al., 2012
	FOR	Pre-partum pasture	*Ad libitum* access		+0.5%	−4.6%	+14.7%	+1.4%	–	–	
	Control	*Post-partum hay*	*Ad libitum*		*5.65*	*48.53*	*9.18*	*10.05*	–	–	
	FOR	Post-partum pasture	*Ad libitum* access		0	−2.9%	+9.9%	−12.9%	–	–	
Churra	*Control*	*LO*	*TMR with 2.7% of LO*	LTL	*5.74*	*49.3*	*2.82*	*13.4*	*13.8*	*78.2*	Gómez-Cortés et al., 2018
	BP	Vit. E	500 mg/kg TMR, on DM		−1.6%	+4.9%	−34.4%	**−26.0**%	**−26.8**%	+1.8%	
	BP	GP-5	5% of TMR, on DM (2.14 g of PFs/kg DM)		−1.0%	+1.0%	+14.2%	**−28.8**%	**−26.8**%	−9.6%	
	BP	GP-10	10% of TMR, on DM (4.28 g of PFs/kg DM)		+0.5%	+2.6%	−12.4%	**−23.9**%	**−25.4**%	−2.6%	
Chamarita	*Control*	*Concentrate without added wine by-product*	*1 kg/d concentrate + ad libitum access to Medicago sativa*	LTL	*5.65*	*47.09*	*10.12*	*3.85*	*22.4*	*10.92*	Pascual-Alonso et al., 2018
	BP	GP	10% of GP on 1 kg of concentrate/d, on DM + *ad libitum* access to *Medicago sativa*		−0.2%	+0.7%	+12.2%	+6.8%	−8.7%	+11.2%	
	BP	GS	5% of GS on 1 kg of concentrate/d, on DM + *ad libitum*		−0.4%	−6.2%	+12.9%	−7.0%	−18.1%	+10.1%	

(*continued on next page*)

Table 6 (*continued*)

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Muscle[4]	Muscle pH 24 h post slaughter	Color parameters					Referencea
						Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Hue angle (H^*)	Chroma (C^*)	
			access to *Medicago sativa*								
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	LTL	*5.56*	*52.43*	*12.29*	*8.08*	–	–	Fusaro et al., 2019
	Fat	LIN	190 g/d		−1.3	1.6	−12.9	−15.0	–	–	
Churra	*Control*	*PO*	*3% of TMR, as fed*	LTL	*5.75*	*45.5*	*5.6*	*10.1*	–	–	Vieira et al., 2012
	Fat	OLI	3% of TMR, as fed		−0.5%	−1.8%	+16.1%	+11.9%	–	–	
	Fat	SO	3% of TMR, as fed		+0.3%	−0.4%	−13.9%	−2.0%	–	–	
	Fat	LO	3% of TMR, as fed		0%	+0.4%	+10.4%	+5.9%	–	–	

Bold and underlined values indicate significant differences ($P < 0.05$) compared to the control group as reported in the original paper. The dash indicates that the data were not reported in the publication.

[1] FOR = Forage; BP = By-product.

[2] PEG = Polyethylene glycol; LO = Linseed oil; Vit. E = Vitamin E; GP = Grape pomace; GS = Grape seed; LIN = extruded linseed; PO = Palm oil; OLI = Olive oil; SO = Soybean oil.

[3] TMR = Total mixed ration; DM = Dry matter; PFs = Polyphenols.

[4] RECT = *Rectus abdominis;* LTL = *Longissimus thoracis et lumborum.*

meat (Lobón et al., 2017), although biologically of little significance. A higher glycolytic potential in muscle at slaughter could explain the lower pH in the meat of lambs from grazing ewes. The latter had, indeed, a higher daily milk yield available *ad libitum* to the lambs until slaughter compared to hay-fed ewes (Lobón, Sanz, Blanco, & Joy, 2016), and this might have influenced the post-mortem energy metabolites (glycogen, lactate, glucose-6-phosphate and glucose content) in the muscle of suckling lambs.

Pasture has been shown to affect meat and fat color in suckling lambs. This is probably due to the increase in carotenoid pigments in milk (Joy, Sanz, et al., 2012; Parrini et al., 2021) or to the direct (albeit minimal) intake of grass by suckling lambs following their dams on pasture. In particular, the intake of fresh pasture herbage in ewes' diet was able to increase the Redness parameter (a^*), both in muscle (Joy,

Table 7

Effect of maternal diet on subcutaneous and caudal fats color of suckling lambs. Data of the control group are reported as the mean value whereas data of the extent of variation are reported as the proportional difference (%) between the treatment group, at the respective level of inclusion, and the control group.

Breed	Dietary group[1]	Maternal diet[2]	Dietary ingredients[3]	Fat	Color parameters					References
					Lightness (L^*)	Redness (a^*)	Yellowness (b^*)	Hue angle (H^*)	Chroma (C^*)	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	Subcutaneous	*68.5*	*4.65*	*7.12*	–	–	Fusaro et al., 2019
	FOR	Pasture	Access for 22 h/d		+0.9%	**+36.1%**	+14.6%	–	–	
Churra	*Control*	*LO*	*TMR with 2.7% of LO*	Subcutaneous	*74.4*	*1.01*	*7.63*	*72.8*	*7.74*	Gómez-Cortés et al., 2018
	BP	Vit. E	500 mg/kg TMR, on DM		+0.4%	+26.7%	+16.0%	−17.9%	+16.0%	
	BP	GP-5	5% of TMR, on DM (2.14 g of PFs/kg DM)		−1.3%	+39.6%	+16.6%	−3.4%	+16.8%	
	BP	GP-10	10% of TMR, on DM (4.28 g of PFs/kg DM)		**−2.3%**	+50.5%	+6.8%	−5.6%	+7.5%	
Comisana	*Control*	*Hay + concentrate*	*0.80 kg/d concentrate + 1.1 kg/d hay*	Subcutaneous	*68.5*	*4.65*	*7.12*	–	–	Fusaro et al., 2019
	Fat	LIN	190 g/d		−1.2	19.1	6.2	–	–	
Churra	*Control*	*PO*	*3% of TMR, as fed*	Subcutaneous	*70.8*	*1.79*	*10.1*	–	–	Vieira et al., 2012
	Fat	OLI	3% of TMR, as fed		+0.4%	+26.3%	+8.9%	–	–	
	Fat	SO	3% of TMR, as fed		+1.4%	−18.4%	−5.0%	–	–	
	Fat	LO	3% of TMR, as fed		+2.1%	−12.3%	0%	–	–	
Aragonesa	*Control*	*Sainfoin*	*Sainfoin (ad libitum) + 200 g/d barley*	Caudal	*68.8*	*2.6*	*12.3*	*78.2*	*12.6*	Baila et al., 2022
	FOR	Sainfoin + PEG	Sainfoin (*ad libitum*) + 200 g/d barley +100 g/d PEG		**+3.8%**	−3.8%	−3.3%	+0.9%	−3.2%	
Churra Tensina	*Control*	*Pre-partum hay*	*Ad libitum*	Caudal	*71.4*	*3.1*	*11.5*	–	–	Joy, Sanz, et al., 2012
	FOR	Pre-partum pasture	*Ad libitum* access		−1.5%	+25.8%	+2.6%	–	–	
	Control	*Post-partum hay*	*Ad libitum*		*71.2*	*2.6*	*10.5*	–	–	
	FOR	Post-partum pasture	*Ad libitum* access		−2.2%	**+42.3%**	**+18.1%**	–	–	

Bold and underlined values indicate significant differences ($P < 0.05$) compared to the control group as reported in the original paper. The dash indicates that the data were not reported in the publication.

[1] FOR = Forage; BP = By-product.

[2] LO = Linseed oil; Vit. E = Vitamin E; GP = Grape pomace; LIN = extruded linseed; PO = Palm oil; OLI = Olive oil; SO = Soybean oil; PEG = Polyethylene glycol.

[3] TMR = Total mixed ration; DM = Dry matter; PFs = Polyphenols.

Sanz, et al., 2012; Lobón et al., 2017; Fusaro et al., 2019; Table 6) and in fat deposits of their lambs (Joy, Sanz, et al., 2012; Fusaro et al., 2019; Table 7), and to decrease the Lightness (L^*) and the Yellowness (b^*) in muscle (Joy, Sanz, et al., 2012; Lobón et al., 2017; Table 6).

These changes in color parameters were expected, as meat from pasture-fed animals is usually reported to be darker than meat from dry-fed animals, which are mainly kept indoors or in feedlots, due to both a higher myoglobin content, as a results of higher oxygen demand for the exercise, and to the presence of carotenoids and tocopherols in pasture herbage (Parrini et al., 2021).

6.2. *Effect of maternal by-product supplementation*

By-products naturally rich in polyphenols may prevent undesirable changes in color, odor and flavor preserving at the same time meat color stability (Dentinho et al., 2023; Gómez-Cortés et al., 2018; Pascual-Alonso et al., 2018; Vieira et al., 2022). The effect of by-products in ewes' diet on meat color parameters of suckling lambs were similar to those reported for pasture (Table 6), probably due to their polyphenolic content. In fact, anthocyanins or other pigments (*i.e.*, carotenoids) from several by-products, as grape marc, might be transferred to the ewe's milk and then to the lamb muscle, thus contributing to the antioxidant capacity of the meat (Vieira et al., 2022). Inclusion of grape pomace in maternal diet increased the Redness *in Rectus abdomins muscle* (+32.6%; Gómez-Cortés et al., 2018; Table 6) and reduced the Yellowness in *Longissimus thoracis et lumborum* muscle of their lambs (Gómez-Cortés et al., 2018; Table 6) whereas in subcutaneous fat it reduced the Lightness (−2.3%; Gómez-Cortés et al., 2018*;* Table 7). As color deterioration is mainly due to the increase in myoglobin oxidation and consequent metmyoglobin formation and accumulation, polyphenols might increase the oxidative stability of myoglobin and lipids.

6.3. *Effect of maternal fat supplementation*

Vegetable fat supplementation to the mother diet did not exert significant effects on meat color of suckling lamb (Table 6). Specifically, olive oil, soybean oil and linseed oil, did not significantly alter the color parameters both in *Longissimus thoracis et lumborum* muscle and subcutaneous fat. Although little effect on objective color was observed, certain vegetable oils are often used in animal feeds because they contain antioxidant compounds (*e.g.* α-tocopherol, polyphenols) that could delay color oxidation during storage under retail conditions (Vieira et al., 2012).

7. Effect of maternal diet on odor and flavor of suckling lamb meat

The effect of ewe diet on the sensory characteristics of suckling lamb meat has been investigated in few studies. Moreover, although the sensory analysis followed International Standard methods, the differences in sample preparation, number of evaluators and parameters studied to assess the sensory characteristics related to odor and flavor make difficult an objective comparison between the papers, so that the results could not be adequately summarized in a table. Ewes diet could contribute to the odor and flavor of the meat of suckling lambs with the transfer of specific volatile organic compounds (VOC) from milk (Vasta, D'Alessandro, Priolo, Petrotos, & Martemucci, 2012). However, most of the studies reviewed reported the effect of ewes' diet on the formation of lipid-derived VOC (Wilches et al., 2011). In this sense, improving the nutritional quality of meat by increasing PUFA levels could increase its susceptibility to oxidation, which would cause the development of unpleasant odors and flavors, especially during storage.

7.1. *Effect of maternal forage diet*

The feeding techniques of ewes affect the FAs profile and the VOC of suckling lamb meat and thus its sensory characteristics (Revilla, Vivar-Quintana, Palacios, Martínez-Martín, & Hernández-Jiménez, 2021). Wilches et al. (2011) found that Churra suckling lambs from pasture-fed ewes had different odor attributes and volatile compound profile than lambs from ewes fed concentrate-hay, mainly attributable to fat content and FAs profile. Higher fat deposition and changes in FAs profile are accompanied both by a VOC accumulation and profile modifications, especially for aldehydes, alcohols and hydrocarbons groups (Wilches et al., 2011). The VOC profile of meat of suckling lambs reflect partially that of mother milk (Vasta et al., 2012). Almela et al. (2010) reported that the amount of VOCs was higher in cooked meat of suckling lambs whose mothers were pasture-fed than in lambs whose mothers were stall-fed. The sensory analysis showed lower scores of odor intensity both in raw and cooked meat of lambs that followed mother on pasture than that were reared with ewes fed a grain-based diet (Revilla et al., 2021). Recently, Gutiérrez-Peña et al. (2022) stated that also the sensory quality of meat from heavy suckling lambs raised with mothers fed pasture diets until slaughter (at 2 or 4 months), was affected by the characteristics of the maternal milk.

7.2. *Effect of maternal by-product supplementation*

Maternal by-products supplementation, as grapes and wine by-products, to improve FAs composition of sucking lamb induce also changes in the sensory characteristics of suckling lamb meat. Giller, Sinz, Messadene-Chelali, and Marquardt (2021) underline the effects of polyphenols on sensory perception of lamb meat. Grape pomace and grape seed added to the ration of lactating ewes result in a higher spicy and metallic flavor intensities in suckling lamb meat (Resconi et al., 2018). These aromatic phenolic compounds can come directly from those present in feeds or could be products of rumen microbial fermentation, and then transferred from milk to the suckling lambs. In addition, the lipid oxidation related to the PUFA content of lamb meat could be retarded by inclusion of ingredients containing polyphenols. A recent study reported a positive effect on odor and flavor of suckling lamb meat of fresh grape pomace in ewe diet, due to the delaying in lipid oxidation during storage (Vieira et al., 2022); this by-product was as effective as vitamin E in preventing suckling lamb meat spoilage, when packaged under high oxygen atmosphere and exposed to retail storage conditions.

7.3. *Effect of maternal fat supplementation*

The vegetable oils supplemented to dairy ewes, that increase the intramuscular PUFA of suckling lambs' meat, could cause undesirable odor and flavor, different from those expected in suckling lamb meat. Vieira et al. (2012), observed that the meat of suckling lambs from Churra ewes supplemented with linseed oil, showed lower scores in quality of odor, and general flavor than lambs from ewes fed with other more saturated oil (palm, olive or soy). On the other hand, certain oils rich in phenolic compounds with antioxidant activity, such as olive oil, are effective scavengers of free radicals, subsequently inhibiting lipid oxidation. This antioxidant activity can counteract the greater susceptibility of unsaturated fats to oxidation (Vieira, Rubio, Martínez, Mantecón, & Manso, 2019).

8. Conclusions

The nutritional qualities, the specific odor and flavor and the wide use in traditional Mediterranean dishes, make suckling lamb meat one of the most interesting food products in the panorama of ewe meat production in the Mediterranean area. This review has helped to clarify the role of the mother's diet in defining the quality of the meat of lambs. The pasture herbage can transfer several FAs and antioxidants beneficial to human health through mother's milk to the lamb's fat. In the absence of lush pasture, or in the case of indoor feeding technique, the dietary inclusion of linseed oil in the maternal diet seems to be the most effective strategy to increase PUFAn-3, VA and CLA contents in lamb meat and reduce PUFA n-6/PUFA n-3 ratio, while marine oils are effective for increasing high molecular weight FAs, as EPA and DHA. However, the enrichment with these FAs could increase oxidation processes that affect meat shelf life and sensory properties. The transfer of antioxidants from milk to meat seems a useful means to counteract this phenomenon and deserves greater attention from researchers. Unfortunately, research on this topic is limited and almost never directly addresses the suckling lamb, since the information available in literature almost all focuses on qualitative and quantitative milk production. Moreover, the general lack of information on milk intake, due to the objective difficulties of measuring it in animals that suckle several times a day, seriously limits the estimation of adequate nutritional balances for suckling lambs.

Another area of research should concern maternal feeding techniques, which should improve the flavor and odor of lamb meat. Then, the relationships between nutritional quality, an aspect that has been widely emphasized in the literature, and the compounds involved in the odor/flavor and shelf life of meat should be better established. In addition, the profitability of the supply chain for lamb meat, which certainly deserves a market position that reflects its nutritional value, could be improved through the implementation of meat grading methods that define quality objectively and as close as possible to consumer perception. Finally, lamb suckling mother's milk, especially when ewes are reared on pasture, provides a meat whose production cycle should be particularly virtuous in terms of environmental impact. For this reason, studies on the evaluation of its impact and the means of improving its sustainability conditions are of primary importance.

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Gianni Battacone: Conceptualization, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing, Funding acquisition. **Mondina Francesca Lunesu:** Investigation, Data curation, Software, Writing – original draft, Writing – review & editing. **Teresa Manso:** Conceptualization, Investigation, Writing – original draft. **Ceferina Vieira:** Conceptualization, Investigation, Writing – original draft. **Giuseppe Pulina:** Conceptualization, Investigation, Methodology, Software, Validation, Writing – review & editing, Supervision. **Anna Nudda:** Conceptualization, Investigation, Methodology, Validation, Writing – original draft, 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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