Suckling lamb meat: A smart and sustainable food combining tradition and innovation

IOP Conf. Series: Earth and Environmental Science **333** (2019) 012005 doi:10.1088/1755-1315/333/1/012005

Suckling lamb meat: A smart and sustainable food combining tradition and innovation

G Battacone[1], A Nudda[1], A S Atzori[1] and G Pulina[1]

[1] Dipartimento di Agraria, Università degli Studi di Sassari, viale Italia 39 - 07100 Sassari, Italy

E-mail: battacon@uniss.it

Abstract. Meat from milk-fed lambs is one of the most relevant products in the traditional dairy sheep industry. This product is the meat from suckling lambs fed maternal milk in flocks raised almost only on pasture. The aim of this paper is to briefly summarise current knowledge of the qualitative traits of suckling lamb meat, with special attention paid to the lipid fraction. We report the main scientific data for suckling lamb meat that contributes to its alleged properties as a functional and environmentally sustainable food. Furthermore, reference is made to how innovative chill/freeze technologies can be profitable, enlarging consumption of this meat in the dynamic global markets.

1. Introduction

The sheep industry is one of the most ancient and traditional worldwide farming systems since the domestication of sheep occurred about 11,500 years ago [1]. In comparison with other livestock species, sheep are characterised by their ability to efficiently exploit pastures, even when these are scarce or inadequate for large ruminants. Modern dairy sheep breeds are high performing in terms of milk yield when their diet is properly balanced with their genetic potential.

The main relevant income of dairy sheep flocks is from their milk, which is mostly processed into dairy products, apart from the milk suckled by lambs. However, in dairy sheep systems, meat production from suckling lambs can be found worldwide [2].

Livestock systems with ruminants fed on pasture do not compete directly with humans because the lands used are usually unsuitable for other crop-foods, and this diversity contributes to food security. In fact, ruminants play a fundamental role in food chain sustainability, since they are able to convert renewable resources from rangeland like pastures into food edible for humans, like milk and meat. The efficiency of ruminant livestock in converting feeds into edible energy and protein for humans is extremely dependent on the farming system. Suckling lambs, finished to an approximate body weight of 10 kg at 30-35 days of age, are a traditional product in many dairy sheep farms in Mediterranean regions. Meat production from suckling lambs in grazing flocks is a food production process whereby grass is converted into meat, milk being an intermediate product. In the first weeks of life, lambs do not have a fully functional forestomach, and therefore, their digestive physiology behaves as in monogastric animals. This means the gastrointestinal tract of suckling lambs does not host microbial fermentation processes, which generate the by-product methane that contributes to greenhouse gas emissions. The wide diversity of sheep breeds and production systems are the main variables affecting the large variability of suckling lamb carcasses on the markets [2]. Among this variability, a singular product is

obtained when lambs are nourished solely on milk from ewes fed on pasture during lactation. Suckling lamb meat, as well as being a traditional food in the Mediterranean area, has some unique nutritional characteristics that make it particularly suitable for childhood nutrition [**3**] [**4**].

This short review summarises the nutritional characteristics of suckling lamb meat produced by dairy sheep reared in pasture-based production systems. Moreover, it presents the advantageous nutritional composition of key nutrients such as the lipid fraction, with particular reference to fatty acids (FAs). This affects the degree of acceptance of this meat by consumers, who are also interested in the ecological sustainability of the product.

2. Suckling lamb – "smart" meat

Innovation in the food industry is strongly aimed at improving the nutritional profiles of meat and meat products to produce those with healthier properties for consumers.

Many studies have demonstrated that meat and meat products can be considered as functional foods, as sources of indispensable nutrients with proven health benefits for humans [**5**]. Meat plays an important role in the human diet by being a good source of high quality protein as well as beneficial FAs and a range of micronutrients, like vitamins (especially B12) and minerals (especially iron) with a high degree of bioavailability. However, the breeding system has an important effect on the nutritional characteristics of meat. The presence of pasture in the diets strongly enhances the nutritional quality of intramuscular fat compared to dry forage diets. Fresh grass in the diet of lactating ewes is useful to increase the presence of biologically active compounds in milk such as unsaturated FAs with positive health properties [**6**] [**7**] [**8**] [**9**], particularly vaccenic acid (VA; C18:1 t11), rumenic acid (RA; c9,t11 conjugated linoleic acid), and α-linolenic acid (ALA; C18:3n-3.

These nutraceutical properties of ovine milk can contribute to enriching the health value of meat from lambs suckling maternal milk and improve the meat's value as functional food. A comparison of the FA profile of fresh meat (FM) from suckling lambs with commercial infant foods based on lamb meat, such as homogenised and lyophilised meats, was reported [**4**]. FM contained greater contents of ALA (1.5-fold higher) and its elongation products (eicosapentaenoic acid, 20:5n-3, EPA; and docosahexaenoic acid, 22:6n-3, DHA), and arachidonic acid (C20:4n-6, ARA) derived directly from the linoleic acid (C18:2n-6, LA), than the infant foods [4]. Those results documented that suckling lamb meat is also an interesting food source of some long-chain polyunsaturated FAs that are essential for proper development of foetal brain and eyes and maintenance of neural and visual system throughout life [**10**] [**11**]. Since the potential lower allergenicity of lamb meat compared to other red meat sources is clear [**12**] [**13**], its enrichment with PUFAn-3 could be of nutritional interest, especially in weaning diets for children.

2.1. Milk suckled by lambs from pasture-fed ewes

Feeding systems of lactating ewes are an effective strategy to improve lamb meat quality in terms of fat content and composition. The composition of ewe milk strongly affects the growth performance and meat characteristics such as the FA composition of suckling lambs.

During lactation of dairy sheep fed on pastures, the FA profile in milk is affected by the variation of diet, i.e. the progressive variation of FAs in maturing grass [**14**]. In pastures, the main FA is ALA [**15**] that decreases as grass matures and in temperate climates (such as in Europe and North America) reaches the highest levels in pastures during the winter-spring months [**16**]. Feeding lactating ewes on pastures is an advisable alternative to increase the contents of VA, RA and long-chain n-3 polyunsaturated FAs (PUFAn-3) in milk, since fresh grass has a higher concentration of ALA than diets containing concentrates or dried forages [**17**]. Actually, the forage species and their phenological phase also affect the FA profile in ovine milk, since the FA contents in different pasture species are highly variable [**18**] [**19**]. In the traditional breeding systems in Mediterranean areas, the lambing period occurs in late autumn to early winter to allow the ewes to exploit the seasonal availability of the natural pastures at their best. This allows the lambs to start suckling at the very time when levels of VA, RA and PUFAn-3 in maternal milk are the highest. Moreover, the presence of pasture in the diet of the ewes is also the

main source of other compounds with antioxidant activities, such as vitamin E and carotenoids that are carried over from milk to meat [**20**].

2.2. Lamb meat affected by ewe milk

The FA profile of suckling lambs reared on maternal milk reflects the FA profile of the suckled milk. In this phase, lambs being functionally non-ruminants, the ruminal biohydrogenation of the milk FAs does not occur before they are absorbed from the intestine. The rate of *de novo* fat synthesis in suckling lambs is very low, and most of the deposited FAs are derived directly from their diets. The FA source in the diet of suckling lambs has been shown to strongly affect the FA profile of different lamb tissues in different manners [**21**]. Moreover, the FA profile of suckling lamb meat could be different when lactating ewes graze on pasture or are fed dry diets. In particular, suckling lamb meat reared from ewes fed on pasture has greater percentages of RA, ALA and PUFAn-3 and a lower percentage of PUFAn-6 [**22**]. However, the composition of suckling lamb meat is affected by the feeding system of the mother rather than the management system (indoor *vs* outdoor) of lambs [**23**]. In some cases, when dairy sheep farmers are focused on achieving the best economic returns for the marketable milk yielded, lambs are removed from their mothers and are raised with artificial milk. In these conditions, milk replacer adversely affected the nutritional value of the FA profile of lamb meat [**24**] [**25**]. The relationships between the proportions of FAs in milk and meat differed markedly for the different FAs. Relationships between the FAs of ewe milk and those of the suckling lamb meat changed for each FA [**22**]. In particular, the percentages of total C18:1 and RA in meat mirrored those in milk, with high correlations, whereas the PUFAn3 in meat is higher than in milk, but is not correlated. In meat, this could be due to *de novo* synthesis from ALA of long-chain PUFAs such as EPA and DHA that are commonly present in muscle tissue, whereas they are not regularly detected in milk. Moreover, the essential FAs in milk could be used to different extents by different tissues in growing lambs, e.g. the brain and the nervous system.

A survey was conducted by our research group to evaluate seasonal variation of the FA composition of meat from Sarda suckling lambs reared in Sardinia (Italy) and slaughtered from December to April. In Sardinia, as in other Mediterranean countries, the main lambing season is during the end of autumn and the early part of winter. During this time, the ewes are fed mainly on pasture and receive a low amount of dry feeds (concentrate and hay). In fact, the weather conditions are favourable for the growth and availability of pasture. In Figure 1, we report the amount of FA of nutritional interest as mg/100 g of edible muscle during December to April. The ALA, CLA and long chain PUFAn-3, i.e. EPA, DPA (22:5 n-3) and DHA, evidenced only slight variation during these months. Because Sardinian suckling lambs are fed almost exclusively milk from their mothers, variations in meat FA profile can be attributed mainly to changes in the diet of their dams, supported by the ALA levels tending to reduce in the pasture over time and, therefore, in milk of the lactating ewes.

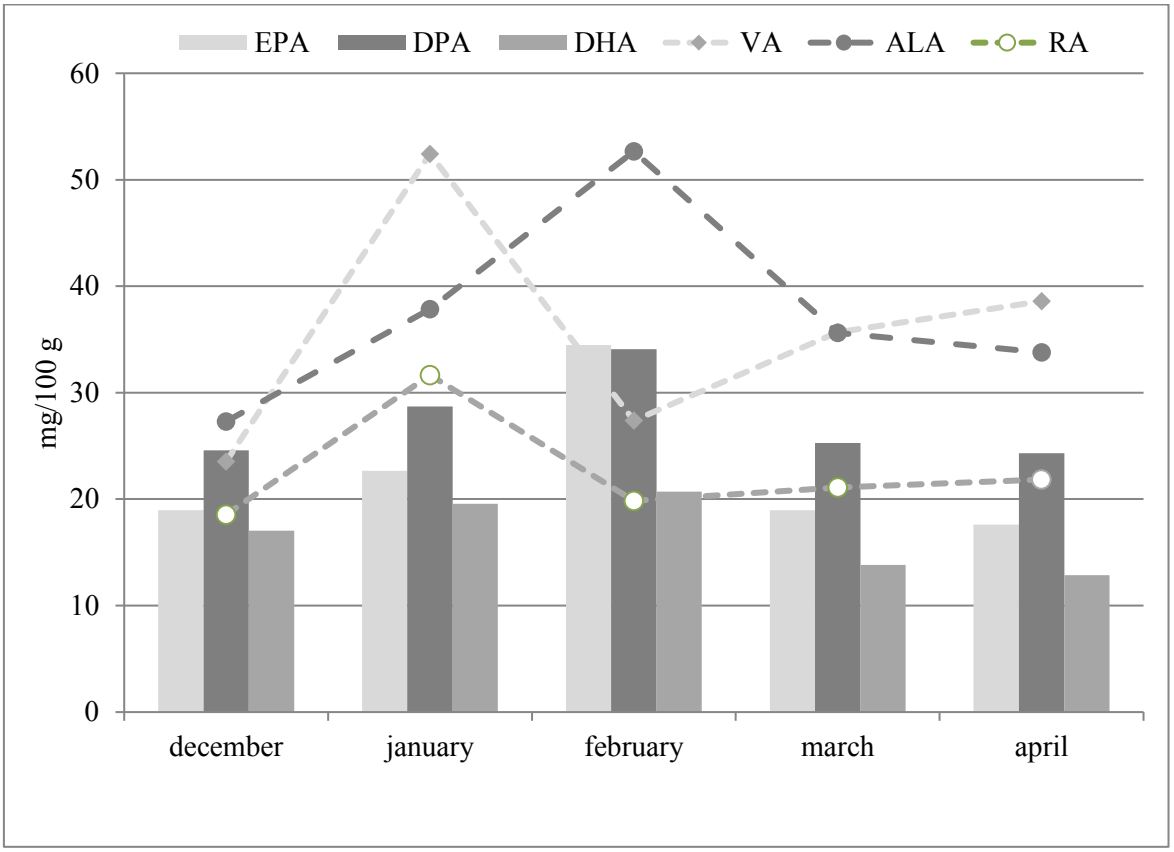

Figure 1. Fatty acids of nutritional interest (as mg/100 g of fresh meat) in the intramuscular fat of *Femoral biceps* from Sarda suckling lambs in different slaughter months (data from [**26**])

3. Suckling lamb as sustainable meat

The dairy sheep system, also in terms of suckling lamb meat, impacts on production and consumption of agricultural products. Life cycle assessment (LCA) is a methodology to account for resource use and emissions throughout the full life cycle of each product and evaluate its environmental sustainability. Application of LCA to livestock production systems is a relatively new area of research [**27**]. Several studies have been published on dairy and beef cattle and on meat sheep. Estimates of the carbon footprint (CF) of lamb meat production were carried out in Europe and Oceania, highlighting the relevance of sheep production systems in these two areas. Among studies, the average CF of lamb meat varied from 5.0 [**28**] (Australia with sub-clover systems) to 25.9 [**29**] kg of CO_2-eq/kg of LW (live weight) lamb meat, depending on the production systems and the estimation method used. Looking at published values, within-study variation can be much higher, and Benoit and Dakpo (2012) [**30**], surveying 1180 farms, obtained values ranging from 12 to 82 kg of CO_2-eq/kg of LW lamb meat. Studies mainly focused on lamb produced from meat breeds, whereas no specific values indicated CF estimates for suckling lambs from dairy breeds. Table 1 shows estimates of CF emissions of suckling lambs produced in Sardinia within mixed production systems. It assumes that milk used for lamb feeding, enteric and manure emissions are the main emission hotspots. In particular, the emissions generated in the milk production processes are the largest emission source, and are mainly related to the feed efficiency and the production level of the flock in recent estimates [**31**] [**32**] [**33**]. Flocks with higher production level per head are able to produce milk with lower CF, which also results in lower emissions for the suckling lamb meat produced. Estimated values ranged from 7.7 to 16.5 kg of CO_2 eq. per kg of LW for 300 and 100 kg/year of milk per head produced by the mothers, respectively. If lambs are separated from the

dams at birth and fed milk replacer until slaughter at 30 days, the CF of the lamb meat is almost doubled (32.5 kg of CO_2 eq. per kg of lamb LW). This is due to the higher emissions of the milk replacer compared to the sheep milk, even if from an economics point of view, the artificial feeding could be more convenient due to the low price of milk replacer (0.25 €/kg of solids) in comparison to the sheep milk (5.5 €/kg of solids). In summary, suckling lamb production from dairy breeds can be considered highly comparable in terms of sustainability, measured as global warming potential, to the lamb meat produced from meat breeds.

Table 1. Carbon footprint estimates of meat production from suckling lambs in mixed production systems in Sardinia. The estimations assume that milk used for lamb feeding and enteric and manure emissions are the main emission sources.

Lamb type	Suckling lamb from dairy breeds raised in mixed systems			
Milk production level of the farm	High production level	Medium production level	Low production level	All
Production level of the mother, kg/year per head	300	200	100	-
Age at lamb slaughter, days[1]	30	30	30	30
Weight at slaughter, kg of LW[1]	10	10	10	10
Carcass weight[1]	6.5	6.5	6.5	6.5
Lamb feeding	Dam milk	Dam milk	Dam milk	Milk replacer
Feed conversion ratio, kg milk/kg LW[1]	5.5	5.5	5.5	5.5
Total milk consumption from birth to slaughter, kg	35.2	35.2	35.2	35.2
Emissions from milk production, kg of $CO_{2eq.}$/kg of milk	2.08[2]	3.34[2]	4.60[2]	9.1[3]
Enteric emissions, kg of $CO_{2eq.}$/kg of milk[4]	3.19	3.19	3.19	3.19
Manure emissions, kg of $CO_{2eq.}$/kg of milk[4]	0.270	0.270	0.270	0.270
Other emissions, kg of $CO_{2eq.}$/kg of milk	negligible	negligible	negligible	negligible
CF, kg of CO_2 per kg of live weight	7.7	12.1	16.5	32.5
CF, kg of CO_2 per kg of carcass weight	11.8	18.6	25.4	49.9
% from methane	4.2%	2.6%	1.9%	1.0%

[1] **[34]**; [2] Carbon footprint estimates from preliminary results of the EU Life15 project Forage4CLimate **[32]**; [3] Carbon footprint of milk replacer: considering milk replacer based on 60% of skimmed milk powder. Emissions were based values reported by Ecoinvent, 2018 using economic allocation methods and O'Brien et al. (2014) **[35]**; [4]Based on IPCC, 2006 **[36]**

4. Innovative procedures able to preserve the traditional quality of lamb meat

The chemical composition of suckling lamb meat, which is rich in proteins, lipids and water, makes it a favourable substrate for the growth of microorganisms. Moreover, the lipid fraction, characterised by a sensible content of PUFA, also makes it very susceptible to oxidation. To succeed in international markets, the meat needs to be properly preserved as anoxic vacuum-packaged product and stored either chilled or frozen. Coombs et al. (2017) **[37]** in a recent review, reported the combination of conventional chilled (-1.5 to 5°C)-then-frozen is a valuable procedure for lamb and red meat storage for export purposes. Rapid chilling (at -40°C for about 2 h) followed by frozen storage is a promising innovation in meat storage. Rapid chilling is useful to reduce the meat temperature as soon as possible in order to prevent ice crystal formation before frozen storage, which then inhibits growth of microorganisms and avoids lipid peroxidation. We conducted a study to evaluate the rapid chilled-then-frozen procedure on lipid peroxidation of vacuum packaged suckling lamb meat (loins) when stored at two freezing temperatures. Loins from suckling lambs of the Sarda breed, covered by the Protected Geographical Indication (PGI) *Agnello di Sardegna*, were firstly vacuum packaged, then rapidly chilled and finally

assigned to two freezing temperatures (-12 and -18°C) for 16 weeks. Results of the lipid oxidation, expressed as mg malondialdehyde (MDA)/kg, analysed in lamb muscle during frozen storage are reported in Figure 2. These results evidenced that the MDA levels did not differ between the two frozen storage temperatures, although they increased significantly from day 0 to 4 weeks and then remained stable until 16 weeks of storage. MAD levels were significantly increased from initial levels after 16 weeks of frozen storage, but remained constant until the end of the study. Final MAD levels, though, were much lower than MAD levels reported in lamb meat exposed to the conventional chilled-then-frozen procedure. The MDA level in our lamb loins was markedly below 2 mg MDA/kg, which is the threshold indicating little formation of secondary oxidation products responsible for the characteristic rancid smell of oxidised fats in foods **[38]**. This result strongly evidenced that this procedure should be a promising technique to preserve sensorial and nutritional properties of this meat.

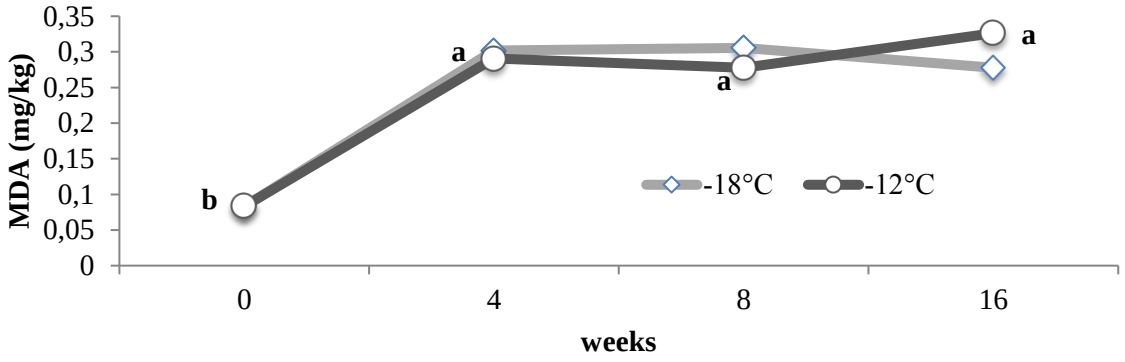

Figure 2. Evolution of MDA values in muscle of lambs during storage at -12°C and -18°C

5. Conclusions

Meat from suckling lambs fed maternal milk from their pasture-reared dams has very interesting and distinctive qualitative traits. The amount of PUFAn-3 ingested by lactating ewes grazing on green pasture is able to increase the presence of beneficial FAs in their milk. This advantage improves the nutritional value of the meat derived from their suckling lambs compared to the meat of other lambs raised on milk replacers. Nowadays, scientific data on suckling lamb meat's composition and carbon footprint supports the allegation that this food is a functional and environmentally sustainable food. Moreover, innovative chill/freeze technologies are available to preserve the unusual nutritional properties of this food and allow its increased release to international markets and consumption.

References

[1] Zeder M A 2008 Domestication and early agriculture in the Mediterranean Basin: origins, diffusion, and impact *Proc. Natl. Acad. Sci. U.S.A.* **105** 11597–604
[2] Erasmus S W, Muller M and Hoffman L C 2017. Authentic sheep meat in the European Union: Factors influencing and validating its unique quality *J. Sci. Food Agr.* **97** 1979–96
[3] Cantani A 2006 A home-made meat-based formula for feeding atopic babies: a study in 51 children *Eur. Rev. Med. Pharmacol. Sci.* **10** 61–68
[4] Nudda A, McGuire M K, Battacone G, Manca M G, Boe R and Pulina G 2011 Documentation of fatty acid profile in lamb meat and lamb-based infant food *J. Food Sci.* **76** 43–7
[5] Pogorzelska-Nowicka E, Atanasov A G, Horbańczuk J and Wierzbicka A 2018 Bioactive Compounds in Functional Meat Products *Molecules* **23** 307
[6] Jacome-Sosa M, Vacca C, Mangat R, Diane A, Nelson R C, Reaney M J, Shen J, Curtis J M, Vine D F, Field C J, Igarashi M Piomelli D, Banni S and Proctor S D 2016 Vaccenic acid suppresses intestinal inflammation by increasing anandamide and related N-acylethanolamines in the

JCR:LA-cp rat *J. Lipid Res*. **57** 638–49
[7] Pintus S, Murru E, Carta G, Cordeddu L, Batetta B, Accossu S, Pistis D, Uda S, Ghiani M E, Mele M, Secchiari P, Almerighi G, Pintus P and Banni S 2013 Sheep cheese naturally enriched in α-linolenic, conjugated linoleic and vaccenic acids improves the lipid profile and reduces anandamide in the plasma of hypercholesterolaemic subjects *Brit. J. Nutr.* **109** 1453 –62
[8] Del Gobbo L C 2016 Omega-3 polyunsaturated fatty acid biomarkers and coronary heart disease: pooling project of 19 cohort studies. Cohorts for Heart and Aging Research in Genomic Epidemiology (CHARGE) Fatty Acids and Outcomes Research Consortium (FORCe) *JAMA Intern Med*. **176** 1155–66
[9] Yamagishi K, Ikeda A, Chei C L, Noda H, Umesawa M, Cui R, Muraki I et al. 2017 Serum α-linolenic and other ω-3 fatty acids, and risk of disabling dementia: Community-based nested case-control study *Clin. Nutr*. **36** 793–7
[10] Koletzko B, Lien E, Agostoni C, Böhles H, Campoy C, Cetin I, Decsi T, Dudenhausen J W, Dupont, C., Forsyth, S., Hoesli, I., Holzgreve, W., Lapillonne, A., Putet, G., Secher, N.J., Symonds M, Szajewska H, Willatts P and Uauy R 2008. World Association of Perinatal Medicine Dietary Guidelines Working Group. The roles of long-chain polyunsaturated fatty acids in pregnancy, lactation and infancy: review of current knowledge and consensus recommendations *J. Perinatal Med*. **36** 5–14
[11] Ruxton C H S, Reed S C, Simpson M J A and Millington K J 2004 The health benefits of omega-3 polyunsaturated fatty acids: a review of the evidence *J. Hum. Nutr. Diet.* **17** 449–59
[12] Cardi E, Corrado G, Cavaliere M, Grandina G, Pacchiarotti C, Rea P, Mazza M L, Nardelli F and Agazie E 1998 Rezza-Cardi's diet as dietary treatment of short bowel syndrome *Gastroenterology* **114**(1) A869
[13] Martino F, Bruno G, Aprigliano D, Agolini D, Guido F, Giardini O and Businco L 1998 Effectiveness of a home-made meat based formula (the Rezza-Cardi diet) as a diagnostic tool in children with food induced a topic dermatitis *Ped. Allergy Immunol*. **9** 192–6
[14] Nudda A, McGuire M A, Battacone G and Pulina G 2005 Seasonal variation in conjugated linoleic acid and vaccenic acid in milk fat of sheep and its transfer to cheese and ricotta *J. Dairy Sci.* **88** 1311–19
[15] Valvo M, Lanza M, Bella M, Fasone V, Scerra M, Biondi L and Priolo A 2005 Effect of ewe feeding system (grass v. concentrate) on intramuscular fatty acids of lambs raised exclusively on maternal milk *Anim. Sci*. **81** 431– 6
[16] Glasser F, Doreau M, Maxin G and Baumont R 2013 Fat and fatty acid content and composition of forages: a meta-analysis *Anim. Feed Sci. Technol.* **185** 19–34
[17] Atti N, Rouissi H, Othmane M H 2006 Milk production, milk fatty acid composition and conjugated linoleic acid (CLA) content in dairy ewes raised on feedlot or grazing pasture *Livest. Sci*. **104** 121–27
[18] Addis M, Cabiddu A, Pinna G, Decandia M, Piredda G, Pirisi A and Molle G 2005 Milk and cheese fatty acid composition of sheep fed different Mediterranean forages with particular reference to conjugated linoleic acid cis-9, trans-11 *J. Dairy Sci.* **88** 3443–54
[19] Cabiddu A, Decandia M, Addis M, Piredda G, Pirisi A and Molle G 2005 Managing mediterranean pastures in order to enhance the level of beneficial fatty acids in sheep milk *Small Rumin. Res*. **59** 169–80
[20] Valdivielso I, Bustamante M A, Buccioni A, Franci O, Ruíz de Gordoa J C, de Renobales M and Barron L J R 2015 Commercial sheep flocks–fatty acid and fat-soluble antioxidant composition of milk and cheese related to changes in feeding management throughout lactation *J. Dairy Res*. **82** 334–43
[21] Osorio M T, Zumalacarreguim J M, Figueira A and Mateo J 2007a. Fatty acid composition in subcutaneous, intermuscular and intramuscular fat deposits of suckling lamb meat: effect of milk source *Small Rumin. Res*. **73** 127–34

[22] Lobon S, Joy M, Sanz A, Alvarez-Rodriguez J and Blanco M 2018. The fatty acid composition of ewe milk or suckling lamb meat can be used to discriminate between ewes fed different diets *Animal Production Science* **59** 1108–18
[23] Nudda A, Battacone G, Boe R, Manca M G, Rassu S P G and Pulina G 2013. Influence of outdoor and indoor rearing system of suckling lambs on fatty acid profile and lipid oxidation of raw and cooked meat *It. J. Anim. Sci.* **12** 459–67
[24] Napolitano F, Cifuni G F, Pacelli C, Riviezzi A M and Girolami A 2002 Effect of artificial rearing on lamb welfare and meat quality *Meat Sci.* **60** 307–315
[25] Osorio M T, Zumalacàrregui J M, Bermejo B, Lozano A, Figueira A C and Mateo J 2007b Effect of ewe's milk versus milk-replacer rearing on mineral composition of suckling lamb meat and liver *Small Ruminant Research* **68** 296–302
[26] Nudda A, Atzori A S, Boe R, Francesconi A H D, Battacone G and Pulina G 2019 Seasonal variation in the fatty acid profile in meat of Sarda suckling lambs *Italian J. Anim. Sci*. **18** 488 –97
[27] Cottle D J, Nolan J V and Wiedemann S G 2011. Ruminant enteric methane mitigation: a review *Animal Prod. Sci*. **51** 491–514
[28] Biswas W K, Graham J, Kelly K and John M B 2010 Global warming contributions from wheat, sheep meat and wool production in Victoria, Australia – A life cycle assessment *J. Cleaner Prod.* **18** 1386–92
[29] Ripoll-Bosch R, de Boer I J M, Bernués A and Vellinga T V 2013 Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: A comparison of three contrasting Mediterranean systems *Agricultural Systems* **116** 60–8
[30] Benoit M and Dakpo H 2012 Greenhouse gas emissions on French meat sheep farms. Analysis over the period 1987–2010. In: Proceedings of the Conferenceon Emission of Gas and Dust from Livestock, 10–13 June, Saint Malo, France.Rennes, France INRA.
[31] Atzori A S, Cannas A and Pulina G 2014 Small ruminant greenhouse gas emissions with broaden focus on Italian sheep and goats *Large Animal Review* **4** 2–5
[32] Lunesu M F, Atzori A S, Correddu F, Lai F, Rubattu R, Spanu G and Cannas A 2019 Carbon footprint of dairy sheep farms located in different forage systems of Sardinia. Proceedings of the XXIII Congress of the Animal Science And Production Association June 11-14, 2019 - Sorrento (Italy)
[33] Cannas A, Tedeschi L O, Atzori A S and Lunesu M F 2019 How can nutrition models increase the production efficiency of sheep and goat operations *Animal Frontiers* **2** 33–44
[34] Brandano P, Rassu S P G and Lanza A 2004 Feeding Dairy Lambs. In Dairy sheep nutrition. (ed. Pulina, G.; Bencini, R). Pag: 151 -164. Wallingford UK
[35] O'Brien D, Capper J L, Garnsworthy P C, Grainger C and Shalloo L 2014 A case study of the carbon footprint of milk from high-performing confinement and grass-based dairy farms *J. Dairy Sci.* **97** 1835–51
[36] IPCC 2006 IPCC guidelines for national greenhouse Gas inventories. In: Inter-governmental Panel of Climate Change (IPCC), National Greenhouse Gas Inventories Programme.
[37] Coombs C E O, Holman B W B, Friend M A and Hopkins D L 2017 Long-term red meat preservation using chilled and frozen storage combinations: A review *Meat Sci.* **125** 84–94
[38] Campo M M, Nute G R, Hughes S I, Enser M, Wood J D, Richardson R I 2006 Flavour perception of oxidation in beef *Meat Sci*. **72** 303–11