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"Innovative feed resources to improve small ruminant meat quality"

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Abstract

The aptitude of ruminants to use feed without competing with human resources besides their capacity to take advantage of feed of low nutritional value and exploit poorly productive and marginal areas represent a great benefit in terms of environmental sustainability. Small ruminant, namely sheep and goat, represent a great part of ruminant sector (56 %), with a world population of about 1209 and 1045 million of units respectively. The husbandry of small ruminants has enormous growth potential, particularly in developing countries, where there will be the greatest growth of the world population in the next years. Moreover, given the favorable commercial characteristics observed in both sheep and goat carcasses, the production of their meat is believed to increase and acquire a significant share of international meat trade in short to medium time. Within this framework, I first analyzed sheep and goat carcass characteristics and meat quality as well as the factors that can influence them by means of a literature review on the topic. The main intrinsic and extrinsic factors that may affect animal performances and productivity were examined, also presenting a comparison among different breeds. Moreover, the review provides a description of meat physical characteristics, namely pH, shear force, color and water holding capacity as well as chemical and nutritional characteristics, focusing on protein, fat, minerals and vitamins. Overall, meat from small ruminant represents an important source of protein of high biologic value and contains some compounds that are considered bioactive such as taurine, carnosine, coenzyme Q, creatine, and creatinine. In addition, it provides essential fatty acids such as α-linolenic and show higher levels of conjugated linoleic acids and represent an important source of minerals and vitamins with particular regards to iron, which is also highly available for humans, and Vitamin B12, which is synthesized by ruminal bacteria.

Meat quality depends upon overall carcass characteristic but is strictly related to the structural and biochemical characteristics of muscles. Among intrinsic and extrinsic factors that can influence them, the feeding regime is recognized as a major one.

In this context, aiming to enhance an innovative approach to a circular bio-economy model, which is addressed to reduce and recycle agro-industrial wastes, an experiment was conducted in order to investigate the influence of dietary inclusion of cardoon meal on the sensory quality of lamb meat aiming to detect those volatile compounds mainly involved in its final flavour and

odour. Indeed, cardoon meal is a by-product composed of partially defatted seed of the cultivated cardoon (*Cynara cardunculus* var. *altilis*) that has been proposed as an innovative feed for ruminants due to its valuable content of fibre, protein, amino acids, unsaturated fatty acids and bioactive compounds. For the purpose of this experiment, fifteen Sarda x Comisana male lambs were divided in two groups and fed for 75 days with a concentrated-based diet containing 15 % cardoon meal or dehydrated alfalfa. The complex nature of meat required an investigation of the essential flavour-active compounds isolated from both adipose tissue and lean meat and their joint contribution to perceived flavour. A first comparison between the two treatment groups, aimed to obtain a volatile fingerprint screening of meat samples, was achieved performing a SMart Nose analysis, which functions as a non-separative mechanism providing a global odour perception. In addition, a Quantitative Descriptive Analysis of meat as well as an olfactory evaluation of kidney fat were performed. Moreover, attempting to identify the volatile compounds responsible for the sensory differences between treatments found carrying out the previous analyses, a headspace SPME/GC-MS analysis was performed on both meat and kidney fat. Aiming to deeper the investigation of those volatiles potentially implicated in the odours perceived in kidney fat, short- branched fatty acids (BCFA), indole and skatole, considered as the main responsible of flavours that may be regarded as unpleasant, have been measured performing a GC-MS and an HPLC analysis respectively.

Results showed that the substitution of alfalfa with cardoon meal slightly influenced lambs fat odour. Cardoon inclusion reduced the "animal/barnyard" odour perceived in the kidney fat of alfalfa-fed lambs, which could be linked with the aromatic compound *p*-cresol detected only in that group. Regarding the other volatiles that are considered to be determinants of the characteristic lamb flavour (i.e. BCFAs, skatole, indole), both diets were characterized by their absence or a moderate to low level detection.

Another experiment was carried out to investigate the effect of dietary inclusion of different tannin extracts on lamb meat volatile compounds and flavour. Tannins, widespread among plants commonly consumed by ruminants, are able to form complexes with proteins, limiting their ruminal degradation and thus the synthesis of some odour-active compounds that may be considered as unpleasant. The extracts were: mimosa (*A. mearnsii*; condensed tannins), chestnut (*C. sativa*; hydrolysable ellagitannis) and tara (*C. spinose*; hydrolysable gallotannins). Thirty-six Comisana male lambs were divided into four groups and fed for 75 days with a concentrate-based diet or with the same diet supplemented with 4 % of one of the tannin

extracts. For the purpose of this experiment, except Smart Nose screening, the same analysis techniques adopted to investigate the use of cardoon meal were carried out.

Results clearly demonstrated that tannins reduced pastoral odour in perirenal fat of lambs the meat of which was characterized by a very low perception of this attribute. It was assumed that *p*-cresol and 8-methylnonanoic acid mostly contributed to pastoral odour expression in the diet without condensed or hydrolysable tannins.

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1. Introduction

Meat is an essential component of human diet in several populations, providing high-quality nutrients. It contains essential fatty acids as well as high biological value proteins and is particularly rich in micronutrients such as vitamin B12, iron, selenium and zinc (Wyness, 2016). Meat consumption varies among and within countries and several aspects can influence this feature such as socio-economic, ethical and religious factors (Font-I-Furnols & Guerrero, 2014; Borgogno et al., 2017). Globally, pork is consumed the most (16.0 kg/capita/year), followed by poultry (14.0 kg/capita/year), beef (9.3 kg/capita/year) and sheep and goat meat (1.9 kg/capita/year) (FAOSTAT, 2020).

Considering the increasing demand for animal products and a presumed lack of food resources for humans in the next decades (FAO, 2020), the ability of ruminants to use feeds without competing with human for edible food resources, is a great advantage in terms of sustainability. In addition, ruminants can take advantage of feed of low nutritional value and exploit marginal and poorly productive areas, representing a great benefit in limiting and preventing environmental systems deterioration (Seidavi et al., 2018).

The ruminant sector is globally represented for about the 56% by small ruminant, namely sheep and goats, with a population of about 1209 and 1045 million of units respectively (FAOSTAT, 2020).

The husbandry of these small ruminants has enormous growth potential, particularly in developing countries, where there will be the greatest growth of the world population in the next years (FAO, 2020). Moreover, given the favorable commercial characteristics observed in both sheep and goat carcasses, the production of their meat is believed to increase and acquire a significant share of international meat trade in short to medium time (FAO, 2020). Sheep and goat meat is reaching a significant interest for its nutritional and sensorial properties and can represent an important resource for satisfying meet consumers tendency to search for foods with health-promoting properties (Chikwanha et al., 2018). Consumers' meat acceptance is also strongly affected by odour and flavour, considered among the most important product characteristics (Borgogno et al., 2015). These features vary according to a wide range of intrinsic and extrinsic parameters some of which can sometimes be shaped to obtain a product more desirable (Font-i-Furnols & Guerrero, 2014). For this purpose, dietary manipulation may represent an effective means since it may strongly impact the final flavour of a product.

1.1 Carcass characteristics and meat quality of sheep and goat

Sheep and goat have carcasses with highly variable characteristics and, from this point of view, have wide margins for improvement. The potential of meat production depends upon the growth and the development of an animal and the quality of the carcass is mainly influenced by its distribution of muscle, fat and bone (Dahanda et al., 2003).

To evaluate the characteristics of sheep and goat carcasses, the main variables that are commonly considered are the dressing percentage, the cuts weight, the conformation and the fatness (Ramírez-Retamal and Morales 2014).

Dressing percentage is the ratio between the hot carcass weight and the live weight of the animal, and therefore this variable has a strong impact from the economic perspective. This parameter depends on several factors, principally on the age and weight at slaughter, on the breed, the sex and the rearing system. It can be also influenced by the gastrointestinal content, on the basis that dressing percentage is calculated considering the empty or the full body weight (Assan, 2015). Considering the composition of the carcass and its main edible cuts, sex, breed, nutritional level, and carcass weight are the main factor that can affect the relative abundance of the different cuts, organs or tissues (Negussie et al. 2015; Skapetas et al. 2006). The effect of sex on carcass characteristics is mainly related to the different precocity between males and females, being the latter more precocious. As for the sex, the breed effect is mainly associated to the different precocity/maturity and productive aptitude and can mainly determine different fat distribution in the body (Assan 2015; Tshabalala et al. 2003). Taking into account the nutritional level of the diets, the high nutritional diets favor an increase in carcass weight because of the higher availability of nutrients. In addition, by reducing the energy concentration of the diet, fat proportion can be reduced, and the lean tissue increased respectively (Assan, 2015). With regard to the weight at slaughter, an increase in carcass weight corresponds to an increase in the percentage of fat and a reduction in the percentage of bone in more and less proportional way, respectively (Colomer-Rocher and Kirton, 1989).

From a commercial perspective, muscle and fat content valuation is an extremely important assessment in order to attribute an objective economic value to the carcasses. Different grading systems of carcasses of small ruminants exist. The European Union adopts two different systems for the evaluation of small ruminant carcasses. One intended for the dairy farming of Mediterranean area, the major meat product of which is light lamb (carcass weight ≤ 13 kg). The other, with a general value, adopted for heavier carcasses that, following the beef carcass grading, classifies sheep carcasses in 5 categories for conformation (EUROP, from E: superior,

good to P: poor) and five for fatness (from 5: extremely fat to 1: extremely lean). The conformation categories are based on the muscular development and on the convexity or concavity of the shoulder, back and hindquarter profiles, while the fatness score is evaluated on the bases of the fat quantity both outside and inside the carcass.

Meat quality in its turn, even if strictly related to the carcass overall quality, is mainly dependent on the structural and biochemical characteristics of muscles that determine its eating quality. The nutrional, dietetic and sensory properties of meat are influenced by the already mentioned intrinsic and extrinsic factors that characterize the husbandry systems. Among them, the feeding regime is recognized as a major one (Chikwanha et al., 2018). Indeed, it is well known that diet influences chemical characteristics such as the fatty acid profile, antioxidant properties, rate of protein synthesis as well as flavour and odour (Kim et al., 2013; De Brito et al., 2017; Realini et al., 2017) and thus in consumers' behavior and attitude towards meat (Borgogno et al., 2015; Jiang et al., 2015).

1.2 Plant by-product as feed for ruminants in a circular-bioeconomy perspective. The use of cardoon meal.

Agricultural industry produces billions of tons of human non-edible by-product derived from the cultivation and processing of a particular crop, accounting for approximately 30% of worldwide agricultural production (Ajila et al., 2012). In addition, it is widespread to consider as wastes, residues that have no further economic value and that may cause management, economic and pollution problems (Santana-Méridas et al., 2012). In this context, economy strategies increasingly consider a new approach based on the new concept of circular-bioeconomy, a word that arises from the merger of the terms bioeconomy and circular economy. Bioeconomy includes the sectors of the economy that rely on renewable biological resources such as forestry, marine and zootechnical resources, as well as by-products and waste from agro-industrial origin, aiming to valorize them in an economically, environmentally and socially sustainable way (European Commission, 2018). This concept largely overlaps with that of circular economy, that is an economic system based on a closed-loop approach aimed at minimize waste production and at a continual use of resources, virtually exploiting their value indefinitely (Sherwood, 2020). This is among the main reason of a growing interest in the development of innovative strategies for the valorization of agricultural and industrial residues as a source of high value-added products ensuring sustainable and cleaner production

processes that are economically reasonable, eco-friendly and socially beneficial (Santana-Méridas et al., 2012).

Agro-industrial by-products represent a human-inedible resource that can be successfully used as ingredients in small ruminant diets, without compromising animal performance (Vasta et al., 2008). Indeed, ruminants are provided with a gastrointestinal microbial population and physiological adaptation that makes them skills to efficiently utilize by-product. This characteristic allows them to convert feed of low nutritional value into high-valued protein edible products (Salami et al., 2019). Furthermore, dietary utilization of agro-industrial residues, represent a low-emission and low-input feeding strategy suitable for mitigate the environmental impact of livestock production (Wilkinson, 2011; Seidavi et al., 2018).

Cardoon meal is a by-product composed by partially defatted seed obtained after mechanical oil extraction of the cultivated cardoon (*Cynara cardunculus* var. *altilis*), a drought resistant perennial specie, native from to the Mediterranean region (Genovese et al., 2016) that is of increasing interest and economic value for its multipurpose uses (Cabiddu et al., 2019).

Preliminary studies concerning the nutritive value of cardoon industrial by-product (Fernàndez and Manzanares, 1990; Romero et al., 1997) have spurred many studies on this crop, including its potential use for feeding ruminants. Moreover, it could be attractive to promote the value of meat provided from plant by-product fed ruminants, underling their distinctive quality attributes and ecological benefits (Salami et al., 2019). Cajarville et al. (2000) investigated the potential use of the entire cardoon seed, analyzing its chemical composition, rumen degradability and digestibility, reporting seeds to be suitable as small ruminant feed. More recently, in a circular-bioeconomy perspective, research has been addressed at elucidating the evaluation of cardoon meal as an innovative supplement for small ruminants, lambs in particular. Considering its valuable content of fibre, protein, amino acids, unsaturated fatty acids and bioactive compounds, cardoon meal has been considered a valuable by-product which could enhance animal feed efficiency in terms of crude protein utilization and ruminal biohydrogenation (Genovese et al., 2016; Cabiddu et al., 2019). Salami, Valenti et al. (2019) investigated the influence of dietary cardoon meal on lamb growth performance and on selected quality parameters of their meat as well as the antioxidant potential of cardoon extract in ovine muscle homogenates. Results showed no effect on lamb performances and carcass traits nor on the colour stability of raw meat and the oxidative stability of cooked meat, while little effect was observed on fatty acid profile. In addition, they demonstrated an antioxidant

potential of compounds present in cardoon meal since adding 5% cardoon extract in muscle homogenate reduced lipid oxidation.

Since it is well-established that diet composition may also affect meat flavour (Chikwanha et al., 2018), in order to achieve a better understanding on the effect of cardoon meal on overall meat quality of lamb, we deemed of great importance to assess the effect of feeding this by-product on volatile compounds and flavour in lamb meat.

1.3 Plant secondary compounds in small ruminant nutrition and product quality. The role of tannins.

It is well established that nutritional strategies may represent a tool to modulate the quality of meat allowing meat sector to better satisfy consumer expectations (Font-I-Furnols & Guerrero, 2014). For this purpose, plant secondary metabolites (i.e. tannins, essential oils and saponins) are reaching an increasing interest since they are reported to have beneficial on animal health and productivity besides improve the quality of their products. Evidences has been provided for potential positive effects of feeding lambs with these bioactive compounds on meat quality traits such as intramuscular fatty acid composition, oxidative stability and sensory properties (Luciano et al., 2011; Serrano et al., 2014; Ortuño et al., 2017; Ranucci et al., 2019). These positive effects are reported to be mainly related to the inhibition of pathogenic bacteria proliferation in gastro-intestinal tract, immune response modulation as well as the enhancement of nutrients utilization thus improving animal growth performance and production (Arowolo & He, 2018).

Among plant secondary metabolites, tannins received considerable attention. They represent a complex family of phenolic compounds produced by a wide range of plant species as a chemical defense system against insects and pathogens (Huang et al., 2018) besides to function as a protection toward herbivores predation (War et al., 2012). According to their chemical structure and properties, they are commonly classified in two main groups: condensed tannins (CT), or proanthocyanidins, and hydrolysable tannins (HT). CT are complexes of oligomers and polymers of flavonoid units commonly linked by carbon-carbon bonds. HT contain a carbohydrate as a central core (generally glucose) the hydroxyl groups of which are esterified with gallic acid (gallotannins) or ellagic acid (ellagitannins) (Noumann et al., 2017). Several factors may influence tannins interaction with ruminant metabolism such as their source, concentration and chemical structure, as well as the animal species to which they are supplied, their physiological state and the basal diet (Piluzza et al., 2014). Both classes have traditionally

been regarded as “anti-nutritional” due to the impairment on feed intake and nutrient utilization they can cause, respectively ascribed to a lower palatability related to the sensation of astringency and to their strong affinity with proteins with which they form soluble or insoluble complexes and thereby probably reducing their bioavailability (Makkar, 2003; Waghorn, 2008; Le Bourvellec, 2012). Nevertheless, numerous studies have been conducted in order to elucidate their potential beneficial effects, concluding that the effects of dietary tannin supplementation may vary greatly depending on type and chemical structure of tannins, amount ingested, composition of the diet, and animal species (Morales & Ungerfeld, 2015; Jeronimo et al., 2016; Naumann et al., 2017; Huang et al., 2018). Several benefits of dietary tannins have been reported, such as the limitation of dietary protein degradation in the rumen, microbial protein synthesis increase, methanogenesis decrease, and bloat prevention (Makkar, 2003; Waghorn & McNabb, 2003; Patra and Saxena, 2011; Liu et al., 2016). Among tannin properties, the well-established capacity to bind proteins thus preventing their ruminal degradation leads to limiting the availability of such metabolites that can cause the synthesis of specific odor-active compounds that may be considered as unpleasant by some consumers (Young et al., 2003; Schreus et al., 2008; Watkins et al., 2014). Indeed, odour and flavour are crucial product characteristics that strongly affect consumers’ acceptance and willingness to purchase (Borgogno et al., 2015). Among odor-active compounds, skatole, indole both of which originate from the ruminal catabolism of tryptophan and *p*-cresol, which derive from tyrosine, are considered to be among the main contributors to “pastoral flavour”, which includes attributes like “barnyard”, “fecal” and “sheepy”, and that, together with the “mutton flavour”, attributed to the presence of some short-chain branched fatty acids (BCFA, C8-C10; Schreurs et al., 2008; Watkins et al., 2014), mostly characterize lamb meat and may be considered as unpleasant by some consumers (Young et al., 2003; Schreurs et al., 2007; Priolo et al., 2009).

2. Thesis aims

The thesis is composed of three section with the following aims:

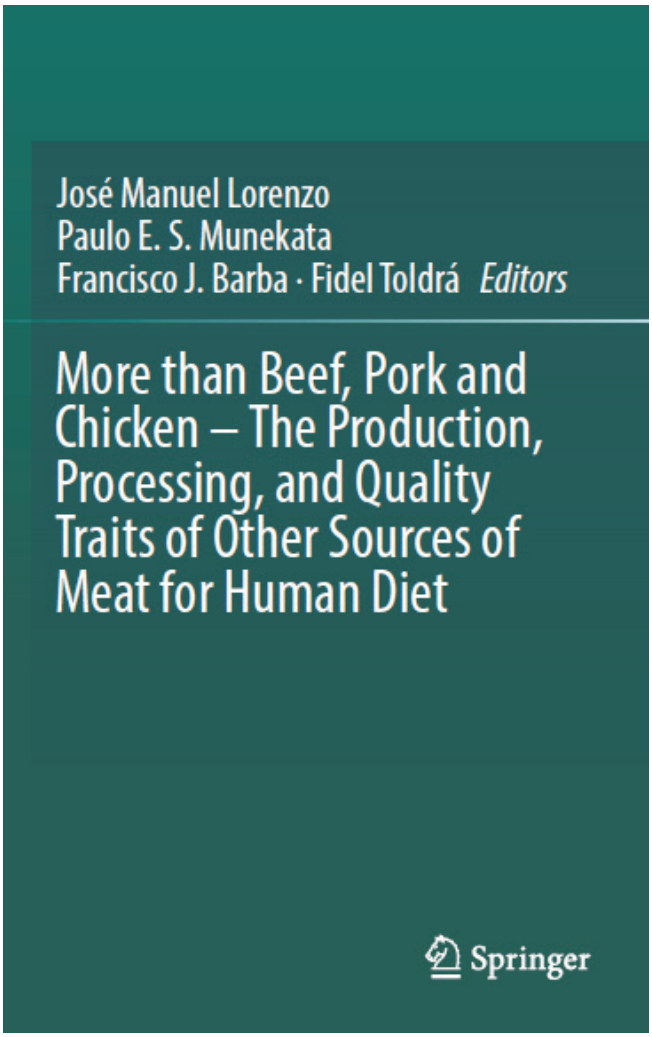
1. the first contribution of my research project aimed to provide a description of sheep and goat carcass characteristics and meat quality as well as the factors that can influence them. For this purpose, a literature review was addressed to examine the main intrinsic and extrinsic factors that may affect animal performances and productivity also providing a comparison among different breeds. Furthermore, the review aimed to describe meat physical characteristics, namely pH, shear force, color and water holding capacity as well as chemical and nutritional characteristics, focusing on protein, fat, minerals and vitamins.

Among the topics examined in the first contribution, those related to the dietary effect on meat quality were considered in the experimental section. The animal husbandry and the sample collection were carried out at the University of Catania.

2. The first experiment was addressed to enhance an innovative approach to a circular bio-economy model, which aimes to reduce and recycle agro-industrial wastes using the cardoon crop as a paradigmatic example. Indeed, cardoon meal is a by-product composed of partially defatted seed of the cultivated cardoon (*Cynara cardunculus* var*. altilis*) that has been proposed as an innovative feed for ruminants. My thesis was devoted to investigate the influence of 15 % dietary inclusion of cardoon meal in total substitution of alfalfa in a concentred-based diet, on the sensory quality of lamb meat, attempting to detect those volatile compounds mainly involved in its final flavour and odour.

3. The second experiment was conducted in order to investigate the effect of 4 % dietary inclusion of tannin extracts, in a concentred-based diet, on lamb meat volatile compounds and flavour. Indeed, tannins, widely distributed among plants commonly consumed by ruminants, are able to complex with proteins limiting their ruminal degradation and thus the synthesis of some odour-active compounds that may be considered as unpleasant. The extracts, included separately to the diets of three different groups of lambs, were: mimosa (*A. mearnsii*; condensed tannins), chestnut (*C. sativa*; hydrolysable ellagitannis) and tara (*C. spinose*; hydrolysable gallotannins).

3. Carcass Characteristics and Meat Quality of Sheep and Goat



Chapter 6
Carcass Characteristics and Meat Quality of Sheep and Goat

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3.1 Introduction

The worldwide population of sheep and goats totals 2.18 billion head (FAO 2018). Fifty-five percent of all goats, 1 billion head, are reared in Asia and 38% in Africa; Africa and Asia are also the most important continents for number of animals per inhabitant, with 316 and 125 heads per 1000 capita, respectively (Table 1). Moreover, 28% of the world goat stock is in China and in India. In the last 20 years, there has been a steady increase in the number of goats worldwide (+2% per year) involving most continents, with the highest values in Africa (+87%), Oceania (+42%) and Asia (+25%). The exceptions are Europe (−13% in 20 years) and North America, where goats underwent an 8% reduction in the last 10 years.

Table 1. Goat population

	1996	2006	2015	2016
Goat head (*1000)				
World	704,094	840,371	979,247	1,002,810
Africa	207,186	281,690	376,360	387,667
Asia	443,480	498,978	544,443	556,020
Europe	19,435	17,916	17,035	16,966
North America	1929	2867	2680	2650
South Central America	29,750	35,172	34,694	35,216
Oceania	2314	3748	4033	4291
Goat head per 1000 capita				
World	121	127	133	134
Africa	280	297	315	316
Asia	125	124	123	125
Europe	27	24	23	23
North America	6	9	8	7
South Central America	60	62	55	55
Oceania	78	110	102	107

FAO (2018)

The total number of sheep has increased to 1.17 billion head over the last 20 years, half the rate of growth compared to goats. The largest increases were observed in Africa (+60% in 20 years), and Asia (+24% in 20 years), while the number fell in Oceania (−43% in 20 years) and in Europe (−21% in 20 years). The country with the highest sheep population is China (over 162 million head), followed by Australia, over 67 million, and India, over 63 million. Considering the number of animals per inhabitant, Asia and Oceania are the most important continents with 287 and 2372 heads per 1000 capita, respectively (Table 2).

Table 2. Sheep population

	1996	2006	2015	2016
Sheep head (*1000)				
World	1,062,755	1,098,662	1,160,315	1,173,354
Africa	220,112	280,667	342,471	351,579
Asia	412,164	458,176	503,045	511,711
Europe	165,512	136,629	130,599	131,059
North America	9130	7143	6143	6146
South Central America	87,312	84,922	78,002	77,703
Oceania	168,525	131,125	100,056	95,154
Sheep head per 1000 capita				
World	182	166	157	157
Africa	297	296	287	287
Asia	116	114	114	115
Europe	227	187	176	177
North America	31	22	17	17
South Central America	176	149	123	122
Oceania	5695	3841	2530	2372

FAO (2018)

The world production of goat and sheep (Table 3) has exceeded 5 and 8 million tons of carcass equivalent, respectively, while Asia is the largest producer of both sheep and goat meat.

Table 3. Goat and sheep meat production

	1996	2006	2015	2016
Goat meat (1000 tones)				
World	3168	4573	5141	5211
Africa	807	1132	1151	1169
Asia	2107	3162	3711	3775
Europe	136	127	123	113
North America	<1	<1	<1	<1
South Central America	103	126	127	126
Oceania	14	26	29	29
Sheep meat (1000 tones)				
World	7075	8382	8032	8214
Africa	1014	1475	1375	1378
Asia	2859	3929	4022	4107
Europe	1556	1312	1171	1171
North America	141	105	92	87
South Central America	294	308	319	317
Oceania	1212	1254	1054	1153

FAO (2018)

It is interesting to note that the average carcass weight for goats varies from 11.0 kg/head in Europe to 23.5 kg/head in Oceania. Also for sheep, the weight at slaughter appears quite variable ranging from 14.1 kg/head in Africa to 20.6 kg/head in Oceania (FAO 2018). Indeed, large differences are recorded at individual country levels with slaughter weights for goats of 13.7 kg/ head in China and of 10.0 kg/head in India and slaughter weights for sheep of 16.0 kg/head in China and of 21.7 kg/head in Australia (FAO 2018). These differences can be explained both by different husbandry systems and by the fact that in some areas, such as Africa, the slaughtering of small ruminants often takes place locally and the meat is consumed directly by the producer family, influencing the reliability of previously reported data (Dhanda et al. 2003). This fact seems to be supported by the data on sheep and goat meat exports in Africa, which regards 1.2% and 1.3% of the total amount of the meat produced respectively; conversely, this percentage exceeds 70% in Australia for both goat and sheep meat exports. On the other hand, the acceptability of the small ruminant carcasses is different around the world. In the Mediterranean basin, light carcasses are preferred and derived from the traditional dairy systems, where kids and lambs are fed on milk and mainly consumed during the Easter and Christmas periods. In Italy, over 80% of the total amount of the goats slaughtered have a weight lower than 10 kg (Borgogno et al. 2015; ISTAT 2010). In Northern Europe, and in other parts of the world heavier carcasses are preferred (Mioč et al. 2013). In Australia, trade lambs have a carcass weight from 18 to 22 kg and heavier animals are commonly exported to the USA. Moreover, the weight of the carcasses is increasing (Hufton et al. 2008).

It is hard to understand what to expect from future trends of goat and sheep populations because the rearing of these animals in the near future will have to deal with increasing issues such as the reduction of water availability, competition for the use of soil, and the degradation of pastures (Skapetas and Bampidis 2016). In general, an increase in ruminant meat production and consumption is expected in the next years, especially in developing countries, also due to the increase in world population (Corazzin et al. 2015). OECD-FAO (2017) predicts a yearly increase in sheep meat production of 2% in the near future, 40% of which from the increase in Chinese production and 23% from that of Sub-Saharan Africa production. At the same time, the global consumption of mutton will increase from 1.73 kg of retail weight equivalents/person/year to 2.10 kg of retail weight equivalents/person/year in 2026 (OECD-FAO 2017).

Sheep and goats are reared in similar systems, mainly extensive, with goat husbandry that being preferred in poor and marginal areas and often following a multispecies grazing system.

In semi-arid areas, the predominant sheep rearing system is pastoralism, and more than 40% of the total of the goat population is reared in arid and semi-arid areas (Devendra 2014). In general, in developing countries, small ruminants are kept mainly in extensive conditions under nomadic or transhumant systems. In these systems, meat production is predominant, and the milk is self- consumed (Morris 2017; Escareño et al. 2012). Conversely, in developed countries sheep and goats are reared in several husbandry systems, from extensive, transhumant, to intensive. The intensive husbandry systems regard mainly dairy goat and sheep, the production of which is common in the Mediterranean basin (Escareño et al. 2012). In Australia and New Zealand, the sheep rearing system is extensive and the main product is lamb. New Zealand constitutes over 40% of the world trade of lamb, and wool; Australia is the most important producer of fine wool in the world. In South America the rearing system is mainly extensive and oriented to wool production or characterized by the presence of small-holder producers (Morris 2017). Morris (2017) argues that in the near future pastoralism will decrease because of the increase in arable land, and sheep products will move from wool to meat faster and faster. In the world, there are 570 goat breeds, and around the 25% of the total world breeds are sheep (Cottle 2010). For both sheep and goats, the majority are meat breeds, in agreement with the widespread production systems. In Asia, 94% of the total breeds are meat breeds (Devendra 2014). Crossing is the most widespread breeding technique; Shrestha and Fahmy (2007) explained that the main part of the goat meat trade in developing countries comes from crossbred animals. Moreover, the different sheep and goat breeds are characterized by a huge variation in terms of growth performance and carcass weight. Dhanda et al. (2003) reported a mature weight of goat from 9 to 13 kg for some tropical breeds to over 100 kg. This wide variation corresponds to the development and adaptation of the different breeds to the wide range of husbandry environments.

3.2 Carcass

To evaluate the characteristics of sheep and goat carcasses, the main variables that are used are the dressing percentage, the cuts weight, the conformation and the fatness (Ramírez-Retamal and Morales 2014).

Dressing percentage is the ratio between the hot carcass weight and the live weight of the animal, and therefore this variable has considerable economic importance. Dressing percentage is highly variable in small ruminants, from 36% to around 60% (Tables 4 and 5), because it depends on many factors: age or weight at slaughter, husbandry system, breed and sex, but also

on the slaughtering method, and whether it is calculated on the bases of empty or full body weight, which can be influenced by gastrointestinal content (Assan 2015). However, in general, goat has a lower dressing percentage than sheep at similar weight of slaughter (Rodríguez et al. 2014). In fact, goats tend to deposit more visceral and less subcutaneous fat than sheep, and fat is deposited according to a temporal order: first internal, then intermuscular, subcutaneous, and finally intramuscular fat. Higher dressing percentage in lamb than kid was also found in suckling animals (Santos et al. 2008). Moreover, Mioč et al. (2013) explained that kid has a higher weight of stomach and intestine than lamb, contributing to explain the differences in dressing percentage. As reported by Alexandre et al. (2009), the husbandry system, and the nutritional level of diets in particular, is one of the most important factors affecting the dressing percentage of small ruminants. It is widely recognized that the dressing percentage can be improved by increasing the nutritional level of the diet of animals both in sheep and in goat and it is related to the increased muscle and especially fat tissue deposition in the carcasses of animals fed with high nutritional diets (Bovolenta et al. 1998; Das et al. 2008; Gürsoy et al. 2011). Kabir et al. (2011) showed a gradual increase in dressing percentage, increasing the energy concentra- tion of the diet from 9.2 to 11.6 MJME/kg DM. However, the dressing percentage can also be affected by the feeding system. Indeed, lambs reared indoors and fed with concentrate have higher dressing percentages than those reared on pasture (Karaca et al. 2016). In this case, the results can be explained not only by the higher nutritional level of the diet, but also by the higher development and weight of the digestive tract, which is a non-carcass component, in animals grazed on pasture (Priolo et al. 2002). In addition, the age/weight at slaughter can influence the dressing percentage of small ruminants. Increasing the age at slaughter also increased the dressing percentage (Casey et al. 2003). As with the effect of the diet's nutritional level, it is probably due to an increase in fat and muscle deposition relative to bone and non-carcass components of the body, and because the internal organs are of early or intermediate maturation (Cardoso et al. 2013). Indeed, Alexandre et al. (2009) showed that the organs weight proportion decrease with the increasing the age of lambs. Accordingly, the same authors, slaughtering Creole kids 4, 8 and 11 months after weaning, observed an increase of dressing percentage from 51.9%, to 53.7%, and to 55.0%. Also Kaić et al. (2012) observed similar results in the Boar goat, as did Mayi and Alkass (2010) in the Meriz and Black goats. In these studies, however, the increase in dressing percentages were not statistically significant.

It is interesting to note that despite being slaughtered at a very young age, suckling animals have higher dressing percentages than weaned animals. Beriain et al. (2000) showed that, in the Lacha breed, suckling lambs have higher dressing percentages than those slaughtered at 24 kg or 36 kg, 50.5%, 41.7%, and 45.4% respectively; the same authors also showed the same trend in the “Raza Aragonesa” breed.

Table 4. Sheep carcass quality

Breed	Sex	Feed	LW (kg)	CW (kg)	Carcass composition (%)			Fatness	Conformation	Reference
Assaf	Fe/Ma	M	10	5.3[a]	24.1[j]	58.1-61.5[j]	14.2–11.3[j]			Landa et al. (2004)
Churra	Ma	M		5.5[a]	25.0[j]	61.3[j]	11.9[j]	5.5[d]	2.9[d]	Sañudo et al. (2012)
Merino Precoce	Fe/Ma	M	9.1–14.5	4.9–5.4[b]	20.9–25.5[j]	56.3–58.1[j]	9.9–14.6[j]			Pérez et al. (2012)
Leccese	Ma	M/C/H	12.1–16.4	7.4–10.8[b]	36.6–44.3[j]	49.2–54.2[j]	6.1–13.2[j]			D'Alessandro et al. (2013)
Mountain Greek	Ma	M	11.6–15.3	6.6–8.6[b]	18.2–19.7	54.7–55.0	20.8–23.0			Skapetas et al. (2006)
Serra da Estrela	Ma	M-C/H	16–35	11.8[b]	21.1	59.5	17.1			Santos-Silva and Vaz Portugal (2001)
Merino Branco	Ma	M-H	16–35	11.8[b]	23.5	61.1	14.0			Santos-Silva and Vaz Portugal (2001)
Canaria	Fe/Ma	M-C/H	14.6–22.4	7.4–10.4[b]	21.7–20.3	49.0	24.7–25.6	7.5–8.9[f]	7.0–9.7[d]	Camacho et al. (2015)
Canaria Hair	Fe/Ma	M-C/H	14.8–23.0	7.2–11.0[b]	20.3–22.6	53.9–55.3	17.6–19.2	6.0–7.3[f]	6.1–10.6[d]	Camacho et al. (2015)
Romanov	Fe/Ma	M/Si/H	14.1	5.7[a]						Kuchtík et al. (2011)
Suffolk × Romanov	Fe/Ma	M/Si/H	13.9	5.8[a]						Kuchtík et al. (2011)
Slovak dairy	Fe/Ma	M/C/H	16.9–17.1	8.1–8.3[b]	27.0–29.2	59.4–63.5	9.5–11.4			Margetín et al. (2013)
Mountain Greek	Ma	C/H	15.8–23.9	9.9–13.3[b]	17.4–18.2	54.9–55.3	22.4–23.6			Skapetas et al. (2006)
Wrzosówka	Ma	C/H/S	20.3–20.5	7.1–7.8[a]	20.4[i]	74.4[i]	5.2[i]			Kawęcka et al. (2018)
Corriedale	Ma	P	31.7	14.6[a]	24.3	48.1	21.9	3.2[c]	2.7[e]	Bianchi et al. (2005)
Hampshire Down × Corriedale	Ma	P	40.2	20.0[a]	25.6	50.1	18.1	3.1[c]	3.0[e]	Bianchi et al. (2005)
Norwegian White	Fe	P-C/Si		30.4–33.1				7.4–8.0[d]	5.0–7.6[d]	Bjelanović et al. (2015)
Pramenka	Fe	P		25.0–27.3				7.7–9.8[d]	5.3–7.9[d]	Bjelanović et al. (2015)
Dorper	Ca		34.3	21.6[a]	14.4	75.4	10.2			Tshabalala et al. (2003)
Damara	Ca		31.2	18.7[a]	19.7	70.0	10.3			Tshabalala et al. (2003)
Santa Ines	Fe/Ma	C/H	30–45	17.6[b]				3.4[c]		Cardoso et al. (2013)
Ile de France × Santa Ines	Fe/Ma	C/H	30–45	18.1[b]				3.7[c]		Cardoso et al. (2013)

Table 4. (*continued*)

Breed	Sex	Feed	LW (kg)	CW (kg)	Carcass composition (%)			Fatness	Conformation	Reference
Texel × Santa Ines	Fe/Ma	C/H	30–45	19.2[b]				3.6[c]		Cardoso et al. (2013)
Blackhead Ogaden		C/H			20.6–26.7	56.1–62.3	15.2–23.3			Negussie et al. (2015)
Tsigai		P	29–42	9.7–17.0[b]	21.9–30.5	68.2–75.4	0.6–4.2			Polák et al. (2013)
Northeastern Bulgarian Fine Wool	Ma	C/P-C/H	31.5	13.1[a]	27.2	62.3	11.4			Popova and Marinova (2013)
Northeastern Bulgarian Fine Wool × Ile de France	Ma	C/P-C/H	33.3	14.1[a]	26.5	60.6	12.9			Popova and Marinova (2013)
Limousine	Ma	P	35.2–35.3	14.6–14.8[a]				2.4-2.5[c]	6.5–6.7[d]	Prache et al. (2011)
Suffolk crossing	Fe/Ma	C/H	38–42	20.3–20.7[b]	21.1–22.9[j]	57.7–60.6[j]	17.6–20.8[j]	2.7–3.2[c]	2.4–2.8[c]	Ringdorfer et al. (2015)
Local Indian breed	Fe	C/H	28.5	14.9[b]	13.5	59.1	27.4			Sen et al. (2004)
Local Tanzanian breed			22.3	9.4[b]	26.4	66.2	7.4			Shija et al. (2013)
Jezersko-solèava	Fe/Ma	C/H	29.5–43.5	13.5–20.1[b]	21.1–24.0[i]	70.4-72.4[i]	5.7-6.4[i]	3.0-3.4[c]	3.0[c]	Žgur et al. (2003)
Kivircik	Ma	C/H	33.0	16.9[b]	22.7	49.2	10.7[k]			Koyuncu (2008)
Karacabey Merino	Ma	C/H	39.6	19.5[b]	23.3	51.1	9.0[k]			Koyuncu (2008)
Merino	Ma	C/S	25	12.7[b]	18.6[j]	60.3[j]	18.5[j]	4.9[h]	5.1g	Manso et al. (2009)

LW Slaughter weight, CW Carcass weight, CL carcass length, Ma male, Fe female, Ca castrated, C concentrate, H hay, M milk, P pasture, S straw, Si silage

[a]Cold carcass weight

[b]Hot carcass weight; Fatness and Conformation, lower the score lower the fatness and poorest the conformation

[c]1–5 point scale

[d]1–15 point scale

[e]1–6 points scale

[f]1–12 point scale

[g]0–5 point scale

[h]0–4 point scale

[i]Leg dissection

[j]Shoulder dissection

[k]Intermuscular fat

Table 5. Goat carcass quality

Breed	Sex	Feed	LW (kg)	CW (kg)	Carcass composition, %			Fatness	Conformation	Reference
Gokceada	Ma	M/C/H	9.4	4.8[b]						Ekiz et al. (2010)
Maltese	Ma	M/C/H	14.5	7.7[b]						Ekiz et al. (2010)
Bravia	Ma/Fe	M/P	7.9–9.2	3.9–4.7[b]	20.4	66.1	11.9			Santos et al. (2007)
Serrana	Ma/Fe	M/P	10.7–11.7	5.6–6.0[b]	21.1	63.0	15.0			Santos et al. (2007)
Criollio Cordobes	Ma	M/P	10.4–11.7	5.0–5.7[b]						Peña et al. (2009)
Anglonubian	Ma	M/P	10.2–11.3	5.2–5.8[b]						Peña et al. (2009)
Murciano-Granadina	Ma/Fe	M/H/S-M/H	7.0	3.6–4.1[b]	31.3–32.5	54.1–57.4				Zurita-Herrera et al. (2011)
Moncaina	Ma	M		5.3[a]	21.8[e]	64.2[e]	12.2[e]	2.8[d]	2.3[d]	Sañudo et al. (2012)
Pirenaica	Ma	M		4.7[a]	21.3[e]	64.0[e]	13.0[e]	3.0[d]	2.7[d]	Sañudo et al. (2012)
Blanca Celtibérica	Ma	M		6.6[a]	21.4[e]	60.6[e]	16.7[e]	2.8[d]	2.4[d]	Sañudo et al. (2012)
Murciano-Granadina	Ma	M		4.4[a]	23.7[e]	62.2[e]	11.9[e]	4.1[d]	2.3[d]	Sañudo et al. (2012)
Negra Serrana	Ma	M		5.8[a]	23.0[e]	63.1[e]	12.3[e]	2.8[d]	1.7[d]	Sañudo et al. (2012)
Boer	Ca		25.2	14.0[a]	20.6	76.6				Tshabalala et al. (2003)
South African indigenous	Ca		19.8	11.0[a]	24.6	74.2				Tshabalala et al. (2003)
Creole	Ma	P/H	20.2–21.3	7.9–8.2[b]	22.4–22.6[e]	70.0–70.2[e]	4.7–5.5[e]		2.9–3.0[c]	Alexandre et al. (2009)
Boer crossing	Ca	P	25.9–29.4	13.7–15.4[a]					10.2–10.6[d]	Turner et al. (2015)
Kilis	Ma	C/F	35.5–40.5	15.4–19.3[a]						Gürsoy et al. (2011)
Sudan Desert	Ma/Ca	C/H	19.1–18.8	6.4–7.9[b]						El-Hag et al. (2007)

Table 5. (*continued*)

Breed	Sex	Feed	LW (kg)	CW (kg)	Carcass composition, %			Fatness	Conformation	Reference
Boer	Ma/Fe	M/C/H	22.4–25.5	11.0–12.0[b]					8.2–8.5[d]	Kaić et al. (2012)
Meriz		C/S	23.7–26.2	10.8–12.7[b]	19.3–18.7[f]	64.0–64.2[f]	16.5–17.4[f]			Mayi and Alkass (2010)
Black		C/S	37.5–40.8	18.3–20.4[b]	19.4–19.6[f]	63.1–64.5[f]	15.9–17.5[f]			Mayi and Alkass (2010)
Boer × Spanish	Ma	C/H-P	20.5–38.2	10.0–21.7[b]	26.5–36.9	55.8–57.8	7.3–15.7			Oman et al. (1999)
Spanish	Ma	C/H-P	18.4–33.5	8.8–19.2[b]	27.6–36.5	55.3–57.6	8.2–13.4			Oman et al. (1999)
Boer × Saanen	Ma/Fe	C/H	25.6–25.7	12.1–12.3[b]						De Oliveira Maia et al. (2012)
Croatian multicoloured	Ma/Fe	M/P-P	18.0–33.5	8.2–16.6[b]						Prpic et al. (2010)
Sirohi	Ma	C/H-P/C/H	24.5–32.6	11.3–16.0[b]	23.5–25.7	66.8–68.3	3.4–6.8			Rajkumar et al. (2010)
Local Indian breed	Fe	C/F	20.5	10.1[b]	17.6	68.4	14.1			Sen et al. (2004)
Local Tanzanian breed			20.5	9.7[b]	24.9	71.6	3.4			Shija et al. (2013)
Hair goat	Ma	C/H	17.4	6.5[a]	31.3[f]	63.1[f]		1.4[d]	1.3[d]	Yilmaz et al. (2010)
Saanen × Hair goat	Ma	C/H	16.8–18.2	6.7–7.3[a]	33.1[f]	60.6–61.2[f]		1.6[d]	1.6[d]	Yilmaz et al. (2010)

LW Slaughter weight, CW Carcass weight, CL carcass length, Ma male, Fe female, Ca castrated, FA total fatty acids, C concentrate, H hay, M milk, P pasture, S straw, F forage

[a]Cold carcass weight

[b]Hot carcass weight; Fatness and Conformation, lower the score lower the fatness and poorest the conformation

[c]1–5 point scale

[d]1–15 point scale

[e]Shoulder dissection

[f]Leg dissection

The higher dressing percentage of the carcasses of suckling animals, which are even characterized by low muscle/bone and fat/bone ratio, can be explained by the low and incomplete development of stomachs and intestine. Indeed Marichal et al. (2003) showed that the weight of the gastrointestinal tract of kids slaughtered at 25 kg of live weight is 25% higher than suckling animals. Assan (2015) reviewed that sex has a highly variable effect on dressing percentage, because females are more precocious, and therefore, they deposit higher levels of carcass fat than males at the same slaughter weight. Conversely, males tend to deposit more carcass lean tissue than females, and both these characteristics influence the dressing percentage (McMillin and Brock 2005). Hence, the effect of sex on dressing percentage can be due to the complex interaction between animal precocity, energy and protein content of the diet. The biological value of protein also has a role, being involved in the efficiency of lean tissue deposition. Rodríguez et al. (2014) failed to detect a sex effect on dressing percentages in both goat and sheep, as did Nwachukwu et al. (2015) in goat. In suckling kids and lambs the dressing percentages are often similar between sexes. In this case, the early age at slaughter of animals prevented the occurrence of possible differences between sexes (Bonvillani et al. 2010; Pérez et al. 2012). The effect of genotype on dressing percentage is often reported in the literature, and it is due to differing precocity and to differing weight of the non-carcass components of body across breeds (Assan 2015).

Considering the different carcass cuts, shoulder and leg represent around 50–60% of the entire carcass weight, both in sheep, goat and also suckling animals (El-Hag et al. 2007; Karaca et al. 2016; Mayi and Alkass 2010; Margetín et al. 2013; Pérez et al. 2012). Santos et al. (2008) found, in suckling kids and lambs, lower values, 47.7% and 49.3% respectively. The first quality cuts (leg, loin and anterior ribs) are around 60% of the carcass weight in lamb and 55% of the carcass weight in suckling lambs (Camacho et al. 2015; Margetín et al. 2013). In general, the composition of the carcass in terms of muscle, fat and bone is highly variable both in sheep and goat, as reported in Table 4 and in Table 5. Apart from the differences observed in the fat distribution previously reported, goat carcass has a relatively higher weight of some cuts in the forequarter limbs, and in particular the neck and shoulder (26.2 vs. 23.0; Sen et al. 2004), than sheep. This is probably due to the different dietary behavior of these two species. Indeed, goats are able to browse trees and shrubs standing in an “erect” position (Sen et al. 2004). Moreover, goats have a higher muscle/bone ratio than sheep, confirming their low aptitude to deposit fat (Shija et al. 2013), also in suckling animals (Santos et al. 2008). Conversely, sheep have a higher proportion of high value leg cuts (Casey and Webb 2010). Tshabalala et al. (2003) claimed that

goats have a higher muscle proportion than sheep but located in cuts of less economic importance. Santos et al. (2008) found a higher proportion of leg, loin, and chump cuts in suckling lambs than in suckling kids (46.3% vs. 43.9%).

The main factors influencing the cuts and composition of the carcasses of small ruminants are the breed, the nutritional level of animals' diets, and the age at slaughter (Negussie et al. 2015; Skapetas et al. 2006). It is well known that the weight at slaughter or the carcass weight can affect in different way the different cuts, organs, or tissues. If we consider the relationship: carcass weight = a × variableb, where b is called allometric coefficient, and if b = 1 it means that the variables (organ, cut or tissue) grow proportionally to carcass weight; if b < 1 or if b > 1, it means that the variable grows in a less or more proportional way to carcass weight, respectively. Carvalho et al. (2016), considering sheep from 23 to 40 kg of body weight, reported as allometric coefficients 0.56, 0.90, 1.64 for bone, muscle and fat respectively. In goat the allometric coefficients ranged between 0.49–0.87, 0.83–1.11, 1.26–2.25, 1.26–1.76 for bone, muscle, subcutaneous fat and intermuscular fat, respectively (Al-Owaimer et al. 2013; Colomer-Rocher and Kirton 1989). In comparison to sheep, kids have a higher rate of development of muscle and a lower rate of development of fat tissue (McGregor 1984). It is important to note that these coefficients are closely related to the animal breed, determining its precocity (Garcia et al. 2014) and to the sex. Indeed, Colomer-Rocher and Kirton (1989) reported allometric coefficients statistically different between sexes, with males that showed higher values for muscle (0.99 vs. 0.83) and bone (0.87 vs. 0.49) and lower values for subcutaneous (1.37 vs. 2.25) and intermuscular (1.26 vs. 1.79) fat than females, explaining why female are more precocious than males, as previously stated. Therefore, in accordance with the allometric coefficients, an increase in carcass weight corresponds to an increase in the percentage of fat and a reduction in the percentage of bone in more and less proportional way, respectively. Moreover, the allometric coefficients explain the linear regression between the greater part of the lean cuts and the carcass or live weight, with the exclusion of the leg that follows a quadratic relation- ship (Cardoso et al. 2013). In lambs, Cardoso et al. (2013) showed that carcass weight has a positive correlation with the weight of shoulder (r = 0.55) and belly (r = 0.51), but a negative correlation with the weight of ribs (r = −0.65). However, Mayi and Alkass (2010), slaughtering goats at two fattening periods, observed that by lengthening the fattening period from 90 to 150 days, a reduction of the percentage of shoulder could be observed in Meriz, but not in Black goats. The effect of sex on carcass characteristics is evident and mainly related to the higher precocity of females compared to males. Indeed, at specific slaughter weight, intact

males have higher lean to bone and lower fat to bone ratios than castrated males, which are, in turn, leaner than females (McGregor 1984; McMillin and Brock 2005). Moreover, Cardoso et al. (2013), in sheep, showed that males have heavier rumen, head, skin and neck, but lighter belly and abdominal organs than females. Conversely, in suckling animals the effect of sex on cuts, organs and carcass composition is small or non-significant (Pérez et al. 2012; Santos et al. 2008).

The breed effect is also evident and, similarly to the sex effect, is mainly related to the different precocity/maturity and productive aptitude. McGregor (1984) reviewed that the lean/bone ratio ranges between 2.7 in dairy breeds, to 4.7 in Boer goats, that have a high aptitude for meat production. Moreover, the different breeds can have different fat partitioning in the body, both in sheep and in goats (Assan 2015; Tshabalala et al. 2003). Indeed, Sañudo et al. (2012) reported that dairy breeds tend to deposit fat in the viscera rather than in the carcass. Tshabalala et al. (2003) observed higher proportions of head, spleen plus liver, and lower proportions of skin in indigenous goats than in Boer goats. These observations could suggest that genetic selection can also influence the different carcass components. Skapetas et al. (2006), in sheep, reported that at 40% of the adult body weight, the breeds selected for meat production have a fat level of 19–20% of the carcass weight against 22–24% of the breeds selected for milk production. Considering the nutritional level of the diets, the high nutritional diets favor an increase in carcass weight and therefore an increase in the carcass measurements because of the higher avail- ability of nutrients (Gürsoy et al. 2011). The carcass fat proportion can be reduced, and the lean tissue proportion increased by reducing the energy concentration of the diet (Assan 2015). Moreover, the proportions of non-carcass components, such as feet, are higher in low than high-energy diets (Karaca et al. 2016).

From a commercial point of view, the assessing of muscle and fat content is extremely important in order to attribute an objective economic value to the carcasses. In general, different grading systems of carcasses of small ruminants exist.

The European Union adopts a system that is regulated by Reg. EEC No 2137/92, and Reg. no. 461/93 as amended. Ovine carcasses are classified on the bases of weight, fatness and conformation. In particular, carcasses are divided in 5 categories for conformation (EUROP, from E: superior, good to P: poor) as well as for fatness (from 5: extremely fat to 1: extremely lean). The conformation categories are based on the muscular development and on the convexity or concavity of the shoulder, back and hindquarter profiles, while the fatness score is evaluated on the bases of the fat quantity both outside and inside the carcass. If the carcass

weight is lower than 13 kg, the conformation is not evaluated; otherwise, since the young animals have poor conformation, they would be constantly penalized (Russo et al. 2003). Moreover, these carcasses are divided on the bases of their weight, <7 kg, from 7.1 to 10 kg and from 10.1 to 13 kg, and of the color, red or pink meat (Russo et al. 2003). Webb et al. (2005) argued that this type of classification is too penalizing for goat carcasses, because, as previously reported, these animals have a different distribution of fat, with subcutaneous fat levels naturally inferior to sheep and there- fore, with this classification, they would be systematically downgraded. Colomer-Rocher et al. (1987) reported a goat carcass evaluation system that divides carcasses on the bases of the color of fat (1: white, 2: cream, 3: yellow), the color of lean (1: pale, 2: pink, 3: red), the abundance of subcutaneous fat (from 1: low fat cover to 5: very high fat cover), the abundance of kidney fat (from 1: little to 3: excessive) and the age of the animal. Goats have a poorer conformation score and morphology than sheep (Santos et al. 2008; Sañudo et al. 2012). Eythórsdóttir (2012) and Piasentier et al. (2002b) reported that the conformation and fatness score increase by increasing the carcass weight; moreover, the conformation and fatness score can be improved by increasing the nutritional level of the animals' diets (Carrasco et al. 2009; Oman et al. 1999).

3.3 Meat

3.3.1 *Physical Characteristics*

3.3.1.1 pH

After the death of the animal the provision of oxygen and of substrates for the energy production to the cells is interrupted quickly. To maintain the production of ATP necessary for its metabolism, the muscle cell must then resort to the reserves of creatine phosphate. When these are terminated, the cell maintains the energy production through the anaerobic glycolysis that has the glycogen as substrate. The products of this metabolic pathway are pyruvate at first, and lactate and H+ ions thereafter. Obviously, anaerobic glycolysis lasts until the end of the glycogen reserves and generates a progressive reduction of tissue pH especially in the first 24 h post-mortem, with a value that goes from about 7.0 in the live animal to below 6.0. At the same time, the occurrence of mitochondrial outer membrane permeabilization with the release of the pro-apoptotic factor cytochrome c from intermembrane space have been observed (Cao et al. 2014). The result is a modification of the reticulum/mitochondria calcium cross-talk with an increase in the cytosolic calcium. The lowering of the pH and the increasing of the cytoplasmic Ca activate proteolytic enzymes such as caspases and calpains. Kouakou et al.

(2005) have found a positive correlation between final muscle pH and the activity of m-calpain. Caspase activation is probably the first proteolytic system implicated in post-mortem disruption of the cytoskeletal network, including actin (Gagaoua et al. 2013). In addition, Calpains degrade some structural proteins such as desmin, filamin, connectin, nebulin, C- and M-proteins (van Rensburg and Oguttu 2013).

The degradation of structural proteins favors an increase in the tenderness of the meat. Gheisari et al. (2007) reported that calpains activity are responsible for 90% of the proteolytic tenderization of meat. We must not forget that even the chilling temperature and the temperature/pH combination can influence the activity of proteolytic enzymes. In fact, high temperatures favor the calpain activity (Mohrhauser et al. 2014), but at the same time, they favor the bacterial spoilage, while, if the carcass temperature is brought to a level below 10 °C before rigor-mortis, cold-shortening is obtained because of muscular contractions (McNeil et al. 1991). From this point of view, since the subcutaneous fat of goats is lower than that of cattle and of sheep, the carcass cools faster and there is a slower reduction of the glycolysis process with a greater incidence of cold shortening (Kadim and Mahgoub 2012). The electric stimulation of the goat carcasses seems to be an effective method to accelerate the post-mortem reduction of pH by increasing the conversion rate of glycogen into lactic acid, and therefore, to prevent cold-shortening (Kadim and Mahgoub 2012).

Glycolysis ceases when the level of lactic acid in the muscle cell reaches 80–100 μmol/g, and in small ruminants this level is reached 24 h post-mortem (Dransfield 1994; Simela 2005). In general, therefore, the measurement of the ultimate pH (pH measured after 24 h from slaughter) is an indicator of the progression of muscle proteolysis and can directly influence some chemical-physical characteristics of the meat that will be investigated later in the paragraph. In small ruminants, a normal and desirable value of ultimate pH fall within the range 5.5 and 5.8 (Brzostowski et al. 2008; De Almeida Rego et al. 2017). An ultimate pH value higher than 5.8 is associated to a dark, tough meat with a lower shelf life due to greater bacterial spoilage (Lawrie 1991). However, Webb et al. (2005) reviewed that in goat the ultimate pH frequently ranged between 5.8 and 6.2. It could be due to the excitable nature of goats, which are more susceptible to emotional stress than sheep, and therefore are more sensible to the stress related to pre-slaughter conditions. In fact, stress conditions during the rearing or pre-slaughter period favor the activation of the hypothalamus-hypophysis axis with the release of hormones such as adrenaline and cortisol that promote the mobilization and consequently the reduction and depletion of glycogen in cells. The reduction of the level of cellular glycogen leads

to a reduction of the substrate for glycolysis and consequently a lower acidification of the muscle cell in the post-mortem. If the stress that the animal undergoes is important, the pH level in the post-mortem can be higher than 5.8 and therefore undesirable for the quality of the meat. Webb et al. (2005) reported that a glycogen level of 50 μmol/g is the minimum level for achieving an appropriate ultimate pH in small ruminants. Another factor that affects glycogen concentrations in cells in post-mortem is the type of muscle fiber. On the bases of the myosin heavy-chain isoforms, in general, the muscle fiber can be classified in I, IIa, IIx, and IIb (Listrat et al. 2016). Moreover, based on the contraction properties, the muscle fiber can be classified as slow (type I) or fast (types IIa, IIx, and IIb).

From the metabolism point of view, the muscle fibers can be further classified in oxidative/red (rich in myoglobin, poor in glycogen) or glycolytic/white (poor in myoglobin, rich in glycogen) (Listrat et al. 2016). However, while the oxidative fibers can be both slow and fast, the glycolytic fibers are only fast. De Lima Júnior et al. (2016) explained that the content of oxidative fibers in the muscle of goat are positively related to the ultimate pH value. Ithurralde et al. (2017) explained that, within fast-glycolytic and intermediate muscles, larger fast-glycolytic fibers are associated with lower ultimate pH. Based on previous considerations, most of the bibliography results can be interpreted. In fact, animals subjected to adequate nutritional levels with respect to their needs have greater glycogen reserves and therefore also a greater lowering of the pH in the post-mortem compared to animals fed with low energy levels. De Brito et al. (2017) reported that the low energy level of the diet of lamb is one of the most important factors explaining the high ultimate pH.

Costa et al. (2015), feeding lambs with diets with 50:50 or 20:80 forage/concentrate ratio, did not find a difference in the ultimate pH. However, in this study, both diets were formulated to meet the energy requirements for an average daily gain of 250 g/d. Lanza et al. (2011), when replacing soybeans with other protein sources, did not find effects on the ultimate pH, in general. Ramírez-Retamal and Morales (2014) reviewed that that type of feed in diets with similar nutritional levels have no influence on ultimate pH. Similar results were found in goats; Liméa et al. (2009) showed that kids supplemented with concentrate had lower and more desirable pH than those kept exclusively on pasture. Moreover, the diet nutritional level can influence the percentage of muscle fiber types. Greenwood et al. (2006) observed an increase in the ratio between the proportion of total area of glycolytic and oxidative fibers in semitendinosus muscle, but not in longissimus dorsi muscle and in semimembranosus muscle of lambs grazing on high availability and high nutritional value pasture with respect to those

grazing on low availability and low nutritional value pasture, suggesting a different reaction of muscles to the nutritional level of the diet.

Suzuki (1973) observed that, in sheep, starvation reduced the size of white rather than red fibers. Moreover, prolonged endurance events can lead a swift from type II to type I fiber as suggested by Siqin et al. (2017), and it could be the case of small ruminants during grazing on high mountain pastures. Indeed, Karaca et al. (2016) reported that the ultimate pH could be positively associated to higher muscular activity. The small ruminants breed has little importance on the ultimate pH of meat as reviewed by Sañudo et al. (2007) and as also showed by many other authors (Bianchi et al. 2005; Costa et al. 2015). However, Ringdorfer et al. (2015), crossing Suffolk with different other breeds found different ultimate pH, as well as Bjelanović et al. (2015) comparing Pramenka and Norwegian White sheep. Similarly, in goats, Ivanovic failed to detect differences in the ultimate pH between Serbian White and Balkan goats as well as Ekiz et al. (2010) comparing Turkish Saanen, Gokceada and Maltese breeds. Conversely, a genetic type effect was found by Santos et al. (2007). Especially for goats, the differences between genotypes may be mainly due to the different responses of the animals to slaughter and pre-slaughter stress, as also sug- gested by Ekiz et al. (2010). Another aspect that must be considered is the genetic selection for improving the eye muscle depth, which in lamb tends to increase the glycolytic fibers (Greenwood et al. 2006).

Accordingly, lambs characterized by Callipyge phenotype and therefore by a muscular hypertrophy, present a high percentage of fast glycolitic fibers (Greenwood et al. 2006). In general, sex does not affect the ultimate pH of meat (Çelik and Yilmaz 2010), although some authors have found a higher ultimate pH in males than females (Santos et al. 2008; Scerra et al. 2001) and this could be due to a more nervous temperament of the male that favors the reduction of the glycogen stores in muscle cell (De Lima Júnior et al. 2016). Another aspect to consider is the age at slaughter of the small ruminants; frequently older animals have a lower and more desirable ultimate pH compared to young animals, especially when compared to animals slaughtered at a few weeks of life. The young small ruminants, and especially young animals, are very sensitive to pre-slaughtering stress (Sañudo et al. 2012). Furthermore, as hypothesized by Mazon et al. (2017), the greater the age of the animal, the greater the time on feed with a greater level of glycogen reserves in the muscle cell. Marichal et al. (2003) showed a decrease of ultimate pH by increasing the slaughtering weight of goats from 6 to 25 kg. The ultimate pH decreases by increasing the slaughter weight also within suckling animals, as shown by Teixeira et al. (2011b) who slaughtered young animals with 4–8 kg of carcass weight.

In addition, the muscle composition in terms of different muscle fibers seem to play a role. In cattle, Wegner et al. (2000) showed that in the first months after birth the percentage of fiber IIb increase, while the percentage of fibers I remain constant and unaffected by age in cattle. In sheep, Siqin et al. (2017) observed that the effect of age on the percentage of fibers composition is highly dependent on muscles. In particular, they reported an increase in fiber IIb and a reduction of fiber I from 1 to 18 months of age in *triceps brachii* muscle. Conversely, in *biceps femoris* muscle the fibers IIb increased from 1 to 6 months of age and then decreased from 6 to 18 months of age, while the fiber I tended to have opposite trend.

3.3.1.2 Shear Force

Shear force, which can be defined as the maximum load needed to cut the meat perpendicular to fibers, is a measure of tenderness and is often measured through Warner Bratzler probe. From the consumer point of view, tenderness is one of the most important characteristics that influence the purchase choices of sheep and goat meat (Argüello et al. 2012; De Andrade et al. 2016). Generally, it is believed that the consumer perceives ruminant meat to be too tough if it has a shear force of more than about 44–55 N (Duckett 2001; Shackelford et al. 1991 in Sen et al. 2004). Boleman et al. (1997) classified the meat as tender until 35 N, intermediate from 40 to 53 N and tough if the shear force was higher than 58 N. However, as reported in Tables 6.3 and 6.4, the tenderness of meat is quite variable both in sheep and goats. For example, Polák et al. (2013) considering Tsigai lambs, found a shear force rang- ing between 15.8–90.4 N, while Sañudo et al. (2003) considering 22 European ovine breeds found a shear force ranging between 16.7 N and 40.2 N. Tenderness depends on intrinsic and extrinsic factors. Among the intrinsic factors, are the intensity and duration of post-mortem proteolysis, the content and solubility of collagen, the length of sarcomeres and the amount of intramuscular fat. Among the extrinsic factors are the sex, the husbandry system, the type of muscle, the possible pre-slaughtering stress, the cooling speed of the carcass, the ageing time, and the cooking time and temperature.

Hence, tenderness is the complex result of the physico-chemical modification of the muscle that depends on the interaction between intrinsic and extrinsic factors. However, it is interesting to highlight that shear force is related to ultimate pH of meat, and an ultimate pH lower than 5.8 results in more tender meat than meat that presents an ultimate pH from 5.8 to 6.2 because of a higher proteolysis (Li et al. 2014). Similarly, Webb (2014) stated that goat meat with lower ultimate pH has also lower shear force. Therefore, all the factors that affect the value and the fall of the pH in the post-mortem and that were reported previously can influence the meat

shear force. Therefore, in general terms, the meat from goat, although generally acceptable (Webb 2014), tend to be less tender than that from sheep (Santos et al. 2008). In addition, another element that can explain the different shear force within small ruminants is that sheep have more soluble collagen than goat as reported by Tshabalala et al. (2003). In fact, an important element that increases the shear force is the solubility rather than the quantity of collagen (Hopkins et al. 2013; Santos- Silva and Vaz Portugal 2001; Starkey et al. 2017).

Collagen is the most important protein of the muscular connective tissue, and it is little influenced by the breed. With the increase in age of the animal, its concentration in the muscle changes little, while its insolubility increases due to the increase in the number of cross-links between its molecules (Young and Dobbie 1994; Berge et al. 2003). Young and Dobbie (1994) found a positive strong correlation between the age of sheep and the insolubility of the collagen ($r = 0.72$). In addition, sex has an influence on collagen. Testosterone increases the deposit and the insolubility of collagen in muscle (40% more crosslinks between molecules in the muscle of rams than wethers; McCormick 2009). Gökdal et al. (2010) showed a much lower collagen content in the meat of castrated in comparison to that of intact males. Therefore, even sex can influence the shear force of meat and not only because of the different solubility of the collagen, but also because females present a higher content of subcutaneous and intramuscular fat than males, as they are more precocious (Horcada-Ibáñez et al. 2009).

Indeed, Starkey et al. (2017) found that the male lamb's meat had higher shear force than of female's even if adjusted for the collagen solubility. Ablikim et al. (2016) found a high negative correlation between intramuscular fat and tenderness of meat ($r = -0.972$) in lamb. Considering the genetic selection in Australia, Anderson et al. (2015) showed that one percent of the increase in lean meat yield leads to a reduction of the 0.16% of the intramuscular fat. The other important aspect concerning the level of subcutaneous fat, as previously discussed, is that a higher level of subcutaneous fat, creating greater thermal insulation of carcasses, can reduce the incidence of "cold shortening" as hypothesized by Mazon et al. (2017). The effect of breed on the shear force is difficult to interpret, and often conflicting results have been found in the bibliography (Ekiz et al. 2010; Ivanovic et al. 2014; Lopes et al. 2014). The differences between breeds are probably to be found in the different fatness of carcasses and in the different content of insoluble collagen in meat (Ablikim et al. 2016). At the same time, the different nutritional level of small ruminants' diets can influence the meat shear force through the effect on the pH previously discussed, but also for the meat and carcass fat content, with animals subjected to higher energetic levels, which have a higher content of intramuscular and subcutaneous fat.

Considering the age at slaughter of lambs and goats, generally, the meat of younger animals is more tender, because of less insoluble collagen (Sañudo et al. 2007).

However, Teixeira et al. (2011b), increasing the slaughtering weight of young suckling animals showed a reduction of the shear force. This inconsistence could be due to the higher sensibility to stress to young animals, and to the low-fat cover of the carcasses of these animals. In addition, the length of the sarcomeres can modify the tenderness of the meat. In fact, Veiseth et al. (2004) reported that the sarcomere length is positively associated to tenderness if its length is lower than 2.0 μm, which is often the case of the muscles of lamb and goat (Lokman et al. 2017). The length of sarcomeres in small ruminants seems to be related to the type of muscle rather than to sex, breed or age at slaughter of animals (Solomon et al. 1981). However, Wheeler and Koohmaraie (1999) failed to detect an influence of sarcomere length on the extent of proteolysis in the longissimus and psoas major muscle of ovine. In general, it seems that the length of sarcomeres together with the collagen solubility are the most important determinant of the background of toughness in small ruminant meat (Veiseth et al. 2004).

The others determinants are the previously discussed intrinsic factors. On the other hand, an important extrinsic factor able to influence tenderness is the extent of proteolysis during the ageing time. Starkey et al. (2015) showed that the collagen content, sarcomere length and the post-mortem proteolysis explain about 40% of the variation in the final shear force in lamb. As previously discussed, the proteolysis post-mortem is highly influenced by the reduction of post-mortem pH, and the longer the ageing time, the higher the tenderness of meat (Guerrero et al. 2013; Teixeira et al. 2011a). Duckett (2001) reported a reduction of shear force of over 45% from 1 to 12 days of ageing. Therefore, the issue is to understand the duration of ideal ageing for a meat that can fulfill the expectations of the consumer. According to Guerrero et al. (2013), the appropriate ageing time depends on the muscle, i.e. four days for semitendinosus muscle and eight-sixteen days for gluteus biceps muscle, but, in general, four days is enough for lamb meat. Finally, even cooking meat can influence its tenderness, due to the physic-chemical changes that the muscle goes through. From 40 °C to 70 °C of heating there is the denaturation of actin and myosin, from 60 °C to 70 °C the denaturation of collagen, at around 70–75 °C the gelatinization and solubilization of collagen can be observed in lamb meat (Roldán et al. 2013; Yu et al. 2017). However, while collagen solubilization favors tenderness, protein denaturation has an opposite effect (Pathare and Roskilly 2016). Meat become more and more tougher, if the cooking temperature is higher than that of collagen gelification, because denatured proteins increase their aggregation and shrink the muscle fibers (Hillman 2003). Therefore, in order to

obtain tender meat, the appropriate cooking temperature should take into account the quantity and the solubility of meat collagen.

3.3.1.3 Color

One of the most widespread systems for the expression of meat color is the CIE Lab system (Commission International De l'Eclairage 1976). This system expresses the color through three parameters: L*, which defines the lightness and ranged between 0 (black) to 100 (white); a* redness, ranged between −a* (green) to +a* (red); and b* yellowness, ranged between −b* (blue) to +b* (yellow). Other parameters that derived from the last two principal ones, are hue (tan−1(b*/a*)), and chroma (a*2 + b*2)1/2. In general, in meat science and industry, b* is an indicator of the fat color (Ponnampalam et al. 2013). It is widely known that color, together with tenderness, is one of the most important characteristics of the meat driving the purchase intentions of consumers. In particular, consumers express a high level of satisfaction for meat that has a bright red bloom color (Howes et al. 2015). From an analytical point of view, it means that fresh lamb meat should have values higher than 9.5 for a* and 34 for L* to be considered acceptable by consumers, and these values should rise to 14.5 and 44 for a* and L*, respectively to satisfy 95% of the consumers (Khliji et al. 2010).

The factors that mainly influence small ruminant meat color are the meat pH, the amount and the chemical state of the muscle myoglobin, and the characteristics of the intramuscular fat of the meat. These factors contribute to explain the effect of sex, breeds, husbandry system, age at slaughter, and ageing time on the color of the meat of sheep and goat. In particular, meat color is highly related to the reduction of pH in the post-mortem. Indeed Teixeira et al. (2011b), in kids, found a negative significant correlation between ultimate pH and a* (r = −0.300), and ultimate pH and b* (r = −0.453) value, while the most desirable color is reached at a normal range of pH, from 5.5 to 5.8 as previously stated. Conversely, an ultimate pH higher than 6.0 favors the dark color of the meat because of the low level of myofibrils protein denaturation, and consequently the meat holds more water and reflects lower light, at the same time, a more reducing environment, created both by the reduction of oxygen penetration due to the low level of myofibrils degradation, and by a higher mitochondrial activity, favors the formation of deoxymyoglobin instead of oxymyo- globin and the meat appears darker (Adzitey and Nurul 2011; Li et al. 2014). Accordingly, Simela et al. (2004) showed that the color characteristics of goat meat is highly influenced by post-mortem pH.

Another important aspect is the fat content of meat; in particular, a higher level of intramuscular fat increases the colorimetric parameters of meat, since fat has a higher light

reflection than protein. Moreover, intramuscular fat can influence the oxygen penetration in meat, retarding the formation of metmyoglobin, and consequently it allows for the maintaining of appropriate color level of meat for a longer period (Swatland 1995). In addition, Calnan et al. (2017) demonstrated that an intramuscular fat increase from 2% to 8% increases L*, a* and b*, which consequently also influence hue and chroma values in lamb. On the other hand, the color of meat is also directly related to the myoglobin content of muscle. Indeed, myoglobin is a protein involved in oxygen storage and has an atom of Fe; this atom has a key role in the definition of the muscle color. In general, the higher the myoglobin content, the higher the content of iron, which makes the meat more reddish. In lamb, Komprda et al. (2012) found a significantly strong negative correlation between myoglobin concentration in muscle and L* ($r = -0.630$). The authors found a strong positive correlation between myoglobin and a* ($r = +0.840$). However, due to the presence of Fe, the oxidative status of myoglobin can change during storage. Basically, in the deep muscle, where the oxygen penetration is limited, the myoglobin is in the form of deoxymyoglobin, and the meat appears with a purple reddish color. After the exposure of the meat to air (because of the oxidation) myoglobin changes oxidative its status to oxymyoglobin and the color of meat becomes the more desirable bright red. If the oxidation is prolonged, the myoglobin becomes metmyoglobin with a brown color of meat. The conversion from deoxymyoglobin to metamyoglobin is accompanied by a reduction of L* and a* (Bjelanović et al. 2015).

These three forms of myoglobin are reversible in relation to the oxidative status of the meat and of the environment. The composition in the different types of muscle fibers can influence the color of the meat, not only for the effects previously described on the pH, but also for the different content of myoglobin; indeed, fast- glycolytic muscles show the lowest content of myoglobin with the highest L*, and the lowest a* values (Ithurralde et al. 2017). Conversely, muscles rich in Type I fibers show high a* values, and lower color stability because of their oxidative metabolism that favors the conversion of oxymyoglobin to metmyoglobulin (Joo et al. 2013). In general, the meat from males have higher L* values than that of females, both in young and older animals (Bonvillani et al. 2010; Vnučec et al. 2014; Yarali et al. 2014). The husbandry system is probably one of the most important factors affecting the color parameters of sheep and goat. Indeed, young suck- ling animals produce a meat that can be classified as pale red (Bonvillani et al. 2010) because of the low level of iron in milk and, consequently, the low level of myoglobin in muscle. This color is highly desirable by consumers (Miguélez et al. 2008).

Moreover, the nutritional level of an animals' diet can influence the L* values; higher nutritional levels allow the animals to deposit more intramuscular fat (Karaca et al. 2016). Animals reared on pasture show higher a* and b* values than those reared indoors and fed concentrate; physical activity favors the synthesis of myoglobin, increases a* values and carotenoids deposition in fat, naturally present in fresh herbage, which causes a more yellow color of the meat (Howes et al. 2015). The effect of breed on the color of the meat from small ruminants seems small and highly variable. Some authors found differences between genotypes (Kuchtík et al. 2012; Lopes et al. 2014), while others did not (Ivanovic et al. 2014; Kuchtík et al. 2011). These inconsistencies could be explained by the different ability to deposit myoglobin in muscles across breeds (De Lima Júnior et al. 2016). It is widely accepted both in sheep and goats that the increase in age or weight at slaughter increases a*, and, despite a possible increase in fat deposition, reduce L* value (Alexandre et al. 2009; Guerrero et al. 2013; Peña et al. 2009). The reason is probably due to the higher level of myoglobin in the muscle of older animals (Sañudo et al. 2007). During 7 days of ageing, the color of sheep and goat meat change with a decrease in a* value, due to the conversion of oxymyoglobin to metmyoglobin (Sañudo et al. 2007), and an increase in b* value (Cetin et al. 2012).

The evolution of color during ageing is influenced by electric stimulation of carcasses. Despite a muscle-dependent effect, the electric stimulation, in general, improves the color of the meat of small ruminants (Adeyemi and Sazili 2014). Cetin et al. (2012) showed that electric stimulation, even at different voltages, increased L* and a*, and decreased the b* value compared to non-electrically stimulated lamb and goat carcasses during ageing, with an influence on color stability. Moreover, the stability of meat color can also be influenced by vitamin E and, to a lesser extent, by the unsaturated fatty acids concentration in muscle (Ponnampalam et al. 2012). Indeed, vitamin E, which can be increased in the diet of the animals through con- centrate or the use of pasture, is an antioxidant, and therefore can delay the formation of metmyoglobin from oxymioglobin. Bjelanović et al. (2015) observed higher color stability in the meat of sheep that have a higher level of vitamin E in muscle; the same authors reported that a level of around 3 μg α-tocopherol/g meat is able to increase the color stability of meat. On the other hand, high levels of unsaturated fatty acids in meat, which can be quantified by a concentration of C18:3n-3 acid around 3 g/100 g of total lipids increases the oxidation potential of the meat raising the conversion of oxymyoglobin to metmyoglobin (Howes et al. 2015). In general, goat meat appears darker than sheep meat because of the

possible differences in the ultimate pH, and because of the lower intramuscular fat content (Rodríguez et al. 2014; Webb et al. 2005).

3.3.1.4 *Water Holding Capacity*

Water holding capacity (WHC) is defined as "the ability of meat to hold all or part of its own water" (Honikel 1987). WHC is often assessed through drip loss, that is the water that is lost by meat as a consequence of gravity force (Fisher 2007), and/ or cooking loss, which is the amount of water that is lost by meat during cooking due to shrinkage of meat, and including both volatile and drippings losses (Honikel 2004). WHC and cooking loss are closely related. Ablikim et al. (2016) showed a strong negative correlation between WHC and cooking loss ($r = -0.894$). WHC is important from the consumer point of view, because cooking temperature influences the perception of juiciness, so higher WHC favors higher perception of juiciness (Warner 2017) also in meat from small ruminants (Webb 2014). Generally, the meat of small ruminants has cooking loss values falling within the range 14–41% (Ayeb et al. 2016), while in suckling-lambs a normal range is considered 15–24% (Miguélez et al. 2008). Considering the factors that can influence WHC, Sañudo et al. (2007) reported that 80% of the WHC variability is explained by the ultimate pH and by the reduction of pH during post-mortem. Therefore, the WHC is closely related to the rate and extent of the proteolysis post-mortem, and consequently to the protein degradation and to the fragmentation and shrinkage of the myofibrils. In other words, once proteins are degraded their ability to retain water is reduced. If the pH reached the isoelectric point of the myofibril protein (around 5.1), the WHC is reduced to a minimum (Keeton et al. 2014).
Li et al. (2014) reported a relationship between WHC and L* value. While less important than those previously discussed, other factors that are able to modify the WHC is the meat composition in terms of protein and fat. Indeed, WHC is favored by an increase in the protein content of meat, because proteins can bind with water (Das et al. 2008). In addition, Çelik and Yilmaz (2010) argue that proteins can bind with water at a level of around 10% of the muscle weight. Considering the fat content of meat, Frank et al. (2016) reviewed that increasing the intramuscular fat of beef from 5% to 22%, the water content decreased, but, at the same time, the cooking loss also decreased. Lopes et al. (2014) explained that intramuscular fat can alter muscular structure, allowing for the retention of higher levels of water, giving physical protection against muscle dehydration. Although Webb et al. (2005) reviewed that the goat meat has a high level of cooking loss (35%), Santos et al. (2008), considering suckling lambs and kids, found a higher cooking loss value in lamb than kids (14.3% vs. 11.1%). The different

muscle fiber types have a role in WHC of meat of sheep and goat; De Lima Júnior et al. (2016) explained that fast contracting muscles have lower WHC than slow contracting muscles, while Ablikim et al. (2016) showed higher WHC values in sopraspinatus muscle than longissimus dorsi muscle. The effect of breed on WHC or on cooking loss is highly variable both in sheep and in goat (Freitas et al. 2011; Ivanovic et al. 2014; Kuchtík et al. 2012; Popova and Marinova 2013) probably because of the different ultimate pH or the decrease in the pH post-mortem also related to the different carcass fatness, or to a different meat composition in terms of protein and intramuscular fat levels.

While Çelik and Yilmaz (2010) and Mazon et al. (2017) have not found differences between sexes, the post-mortem pH can have a role for explaining the lower WHC found by Bonvillani et al. (2010) in females than in male young animals. Also, the effect of the husbandry system on the capacity of the meat to retain water is unclear, Santos-Silva et al. (2002) showed that lambs kept on pasture had higher WHC than those fed with concentrate. Conversely, Popova and Marinova (2013) and Rajkumar et al. (2010) did not detect differences between husbandry systems in lamb and kids respectively. The variability of these results could be due to the different ultimate pH or the different reduction of the pH post-mortem related to the different nutritional level of the animals' diets. The effect of weight at slaughter on WHC is also unclear, Santos-Silva and Vaz Portugal (2001) showed, as the WHC of the meat of lambs increased from 16 to 35 kg of slaughter weight. Conversely, Bonvillani et al. (2010) and Peña et al. (2009) have not found an effect on it, but in these studies the differences between experimental groups in terms of slaughter weight were very limited. An increase of the intramuscular fat content might have a role in explaining these results. Considering ageing time, the WHC decreases and the drip loss increases from 1 to 7 days of ageing both in sheep and goats (Cetin et al. 2012), Lokman et al. (2017) found an increase in drip loss from 1 to 7 days of ageing in goats. These results can be explained by the reduced capacity of the muscle to retain water as a consequence of the extent of myofibrils proteolysis. The electrical stimulation of the carcasses can also increase the drip loss from 1 to 7 days of ageing both in sheep and goats, and the effect is higher when increasing the voltage from 50 to 250 volts (Cetin et al. 2012). Similarly to tenderness, the cooking temperature can influence the WHC of meat because of the muscle proteins shrinkage.

3.3.2 *Chemical and Nutritional Characteristics*

3.3.2.1 Protein

As shown in Table 6 and in Table 7, the protein content of goat and sheep meat is rather similar and ranged between 17% to 23%. Also, Sen et al. (2004) have not found differences between the meat of sheep and goat in the protein content. Conversely, Tshabalala et al. (2003) found higher protein content in goat than in sheep meat. However, when considering the other constituents of meat as well, the protein content had differences around 8%. In general, in lamb, the protein of muscle is composed of about 50% from myofibrillar protein, the remaining part is com- posed of stromal (collagen, elastin, and reticulin) and sarcoplasmatic (hemoglobin, myoglobin, and enzymes) protein (Asghar and Yeates 1979). Within the constituents of the meat, protein seems to be subjected to lower variations. Indeed, many authors fail to detect an effect of the husbandry system on the protein content of meat from both sheep and goat (Das et al. 2008; Rodríguez et al. 2014; Romero- Bernal et al. 2017).

Conversely, Karaca et al. (2016) showed that lambs reared with concentrate had a higher protein level in meat compared to those kept on pasture. The higher physical activity of grazing animals can influence the muscle metabolism, increasing the protein synthesis compared to protein breakdown, and therefore increasing the protein deposition in muscle (Atherton and Smith 2012; Díaz et al. 2002). This effect can be confounded by the fact that the amount and the quality of protein intake, in terms of essential amino acids concentration and ruminal by-pass proportion, can have a role in small ruminants for the growth and for the deposition of protein in carcasses and meat (Khalid et al. 2012). Indeed, Lopes et al. (2014) observed a reduction of muscle protein in goat feed restricted at 50% of ad libitum intake. However, Beauchemin et al. (1995) argue that increasing the protein content of lamb's diet over 15% DM does not increase the carcass leanness. On the other hand, the effect of spatial and temporal variability of pastures and their nutritional value, especially if natural or semi-natural is consumed by animals, is huge (Bovolenta et al. 2008), making the interpretation of the results of the bibliography even more difficult. The effect of genotype is rather variable, while Bjelanović et al. (2015) and Ivanovic et al. (2014) found an effect of genotype on meat protein; other authors did not (Komprda et al. 2012; Kuchtík et al. 2012).

Table 6. Sheep meat quality

Breed	Sex	Feed	Muscle	LW (kg)	pH	WBSF (N)	Color			Proximate composition (%)			Fatty acid composition (% FA)			Reference
							L*	a*	b*	Protein	Fat	ash	CLA	SFA	UFA	
Sarda	Fe/Ma	M	Mix[l]	9.6–9.5						22.9–22.7	2.5–2.8	1.2	1.5	61.1–61.9	38.0–38.9	Nudda et al. (2013)
Churra		M	Ld	5.4–5.9[k]	5.61–5.65[c]	42.5–45.6[c]	46.7–48.5[c, m]	6.8–7.7[c, m]	5.7–6.3[c, m]		1.8–1.9[j]					Osorio et al. (2008)
Spanish breeds		M	Ld	11	5.6[b]	19.8–16.2[b]					6.5–5.8[j]			63.5–68.5	31.5–35.2	Revilla et al. (2008)
Portuguese local	Fe/Ma	M	Ld	8.6–9.9	5.6[b]	88.3[f, g]	46.0[b]	16.5[b]	11.1[b]		2.1					Santos et al. (2008)
Churra, Castellana, Ojaleda	Fe/Ma	M	Lt, Ll	5.3[k]	5.62[g]	49.3[g]				20.2	2.0[j]	1.2		49.3	48.7	Miguélez et al. 2008
Slovak dairy	Fe/Ma	M/C/H	Ld	16.9–17.1	5.36–5.38[c]		40.3–41.3[c]	7.2–7.3[c]	7.9[c]	20.2–20.6	3.7–4.5		0.2–0.7	44.8–45.6	55.2–44.4	Margetín et al. (2013, 2014)
Norwegian White	Fe	P-C/Si	Lt, Ll	30.4–33.1[k]	5.55–5.61[b]	52.4–54.6[d, h]				21.4–21.6	3.9–3.4			48.3–50.9	49.1–51.7	Bjelanović et al. (2015)
Norwegian White		P	Lt, Ll	17.1[k]	5.64[b]	40.1[d, h]				20.6	2.6			48.8	51.2	Bjelanović et al. (2015)
Pramenka	Fe	P	Lt, Ll	25.0–27.3[k]	5.75[b]	38.9–47.4[d, h]				17.1–20.5	7.4–7.5			50.2–53.3	46.7–49.7	Bjelanović et al. (2015)
Pramenka		P	Lt, Ll	16.0[k]	5.75[b]	31.8[d, h]				20.6	2.4			45.4	54.6	Bjelanović et al. (2015)
Norduz	Ma	P – C/H	Ld	40.7–54.8	5.94–6.15[b]		34.5–38.7[b, m]	20.4–21.5[b, m]	5.3–6.7 [b, m]	18.9–21.0	1.7–3.2	0.8–0.9		48.1–51.8	41.9–50.2	Karaca et al. (2016)

Table 6. (*continued*)

Breed	sex	Feed	Muscle	LW (kg)	pH	WBSF (N)	Color			Proximate composition (%)			Fatty acid composition (% FA)			Reference
							L*	a*	b*	Protein	Fat	ash	CLA	SFA	UFA	
Wrzosówka	Ma	C/H/S	Ld	20.3–20.5	6.0–6.24[b]		54.0–53.9[c]	16.2–16.6[c]	4.6–6.1[c]	19.4–19.6	2.1–2.9	1.1	0.6–1.6	48.0–48.2	51.8–52.0	Kawęcka et al. (2018)
Tsigai		P	Lt, Ll	29–42	5.38–5.78[c]	15.8–90.4[d]	36.0–44.5[c]	5.8–9.1[c]	5.9–10.0[c]	20.1–21.3	1.0–3.2					Polák et al. (2013)
Limousine	Ma	P	Lt, Ll	35.2–35.3			35.3–36.1[b, n]	14.0–14.2[b, n]	7.8–8.4[b, n]				1.6	46.0–47.2	50.6–51.6	Prache et al. (2011)
Suffolk crossing	Fe/Ma	C/H	Ld	38–42	5.65–5.72[b]	41.6–47.1[d]	43.7–45.1[d]	9.5–9.9[d]	10.0–12.4[d]	19.8–19.9	2.6–2.8[j]	1.1	0.7–1.0	45.9–47.1	52.9–54.1	Ringdorfer et al. (2015)
Puerto Rico Crossbreed	Ma	C/H/P--H/P	Ld	20.1–21.5	6.02–5.66[a]		50.4-1.7[a]	10.9-4.1[a]	9.9-10.9[a]	16.2–19.3	4.7-5.6					Rodríguez et al. (2014)
Local Indian breed	Fe	C/H	Ld	28.5	5.46[b]	36.7[b, h]				21.0	8.5					Sen et al. (2004)
Dorper	Ca		Ld	21.6[k]						21.4[i]	19.4[i]	0.8[i]		52.8	47.2	Tshabalala et al. (2003)
Damara	Ca		Ld	18.7[k]						22.5[i]	20.4[i]	0.8[i]		51.8	48.2	Tshabalala et al. (2003)
Zwartbles		P	Qf	38.1	5.68[b]		48.4[b, m]	8.5[b, m]	12.5[b, m]	19.0	0.2[j]	1.1				Komprda et al. (2012)
Suffolk		P	Qf	38.8	5.69[b]		47.2[b, m]	8.6[b, m]	12.1[b, m]	18.9	0.3[j]	1.1				Komprda et al. (2012)
Oxford down		P	Qf	36.3	5.74[b]		50.1[b, m]	9.2[b, m]	13.4[b, m]	18.9	0.3[j]	1.1				Komprda et al. (2012)
Awassi crossing	Ma	C/S	Ld	51.2–62.2	5.89–5.59[d]	14.6–22.6[d, h]	36.6–41.0[d]	5.31–5.57[d]	10.5–12.9[d]							Abdullah et al. (2011)

Table 6. (*continued*)

Breed	Sex	Feed	Muscle	LW (kg)		pH	WBSF (N)	Color			Proximate composition (%)			Fatty acid composition (% FA)			Reference
								L*	a*	b*	Protein	Fat	ash	CLA	SFA	UFA	
Awassi	Ma	C/S	Ld	43.9	5.58[d]	19.9[d, h]	43.6[d]	5.4[d]	12.6[d]							Abdullah et al. (2011)	
Herik	Ma	C/H	Ld	42	5.52[b]	33.0[f, h]	42.2[b]	20.0[b]	8.47[b]	22.2	3.0	1.0				Uğurlu et al. (2017)	
Texel	Ma	C/Si	Ld	35	5.58–5.70[b]	50.1–57.7[b]	41.1–42.9[b, m]	12.7–13.7[b, m]	8.1–5.8[b, m]	18.8–22.0	3.0–4.0	3.3–3.8	0.2	41.5–43.5	58.5–56.5	De Almeida Rego et al. (2017)	
Santa Inês	Ma	C/H	Ll	36.6	5.5[b]					24.0–26.6	2.1–2.2	0.8–1.0		42.0–42.3	57.3–57.9	Costa et al. (2015)	
Dorper × Santa Inês	Ma	C/H	Ll	35.5	5.5[b]					25.3–26.2	3.6–3.8	1.0–1.2		42.1–42.6	55.9–57.7	Costa et al. (2015)	
Comisana × Valle del Belice	Ma	C/H	Ld	35.6–37.1	5.72–5.86[b]	75.2–88.7[f]				22.3–23.3	1.2–1.3	1.4	0.9–1.0	39.1–40.4	59.6–60.3	Lanza et al. (2011)	
Dorper × Santa Inês	Ma/Ca	C/H	Ld	46.6–52.3	5.6[b]	31.3–36.3[b]	32.8–33.3[b]	16.4[b]	14.8[b]				0.2–0.3	40.4–40.8	59.6–59.2	Mazon et al. (2017)	
Suffolk	Ma	P/H--P/C	Ld	50						20.3–23.5	2.4–3.4	1.2		50.5–53.0	47.0–49.5	Romero-Bernal et al. (2017)	
Kivircik	Fe/Ma	C/H	Ld	33.0	5.57–5.67[b]	16.6[b, h]	42.2–39.6[b]	17.9–18.6[b]	−1.4–1.2[b]				0.2	40.9–42.1	57.9–58.1	Yarali et al. (2014)	
Charolaise × Romanov	Ma	P	Qf	31.8	5.63[b]		46.6[b, m]	8.3[b, m]	11.8[b, m]	18.6	1.8[j]	1.1		47.5	52.5	Kuchtík et al. (2012)	
Suffolk × Romanov	Ma	P	Qf	31.2	5.77[b]		48.2[b, m]	7.7[b, m]	12.3[b, m]	18.2	1.3[j]	1.1		47.5	52.5	Kuchtík et al. (2012)	

Table 6. (*continued*)

Breed	Sex	Feed	Muscle	LW (kg)		pH	WBSF (N)	Color			Proximate composition (%)			Fatty acid composition (% FA)			Reference
								L*	a*	b*	Protein	Fat	ash	CLA	SFA	UFA	
Merino	Ma	C/S	Ld	25		5.83[b]		38.7[b]	11.5[b]	3.38[b]	18.3	2.7	1.8	0.4	43.0	57.0	Manso et al. (2009)

LW slaughter weight, *WBSF* Warner Bratzler Shear Force, *CLA* conjugated linoleic acids, *SFA* saturated fatty acids, *UFA* unsaturated fatty acids, *Ma* male, *Fe* female, *Ca* castrated, *FA* total fatty acids, *C* concentrate, *H* hay, *M* milk, *P* pasture, *S* straw, *F* forage, *Si* silage, *Ld longissimus dorsi muscle*, *Ll longissimus lumborum muscle*, *Lt longissimus thoracis muscle*, *Qf quadriceps femoris muscle*, Se *semitendinosus muscle*, *Leg* Leg muscles

[a]0 h [b]24 h [c]48 h [d]7 d [e]8 d [f]72 h

[g]58–62 h from slaughter

[h]WBSF (N/cmq)

[i]Muscle and subcutaneous fat mixed

[j]Intramuscular fat

[k]Carcass weight

[l]Mix of *semitendinosus muscle*, *semimembranosus muscle*, *femoral biceps muscle*

[m]CIE, D65,10°

[n]CIE, D65,2°

[o]subcoutaneous fat

Table 7. Goat meat quality

Breed	Sex	Feed	Muscle	LW (kg)	pH	WBSF (N)	Color			Proximate composition (%)			Fatty acid composition (% FA)			Reference
							L*	a*	b*	Protein	Fat	ash	CLA	SFA	UFA	
Criollo Cordobes	Ma/Fe	M	Ld	11.1–11.3	5.72–5.73[b]	44.8–63.3[d, e]	39.5–42.7[d, j]	10.6–11.8[d, j]	15.5–15.6[d,j]		0.9–1.2[h]		0.8–1.0	41.1	58.9	Bonvillani et al. (2010)
Criollio Cordobes	Ma	M/P	Lt, Ll	10.4–11.7	5.72–5.75[b]	66.1–59.7[b, e]	42.5–42.9[b, j]	10.5–10.8[b, j]	15.2–15.7[b,j]				0.9–1.1	40.1–41.9	57.6–58.6	Peña et al. (2009)
Anglonubian	Ma	M/P	Lt, Ll	10.2–11.3	5.71–5.74[b]	77.8–80.7[b,e]	47.1–48.8[b, j]	8.2–9.3[b, j]	15.7–16.2[b,j]				0.7–0.8	37.6–37.9	61.1–61.4	Peña et al. (2009)
Serrana Transmontana	Fe/Ma	M	Ld	7.2–14.2	5.8–5.9[b]	57.9–76.5[b]	43.6–49.0[b]	9.5–13.8[b]	9.3–10.0[b]							Teixeira et al. (2011b)
Gokceada	Ma	M/C/H	Ld	9.4	5.79[b]	62.8[d]	46.5[a]	8.0[a]	2.1[a]							Ekiz et al. (2010)
Maltese	Ma	M/C/H	Ld	14.5	5.75[b]	58.9[d]	44.3[a]	9.1[a]	1.4[a]							Ekiz et al. (2010)
Bravia	Fe/Ma	M/P	Lt, Ll,Gb	7.9–9.2	5.67[b]	89.2–92.1[c, e]	48.7–49.1[b]	16.4[b]	5.7–5.9[b]					50.3	47.8	Santos et al. (2007)
Serrana	Fe/Ma	M/P	Lt, Ll, Gb	10.7–11.7	5.88[b]	85.3–96.0[c, e]	48.2–49.9[b]	16.4[b]	5.2–5.8[b]					52.6	46.9	Santos et al. (2007)
French Alpine	Ma	M/C/ H/P	Qf	13.8	5.78[b]					19.4	1.7	1.1		49.3	50.7	Brzostowski et al. (2008)
Boer crossbreeds	Ma	M/C/ H/P	Qf	14.9	5.70[b]					19.7	2.0	1.1		48.1	51.8	Brzostowski et al. (2008)
Boer	Ca		Ld	14.0[i]						22.8[g]	10.5[g]	0.95[g]		54.7	45.3	Tshabalala et al. (2003)
S. African local	Ca		Ld	11.0[i]						24.3[g]	7.9[g]	0.97[g]		53.6	46.4	Tshabalala et al. (2003)
Ethiopian local										20.1	12.6	1.19				Sebsibe (2008)

Table 7. (*continued*)

Breed	Sex	Feed	Muscle	LW (kg)	pH	WBSF (N)	Color			Proximate composition (%)			Fatty acid composition (% FA)			Reference
							L*	a*	b*	Protein	Fat	ash	CLA	SFA	UFA	
Creole	Ma	H/P	Ld	20.2–21.3	5.70–6.40[b]		43.4–44.7[b]	15.5–17.3[b]	5.8–5.7[b]	19.8–20.5						Alexandre et al. (2009)
Boer crossing	Ca	P	Ll	25.9–29.4						22.3–25.6	0.7–1.0[h]	4.6		43.8–45.0[f]	54.0–55.7[f]	Turner et al. (2015)
Meriz		C/S	Leg	23.7–26.2						16.9–17.0		0.9				Mayi and Alkass (2010)
Black		C/S	Leg	37.5–40.8						16.8–17.4		0.9				Mayi and Alkass (2010)
Boer × Saanen	Fe/Ma	C/H	Ld	25.6–25.7						20.4–20.7	1.5–1.6	0.9	0.2–0.4	37.0–37.1	63.0	De Oliveira Maia et al. (2012)
Sirohi	Ma	C/H-P/C/H	Lt	24.5–32.6	5.53–5.87[a]					17.6–19.4	5.4–9.3	1.1–1.4				Rajkumar et al. (2010)
Puerto Rico Crossbreed	Ma	C/H/P-H/P	Ld	17.9–20.5	5.59–5.94[a]		34.0–38.2[a]	14.7-16.2[a]	9.7-10.3[a]	17.8–19.3	3.1–3.9					Rodríguez et al. (2014)
Local Indian	Fe	C/H	Ld	20.5	5.48[b]	72.8[b, e]				20.4	3.2					Sen et al. (2004)
Saanen × Boer	Ma	C/H	Ld	30.5		65.8[b]				21.6	1.3	1.0				Freitas et al. (2011)
Saanen	Ma	C/H	Ld	29.5		47.9[b]				21.9	1.5	1.1				Freitas et al. (2011)
Canindé	Ma	C/H	Ll	26.5		25.6[b, e]	24.5[b, j]	9.4[b,j]	8.3[b,j]	17.1	2.6	4.7		52.3	42.1	Lopes et al. (2014)
Moxotó	Ma	C/H	Ll	23.5		27.1[b, e]	24.7[b, j]	10.5[b, j]	8.9[b, j]	17.8	2.2	4.8		54.2	40.6	Lopes et al. (2014)
Boer crossbreeds	Ma	C/H	Ll	33.5		24.9[b, e]	24.9[b, j]	9.3[b, j]	7.2[b, j]	16.7	1.6	5.0		51.5	40.4	Lopes et al. (2014)

LW slaughter weight, *WBSF* Warner Bratzler Shear Force, *CLA* conjugated linoleic acids, *SFA* saturated fatty acids, *UFA* unsaturated fatty acids, *Ma* male, *Fe* female, *Ca* castrated, *FA* total fatty acids, *C* concentrate, *H* hay, *M* milk, *P* pasture, *S* straw, *Ld longissimus dorsi muscle*, *Ll longissimus lumborum muscle*, *Lt longissimus thoracis muscle*, *Qf quadriceps femoris muscle*, *GB gluteobiceps muscle*, *Leg* leg muscles

[a]0 h

[b]24 h

[c]6/7 d

[d]72 h from slaughter

[e]WBSF (N/cmq) [f]Expressed as % of fat

[g]Muscle and subcutaneous fat mixed

[h]Intramuscular fat

[i]Cold carcass weight

[j]CIE, D65,10°

In general, animals with higher aptitude to meat production or selected for growth rate can present higher content of protein in meat by increasing the efficiency of protein metabolism (Oddy et al. 1995; Rauw 2012). Sex has little effect on meat protein (Gashu et al. 2017; Margetín et al. 2013; Nudda et al. 2013). Pérez et al. (2012) showed that by increasing the slaughter weight from 10 to 15 kg, the protein content and moisture of muscle decrease, while fat considerably increases. Indeed, in sheep, the percentage of protein deposition decreased, increas- ing the carcass weight, but this trend is particularly evident from 14 to 22 months of age (Ponnampalam et al. 2008). It is known that the meat of small ruminants has a high biological value, expressed as the proportion of protein that is absorbed by the intestine and deposited in human tissues, and therefore it is related to the presence of essential amino acids (Table 8). Indeed, Webb et al. (2005) reported a biological value for goat meat and beef of 60.4% and 68.6% respectively. Löest et al. (1997), taking into account six different studies, clearly showed how the concentration of essential amino acids in lamb muscle is very similar, and even higher than those in beef.

Table 8. Essential amino acid composition (%) of *longissimus dorsi* muscle of sheep and goat

Amino acid	Sheep[a]	Goat[b]
Arginine	6.7	5.7
Histidine	2.9	3.1
Isoleucine	4.5	4.4
Leucine	8.0	7.8
Lysine	8.5	8.1
Methionine	2.7	2.8
Phenylalanine	4.0	4.0
Threonine	4.2	4.9
Valine	5.2	4.6
Tryptophan	3.5	1.0

[a]Average values of males from Brzostowski and Tański (2006), Crăciun et al. (2012), and Löest et al. (1997).
[b]Average values from adult female from Webb et al. (2005) and Ivanovic et al. (2014).

Krishtafovich et al. (2016) explained that 100 g of lamb meat can provide from 13.6% to 50.3% of the required essential amino acids for humans. Webb et al. (2005) reported that 100 g of goat meat can completely satisfy the human daily requirements of alanine, leucine, lysine, threonine,

and valine. The same authors reported that lamb and chevon meat have a content of thiamine and riboflavine even higher than beef. Moreover, the genotype can slightly influence the percentage of essential amino acids in goat and lamb meat (Brzostowski et al. 2008; Brzostowski and Tański 2006), and adult sheep, in comparison to lamb, has lower concentration of isoleucine, treonine, valine and methionine, but a higher concentration of tryptophan (Crăciun et al. 2012). In the meat of small ruminants, some compounds are considered bioactive, such as taurine, carnosine, coenzyme Q, creatine, and creatinine, which have a beneficial role for human health, reducing oxidative stress and regulating the energetic metabolism of muscles (Pauselli et al. 2014). Purchas et al. (2004) reported mean values of 31.0, 491.1, 1.71, 346, 5.90 mg/100 g for taurine, carnosine, coenzyme Q, creatine, and creatinine, respectively in the *longissimus lumborum* muscle and values of 108.7, 356.7, 1.07, 335, 4.69 mg/100 g for taurine, carnosine, coenzyme Q, creatine, and creatinine, respectively in semitendinosus muscle of lamb, with the content of taurine even much higher than that reported in the s*emitendinosus* muscle of cattle.

3.3.2.2 *Fat*

The consumer identifies the quality of the meat not only with tenderness and color, but also with the fat content, which is appreciated when in moderate quantity (Joo et al. 2013). It is well known that the amount of intramuscular fat, not only has nutritional implications related to the type of fatty acids, but is also linked to tenderness, juiciness and flavour of meat (Frank et al. 2016). Kim et al. (2014) reviewed that the juiciness of the meat is related mainly to cooking temperature and to intramuscular fat level. Several studies have tried to reveal the ideal level of the intramuscular fat in small ruminant meat for the consumer. Santos et al. (2008) reported a value of 2–3%, while Hopkins et al. (2006) stated that it should be at least 5%. Although Webb et al. (2005) reported intramuscular content up to 21.2% in the Boer breed, the intramuscular fat content of goat usually ranges between 0.6–2.6% (Casey et al. 2003). Conversely, Pannier et al. (2014b) showed that the intramuscular fat of lamb ranged between 1.5–9.5% with a carcass weight from 12.8 to 40 kg. Suckling animals tend to have lower intramuscular fat content in comparison to older animals (Tables 6 and 7). Moreover, it is widely accepted that meat from goat is leaner than that from sheep. Indeed, goats store fat around the internal organs rather than intramuscularly, and therefore, it deposits intramuscular fat later than sheep (Casey and Webb 2010; Sen et al. 2004).

As reported by Rajkumar et al. (2010), in the meat of small ruminants, the higher the fat, the lower the water content. As previously reported, the concentration of intramuscular fat can

influence physical characteristics of meat to a different extent, and depends on many factors. Females, being more precocious, deposit more fat than males at the same body weight (Horcada-Ibáñez et al. 2009). Similarly, the difference between breeds can be related to the different precocity or to the different aptitude for meat production. Animals with higher aptitude to produce meat or those selected for meat production have lower intramuscular fat content because of a higher percentage of muscle fibers, or because of a modification in the activity or expression of enzymes and genes involved in the fat synthesis (De Lima Júnior et al. 2016). As reported by Joo et al. (2013), the intramuscular fat content is closely related to the percentage of type I fibers because of the oxidative metabolism of these fibers. The higher the weight at slaughter, the higher the intramuscular fat content (Santos-Silva and Vaz Portugal 2001), Miguélez et al. (2008) found a positive correlation between carcass weight and intramuscular fat content. However, Ivanovic et al. (2016) reported that the nutritional level of the animal diets is one of the most important factors that affect the intramuscular fat content of sheep meat. As shown by Karaca et al. (2016), the higher the nutritional level of the diet, the higher the deposition of intramuscular fat. However, from the nutritional point of view, not only the amount of fat is important, but also its composition in terms of fatty acids (FA). A possible distinction of FA can be made on the basis of the num- ber of double bonds in the carbon chain; if there is no double chain, one, or more than one, the FA are called saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) respectively.

The FA present in the reserve tissues derive essentially from diet or tissue synthesis. A concentrate consisting of corn and soybean meal contains linoleic (C18:2n-6) and oleic acid (C18:1n-9) for over 60–70% of total FA, while in herbage 50–75% of total FA is α-linolenic acid (C18:3n-3) (Elgersma 2015). In the rumen, unsaturated fatty acids (UFA) from the diet undergo bio-hydrogenation by microorganisms. This bio-hydrogenation leads mainly to the formation of stearic acid (C18:0) as final product. At the same time, several intermediate compounds are formed, among which the most important are vaccenic acid (trans-11 C18:1) and rumenic acid, which is an isomer of C18:2 (conjugated linoleic acid, cis-9, trans- 11), but also several other C18:2 isomers that are CLA (conjugated linoleic acid): trans-10, cis-12 CLA and trans-9, and cis-11 CLA are formed. Interestingly, cis-9 and trans-11 represents more than half of the CLA in the meat of ruminants (Juárez et al. 2011). As reported by Scollan et al. (2003), the bio-hydrogenation of C18:2n-6 and C18:3n-3 regards more of 70% and 85% of the total, respectively. Therefore, the by-pass FA, the intermediate and final products of ruminal bio-hydrogenation can be found in the meat of ruminants. However, the FA in intramuscular fat can

also be derived from endogenous synthesis. The endogenous synthesis has acetic acid as main precursor, which is derived from the synthesis of the ruminal microorganisms. From acetic acid and through the action of different enzymes, such as acetyl-CoA carboxylase alpha and fatty acid synthase, it is possible to lengthen the carbon chain up to palmitic acid (C16:0) (Ladeira et al. 2016).

The chain can then be further elongated and/or desaturated for the formation of oleic acid (C18:1n-9) and palmitoleic acid (C16:1n-9), due to the action of the stearoyl-CoA desaturase enzyme. This enzyme is also responsible for the tissue production of CLA from trans-11 C18:1 which derives from the ruminal biohydrogenation of dietary FA (Ladeira et al. 2016). The main fatty acids present in the meat of sheep and goat are C18:1n-9, C16:0 and C18:0 (Prache et al. 2011; Turner et al. 2015). Although low in quantity (around 2% of the total of FA, Vasta et al. 2009), the meat of small ruminants also contains odd branched-chain fatty acids that are present in the membrane of the ruminal bacteria (Vlaeminck et al. 2006). From a nutritional point of view, meat fat has a controversial role. De Andrade et al. (2016) showed how the fat level is the main negative consumer perception towards the nutritional characteristics of sheep meat. In effect, in humans the high intake of dietary fat can lead to some diseases such as an increase in cardiovascular risk or the reduction of the sensitivity to insulin.

Therefore, EFSA (2017) proposed an appropriate daily fat intake from 20% to 35% of total energy. However, from this point of view, the intramuscular fat con- tents of sheep and particularly that of goat meat are rather low, as previously reported. Pannier et al. (2014b) considered over 5500 samples of lamb meat and found that less than 45% had an intramuscular fat level higher than 4%. However, within fat, not all the different categories of FA have the same effect on human health. SFA can be synthesized by humans, and can favor cardiovascular diseases. For this reason, EFSA (2017) suggests reducing as much as possible the intake of SFA as well as the intake of trans FA that are not necessary for humans. In sheep and goat meat SFA range between 40–49% and 37–44% of total FA respectively. However, C18:0 which is considered to have very little involvement in cardiovascular disease (McAfee et al. 2010), ranges between 11–27% and 13–16% of total FA in sheep and goat meat respectively. Conversely, PUFA seems to have a positive effect on human health. In particular, C18:2n-6 (linoleic acid) is considered essential because the human body is not able to synthesize it, and it favors the reduction of blood low-density lipoprotein and cholesterol; therefore, an appropriate intake was set at 4% of the daily energy intake (EFSA 2017).

Even C18:3n-3 is essential for humans, and has a positive role for human health because it reduces the risk of cardiovascular disease, and an appropriate intake was set at 0.5% of the daily energy intake (EFSA 2017). In sheep meat the level of PUFAn-6, C18:2n-6, PUFAn-3, C18:3n-3 ranges between 5–15%, 3–14%, 0.8–4% and 0.3–3% of total FA, respectively, while in goat meat the level of PUFAn-6, C18:2n-6, PUFAn-3, C18:3n-3 ranges between 11–18%, 5–10%, 4–6%, 1.3–1.8% of total FA, respectively. Moreover, the long chain PUFA (eicosapentaenoic acid, C20:5n-3, docosahexaenoic acid, C22:6n-3), which derive from the desaturation and elongation of C18:3n-3, have a positive role in the reduction of blood triacylglycerol concentrations, vasodilatation, and inflammatory response. An appropriate daily intake of C20:5n-3 plus C22:6n-3 was set at 250 mg (EFSA 2017). It is interesting to note that, as reported by McAfee et al. (2010), the conversion of C18:3n-3 into long chain PUFAn-3 is rather inefficient in humans. These FA are also present in the meat of small ruminants; the sum of C20:5n-3 and C22:6n-3 ranges between 0.4–1.5% and 1.3–2.8% of total FA in sheep and goats, respectively (Bonvillani et al. 2010; De Oliveira Maia et al. 2012; Kawęcka et al. 2018; Kuchtík et al. 2012; Lanza et al. 2011; Margetín et al. 2014; Miguélez et al. 2008; Peña et al. 2009; Prache et al. 2011; Ringdorfer et al. 2015; Turner et al. 2015; Yarali et al. 2014).

While EFSA (2017) has not set an indication for daily intake, CLA seems to have a beneficial effect on the immune function, and have an anti-carcinogenic action in humans (McAfee et al. 2010).

Within meats of different species, small ruminants show the highest level of CLA (Pauselli et al. 2014), ranging between 0.2–1.6% of total FA (Tables 6.6 and 6.7). Cholesterol intake is usually closely linked to the intake of SFA (EFSA 2017). In the meat of small ruminants, the cholesterol concentration ranges between 49–91 mg/g of meat (Miguélez et al. 2008; Pauselli et al. 2014; Peña et al. 2009). However, Freitas et al. (2011) reported that meat from goats has lower cholesterol, 40 mg/100 g, than that of sheep, 62 mg/100 g, and cattle, 70 mg/100 g. Ivanovic et al. (2016) reported a cholesterol level of 63.8 mg/100 g, 76.0 mg/100 g, 73.1 mg/100 g, 73.1 mg/100 g, 78.2 mg/100 g in the meat of goat, chicken, beef, pork and lamb, respectively. The possibility of modifying the acid profile of ruminant meat to make it more beneficial to human health is a topic that has been debated many times in the past. As previously reported, from this point of view, the diet of the animal is certainly one of the main factors (Ivanovic et al. 2016; Piasentier et al. 2002a).

However, in general, the levels of C16:0 and C18:1n-9, which are among the most important FA of small ruminant meat display a small variation (Yarali et al. 2014). As previously reported,

the high levels of C18:3n-3 of the grass allow for a greater ruminal by-pass of this FA that can then deposit at intramuscular fat level in higher concentrations compared to animals fed with concentrates (Noci et al. 2005). The high level of C18:3n-3, as precursor, also increases the long-chain PUFAn-3 level (Juárez et al. 2011). Moreover, as reported by Juárez et al. (2011), the higher intake of C18:3n-3 favors and influences the formation of many intermediates of bio-hydrogenation of FA such as trans-11 C18:1. On the contrary, a diet rich in concentrates increases the formation of other intermediates of bio-hydrogenation of FA such as trans-10 C18:1. As suggested by Costa et al. (2015), the effect of diet on the FA composition of meat is further complicated considering that diets with high levels of concentrate can reduce ruminal pH, and therefore modify the different bacterial populations with effects on the rate and extent of ruminal bio-hydrogenation. Furthermore, because a different floristic composition of ingested pasture involves a different grass FA composition, a different presence of secondary plant metabolites can affect the metabolism of ruminal bacteria (Elgersma 2015; Prache et al. 2011). The effect of breed on the FA profile of meat of small ruminants is quite variable in both lamb and goat (Costa et al. 2015; Komprda et al. 2012; Kuchtík et al. 2012; Santos et al. 2007) probably due to different precociousness of the animals, which, with the same weight, deposit different levels of fat. In fact, the fattest animals have a higher ratio of neutral lipids/phospholipids since the neutral lipids, rich in saturated fatty acids, are the main constituents of fat reserves, while the phospholipids, rich in PUFA, are mainly present in cell membranes (De Smet et al. 2004). Moreover, the difference between breeds may be due to a different expression and/or activity of the stearoyl enzyme CoA desaturase (Kuchtík et al. 2012). The effect of sex on meat FA seems rather limited, and discordant results are present in scientific studies. For instance, Bonvillani et al. (2010) found only few differences between sexes whereas De la Vega et al. (2013) showed that males had higher SFA and lower MUFA than females. Never (2015) reviewed that castrated had higher levels of PUFA in fat than intact goat males. In addition, the age at slaughter is important for the FA profile of small ruminant meat. In fact, the FA of suckling goat and lamb is linked to the FA of the mother's milk, considering that the rumen of these animals does not work properly (Manso et al. 2011; Vicenti et al. 2004). Indeed, Radzik-Rant et al. (2012), comparing the meat of suckling lamb to that of early-weaned lamb, showed that the suckling lambs had higher levels of C12:0, that derives from mammary gland synthesis, C18:3n-3, C18:2n-6 and PUFA, and lower levels of CLA. In weaned animals, as reviewed by De Lima Júnior et al. (2016), by increasing the weight at slaughter, an increase in MUFA and a reduction in PUFA is observed probably due to increased fat deposited, or

increased activity of ruminal microorganisms (Margetín et al. 2014). Accordingly, Mazon et al. (2017) found an increase in MUFA, and a reduction of PUFA in the fat of animals slaughtered at 26.0 kg of carcass weight over those slaughtered at 20.6 kg of carcass weight. Moreover, Werdi Pratiwi et al. (2004) observed that, in Boer goats, C18:1n-9 increased, while C18:0 decreased, as slaughter weight increases. Miguélez et al. (2008) found a positive correlation between carcass weight of suckling lamb and C18:0. Moreover, they found a negative correlation between carcass weight and PUFA, and branched-chain FA, failing to detect higher ruminal bacterial activity increasing the weight of animals. In general, the FA profile of meat of suckling goat is different of that of suckling lamb. As previously stated, in suckling animals the FA profile of meat is related to the FA profile of the milk (Morgante et al. 2007; Piasentier et al. 2005). From this point of view, the milk of goat has higher levels of SFA, but lower levels of MUFA and PUFA than that of sheep (Markiewick-Kęszycka et al. 2013). Horcada et al. (2014) showed that suckling kids had lower PUFA level than suckling lamb. In the meat of older animals, Webb et al. (2005) reported that the sum of C18:0 and unsaturated FA, which are defined as desirable FA, ranged between 61–80% in goat and lower in lamb and mutton, 63–71%.

3.3.2.3 Minerals and vitamins

Red meat is considered an important source of minerals and vitamins for human nutrition with particular regards to iron, selenium, zinc, and vitamins mainly those of the B group (Ivanovic et al. 2016). As reported by McAfee et al. (2010), iron is a constituent of hemoglobin and therefore is fundamental for the oxygen transport in tissues, and iron-deficiency anemia is considered one of the most important nutri- tional deficiencies in humans. The meat from small ruminants is particularly rich in iron; the content of iron is 0.8–4.0 mg/100 g in lamb, 2.2–4.3 mg/100 g in mutton (Ono et al. 1984; Pannier et al. 2014a; Williams et al. 2007), and 3.2–4.4 mg/100 g in goat (Correa 2011; Webb et al. 2005). Conversely, values of iron content of 0.7– 1.5 mg/100 g, 1.2–2.9 mg/100 g, 2.7 mg/100 g, and 1.5 mg/100 g were reported in veal, beef, pork and chicken meat, respectively (Correa 2011; Williams et al. 2007). From a nutritional point of view, as reported by Pourkhalili et al. (2013) heme iron has more nutritional importance than the total amount because the heme iron has a higher bioavailability than the non-heme iron (15–35% vs. 2–20%).

Regarding the iron content in small ruminant meat, Pourkhalili et al. (2013) showed that the 65.7% of the iron in lamb muscle is heme iron. Considering the same variable, Beal et al. (2017) reviewed a value of 72% for lamb and mutton, 65% for cattle, 26% for chicken and 39% for pork meat. These data clearly showed how the meat from small ruminants is important for the

iron intake in the human diet. The meat of small ruminants is also a relevant source of selenium, which is important because it has a role in immunity, in many metabolic pathways and is a co-factor of enzymes that have antioxidant activity (Pauselli et al. 2014). Williams et al. (2007) reported a concentration of 10–20 μg/100 g, similar between lamb and beef. Pauselli et al. (2014) reported a level of 14 μg/100 g in lamb and of 17 μg/100 g in beef. Conversely, few data are available for goat meat (Osman and Mahgoub 2012). However, it is well known that the concentration of selenium in the meat of ruminants is related to the presence of this element in pasture or in concentrates. Zinc is involved in the protein synthesis of the body and many other metabolic functions. It has a role in immunity and it is essential for the neurobehavioral development of the individual (Pauselli et al. 2014). The concentration of zinc in lamb and mutton meat is about 2.9–5.5 mg/100 g according to Williams et al. (2007) and 1.2–4.5 mg/100 g according to Pannier et al. (2014a). Similar values were also reported in goat meat (3.5–4.6 mg/100 g, Ivanovic et al. 2014; Webb et al. 2005). Moreover, 100 g lean lamb meat is able to meet 25%, 21%, 31% of the recom- mended dietary intake for human of iron, selenium and zinc respectively (Williams et al. 2007). The meat of small ruminants is an important source of vitamins, especially those of group B. Cyanocobalamin (vitamin B12) is synthesized by ruminal microorganisms and then deposited in the tissues and organs. For this reason, the meat from ruminants is a very important source of vitamin B12 for the human diet. In the animal, the greatest reserve of this vitamin is found in the liver, about 60%, followed by the muscle, about 30%. Moreover, the ruminal synthesis is linked to the presence of cobalt in the animal's diet and therefore can vary according to the type of pasture (Ortigues-Marty et al. 2005).

Vitamin B12 has a key role in nervous system function, red blood cells synthesis and FA metabolism (Pauselli et al. 2014). In the meat of lamb and mutton the vita- min B12 content is about 1.7–2.8 μg/100 g (Williams et al. 2007); slightly lower values were reported by Johnson et al. (1995) in broiled goat meat, 1.1–1.2 μg/100 g. Conversely, the meat of pork and poultry have a much lower content of this vitamin, 0.7 μg/100 g and 0.4 μg/100 g respectively (Pauselli et al. 2014). Small ruminant meat is also a source of thiamine (vitamin B1), riboflavin (vitamin B2), and niacin (vitamin B3). The meat of lamb and mutton contain 0.09–0.16 mg/100 g, 0.19–0.25 mg/100 g, 8.0–11.2 mg/100 g of vitamin B1, B2, and B3 respectively (Williams et al. 2007); while the goat meat contains 0.10 mg/100 g, 0.56 mg/100 g, 3.6 mg/100 g of vitamin B1, B2, and B3 respectively (Devendra 1988). On average, the meat of small ruminants is rather similar to beef for these vitamins (Webb et al. 2005). Moreover, 100 g lean lamb meat is able to meet

the 71%, 8%, 15%, and 70% of the recommended dietary intake for humans of vitamin B12, B1, B2 and B3 respec- tively (Williams et al. 2007).

3.4 Conclusions

The husbandry of sheep and goat is widespread worldwide, and mainly in developing countries where there will be the greatest growth of the world population in the next years. From this point of view, the rearing of sheep and goat has tremendous potentiality, and the meat from these small ruminants can be an important resource for satisfying the growing demand of products of animal origin. Moreover, sheep and goat are not competitive with humans for food, can exploit forage of low nutritional value and marginal areas, and are particularly resilient and adaptable to the environment, which is an interesting characteristic in light of possible future scenarios of climate change. These animals have carcasses with highly variable characteristics and, consequently, from this point of view, have wide margins for improvement through genetic selection. The meats have characteristics that can meet the expectations of a consumer who is ever more aware of the health and nutraceutical aspects of food. Indeed, the meat from small ruminants is an important source of protein of high biologic value and contains some compounds that are considered bioactive such as taurine, carnosine, coenzyme Q, creatine, and creatinine. The meat fat is present at modest levels and is rich in essential fatty acids such as α-linolenic and, within the meats of different species, small ruminants show the higher levels of conjugated linoleic acids thanks to the frequent use of pasture. Moreover, these meats are an important source of minerals and vitamins with particular regards to iron, which is also highly available for humans, and Vitamin B12, which is synthesized by ruminal bacteria. The meat of small ruminants, however, and especially that of goat and that derived from heavy animals, is little known in developed countries. While in wide areas of developing countries the consumption of these meats is mainly local and suitable trade structures are lacking, and an appropriate system of goat carcass grading is not yet available.

4. Influence of dietary cardoon meal on volatile compounds and flavour in lamb meat

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Influence of dietary cardoon meal on volatile compounds and flavour in lamb meat

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ABSTRACT

Cardoon meal is a by-product retained after oil extraction from the seeds of cultivated *Cynara cardunculus* var. *altilis* that has been proposed as a valuable resource for animal feeding. The study aimed to assess the influence of its dietary inclusion on volatile profile and flavour of meat and kidney fat from lambs. Fifteen Sarda × Comisana male lambs were randomly divided in two groups and fed for 75 days with a concentrate-based diet containing 15% cardoon meal (CMD, $n = 7$) or dehydrated alfalfa (CON, $n = 8$). Cardoon meal inclusion reduced the "barnyard/animal" odour perceived by a trained panel in kidney fat, which could be associated with the aromatic compound *p*-cresol (4-methylphenol), detected only in CON diet. Considering the other aroma volatiles regarded as the main contributors for the characteristic lamb flavour, both diets were characterized by moderate to low levels of 4-methyloctanoic acid, skatole and indole while 4-methylnonanoic acid and 4-ethyloctanoic acid were not detected.

4.1. Introduction

The growing interest in the establishment of a circular economy model to reduce the production of industrial wastes, has led to investigations into innovative strategies for the valorization of by-products inevitably produced along the supply chains. Specifically, plant by-products represent an important human-inedible feed that could be a valuable resource for animal feeding. Furthermore, dietary utilization of plant by-products is a suitable approach for sustaining low-input and low-emission feeding strategies to mitigate the environmental impact of livestock production (Salami et al., 2019; Seidavi, Tavakoli, Rasouli, & Corazzin, 2018).

Cardoon meal is a by-product composed of partially defatted seed retained after oil extraction of cultivated cardoon (*Cynara cardunculus* var. *altilis*), a perennial crop originating in the

Mediterranean region (Genovese et al., 2016) that is of increasing interest and economic value for its multipurpose uses (Cabiddu et al., 2019). Cardoon meal has been proposed as an alternative feed resource for ruminants due to its valuable content of fiber, protein, amino acids, unsaturated fatty acids and bioactive compounds such as polyphenols, which could enhance animal feed efficiency in terms of crude protein utilization and ruminal biohydrogenation (Cabiddu et al., 2019; Genovese et al., 2016; Salami, Valenti et al., 2019).

It is well known that meat and meat products quality are considered to be essential in order to ensure consumer satisfaction (Font-i-Furnols & Guerrero, 2014) and odour and flavour are among the most important components of eating quality, having a key role in the overall meat acceptability (Borgogno, Corazzin, Saccà, Bovolenta, & Piasentier, 2015; Neethling, Hoffman, & Muller, 2016), especially for lamb meat (Cunha, Andrade, Aguiar, Ares, & Deliza, 2016). Lamb meat is characterized by a typical species-related flavour called "pastoral flavour" that may negatively affect consumers' liking (Sañudo et al., 2003; Young, Lane, Priolo, & Fraser, 2003). Pastoral flavour is described as "animal", "barnyard", "fecal", "sheepy" and "milky" and is mainly related to animal diet (Priolo, Micol, & Agabriel, 2001; Young et al., 2003). Skatole (3-methylindole) and indole, which derive from ruminal degradation of tryptophan, and *p*-cresol (4-methylphenol), are compounds that have been detected in the adipose tissue of lamb and are thought to be partly responsible for the unpleasant pastoral flavour (Watkins et al., 2014). In addition to pastoral flavour, lamb meat has a characteristic "mutton flavour", mainly associated with animal age, that could be problematic for some consumers who find the flavour unpleasant, resulting in lower acceptance of lamb meat (Watkins et al., 2010; Young et al., 2003). Mutton flavour has been largely associated with the presence of a range of fatty acids in sheep fat, mainly branched chain fatty acids (BCFA; C8-C10). In particular, 4-methyloctanoic (4-MOA), 4-ethyloctanoic (4-EOA) and 4-methylnonanoic acids (4-MNA), that are more abundant in adipose tissue of aged animals, are considered as the main contributors to the characteristic aroma (Watkins et al., 2010; Wong, Johnson, & Nixon, 1975).

In a recent study (Salami, Valenti et al., 2019), the influence of cardoon meal on fatty acid profile and on oxidative stability of lamb meat was investigated. The present contribution aims to investigate the effect of dietary supplementation with cardoon meal on lamb meat flavour in order to achieve more complete understanding of the influence of this feedstuff on meat quality. The complex nature of meat flavour requires an investigation of the essential flavour-active compounds isolated both from adipose tissue and lean meat and their joint contribution to perceived flavour.

Moreover, to our knowledge, no information has been published regarding the effect of cardoon meal on volatile compounds and flavour of lamb meat. Therefore, the present study investigated the flavour quality and flavour components in both meat and fat depots, (i.e. kidney fat) from lambs fed with cardoon meal.

4.2. Materials and methods

Experimental design, animals and diets

The experimental design and treatments have been described by Salami, Valenti et al. (2019). In brief, the lambs were raised in the experimental farm of the University of Catania and the experimental protocol was approved by the ethics committee of the same University (FIR-2014-PI/LB/Di3A) and complies with the European Union legislation for the protection of animals used for scientific purpose (2010/63/EU Directive). Fifteen Sarda x Comisana male lambs of 75 d of age and an average weight of 19.6 ± 2.0 kg were randomly divided in two experimental groups. After 9 days of adaptation, lambs were fed with the experimental diets for 75 d pre-slaughter. The control group (CON, n = 8) received a concentrate-based diet formulated with barley (48%), wheat bran (23%), soybean meal (10%), molasses (2.0%), vitamin premix (2.0%) and dehydrated alfalfa (15%). The cardoon meal group (CMD, n = 7) received a diet in which the cardoon meal completely substituted the dehydrated alfalfa (15% of dietary dry matter, DM) comprised in the CON group. The main chemical components of the cardoon meal, namely crude protein, ether extract and neutral detergent fibre, were 18.2, 7.99 and 45.46% of dietary DM respectively (data not tabulated), and it was characterized by a total phenolic content of 60.4 GAE/kg DM. The experimental diets (Table 1) were supplied in form of pellets and animal had *ad libitum* access to feeds and water.

Table 1. Main chemical components of control diet (CON) and cardoon meal diet (CMD).

Parameter	Experimental diet	
	CON	**CMD**
Crude protein, % DM	15.7	16.5
Ether extract, % DM	2.68	3.84
Total phenolic content[1]	5.21	13.1
Fatty acids (mg/g DM)		
C16:0	4.36	5.06
C18:0	0.45	0.71
C18:1 *n*-9	3.86	5.36
C18:2 *n*-6	12.2	16.9
C18:3 *n*-3	1.26	1.07

[1] In grams of gallic acid equivalents/kg DM

Slaughter and sampling

At the end of the experimental period, lambs were slaughtered by exsanguination following captive bolt stunning. Kidney fat sample (~10 g) was immediately collected, vacuum packaged and frozen at -30 °C. Carcasses were chilled overnight and then *longissimus thoracis et lumborum* muscle (LTL) was collected, vacuum packaged and aged for 5 days at 4 °C. After this period, it was frozen at -30 °C until analysis.

SMart Nose® analysis of meat samples

The analyses were carried out by the SMart Nose® 1.51, LDZ, CH-2074 (Marin-Epagnier, Switzerland), based on mass spectrometry. The SMart Nose system was equipped with a Combi Pal autosampler CTC Analytics AG (CTC Combi Pal with the Cycle Composer software), a high-sensitivity quadrupole mass spectrometer (Inficon AG) with a mass detection ranging from 1 to 200 amu. Following the method described by Rapisarda et al. (2013), a direct mass spectrometry analysis of the headspace of solid samples was performed, without separation of the individual, organic volatile components. Briefly, a sample (10 g) of vacuum packaged meat was thawed in a cold-water bath for 15 min and then cooked in a conventional ventilated oven at 200 °C to a core temperature of 70 °C (approximately 5 min). A sub-sample (4 g) of cooked

meat sample was placed into a 20-mL vial (adapted for Combi Pal autosampler), closed with a silicone/PTFE septum and a magnetic cap and incubated for 30 min at 60 °C. A duplicate sub-sample was also treated similarly. An aliquot of 2.5 mL of the headspace was extracted using a gas-tight syringe and transferred into the mass spectrometer. For the headspace injection, the syringe temperature was set at 100 °C and the injector temperature at 160 °C. Nitrogen was used as purge gas, to avoid any memory effect, with a purge flow of 200 mL/min. SMart Nose analysis operated in electron ionization (EI) mode at 70 eV, with a mass spectrometer scan speed of 0.5 microscan/s, mass range of 10-160 amu, and scanning electron microscope voltage at 1160 V. The total acquisition time was fixed at 170 s, three cycles per injection were measured.

Sensory analysis

Ten panelists, six males and four females, ranging in age between 22 and 55 years, carried out the Quantitative Descriptive Analysis (QDA) of lamb LTL muscle samples and an olfactory evaluation of kidney fat samples. Eight preliminary sessions were performed to train the assessors to recognize basic tastes (sweet, sour, salty, bitter, umami) and other aromas in cooked meat. During the preliminary sessions, assessors selected 26 attributes to describe cooked lamb meat that led them to select common terms to describe their perceptions: two related to appearance (color, juiciness), seven for odour (orthonasal smell), seven for aromas (retronasal perception) (sheepy, milky, metallic, barnyard/animal, liver, toasted, anomalous), five attributes for basic tastes, and five attributes for texture (toughness, initial juiciness, final juiciness, chewiness, fibrosity). Similarly, the panel identified six attributes for fat odour (sheepy, sweety, rancid, barnyard/animal, pungent, anomalous). Meat and fat samples were thawed at 4 °C overnight for 24 h before each session. Meat samples, trimmed from the visible fat, were cut into pieces of equal size (~20 g) before being cooked. The cooking was done in a convection oven with humidity control (Self Cooking Center® 61, Rational AG, Landsberg, DE), until an internal temperature of 70 °C was reached (taking approximately 5 min), with temperature monitoring by thermocouple. Fat samples were cut in pieces of equal size (~5 g), placed in individual ceramic pots and melted in a microwave oven (800 W, Samsung M746) for 2 min. Immediately before the olfactory evaluation, the melted fat was reheated for 30 s to maximize odorants perception. Panelists were asked to score each sensory attribute, using a linear unstructured scale (0 = absence of the sensation; 10 = sensation extremely intense). Meat and fat samples from the two treatments were coded using a three-digit number and assessed

by the panel immediately after cooking or melting, following a randomized and balanced order. Assessors tasted meat samples in individual testing booths under incandescent white light, while fat samples were evaluated under red light to hide yellow and white shades in order to avoid the stimulus error. Between the samples, a 1-min inter-stimulus interval was maintained in order to let assessors clean their mouths using tap water. The panel evaluated meat and fat samples in two sessions per day (morning and afternoon) to avoid sensory fatigue. This sensory evaluation procedure was repeated four times in four different days (four replicas). The evaluations were performed in the sensory laboratory of the University of Udine, established according to the UNI-ISO 8589:1990 standard. All data was collected using Fizz Acquisition Software (2.47 B, Biosystemes, Couternon, France).

Volatile compounds analysis of muscle

The extraction of volatile compounds (VOC) was performed following the method described by Gkarane et al. (2018) and Vasta et al. (2012) with some modifications. LTL muscle sample, still frozen, was trimmed from visible fat and cooked in a conventional oven set at 200 °C to reach at the centre of the sample a temperature of 70 °C measured by a thermocouple. The cooked meat, added with equal amount of anhydrous sodium sulphate, was minced by a domestic blender and a portion (5 ± 0.05 g) of the mixture was placed in a 20-mL glass vial and sealed using a polytetrafluoroethylene (PTFE, Teflon®)/silicone septum and steel caps. To perform SPME analysis, samples were placed in a water bath set at 90 °C for 20 min equilibration prior to the insertion of the triphasic divinylbenzene/Carboxen®/polydimethylsiloxane (DVB/CAR/PDMS) SPME fibre, with 50/30 μm film thickness (Supelco, Bellafonte, PA, USA) to the headspace over the samples for 20 min at 90°. After adsorption, the fibre was withdrawn and inserted into the gas chromatograph (GC). Analysis of the volatile compounds was carried out using a Varian 3800 GC coupled to a Varian Saturn 2000 ion trap mass spectrometer (Varian Chromatography Systems, Walnut Creek, CA, U.S.A.). Volatile extraction, adsorption, and injection were performed manually. The injector, operated in splitless mode, was set at 250 °C and desorption time was 8 min. Helium was used as the carrier gas with a constant flow rate of 1.0 mL/min. Volatile compounds were separated using a ZB5-MS fused silica capillary column (30 m length x 0.25 mm id x 0.25 μm film thickness, Phenomenex, Cheshire, U.K.). The initial GC oven temperature was set at 40 °C for 5 min and then increased to 230 °C at a rate of 4 °C/min and held for 5 min, with a total acquisition program of 58 min. The GC interface was heated at 280 °C. The mass spectra of volatile compounds were generated by a MS equipped with an ion

trap (Polaris Q; Thermo-Finnigan, San Jose, CA); the acquisition was performed in EI mode (70 eV) at 10 microscan/s, scanning the mass range 33-230 amu. Compounds were identified by comparing the mass spectra to those found in the National Institute of Standards and Technology (NIST) Mass Spectral Library and confirmed by matching their linear retention indices (LRI) with Kondjoyan & Berdaguè (1996) and NIST Mass Spectral Data Center (Version 2.0g, 2011). Wherever possible, identities were confirmed by comparison of LRI values and mass spectra with those of authentic standards. The LRI were calculated by running saturated n-alkanes (C7-C30) under the same GC-MS conditions. The peak area of the volatile compounds was integrated from specific ions for each molecule to avoid overlapping between the compounds.

Volatile compounds analysis of kidney fat

The extraction of volatile compounds (VOC) was performed following the method described by Vasta et al. (2012) with some modifications. An aliquot (2 g) of frozen fat was finely sliced using a scalpel and transferred into a 10 mL vials sealed using a polytetrafluoroethylene (PTFE, Teflon®)/silicone septum and steel caps. To perform SPME analysis, samples were pre-heated at 90 °C for 20 min equilibration in a PAL RSI 85 autosampler (CTC Analytics AG, Switzerland) prior to the insertion of the triphasic DVB/CAR/PDMS SPME fibre, with 50/30 µm film thickness (Supelco, Bellafonte, PA, USA) to the headspace over the samples for 20 min at 90 °C. After adsorption, the fibre was withdrawn and inserted into the GC injector that was set at 255°C and desorption time was 4 min. The GC-MS analysis were performed with an Agilent Technologies 5977A MSD gas chromatograph (Santa Clara, CA, USA) and the volatile compounds were separated using a DB5-MS fused silica capillary column (30 m length x 0.25 mm id x 0.25 µm film thickness, Agilent Technologies, CA, USA). The initial GC oven temperature was set at 40 °C for 5 min and then increased to 230 °C at a rate of 3 °C/min and held for 5 min, with a total acquisition program of 75 min. The GC was operated in split mode with a split ratio of 10:1. The temperature of the source and of the quadrupole were 175 °C and 150 °C respectively, while the transfer line was held at 280 °C. The acquisition was performed in EI mode (70 eV) at 5 microscan/s, scanning the mass range 30-300 amu. Helium was used as the carrier gas with a constant flow rate of 1.0 mL/min. Compounds were identified by comparing the mass spectra to those found in the National Institute of Standards and Technology (NIST) 14 Mass Spectral Library and confirm by matching their linear retention indices (LRI) with Kondjoyan & Berdaguè (1996) and NIST Mass Spectral Data Center. The LRI were calculated by

running saturated n-alkanes (C7-C30) under the same GC-MS conditions. The peak area of the volatile compounds was integrated from specific ions for each molecule to avoid overlapping between the compounds.

Odour-active compounds of kidney fat

Short and medium branched-chain fatty acids (BCFA) analysis

BCFA of perirenal fat were analyzed according to the method proposed by Kaffarnik, Preuß, & Vetter (2014) with minor modifications. Before the GC-MS measurements, the fatty acids of samples were converted into the corresponding methyl esters. For this purpose, samples (~10 mg) were accurately weighed into a 10 mL tubes with screw cap and 0.5 mg of the internal standard (IS) 10-undecenoic acid (11:1 n-1), purchase from Sigma Aldrich (Milano, Italy), was added. It was followed by the addition of 3 mL of a methanolic solution with 1% sulfuric acid. The tubes were then sealed and heated for 2 h at 80 °C. After cooling, 1 mL aqueous saturated NaCl solution and 1 mL distilled water were added and the fatty acid methyl esters were extracted with 1 mL n-hexane via vigorous shaking. The n-hexane extract was diluted two fold to a final concentration suitable for the detection. GC-MS analyses were performed in EI mode (70 eV) with a 5977E MSD system (Agilent Technologies, USA) equipped with a 7683A autosampler and automatic split/splitless injector. Solutions (1 µL) were injected in splitless mode (split opened after 1.5 min) and separations were carried out on a Supelcowax-10 fused silica capillary column (30 m length, 0.25 mm internal diameter coated with 0.25 µm film thickness) (Supelco, Bellefonte, PA). The GC oven program was as follows: 10 min at 50 °C, 5 °C/min to 160 °C, 20 °C/min to 240 °C holding for 5 min. Helium was used as the carrier gas with a constant flow rate of 1.2 mL/min. The temperatures of the ion source and the quadrupole were set at 240 °C and 150 °C, respectively. GC-MS analyses in the full scan mode (*m/z* 50-350) were performed after a solvent delay of 4 min, with 3 microscan/s. The time event from 36.02 to 41.28 min allowed a better detection of BCFA and lighter molecules, avoiding the detection of more substantial peaks that came out from C16:0 onwards.

Compound identification was performed by comparison with mass spectra of the NIST 14 Mass Spectral Library and by comparison with linear retention indices (LRI) (Kondjoyan & Berdaguè, 1996) and by matching the results with those reported in the literature (Kaffarnik, Kayademir, Heid & Vetter, 2014; Kaffarnik, Preuß & Vetter, 2014; Young, Lane, Priolo, & Fraser, 2003). The LRI were calculated by previous injection of n-alkanes from 5 to 16 carbon atoms under the same GC-MS conditions.

Indole and skatole analysis

Indole and skatole (3-methylindole) content was measured according to the method proposed by Tuomola, Vahva, & Kallio (1996). An aliquot (2.5 g) of perirenal fat sample was homogenized in 10 mL of methanol together with 30 µL of 2-methylindole as internal standard by means of an Ultra Turrax. The homogenate was cooled for 30 min at -20 °C and then centrifugated at 4000 rcf for 10 min. The supernatant was filtered through a Sep-Pak C18 column and 2 mL of eluate collected in a vial. Two µL were injected onto an HPLC system (Shimadzu Corporation Kyoto, Japan) fitted with an SIL-20AHT autosampler and a fluorimetric detector (RF 20A XS), λ exitation 270 nm and λ emission 350 nm. Chromatographic separation was carried out in a Superspher 100 RP-18 (125 x 4mm i.d., particle size 4 um) column fitted with LiChrospher RP-18 precolumn (4 x 4 mm i.d., particle size 5 um). The column was eluted with a mobile phase consisting of water : acetonitrile (60:40, v/v) at flow rate of 1.0 mL/min and thermostated at 30 °C.

Data processing and statistical analysis

SMart Nose data acquisition and processing were carried out using a specific software provided by the SMart Nose system (SMart Nose 1.51) allowing the application of the multivariate analysis (SMart Nose 1.52, statistical software) on dataset. As described by Rapisarda et al. (2013), the most discriminant ions between the two groups of meat samples derived from the experimental diets were selected and used in the principal component analysis (PCA).
Statistical analysis of sensory data was performed using the statistical software PanelCheck (Nofima Mat & DTU -Informatics and Mathematical Modelling; Norway). The effect of cardoon meal on each descriptor was evaluated by ANOVA analysis that considered both product and assessor effect, assuming the latter as a random factor.
The effect of dietary treatment on chemical data was analyzed by SPSS statistical software SPSS ver.17 (SPSS Inc., Illinois), following a one-way ANOVA design, with individual lambs as experimental units. Significance was declared when $P \leq 0.05$.

4.3 Results and discussion

SMart Nose analysis of meat samples

The SMart Nose analysis simulates human olfaction and functions as a non-separative mechanism providing a global odour perception (Bhandare, Pendbhaje, & Narang, 2013). This

investigation was performed to obtain a volatile fingerprint screening of meat samples for a first comparison of the two treatment groups. The most discriminant ions produced by mass spectrometry of the volatile mixture of lamb meat headspace were used for generating a PCA plot (Fig. 1). Each lamb was scored twice, one for each meat replicate sample.

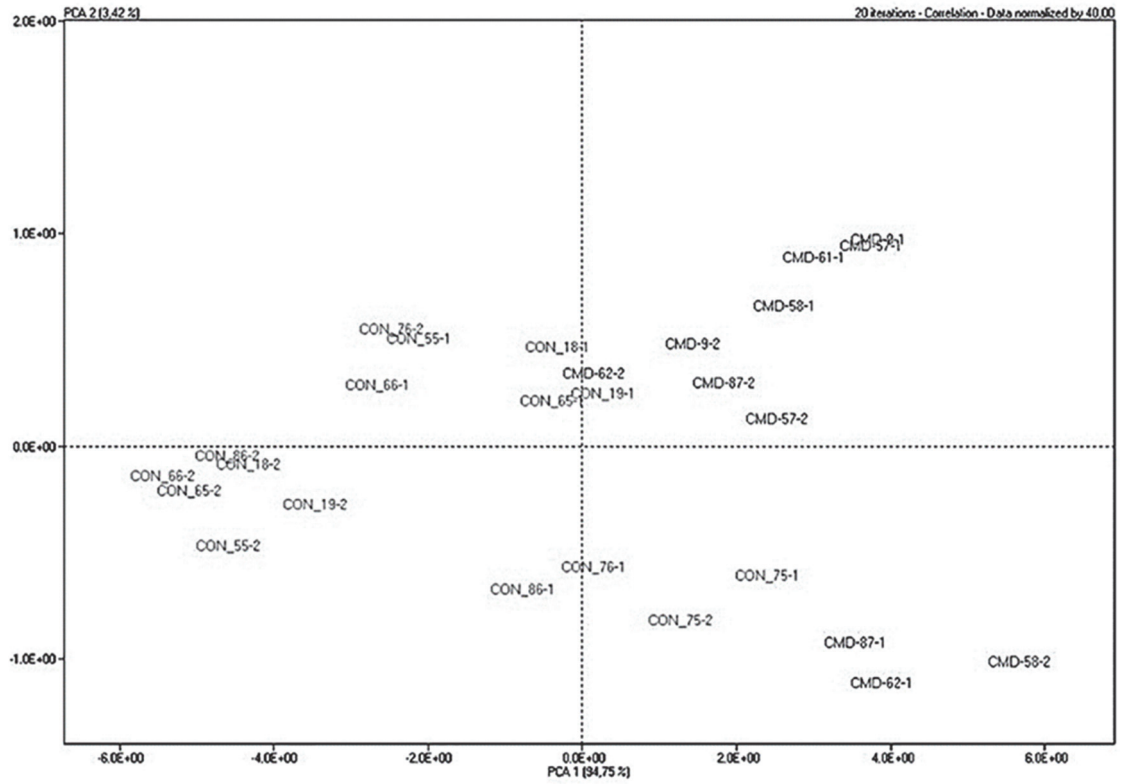

Figure 1. PCA from SMart Nose analysis of lamb meat samples. For each dietary treatment (CON = control diet;CMD = cardoon meal diet), sample are represented with lamb identification and replica number (1 and 2).

As expected, considering the bivalent design of the experiment, the main part of the total variability of lamb meat volatiles (94.75%) was explained by PCA1, along which lamb samples show a bimodal scattering. Indeed, the samples from CON-fed lambs were mainly located on the left of the plot while those from CMD-fed lambs were located on the right side, with a small overlapping around the origin of the PCA plane. The second principal component explained only 3.42% of the total variability. Taking into account the location of some sample replicates (e.g., samples CMD-58, CMD-62 and CMD-87), it may be considered as a within-sample variability, i.e. a measure of the error due to the analytical procedure mainly linked to the

nature of the sample. The results from SMart Nose suggest that some differences regarding meat odour perception and odorants occurred between groups, due to the substitution of alfalfa hay with cardoon meal.

Sensory analysis evaluation

To further investigate the sensory characteristics of meat, a Quantitative Descriptive Analysis (QDA) was performed. The flavour profile of LTL muscle from the two experimental diets is shown in Fig. 2. The trained assessors did not perceive considerable differences ($P > 0.05$) between treatments with respect to odour and flavour, the descriptors of which mostly overlapped. However, regarding taste assessment, samples from CON-fed lambs tended to have a higher "bitter taste" than lambs fed CMD ($P = 0.061$), a result probably attributable to alfalfa included in the former diet.

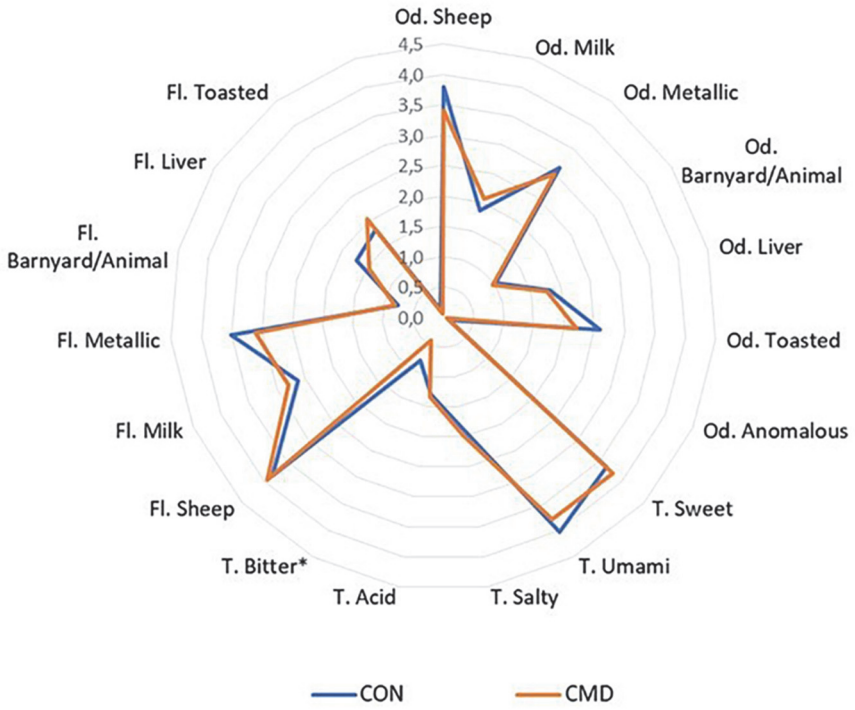

Figure 2. Sensory profile concerning odour (Od), taste (T) and flavour (Fl) attributes of meat from control-diet (CON; blue) and cardoon meal-diet (CMD; orange). * P = 0.06.

Several studies have been conducted to investigate the influence of dietary legumes on meat sensory characteristics with conflicting results. It has been reported that meat provided by lambs fed alfalfa pastures had more intense and unacceptable "foreign" sensory characteristics ("pungent" and "sickly") as compared to lambs fed on grass pasture (Park, Corbett, & Furnival, 1972) and these unpleasant flavours became more intense with the length of time of grazing alfalfa (Park, Ford, Minson & Baxter, 1975). More recently, Devincenzi, Prunier, Meteau, Nabinger, & Prache (2014) reported that raising the level of alfalfa supplementation of grazing lambs, resulted in an increasing intensity of "animal odour" in the lean part of the chop, as perceived by a trained sensory panel. Also Schreurs, Tavendale et al., (2007) found that undesirable meat flavors may be intensified by the legume component of the pasture. On the contrary, Frank et al. (2017) showed no negative effect on meat flavour from finishing lamb that grazed alfalfa or perennial ryegrass. De Brito et al. (2016), comparing the effect of different forage-types on lamb meat sensory attributes, found no sensory differences between treatments. However, this result was attributed to the short duration of the feeding period (49 days), deemed not sufficient for the necessary accumulation of flavor and aroma compounds.

QDA analysis included also the evaluation of meat appearance and texture. No significant differences ($P > 0.05$; data not tabulated) between treatments were found for the attributes assessed: color (4.3 ± 0.15; mean ± SEM), exudation (4.7 ± 0.16), firmness (2.8 ± 0.18), initial (5.0 ± 0.16) and final juiciness (3.2 ± 0.19), chewiness (4.7 ± 0.22) and fibrosity (3.0 ± 0.18).

In addition to the LTL muscle, a visceral fat depot was examined, namely perirenal or kidney fat, since it is well known that fat depots are the principal sources that contribute to the development of the eating quality of meat (Webb & O'Neill, 2008). Furthermore, some target odorants, i.e. BCFA, have been reported to vary less within the same treatment in perirenal fat than in other fat depots (Johnson, Wong, Birch, & Purchas et al., 1977).

Results of kidney fat olfactory evaluation are shown in Table 2. As expected, considering the species, and in accordance with the results for muscle (Fig. 2), kidney fat was mostly characterised by "sheep odour" since this attribute received numerically higher scorings compared to the other aromatic attributes while "anomalous odours" perception was negligible.

Table 2. Mean scores of odour descriptors for kidney fat from lambs fed control diet (CON) or cardoon meal diet (CMD).

Odour attributes	Dietary treatment		SEM	P-value
	CON	CMD		
Sheep	5.3	4.6	0.184	0.139
Sweet	2.8	3.6	0.186	0.084
Rancid	2.1	2.2	0.113	0.828
Barnyard/Animal	3.2	1.8	0.181	0.020
Pungent	2.1	1.6	0.169	0.350
Anomalous	0.5	0.5	0.128	0.979

The fat odour profiles differed significantly for the "barnyard/animal odour" attribute (P = 0.02) which was higher in CON-fed lambs. Barnyard/animal odour, a sensory attribute negatively considered by some consumers (Borgogno et al., 2015), is involved in the occurrence of the umbrella term "pastoral odour/flavour", that has been mainly related with animal's diet (Priolo, Micol, & Agabriel, 2001; Young et al., 2003). Several studies associated the occurrence of this odour descriptor in lamb fat depots with diets containing or based on ryegrass and legumes (Devincenzi, Prunier, Meteau, Nabinger, & Prache, 2014; Young et al., 2003; Young et al., 2006), alfalfa in particular (Devincenzi, Prunier, Meteau, & Prache, 2019; Duckett & Kuber, 2001). Fat provided by CMD-fed lambs scored higher in "sweet odour" (P = 0.08) than that from CON-fed lambs, a tendency that could be attributed to differences in the level of some volatile compounds with low odour threshold as well as to their interaction.

Profile of meat volatile compounds

In order to explain the findings of SMart Nose and QDA analysis, a headspace SPME-GC-MS analysis was performed, attempting to identify the volatile compounds responsible for the sensory differences between diets. The volatile profile of meat is presented in Table 3**.** A total of 71 volatile compounds were detected by SPME-GC-MS analysis: 32 aldehydes, 10 alcohols, 7 hydrocarbons, 5 ketones, 4 phenols, 3 sulfur compounds, 2 compounds within each class of lactones, terpenes, esters, and pyrazines and 1 compound within the classes of furans, thiazoles and indoles. The greater occurrence of aldehydes in comparison with other classes of volatile compounds is, in general, representative of volatile profile of ruminant meat (Larick & Turner, 1990) and could be related with a high level of concentrate-rate in the diet provided to lambs. Indeed, the aldehydes are mostly derived from the oxidation of the polyunsaturated fatty acids (PUFA) during cooking (Elmore, Mottram, Enser, & Wood, 2000) and their level tends to

increase with concentrate-based diets that are characterized by a high content of linoleic acid and low amounts of natural occurring antioxidants (Descalzo et al., 2005; Young, Berdagué, Viallon, Rousset-Akrim, & Theriez, 1997). Consistently with meat sensory evaluation, the substitution of alfalfa with cardoon meal at a rate of 15% DM of dietary treatment, had limited effect on meat volatiles. Within aldehydes, levels of 2-methylbutanal were higher ($P < 0.05$) in meat from CON-diet compared with CMD-diet. These volatile has been reported to originate from proteolysis and amino acid degradation of isoleucine and leucine (Estévez, Ventanas & Heinonen, 2011). Moreover, when present at a concentration above the perception threshold, an assumption not demonstrable by the qualitative assay provided by SPME analysis, it has been mainly associated with "malty" and "pungent" flavour (Madruga, Elmore, Dodson, & Mottram, 2009). Within hydrocarbons, octadecane was detected at a significantly higher level ($P < 0.05$) in meat from lamb fed CMD compared with lamb fed CON. Nevertheless, linear aliphatic hydrocarbons are reported to have high olfactory threshold value (Bianchi et al., 2007) and they poorly contribute to the flavour of meat.

Table 3. Meat volatile profile of lambs fed with control diet (CON) or cardoon meal diet (CON).

Volatile compounds	LRI[1]	Method of identification [2]		Dietary treatment [3]		SEM	P-value
				CON	CMD		
Aldehydes							
3-MethylButanal		Std		4.45	4.11	0.093	0.068
2-Methylbutanal		Std		4.26	3.94	0.082	0.047
Pentanal		Std		5.21	5.16	0.038	0.495
Hexanal	805	Std	+ LRI	6.11	6.11	0.029	0.986
(E)-2-Hexenal	853	Std	+ LRI	4.41	4.47	0.055	0.584
(Z)-2-Heptenal	898	Std	+ LRI	3.96	4.06	0.041	0.240
(Z)-4-Heptenal	898	Std	+ LRI	4.18	4.18	0.058	0.959
Heptanal	901	Std	+ LRI	5.81	5.78	0.036	0.700
Methional	906	Std	+ LRI	4.10	3.98	0.057	0.341
Benzaldehyde	960	Std	+ LRI	6.18	6.18	0.037	0.987
Octanal	1004	Std	+ LRI	6.06	6.09	0.042	0.725
(E,E)-2,4-Heptadienal	1011	Std	+ LRI	4.55	4.55	0.044	0.993
Benzeneacetaldehyde	1042	Std	+ LRI	4.76	4.80	0.059	0.735
(E)-2-Octenal	1058	Std	+ LRI	5.53	5.60	0.029	0.302
(E)-4-Nonenal	1096	MS		4.89	4.87	0.042	0.800
Nonanal	1107	Std	+ LRI	6.51	6.52	0.035	0.852
(E,Z)-2,6-Nonadienal	1152	Std	+ LRI	4.48	4.38	0.095	0.634
(E)-2-Nonenal	1161	Std	+ LRI	5.82	5.81	0.044	0.931
(Z)-4-Decenal	1197	MS	+ LRI	4.82	4.84	0.09	0.92
Decanal	1206	Std	+ LRI	5.31	5.32	0.032	0.832
(E,E)-2,4-Nonadienal	1215	MS	+ LRI	5.04	5.10	0.050	0.573

Table 3. (*continued*)

Volatile compounds	LRI[1]	Method of identification [2]		Dietary treatment[3]		SEM	P-value
				CON	CMD		
(E)-2-Decenal	1263	Std	+ LRI	5.88	5.98	0.074	0.524
Undecanal	1307	Std	+ LRI	4.95	4.94	0.060	0.924
(E,E)-2,4-Decadienal	1318	Std	+ LRI	5.50	5.59	0.041	0.280
2-Undecenal	1364	MS	+ LRI	5.66	5.71	0.048	0.636
Dodecanal	1409	Std	+ LRI	5.04	5.09	0.050	0.648
2,4-Dodecadienal	1421	MS		4.66	4.70	0.064	0.801
Benzaldehyde, 4-pentyl	1459	MS	+ LRI	4.70	4.72	0.059	0.884
Tridecanal	1511	MS	+ LRI	5.14	5.12	0.063	0.885
Tetradecanal	1613	MS	+ LRI	5.41	5.43	0.050	0.869
Pentadecanal	1715	MS	+ LRI	5.52	5.48	0.055	0.772
Hexadecanal	1817	MS	+ LRI	5.61	5.51	0.049	0.316
Ketones							
2-Heptanone	890	Std	+ LRI	4.82	4.79	0.042	0.785
1-Octen-3-one	977	MS	+ LRI	4.65	4.78	0.042	0.118
2,3-Octanedione	987	MS	+ LRI	5.57	5.53	0.048	0.710
2-Nonanone	1091	Std	+ LRI	4.06	4.07	0.040	0.852
Alcohols							
1-Pentanol	758	Std	+ LRI	5.11	5.05	0.043	0.575
1-Hexanol	872	Std	+ LRI	4.97	4.89	0.044	0.417
1-Heptanol	973	Std	+ LRI	5.42	5.45	0.054	0.781
1-Octen-3-ol	982	Std	+ LRI	5.80	5.81	0.032	0.943
4-Ethylcyclohexanol	1036	MS		4.17	4.25	0.051	0.416
(E)-2-Octen-1-ol	1069	Std	+ LRI	5.05	5.16	0.047	0.292
1-Octanol	1073	Std	+ LRI	5.75	5.78	0.045	0.809
2-Ethyl-1-hexanol	1028	Std	+ LRI	4.27	4.38	0.146	0.729
α-Terpineol	1194	Std	+ LRI	4.49	4.53	0.034	0.616
1-Pentadecanol	1779	Std	+ LRI	4.11	4.04	0.067	0.596
Phenols							
2-Isopropylphenol	1194	MS	+ LRI	4.30	4.28	0.040	0.860
4-Isopropylphenol	1222	MS	+ LRI	1.62	1.17	0.460	0.646
Phenol, 4-(1-methylpropyl)-	1314	MS		5.05	5.13	0.051	0.464
2,4-Di-tert-butylphenol	1506	MS	+ LRI	4.83	4.81	0.114	0.937
Sulfur compounds							
Dimethyl sulfide		Std		4.28	4.39	0.184	0.789
Dimethyl disulfide	723	Std	+ LRI	3.19	3.04	0.101	0.493
Dimethyl trisulfide	964	Std	+ LRI	3.81	4.04	0.102	0.292
Pyrazines							
2-Ethyl-3,5-dimethylpyrazine	1075	Std	+ LRI	2.57	2.86	0.398	0.737
2-Ethyl-3,6-dimethylpyrazine	1082	Std	+ LRI	3.99	4.17	0.100	0.389
Hydrocarbons							
Toluene	753	Std	+ LRI	4.45	4.44	0.048	0.922
Dodecane	1200	Std	+ LRI	4.39	4.48	0.031	0.144
Tridecane	1300	Std	+ LRI	5.02	5.17	0.051	0.130
Tetradecane	1400	Std	+ LRI	4.93	4.98	0.059	0.716

Table 3. *(continued)*

Volatile compounds	LRI[1]	Method of identification [2]	Dietary treatment[3]		SEM	P-value
			CON	CMD		
Pentadecane	1500	Std + LRI	4.81	4.93	0.052	0.264
Hexadecane	1600	Std + LRI	4.41	4.52	0.056	0.338
Octadecane	1800	Std + LRI	3.97	4.26	0.068	0.028
Lactones						
γ-Octalactone	1253	Std + LRI	3.66	3.64	0.030	0.773
γ-Nonalactone	1358	Std + LRI	4.03	4.02	0.047	0.862
Terpenes						
p-Cymene	1023	MS + LRI	3.07	3.00	0.033	0.318
(-)-limonene	1029	MS + LRI	5.03	5.07	0.032	0.541
Furan						
2-Pentylfuran	990	Std + LRI	5.61	5.62	0.036	0.922
Thiazol						
2-Acetyl-2-thiazoline	1100	MS + LRI	3.72	3.39	0.407	0.708
Indoles						
Indole	1287	Std + LRI	3.23	3.34	0.069	0.436
Esters						
Propanoic acid, 2-methyl-, 2-ethyl-3-hydroxyhexyl ester	1367	MS + LRI	3.85	4.24	0.598	0.757
Pentanoic acid, 2,2,4-trimethyl-3-carboxyisopropyl, isobutyl ester	1586	MS + LRI	5.00	5.09	0.091	0.650

[1] LRI: Linear retention indices calculated from the n-alkanes (C7-C30) run under the same GC-MS conditions as LTL muscle sample.

[2] Std: identified with standard solution; MS: mass spectrum identified using NIST Mainlib Mass Spectral Database; LRI: in agreement with Kondjoyan and Berdagué (1996) and NIST Mass Spectral Data Center

[3] Values are expressed as log10 specific ions peak area units

Profile of kidney fat volatile compounds

The results of the volatile profile in perirenal fat are shown in Table 4. In total 45 compounds were detected: 19 aldehydes, 6 ketones, 5 alcohols, 4 hydrocarbons, 3 fatty acids, 2 nitric compounds and 1 compound within each class of phenols, furans, lactones, alkenes and sulfur compounds. In accordance with the volatile profile reported for muscle, aldehydes were the most representative class of volatile compounds in fat. Among this class of compounds, levels of *trans*-4,5-epoxy-(E)-2-decenal were significantly higher ($P < 0.05$) in fat provided by CMD-fed lambs. This volatile has been reported to originate from the oxidation of PUFA, particularly n-6 PUFA (Zamora, Gallardo & Hidalgo, 2006), through a pathway involving as a key intermediate the aldehyde 2,4-decadienal (Gassenmeier & Schieberle, 1994) that was detected in both its isomers in lamb fat (Table 4). As previously stated by Salami, Valenti et al. (2019),

dietary inclusion of cardoon meal did not improve the oxidative stability of either raw or cooked meat; while, the higher content of conjugated linoleic acids that they found in the meat from CON-fed lambs could be associated to a reduced lipid oxidation. When its concentration overcomes the perception threshold, *trans*-4,5-epoxy-(*E*)-2-decenal has been correlated with the sweet aroma of butter (Peterson & Reineccius, 2003). Fat provided by CMD-fed lambs demonstrated to have numerically higher levels of (Z)-2-heptenal, (E)-2-octenal, (E)-2-nonenal, and (E)-2-decenal (Table 4). In association with *trans*-4,5-epoxy-(E)-2-decenal, these aldehydes could have contributed in the perception of the slightly higher sweet odor in CMD-fed lambs. Indeed, sweet odor notes have been reported to be associated also with short-chain aldehydes with unsaturation at the 2-position (Pegg & Shahidi, 2007).

Within aldehydes, slightly higher levels (P = 0.082; Table 4) of heptanal have been detected in the fat provided by CMD-fed lambs. This volatile compound has been correlated with "mild", "green" and "floral" odour notes (Bravo-lamas, Barron, Farmer, & Aldai, 2018; Pegg & Shaidi, 2007) and may have had a role in the overall mitigation of the barnyard/animal odour in fat from CMD-fed lambs.

The fat provided by CON-fed lambs was characterized by the occurrence of *p*-cresol (4-methylphenol), not detected in fat from CMD-fed lambs. The presence of *p*-cresol in ruminant fat has been positively correlated to grazed herbages, even those comprising legumes (Raes et al., 2003; Resconi et al., 2010; Young et al., 1997), and to alfalfa-based concentrate diets (Young et al., 2003). Indeed, *p*-cresol is mainly produced by rumen bacteria from transamination and successive decarboxylation of amino acids, tyrosine in particular, and then accumulated in fat tissue (Watkins, Frank, Singh, Young, & Warner, 2013). Having a low threshold value (Raes et al., 2003), this compound has been reported to be one of the main volatile contributors to the barnyard/animal odour (Watkins et al., 2014; Young & Braggins, 1996), a descriptor that was highly perceived in fat provided by CON-fed lamb.

Table 4. Kidney fat volatile profile of lambs fed with control diet (CON) or cardoon meal diet (CON).

Volatile compounds	LRI[1]	Method of identification[2]		Dietary treatment [3]		SEM	P-value
				CON	CMD		
Aldehydes							
Pentanal		MS		4.68	5.02	0.112	0.137
Hexanal	805	MS		5.38	5.62	0.133	0.384
(Z)-2-Heptenal	898	MS	+LRI	4.97	5.43	0.118	0.079
Heptanal	901	MS	+LRI	4.93	5.45	0.137	0.082
Glyceraldehyde	913	MS	+LRI	4.20	4.77	0.233	0.269
Octanal	1003	MS	+LRI	4.92	5.07	0.085	0.404
(E,E)-2,4-Heptadienal	1011	MS	+LRI	5.36	5.52	0.114	0.492
Benzeneacetaldehyde	1042	MS	+LRI	4.83	4.77	0.108	0.800
(E)- 2-Octenal	1058	MS	+LRI	5.05	5.17	0.097	0.556
Nonanal	1107	MS	+LRI	5.31	5.46	0.086	0.396
(E)-2-Nonenal	1161	MS	+LRI	5.44	5.49	0.083	0.755
2,4-Nonadienal	1215	MS	+LRI	5.22	4.99	0.166	0.514
(E)-2-Decenal	1263	MS	+LRI	5.40	5.75	0.109	0.136
cis-4,5-Epoxy-(E)-2-decenal	1264	MS	+LRI	5.07	4.97	0.157	0.771
trans-4,5-Epoxy-(E)-2-decenal	1264	MS	+LRI	4.58	5.33	0.120	0.013
(Z,Z)-2,4-Decadienal	1317	MS	+LRI	5.32	5.34	0.154	0.927
(E,E)2,4-Decadienal	1317	MS	+LRI	5.74	6.17	0.162	0.215
2-undecenal	1364	MS	+LRI	6.54	6.47	0.085	0.695
4-Nonanone, 7-ethyl-	1385	MS	+LRI	4.25	4.45	0.228	0.70
Hexadecanal	1817	MS	+LRI	5.11	5.25	0.074	0.371
Ketones							
2-Tridecanone	1497	MS	+LRI	5.30	5.44	0.076	0.376
2-Pentadecanone	1698	MS	+LRI	5.82	5.97	0.075	0.332
2-Hexadecanone	1805	MS	+LRI	5.04	5.11	0.116	0.749
2-Heptadecanone	1902	MS	+LRI	6.19	6.22	0.080	0.848
2H-Pyran-2-one, tetrahydro-6-nonyl-	1938	MS	+LRI	5.33	5.43	0.090	0.566
Alcohols							
2,3-Butanediol, [R-(R*,R*)]-*	743	MS	+LRI	5.30	5.20	n.e..	n.e.
2,3-Butanediol, [S-(R*,R*)]-*	743	MS	+LRI	5.12	5.22	n.e.	n.e.
1-Pentanol	758	MS	+LRI	4.59	4.84	0.140	0.276
1-Octanol	1073	MS	+LRI	4.65	4.94	0.263	0.622
4,4,6-Trimethyl-cyclohex-2-en-1-ol	1085	MS	+LRI	4.83	4.94	0.151	0.736
Hydrocarbons							
Pentane	500	MS	+LRI	5.46	5.01	0.122	0.141
2-Ethyl-oxetane*	575	MS	+LRI	5.00	5.07	n.e.	n.e.
n-Hexane	600	MS	+LRI	5.79	5.94	0.127	0.589
Octadecane	1800	MS	+LRI	5.07	5.16	0.104	0.680

Table 4. (Continued)

Volatile compounds	LRI[1]	Method of identification[2]		Dietary treatment [3]		SEM	P-value
				CON	CMD		
Fatty acids							
Propanoic acid, 2-methyl-*	732	MS	+LRI	5.57	5.69	n.e.	n.e.
Butanoic acid, 3-methyl-*	816	MS	+LRI	0.00	5.84	n.e.	n.e.
Undecanoic acid, 10-methyl-, methyl ester*	1471	MS	+LRI	5.28	5.46	n.e.	n.e.
Nitric compounds							
Methylamine, N,N-dimethyl*	479	MS	+LRI	4.83	4.78	n.e.	n.e.
Methyl N-hydroxybenzenecarboximidoate	1301	MS	+LRI	5.69	6.22	0.206	0.269
Phenols							
p-cresol*	1077	MS	+LRI	5.19	0.00	n.e.	n.e.
Furans							
2-pentylfuran	990	MS	+LRI	5.46	5.16	0.253	0.600
Lactones							
γ-Dodecalactone	1678	MS	+LRI	5.40	5.35	0.092	0.784
Sulfur compound							
Cyclooctasulphur	2030	MS	+LRI	5.60	5.65	0.420	0.955
Alkene							
2-Hexadecene, 3,7,11,15-tetramethyl-, [R-[R*,R*-(E)]]-	1830	MS	+LRI	5.27	4.93	0.072	0.066
Others							
Caprolactam	1253	MS	+LRI	4.42	5.63	0.400	0.372

[1] LRI: Linear retention indices calculated from the n-alkanes (C7-C30) run under the same GC-MS conditions as kidney fat sample.

[2] MS: mass spectrum identified using NIST Mainlib Mass Spectral Database; LRI: in agreement with Kondjoyan and Berdagué (1996) and NIST Mass Spectral Data Center.

[3] Values are expressed as log10 specific ions peak area units.

* Coumpound found only in one experimental group or in one or two lambs for each experimental group. SEM and P-value non-estimated (n.e.).

Odour-active compounds of kidney fat

Short and medium-chain branched fatty acids

Due to their high volatility, BCFA may actively contribute on flavour perception (Priolo et al., 2001). The BCFA profile of perirenal fat is reported in Table 5. Lambs fed on CMD-diet exhibited

a higher content (P < 0.05) of 10-methyldodecanoic and a tendency to have higher content of 4-methylpentanoic acid (P = 0.051), compared to CON-fed lambs.

Table 5. Concentration (μg/g fat) of short and medium-branched chain fatty acids in kidney fat from lambs fed control diet (CON) and cardoon meal diet (CMD).

BCFA (ug/g)	Dietary treatment		SEM	P-value
	CON	CMD		
4-methylpentanoic acid	5.80	10.49	1.075	0.051
5-methylhexanoic acid	3.19	3.81	0.255	0.244
4-methyloctanoic acid	3.17	4.74	0.520	0.161
2-methylundecanoic acid	20.36	28.36	3.409	0.265
8-methyl-nonanoic acid	10.40	13.89	0.924	0.086
4-methyldodecanoic acid	15.64	25.35	2.835	0.115
10-methyldodecanoic acid	28.33	46.63	3.398	0.021

This result agrees with those of Salami, Valenti, et al. (2019) who, based on meat fatty acid profile, proposed a higher rumen biohydrogenation activity in cardoon meal- than alfalfa-fed lambs. Indeed, microbial metabolism has been reported to be the main cause of BCFA production in the rumen (Chilliard, Ferlay, Rouel, & Lamberet, 2003) that occurs especially when the amount of propionate exceeds the liver's capacity to metabolize it through gluconeogenesis (Priolo et al., 2001). Furthermore, concentrate based diets enhance the proliferation of amylolytic bacteria in rumen and therefore the production of propionate (Vlaeminck, Fievez, van Laar, & Demeyer, 2004).

This finding could be explained by the different influence of alfalfa and cardoon meal secondary metabolites on rumen bacterial activity. The high content of non-tannic phenolics in CMD diet, particularly cinnamic acid, the major cardoon phenolic compound (Falleh et al., 2008), might have stimulated the growth of ruminal bacteria (Borneman, Akin, & Van Eseltine, 1986), even those involved in BCFA occurrence. In contrast, due to its saponins content, alfalfa may have had an antibacterial effect, (Wallace, 2004), causing a general decrease of rumen volatile fatty acids concentration (Lu & Jorgensen, 1987). Between the three BCFA, 4-MOA, 4-EOA and 4-MNA, regarded as the main responsible for mutton flavor (Priolo et al., 2001; Schiller et al.,

2015; Watkins et al., 2014; Wong et al., 1975), only 4-MOA occurred at a measurable, but not statistically different, level in both diets, while 4-EOA and 4-MNA were not detectable in the perirenal fat. This result is in agreement with the finding of Brennand & Lindsay (1992) who investigated BCFA content in various lamb tissues, including fat. Sebastiàn, Viallon, Berge, Dransfield, and Berdague´, (2003) also did not detect 4-MOA and 4-MNA acids in the fat of grain-fed lambs. Moreover, it has been recognized that these compounds increase with animal age and are more associated with mutton odour in old animals (>2 years) rather than lambs (<1 year) (Watkins et al., 2014).

Indole and skatole

Indole and skatole content in perirenal fat is shown in Table 6. Dietary treatments did not significantly influence total indoles content ($P > 0.05$), which was detected at a low concentration both in CON-fed and CMD-fed lambs. The concentrate content of the diets may have influenced their low occurrence. Indeed, though in some instances no significant differences were found comparing skatole concentration in the fat from lambs fed either grass or concentrate (Priolo et al., 2004; Sebastian et al., 2003), several studies found lower concentrations of indoles in fat provided from animals fed concentrates (Devincenzi et al., 2019; Lane & Fraser, 1999; Priolo et al., 2005; Young et al., 1997).

Table 6. Indole, skatole, and total indoles concentration (ng/g fat) in kidney fat from lambs fed with control diet (CON) and cardoon meal diet (CMD)

	Dietary treatment		SEM	P-value
	CON	CMD		
Indole	25.41	27.88	2.728	0.658
Skatole	9.58	16.65	5.211	0.509
Total indoles	34.99	44.53	6.901	0.502

The total indole concentration in fat from CON and CMD-fed lambs (Table 6) was lower than the concentration reported in fat from concentrate-fed lambs by Devincenzi et al. (2019) and Priolo et al. (2005), either for skatole and indole, and lower than 50 ng/g, which is regarded as a critical skatole threshold for the perception of the unpleasant pastoral flavour (Urbach, Stark, & Forss, 1972 cited by Watkins et al., 2014). However, when present at low concentration (12.6

μg/kg for Peterson & Reineccius, 2003), skatole can contribute to confere desirable flavours in foods such as sweet odour notes.

4.4 Conclusions

The substitution of dehydrated alfalfa with cardoon meal in concentrated-based diets for lambs, slightly influenced their fat odour. Cardoon inclusion reduced the "animal/barnyard odour" perceived in the kidney fat of alfalfa-fed lambs, which could be linked with the aromatic compound *p*-cresol detected only in CON diet. Regarding the other volatiles that are considered to be determinants of the characteristic lamb flavour (i.e. BCFAs, skatole, indole), both diets were characterized by their absence or a moderate to low level detection

5. Influence of dietary inclusion of tannin extracts from mimosa, chestnut and tara on volatile compounds and flavour in lamb meat

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Abstract

Tannins are compounds able to form complexes with proteins limiting their ruminal degradation and thus the synthesis of some odour-active compounds may be inhibited. Tannins are broadly divided in condensed tannins (CT) and hydrolysable tannins (HT). The study aimed to assess the influence of dietary inclusion of three commercial tannin extracts, namely mimosa (Acacia mearnsii; CT), chestnut (Castanea sativa; HT) or tara (Caesalpinia spinosa; HT) on volatile profile and flavour of meat and kidney fat from lambs. Comisana male lambs were divided into four groups (n = 9 each) and fed for 75 days with a concentrate-based diet (CON) or CON supplemented with 4% of one of the tannin extracts. Tannins reduced pastoral odour in perirenal fat of lambs the meat of which was characterized by a very low perception of this attribute. It may be assumed that *p*-cresol and 8-methylnonanoic acid mostly contributed to pastoral odour expression in the diet without condensed or hydrolysable tannins.

Submitted to Meat Science

5.1 Introduction

Tannins are a heterogeneous group of phenolic secondary compounds widely distributed throughout the plant kingdom, especially among trees, shrubs and herbaceous leguminous plants where they principally provide protection against insects, microbial pathogens, pests and herbivores (Khanbabaee & Ree, 2001; Min et al., 2003; Piluzza, Sulas, & Bullitta, 2014). According to their chemical structure, tannins are classified in two main groups: hydrolysable (HT) and condensed tannins (CT). HT are esters of gallic or ellagic acid linked to a polyol core, generally glucose. CT, or proanthocyanidins, consist of flavan-3-ol subunits linked together to form oligomers and polymers (Noumann et al., 2017).

Several studies showed that those metabolites are able to modulate ruminal bacterial activities and have some parasitic control (Min et al., 2003; Liu, Zhou, & Li, 2013; Buccioni et al., 2015). In ruminant nutrition tannins have been considered to be either beneficial or detrimental depending on tannin nature and concentration in diets, composition of the basal diet, animal species, age and physiological state (Makkar, Francis, & Becker, 2007; Piluzza et al., 2014). Negative repercussions have been mainly ascribed to a lower feed intake due to the sensation of astringency as well as to a detrimental effect on nutrient utilization (Makkar, 2003; Le Bourvellec, 2012). Nevertheless, the well-recognized properties of tannins to form complexes with proteins have successfully been applied to ruminant nutrition in order to improve dietary protein utilization, enhancing animal production efficiency as well as product quality (Vasta e Luciano, 2011; Jerónimo et al., 2016; Huang et al., 2018). Meat and meat product quality is considered essential in meeting consumer expectations and needs (Grunert, Bredahl, & Brunsø, 2004; Font-i-Furnols & Guerrero, 2014) and among the most important components of eating quality, odour and flavour play a decisive role in overall acceptability (Borgogno, Corazzin, Saccà, Bovolenta, & Piasentier, 2015; Neethling, Hoffman, & Muller, 2016).

Lamb meat is characterized by characteristic species-related flavours, some of which are considered undesirable; these include a “pastoral flavour”, described as “barnyard”, “sheepy” and “fecal”, widely related to animal diet (Sañudo et al., 2000; Priolo, Micol, & Agabriel, 2001; Bernués, Ripoll, & Panea, 2012), and a “mutton” flavour (sometimes referred as “sheepy”), mostly associated with animal age (Young, Lane, Priolo, & Fraser, 2003; Schreurs, Lane, Tavendale, Barry, & McNabb, 2008; Watkins et al., 2014). Skatole (3-methylindole) and indole, which derive from ruminal degradation of tryptophan, and *p*-cresol (4-methylphenol) are

considered to be among the main compounds responsible for the distinctive pastoral flavour (Schreus et al., 2008). Short and medium-chain branched fatty acids (BCFA; C8-C12) particularly 4-methyloctanoic (4-MOA), 4-ethyloctanoic (4-EOA) and 4-methylnonanoic (4-MNA) acid, that are more abundant in adipose tissue of aged animals, are the chemical compounds considered as the main contributors for mutton flavour (Wong, Johnson, & Nixon, 1975; Watkins et al., 2010).

A better understanding of factors that may influence the occurrence of lamb meat flavour-active compounds may help to devise strategies to better satisfy consumer needs and demands. In this context, dietary inclusion of tannins offers a promising approach. So far, the effect of tannins on meat sensory characteristics mainly focused on the effect of tannins on skatole and indole concentration, and in some cases sensory panel tests have been conducted (e.g. Schreus et al., 2007; Priolo et al., 2009). To our knowledge, no studies are available in literature in which the volatile profile, indoles, BCFAs and sensory analysis has been considered together. In addition, most of the experiments which investigated the effects of dietary tannins on meat quality, tested only one specific tannin extract (e.g., quebracho or grape seed extracts as CT and chestnut extracts as HT). In a recent study, Valenti et al. (2019) evaluated the influence of dietary inclusion of three commercial tannin extracts at a 4% level of inclusion in a concentrate-based diet on lamb growth performances, meat oxidative stability and fatty acid composition. The extracts were: mimosa, chestnut and tara. Using the same meat samples of the study by Valenti et al. (2019), the present study was conducted to investigate the effect of the three above mentioned tannin extracts on lamb meat flavour and odour. To our knowledge, no information has been published regarding the effect of chestnut, tara and mimosa tannin extracts on lamb meat flavour. The complex nature of meat flavour requires an investigation of the essential flavour-active compounds isolated both from adipose tissue and lean meat and their joint contribution to perceived flavour. Therefore, the present study investigated the flavour quality and flavour components in both meat and fat depots, (i.e. kidney fat) from lambs fed with CT and HT extracts.

5.2 Materials and methods

Experimental design, animals and diets

All animal procedures used in this study were conducted in accordance with the European Union Directive for the protection of animals used for scientific purpose (2010/63/EU Directive). Full details of the animals used and their management are described by Valenti et al. (2019). In brief, 36 Sarda × Comisana male lambs, two-month-old and with an average initial weight of 20.0 ± 1.87 kg, were randomly divided in four groups (n = 9) and raised in individual pens. After 7 days of adaptation, lambs were fed with the experimental diets for 75 d pre-slaughter. The control group (CON) received the concentrate-based diet described in Table 1. The other three groups were fed the same diet as the CON group in which 4% (as fed) of one of the following commercial tannin extracts were included in the diet: mimosa (A. *mearnsii*; condensed tannins; MI), chestnut (C. *sativa*; hydrolysable ellagitannis; CH) or tara (C. *spinose*; hydrolysable gallotannins; TA). The commercial extracts (Mimosa OP® =mimosa; Nutri-P® = chestnut; Tannino T80® = tara) were purchased from Silvateam (San Michele Mondovì, Cuneo, Italy). As reported by Valenti et al. (2019), the total phenolic content in the diets was: 4.7 (CON), 25.3 (MI), 24.9 (CH) and 29.1 (TA) g/kg of dry matter (DM) (tannic acid equivalents) and the proportion of tannins over the total phenols was: 32.1% (CON), 88.1% (MI), 84.2% (CH), 86.9% (TA). The four experimental diets were supplied in pelleted form and to those with tannins, the extracts were added to the ingredients before pelleting at 40 °C. Lambs had *ad libitum* access to feeds and water until the end of the experimental period.

Table 1. Main chemical composition of the basal diet.

Ingredients (g/100 g of diet)	
Barley	48
Wheat bran	23
Dehydrated alfalfa	15
Soybean meal	10
Molasses	2
Vitamin-mineral premix	2
Chemical composition (g/100 g DM)	
Crude protein	15.67
Ether extract	2.68
NDF	30.36
ADF	15.97
ADL	3.62
Ash	7.01
Fatty acids (g/kg DM)	
C16:0	5.82
C18:0	1.51
C18:1 *n*-9	8.94
C18:2 *n*-6	28.03

NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin

Slaughter and sampling

At the end of the experimental period, lambs were fasted for three hours before slaughter. Animals were slaughtered by exsanguination following captive bolt stunning. A sample of perirenal fat (~10 g) was immediately collected, vacuum packaged and frozen at -30 °C. The longissimus thoracis et lumborum muscle (LTL) was collected 24 h after slaughter, vacuum packaged and aged for five days at 4°C. After this period, it was frozen at -30 °C until analysis.

Sensory analysis

Sensory analysis was performed as described by Del Bianco et al. (2020). In brief, a trained panel of nine assessors performed the Quantitative Descriptive Analysis (QDA) of lamb LTL muscle and an olfactory evaluation of perirenal fat samples. Eight training sessions allowed panelists to develop a common vocabulary to describe their perceptions (26 attributes to

describe meat and six attributes for kidney fat odour). Meat and fat evaluations were performed on four different days (four replicas) with two sessions per day (morning for meat and afternoon for fat). In each session, the four samples, of meat or fat, were separately presented and assessed following a balanced and randomized design. For each sample, panellists were asked to rate attributes by marking a point on a non-structured line scale (0 = absence of the sensation; 10 = sensation extremely intense).

The evaluations were performed in the sensory laboratory of the University of Udine, established according to the UNI-ISO 8589:1990 standard. Panellist evaluations were recorded using Fizz Acquisition Software (2.47 B, Biosystemes, Couternon, France).

Meat and kidney fat volatile profile analysis

Meat and perirenal fat volatile compounds (VOC) were investigated using the solid phase microextraction (SPME) analysis technique. Full details of the methods applied are given in Del Bianco et al. (2020). In brief, meat sample was cooked in a domestic oven until the internal temperature of 70 °C and then blended with an equal amount of anhydrous sodium sulphate. Five grams (± 0.05 g) of mixture were placed in a 20-mL headspace vial and equilibrated for 20 min at 90 °C prior to the exposure of the SPME fibre (50/30 μm DVB/CAR/PDMS; Supelco, Bellafonte, PA, USA) placed over the sample for a further 20 min. Analysis of the volatile compounds was performed using a Varian 3800 gas chromatograph (GC) coupled to a Varian Saturn 2000 ion trap mass spectrometer (Varian Chromatography Systems, Walnut Creek, CA, U.S.A.). Volatile extraction, adsorption, and injection were performed manually. Volatile compounds were separated using a ZB5-MS fused silica capillary column (30 m length x 0.25 mm id x 0.25 μm film thickness, Phenomenex, Cheshire, U.K.). The operating conditions were as follows: initial temperature, 40 °C for 5 min, then increased to 230 °C at a rate of 4 °C/min and held for 5 min. The GC transfer line was heated at 280 °C.

Fat volatiles were analyzed placing two grams (± 0.2 g) of sliced fat into a 10 ml vials and pre-heated at 90 °C for 20 min equilibration in a PAL RSI 85 autosampler (CTC Analytics AG, Switzerland) before the exposure of the fibre over the headspace for 20 min. The GC-MS analysis was performed with an Agilent Technologies 5977A MSD gas chromatograph (Santa Clara, CA, USA) and the volatile compounds were separated using a DB5-MS fused silica capillary column (30 m length x 0.25 mm id x 0.25 μm film thickness, Agilent Technologies, CA, USA). The GC oven temperature was set as follows: 40 °C for 5 min, increasing to 230 °C at 4

°C/min and holding for 5 min, with a total acquisition time of 58 min. The GC transfer line was heated at 280 °C. The linear retention indices (LRI) were calculated by previous injection of standards of saturated n-alkanes (C7-C30) under the same GC-MS conditions. Compounds were identified by comparing their mass spectra with spectra from the National Institute of Standards and Technology (NIST) Mass Spectral Library and confirmed by matching their LRI with Kondjoyan & Berdaguè (1996) and NIST Mass Spectral Database. Wherever possible, identities of meat volatiles were confirmed by comparison of LRI values and mass spectra with those of authentic standards.

Odour-active compounds of kidney fat

Short and medium branched-chain fatty acids (BCFA) analysis

BCFA analysis of perirenal fat was performed according to the method proposed by Kaffarnik, Preuß, & Vetter (2014) with minor modifications. Before the GC-MS measurements, the fatty acids of samples were converted into the corresponding methyl esters. Perirenal fat samples (~10 mg) were accurately weighed into a 10 mL screw cap tubes and 0.5 mg of 10-undecenoic acid (11:1 n-1) (Sigma Aldrich, Milano, Italy) were added to the sample as internal standard (IS). After that, 3 mL of a methanolic solution with 1% sulfuric acid were added. The tubes were then sealed and heated at a temperature of 80 °C for 120 min. After cooling, 1 mL aqueous saturated NaCl solution and 1 mL distilled water were added and the fatty acid methyl esters were extracted with 1 mL n-hexane via vigorous shaking. In order to achieve a final concentration suitable for BCFA detection, the n-hexane extract was diluted two fold. GC-MS was operated in EI mode (70 eV) with a 5977E MSD system (Agilent Technologies, USA) equipped with a 7683A autosampler and automatic split/splitless injector. An aliquot (1µL) of solutions was injected in splitless mode for the first 1.5 min of the analysis and then in the split mode for the remainder of the analysis. Separations were carried out on a Supelcowax-10 fused silica capillary column (30 m length, 0.25 mm internal diameter coated with 0.25 µm film thickness) (Supelco, Bellefonte, PA). The GC oven temperature was set at 50 °C for 10 min and increased at 5 °C/min to 160 °C. It was further increased at 20 °C/min to 240 °C and held for 5 min. Helium was used as the carrier gas with a constant flow rate of 1.2 mL/min. The temperatures of the ion source and the quadrupole were set at 240 °C and 150 °C, respectively. Data were acquired in full scan mode for a range of 50 to 350 amu and analysis were performed

after a solvent delay of 4 min, with 3 microscan/s. The time event from 36.02 to 41.28 min allowed a better detection of BCFA and lighter molecules, avoiding the detection of more substantial peaks that came out from C16:0 onwards. Compounds were identified by comparing their mass spectra of NIST 14 Mass Spectral Library, by comparison with LRIs (Kondjoyan & Berdaguè, 1996) and by matching the results with those reported in the literature (Kaffarnik, Kayademir, Heid, & Vetter, 2014; Kaffarnik, Preuß, et al., 2014; Young et al., 2003). The LRI were calculated by previous injection of n-alkanes from 5 to 16 carbon atoms under the same GC-MS conditions.

Indole and skatole analysis

Indole and skatole (3-methylindole) were measured in perirenal fat according to the method proposed by Tuomola, Vahva, & Kallio (1996). In brief, a perirenal fat sample (2.5 g) was suspended in 10 ml of methanol together with 30 µL of 2-methylindole as internal standard and then homogenized by means of an Ultra Turrax (T 25 basic; Ika-Werke, Staufen, Germany). After cooling for 30 min at -20 °C, the homogenate was centrifuged at 4000 g for 10 min. The supernatant was filtered through a Sep-Pak C18 column and 2 ml of eluate were collected in a vial. Two µl were injected onto an HPLC system (Shimadzu Corporation Kyoto, Japan) fitted with an SIL-20AHT autosampler and a fluorimetric detector (RF 20A XS), λ excitation = 270 nm and λ emission = 350 nm. Chromatograpic separation was carried out on a Superspher 100 RP-18 (125 x 4mm i.d., particle size 4um) column fitted with LiChrospher RP-18 precolumn (4x4mm i.d., particle size 5um). The column was eluted with a mobile phase consisting of water : acetonitrile (60:40, v/v) at flow rate of 1.0 ml/min and thermostated at 30 °C.

Data processing and statistical analysis

The effect of dietary treatment on chemical data was analyzed by SPSS statistical software SPSS ver.17 (SPSS Inc., Illinois), following a one-way ANOVA design, with individual lambs as experimental units. Statistical analysis of sensory data was performed using the statistical software PanelCheck (Nofima Mat & DTU Informatics and Mathematical Modelling; Norway). The effect of tannin extracts on each descriptor was evaluated by ANOVA analysis that considered both product and assessor effect, assuming the latter as a random factor. Contrast analysis was applied to test any significant dietary effect on the various chemical and sensory

characteristics of lamb meat. In line with the experimental design, the "simple" contrast was adopted and tabulated for comparing: first, CON vs. tannin diets; second, condensed (MI) vs. hydrolysable tannins; and, third, TA vs. CH. However, when the effect of tannin type was not significant all through a composites category, as for volatiles compounds, we considered a superscripts tabulation, declaring for $P \leq 0.05$ significant difference between treatments. The principal component analysis of the kidney fat odour attributes in the various dietary treatments was carried out by Unscramble. X version 10.4 (Camo software, 2016).

5.3 Results and discussion

Sensory analysis evaluation

An inclusion rate of 4% tannin extracts did not affect the sensory properties of the meat, since the trained assessors did not perceive considerable differences between treatments ($P > 0.05$; data not shown). The results agree with other studies in which condensed tannins (CT) have been used. Jerónimo et al. (2012) reported that supplementing lamb diet with grape seed extract (2 – 2.5% CT of dietary DM) and *Cistus ladanifer* (2.5 – 3% CT of dietary DM) did not lead a consumer panel to perceive differences in the sensory properties of meat. Also, Priolo et al. (1998) stated that adding 12.4 g CT/kg DM of diet, sourced from carob pulp (200 g carob pulp/kg of diet), did not affect the sensory properties of lamb LTL muscle. In contrast, Priolo, Waghorn, Lanza, Biondi, & Pennisi (2000) found that higher levels of carob pulp (25 g CT/ kg DM) negatively affected overall acceptability of lamb meat, evaluated by the panelists with "foreign" flavours, while 10% of quebracho (*Schinopsis lorentzii*) extract addition (40 g CT/kg DM of diet) reduced "sheep" odour of lamb meat (Priolo et al., 2009). In our study, 4% of the three tannin extracts enriched the experimental diets with an average 2.3 ± 0.2% tannins (Valenti et al., 2019). This level is within the range believed to permit biological effectiveness without impairing nutritional intake and animal performance (Min et al., 2003). The low intramuscular fat (IMF) content of our young lambs (< 5 months; 2.07, 1.98, 1.85 and 1.86 g/100 g muscle for CON, MI, CH and TA respectively; as reported by Valenti et al., 2019), may contribute to explaining the lack of sensory perceived differences among treatments. Indeed, fat depots are the principal sources contributing to meat flavour and odour originating from molecules accumulated in these tissues (Webb & Neill, 2008). Thus, besides the LTL muscle, a

visceral fat depot was analyzed, namely kidney or perirenal fat. Results of kidney fat olfactory evaluation are shown in Table 2.

Table 2. Mean scores of odour descriptors for kidney fat from lambs fed control diet (CON) or a diet integrated with tannin extract from mimosa (MI), tara (TA) or chestnut (CH).

	Dietary treatment[1]					P-value[2]			
Odour attributes	**CON**	**MI**	**TA**	**CH**	**SEM**	**DT**	**C vs T**	**CT vs HT**	**TA vs CH**
Sheep	5.5	4.9	4.6	4.6	0.127	0.038	0.006	0.434	0.853
Barnyard	3.3	2.0	1.6	1.5	0.114	<0.001	<0.001	0.098	0.660
Rancid	2.2	2.3	1.6	2.1	0.095	0.003	0.303	0.055	0.067
Pungent	2.2	1.5	1.5	1.1	0.107	0.039	0.002	0.408	0.247
Sweet	2.7	2.8	3.2	3.4	0.113	0.189			
Anomalous	0.6	0.5	0.1	0.5	0.093	0.421			

[1] Attributes were scored using a non-structured line scale (0 = absence of the sensation; 10 = sensation extremely intense)

[2]DT: dietary treatment; C vs T: control vs tannins contrast; CT vs HT: condensed tannin vs hydrolysable tannins contrast; TA vs CH: tara vs chestnut contrast.

"Sheep" odour was the most distinctive attribute of kidney fat from all treatments, since this descriptor received numerically higher scores compared to the other aromatic attributes. On the contrary, "anomalous" odour was negligible. Moreover, "sheep", "barnyard", "rancid" and "pungent" odours were significantly affected by treatments ($P < 0.05$). In particular, fat provided by the CON group showed a higher intensity of sheep ($P = 0.039$), barnyard ($P < 0.001$) and pungent ($P = 0.002$) odours compared with the average of tannin diets. Sheep and barnyard odours are involved in the occurrence of the so called "pastoral" odour/flavour that may be regarded as undesirable or having negative connotations for some consumers (Borgogno et al., 2015). This sensory attribute has been mainly associated with fat depots of lamb fed herbage (Devincenzi et al., 2014; Young et al., 2006), alfalfa in particular (Devincenzi et al., 2019). It is noteworthy that the basal diet provided to our lambs included 15% DM of dehydrated alfalfa, which may have amplified the perception of pastoral odour in kidney fat. The inclusion of alfalfa may have also emphasized the pungent odour, as highlighted in lamb

meat by earlier studies (Park et al., 1972). Regarding the significant effect of dietary treatment on rancid odour of fat ($P < 0.05$), TA group scored the lowest for this attribute (Table 2). In order to obtain an overall view of sensory results, a principal component analysis (PCA) was performed (Fig. 1).

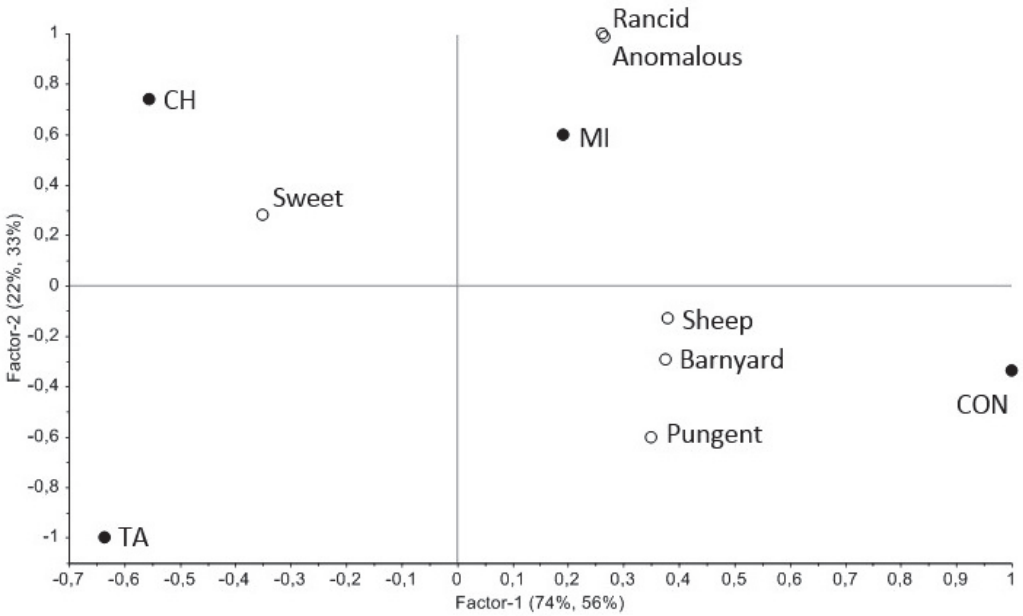

Figure 1. Principal component analysis (PCA) loading biplots indicating the least square means of the kidney fat odour attributes (○) as affected by dietary treatments (●). CON, MI, TA and CH refer to control, mimosa, tara and chestnut dietary treatments respectively.

PC-1 accounted for the great part of the original variability (74%) and was correlated to all the odour attributes. Along PC-1 dietary treatments scattered into clearly distinguished groups, related with attributes having either potentially positive or undesirable connotations. Treatments with hydrolysable tannins (CH and TA) were located on the left side of the plot, in association with the sweet odour. By contrast, CON diet fell in the opposite far-right side, in association with odours that are considered less desirable. These odours include sheep (Young et al., 2003); barnyard, also referred to as animal smell/farm smell (Ames and Sutherland, 1999; Erasmus et al., 2016); rancid (Erasmus et al., 2016), pungent and anomalous. The diet added with condensed tannins (MI) held an intermediate place along such odour range from sweet to less desirable notes. The PC-2, even if accounting for a small proportion of the original variability (22%), provided a segregation of the two diets added with the hydrolysable tannins

(i.e. CH and TA), emphasizing that TA treatment was the less associated with the undesirable odour notes rancid and anomalous.

Profile of meat volatile compounds

Volatile compounds detected in meat samples are shown in Table 3. A total of 75 compounds were identified and classified according to their chemical nature: 32 aldehydes, 10 alcohols, 8 hydrocarbons, 5 ketones, 4 phenols, 4 sulfur compounds, 2 volatiles within lactones, terpenes, pyrazines, and esters and 1 compound within each class of furans, thiazolines, indoles and pyridines. Aldehydes were the predominant chemical group detected in the headspace of cooked meat samples, a result generally common in ruminant meat (Larick & Turner, 1990). It is known that aldehydes are mostly derived from polyunsaturated fatty acids (PUFA) oxidation during thermal processing and from amino acids degradation that occurs during the Maillard reaction through Strecker degradation (Kosowska, Majcher, & Fortuna, 2017). Accordingly, aldehydes tend to be in higher levels in meat from animals fed concentrate-based diets, characterized by a low level of natural occurring antioxidants relative to the content of PUFA, linoleic acid in particular (Descalzo et al., 2005).

Table 3. Meat volatile profile of lambs fed with control diet (CON) or a diet integrated with tannin extract from mimosa (MI), tara (TA) or chestnut (CH).

Volatile compounds	LRI[1]	Method of identification[2]		Dietary treatment[3]				SEM	P-value
				CON	MI	TA	CH		
Aldehydes									
3-MethylButanal		Std		4.45[a]	3.89[c]	4.28[b]	4.19[b]	0.062	0.025
2-Methylbutanal		Std		4.26	3.77	4.11	4.17	0.068	0.076
Pentanal		Std		5.21	5.14	5.09	5.11	0.030	0.526
Hexanal	805	Std	+ LRI	6.11	6.14	6.06	6.07	0.020	0.450
2-Hexenal, (E)-	853	Std	+ LRI	4.41	4.40	4.31	4.43	0.037	0.720
2-Heptenal, (Z)-	898	Std	+ LRI	3.96	3.99	3.94	3.99	0.024	0.869
4-Heptenal, (Z)-	898	Std	+ LRI	4.18	4.13	4.06	4.17	0.038	0.649
Heptanal	901	Std	+ LRI	5.81	5.82	5.76	5.80	0.022	0.764
Methional	906	Std	+ LRI	4.10[a]	3.75[c]	3.96[b]	4.01[b]	0.039	0.028
Benzaldehyde	960	Std	+ LRI	6.18	6.14	6.23	6.14	0.024	0.443
Octanal	1004	Std	+ LRI	6.06	6.11	6.08	6.07	0.029	0.926
2,4-Heptadienal, (E,E)-	1011	Std	+ LRI	4.55	4.57	4.55	4.56	.033	0.033
Benzeneacetaldehyde	1042	Std	+ LRI	4.76	4.79	4.81	4.81	0.033	0.926

Table 3. (*continued*)

Volatile compounds	LRI[1]	Method of identification[2]		Dietary treatment[3]				SEM	P-value
				CON	MI	TA	CH		
2-Octenal, (E)-	1058	Std	+ LRI	5.53	5.58	5.56	5.54	0.020	0.884
4-Nonenal, (E)-	1096	MS		4.89	4.84	4.80	4.88	0.031	0.712
Nonanal	1107	Std	+ LRI	6.51	6.53	6.52	6.52	0.023	0.988
2,6-Nonadienal, (E,Z)-	1152	Std	+ LRI	4.48	4.37	4.30	4.35	0.044	0.685
2-Nonenal, (E)-	1161	Std	+ LRI	5.82	5.85	5.78	5.82	0.031	0.887
4-Decenal, (Z)-	1197	MS	+ LRI	4.82	4.76	4.74	4.92	0.061	0.716
Decanal	1206	Std	+ LRI	5.31	5.33	5.37	5.32	0.020	0.691
2,4-Nonadienal, (E,E)-	1215	MS	+ LRI	5.04	5.17	5.10	5.10	0.040	0.443
2-Decenal, (E)-	1263	Std	+ LRI	5.88	6.01	6.00	5.98	0.052	0.824
Undecanal	1307	Std	+ LRI	4.95	5.05	5.10	5.00	0.037	0.563
2,4-Decadienal, (E,E)-	1318	Std	+ LRI	5.50	5.63	5.61	5.55	0.030	0.831
2-Undecenal	1364	MS	+ LRI	5.66	5.40	5.73	5.59	0.068	0.368
Dodecanal	1409	Std	+ LRI	5.04	5.18	5.23	5.08	0.039	0.285
2,4-Dodecadienal	1421	MS		4.66	4.76	4.74	4.73	0.042	0.218
benzaldehyde, 4-pentyl	1459	MS	+ LRI	4.70	4.85	4.78	4.71	0.042	0.553
Tridecanal	1511	Std	+ LRI	5.14	5.24	5.31	5.12	0.045	0.432
Tetradecanal	1613	MS	+ LRI	5.41	5.55	5.57	5.45	0.034	0.303
Pentadecanal	1715	MS	+ LRI	5.52	5.57	5.62	5.48	0.034	0.550
Hexadecanal	1817	MS	+ LRI	5.61	5.50	5.67	5.51	0.030	0.125
Alcohols									
1-Pentanol	758	Std	+ LRI	5.11	5.12	5.03	5.05	0.029	0.636
1-Hexanol	872	Std	+ LRI	4.97	4.99	4.90	4.94	0.029	0.479
1-Heptanol	973	Std	+ LRI	5.42	5.52	5.44	5.47	0.036	0.346
1-Octen-3-ol	982	Std	+ LRI	5.80	5.85	5.77	5.75	0.021	1.158
2-Ethyl-1-hexanol	1028	Std	+ LRI	4.27	4.26	4.18	4.30	0.094	0.975
4-Ethylcyclohexanol	1036	MS		4.17	4.24	4.18	4.15	0.030	0.718
2-Octen-1-ol, (E)-	1069	Std	+ LRI	5.05	5.22	5.01	5.01	0.032	0.066
1-Octanol	1073	Std	+ LRI	5.75	5.82	5.80	5.80	0.031	0.179
α-Terpineol	1194	Std	+ LRI	4.49	4.45	4.52	4.50	0.025	0.841
1-Pentadecanol	1779	Std	+ LRI	4.11	4.21	4.15	4.09	0.045	0.366
Hydrocarbons									
Toluene	753	Std	+ LRI	4.45	4.32	4.41	4.36	0.039	0.657
Ethylbenzene	858	MS	+ LRI	3.05	2.91	2.92	3.05	0.042	0.521
Dodecane	1200	Std	+ LRI	4.39	4.50	4.54	4.43	0.029	0.274
Tridecane	1300	Std	+ LRI	5.02	5.12	5.10	5.02	0.026	0.404
Tetradecane	1400	Std	+ LRI	4.93	5.02	5.06	4.85	0.037	0.166
Pentadecane	1500	Std	+ LRI	4.81	4.88	4.92	4.83	0.030	0.575
Hexadecane	1600	Std	+ LRI	4.41	4.47	4.61	4.50	0.032	0.173
Octadecane	1800	Std	+ LRI	3.97[c]	4.03[c]	4.61[a]	4.31[b]	0.029	< 0.001
Ketones									
2,3-Butanedione		Std		4.10	4.19	4.30	4.12	0.061	0.534
2-Heptanone	890	Std	+ LRI	4.82	4.86	4.77	4.76	0.028	0.501
1-Octen-3-one	977	MS	+ LRI	4.65	4.78	4.67	4.78	0.045	0.609
2,3-Octanedione	987	MS	+ LRI	5.57	5.62	5.50	5.50	0.029	1.097
2-Nonanone	1091	Std	+ LRI	4.06	4.12	4.11	4.07	0.027	0.841

Table 3. (*continued*)

Volatile compounds	LRI[1]	Method of identification[2]		Dietary treatment[3]				SEM	P-value
				CON	MI	TA	CH		
Phenols									
2-Isopropylphenol	1194	Std	+ LRI	4.30	4.19	4.28	4.26	0.023	0.398
4-Isopropylphenol	1222	Std	+ LRI	3.22	3.24	3.52	3.26	0.090	0.617
Phenol, 4-(1-methylpropyl)-	1314	MS		5.05	5.23	5.21	5.11	0.039	0.351
2,4-Di-tert-butylphenol	1506	MS	+ LRI	4.83	4.53	4.86	4.75	0.080	0.873
Sulfur compounds									
Dimethyl sulfide		Std		4.28	4.23	4.12	4.10	0.114	0.929
Carbon disulfide		MS		4.20	4.07	4.20	4.14	0.038	0.548
Dimethyl disulfide	723	Std	+ LRI	3.19	3.11	3.23	3.17	0.054	0.901
Dimethyl trisulfide	964	Std	+ LRI	3.81	3.95	4.14	4.13	0.050	0.093
Lactones									
γ-Octalactone	1253	Std	+ LRI	3.66	3.78	3.68	3.69	0.032	0.555
γ-Nonalactone	1358	Std	+ LRI	4.03	4.14	4.07	4.06	0.038	0.770
Terpenes									
p-Cymene	1023	Std	+ LRI	3.07	3.00	3.02	3.04	0.019	0.596
(-)-limonene	1029	Std	+ LRI	5.03	5.09	5.05	5.01	0.025	0.471
Pyrazines									
2-Ethyl-3,5-dimethylpyrazine	1075	Std	+ LRI	3.43	2.61	3.30	3.27	0.171	0.418
2-Ethyl-3,6-dimethylpyrazine	1082	Std	+ LRI	3.99	3.98	4.17	4.21	0.066	0.494
Esters									
Propanoic acid, 2-methyl-, 2-ethyl-3-hydroxyhexyl ester	1367	MS	+ LRI	5.13	5.11	4.86	3.06	0.301	0.057
Pentanoic acid, 2,2,4-trimethyl-3-carboxyisopropyl, isobutyl ester	1586	MS	+ LRI	5.00	5.03	5.26	5.11	0.053	0.318
Furans									
2-Pentylfuran	990	Std	+ LRI	5.61	5.68	5.64	5.57	0.024	0.419
Thiazolines									
2-Acetyl-2-thiazoline	1100	MS	+ LRI	4.25	4.05	3.88	4.09	0.056	0.207
Indoles									
Indole	1287	Std	+ LRI	3.23	3.41	3.45	3.27	0.045	0.258
Pyridines									
2-Pentylpyridine	1195	Std	+ LRI	4.33	4.33	4.25	4.38	0.039	0.733

[a,b,c]: differences between treatments on the row $P \leq 0.05$.

[1] LRI: Linear retention indices calculated from the n-alkanes (C7-C30) run under the same GC-MS conditions as kidney fat sample.

[2] Std: identified with standard solution; MS: mass spectrum identified using NIST Mainlib Mass Spectral Database; LRI: in agreement with Kondjoyan and Berdagué (1996) and NIST Mass Spectral Data Center.

[3] Values are expressed as log10 specific ions peak area units.

Volatile profile was minimally affected by dietary treatments in agreement with the results of meat QDA analysis. This result is also in line with the findings of Valenti et al. (2019), who noted no effect of the experimental diets on the concentration of the main fatty acid classes or on the

oxidative stability of meat. Only three compounds, two aldehydes and one hydrocarbon, differed between groups (Table 3). Within the aldehydes, 3-methylbutanal and methional, which derive from leucine and methionine degradation, respectively (Söllner & Schieberle, 2009; Kosowska et al., 2017), occurred at a significantly lower ($P < 0.05$) concentrations in LTL from lambs receiving the tannin extracts compared with the CON group, with the lowest levels detected in MI fed-lambs. This finding could be attributed to the capacity of tannins to form complexes with proteins thus preventing their ruminal degradation (Patra & Saxena, 2011; Piluzza et al., 2014). Furthermore, La Bourvellac & Renand (2012) noted that proteins mainly involved in forming tannin/protein complexes are rather hydrophobic. Leucine and methionine are both regarded as hydrophobic amino acids (Lim et al., 2019), a chemical characteristic that may have further improved the efficiency of tannins on preventing their ruminal degradation.
Regarding the contribution of 3-methylbutanal and methional to meat flavour and odour, it has been reported that, when their levels overcome the odour perception threshold, 3-methylbutanal can confer "nutty", "chocolate", "caramel" but also "pungent", "apple-like" and "malty" odours (Calkins, 2007; Zahn et al., 2017), while methional can confer "cooked potato-like" odour/flavour notes (Bravo-Lamas et al., 2018). However, that was not supported by the sensory analysis in this study, since no significant differences between treatments were perceived. This result may be due to the concentration of 3-methylbutanal and methional being below the level required to reach the detection threshold.
Within hydrocarbons, octadecane was significantly ($P < 0.05$) higher in TA than CON and other tannins groups. There is evidence that volatile hydrocarbons are produced during lipid peroxidation (Bianchi et al., 2007). However, a hydrocarbon only is not a sufficient indicator for discriminating lipid oxidation among groups. In a flavour context, linear aliphatic hydrocarbons have relatively high odour threshold values and are therefore very unlikely to contribute to meat flavours (Narváez-Rivas et al., 2015).

Profile of kidney fat volatile compounds

For the kidney fat volatile profile 23 aldehydes, 7 ketones, 5 hydrocarbons, 4 alcohols, 2 lactones, and 1 compound within each class of furans, phenols and sulfur compounds were detected (Table 4).

Table 4. Kidney fat volatile profile of lambs fed with control diet (CON) or diet integrated with mimosa (MI), tara (TA) or chestnut (CH) tannin extracts.

Volatile compounds	LRI[1]	Method of identification[2]		Dietary treatment[3]				SEM	P-value
				CON	MI	TA	CH		
Aldehydes									
Pentanal		MS		4.64	5.06	5.20	4.74	0.119	0.330
Hexanal	805	MS		5.07	5.52	4.97	5.28	0.100	0.205
(E)-2-Pentenal		MS	+ LRI	4.00	4.47	4.31	4.54	0.131	0.620
(E)-2-Hexenal	853	MS	+ LRI	4.98	4.76	4.42	4.57	0.142	0.611
(Z)-2-Heptenal	898	MS	+ LRI	5.01	5.32	4.87	4.95	0.115	0.463
Heptanal	901	MS	+ LRI	4.75	5.09	5.45	4.98	0.124	0.297
Octanal	1003	MS	+ LRI	4.73	4.97	4.48	5.11	0.091	0.089
(E,E)-2,4-Heptadienal	1011	MS	+ LRI	4.73	5. 51	5.19	5.37	0.101	0.066
Benzeneacetaldehyde	1042	MS	+ LRI	4.30	4.82	4.34	4.44	0.101	0.359
(E)- 2-Octenal	1058	MS	+ LRI	4.68	5.11	4.64	4.88	0.100	0.293
Nonanal	1107	MS	+ LRI	4.86	5.32	4.85	5.15	0.098	0.269
(E)-2-Nonenal	1161	MS	+ LRI	4.95	4.86	5.03	5.08	0.096	0.842
2,4-Nonadienal	1215	MS	+ LRI	4.29	4.86	4.55	4.63	0.107	0.387
(E)-2-Decenal	1263	MS	+ LRI	5.09	5.67	5.23	5.56	0.097	0.154
2-Undecenal	1364	MS	+ LRI	5.98	6.50	6.08	6.44	0.099	0.186
cis-4,5-Epoxy-(E)-2-decenal	1264	MS	+ LRI	4.78	5.11	4.61	4.47	0.121	0.098
trans-4,5-Epoxy-(E)-2-decenal	1264	MS	+ LRI	4,72	4,81	4,42	5,14	0.109	0.098
(E,E)-2,4-Decadienal	1317	MS	+ LRI	5.41	5.32	5.19	5.09	0.103	0.708
(Z,Z)-2,4-Decadienal	1317	MS	+ LRI	4.94	5.81	5.81	5.79	0.126	0.107
(E,E)-2,4-undecadienal		MS	+ LRI	4.17	4.24	4.33	4.36	0.098	0.901
Tetradecanal	1613	MS	+ LRI	4,59^{b}	5,05^{a}	5,14^{a}	5,28^{a}	0.070	0.023
Pentadecanal	1715	MS	+ LRI	4.30	4.62	4.22	4.31	0.102	0.475
Hexadecanal	1817	MS	+ LRI	5.18	5.22	5.07	5.30	0.099	0.845
Ketones									
7-ethyl-4-nonanone	1385	MS	+ LRI	4.75	4.36	4.58	4.32	0.176	0.886
2-Undecanone	1394	MS	+ LRI	4.47	4.70	4.69	4.59	0.073	0.694
2-Tridecanone	1497	MS	+ LRI	5.14	5.44	5.48	5.48	0.058	0.192
2-Pentadecanone	1698	MS	+ LRI	6.02	5.87	6.08	5.62	0.091	0.283
2-Hexadecanone	1805	MS	+ LRI	4.76	4.85	5.06	4.88	0.095	0.398
2-Heptadecanone	1902	MS	+ LRI	5.56^{b}	6.22^{a}	6.32^{a}	6.23^{a}	0.094	0.042
Tetrahydro-6-nonyl-2H-pyran-2-one	1938	MS	+ LRI	5.05	5.09	5.37	5.28	0.068	0.318
Hydrocarbons									
Pentane	500	MS	+ LRI	4.40	4.45	4.40	4.36	0.059	0.903
n-Hexane	600	MS	+ LRI	4.33	4.56	4.44	4.78	0.094	0.321
Heptadecane	1700	MS	+ LRI	4.29	4.36	4.41	4.79	0.128	0.413
Octadecane	1800	MS	+ LRI	5.10^{b}	4.93^{b}	5.58^{a}	5.24^{ab}	0.069	0.011
3,7,11,15-tetramethyl-2-hexadecene	1830	MS	+ LRI	5.41	4.46	4.79	5.35	0.133	0.064

Table 4. (*Continued)*

Volatile compounds	LRI[1]	Method of identification[2]		Dietary treatment[3]				SEM	P-value
				CON	MI	TA	CH		
Alcohols									
1-Pentanol	758	MS	+ LRI	4.48	4.79	4.55	4.77	0.080	0.418
1-Hexanol	872	MS	+ LRI	4.13	4.40	4.29	4.41	0.131	0.888
1-Octanol	1073	MS	+ LRI	4.58^{ab}	4.38^{b}	4.90^{a}	4.46^{b}	0.070	0.011
4,4,6-Trimethyl-cyclohex-2-en-1-ol	1085	MS	+ LRI	4.49	4.98	4.48	4.55	0.111	0.313
Lactones									
γ-Dodecalactone	1678	MS	+ LRI	5.37^{a}	5.41^{a}	5.23^{a}	4.63^{b}	0.098	0.020
δ-Dodecalactone	1678	MS	+ LRI	4.35	4.48	4.42	4.40	0.068	0.950
Furans									
2-pentylfuran	990	MS	+ LRI	4.98	4.95	4.77	5.01	0.116	0.831
Phenols									
p-cresol*	1077	MS	+ LRI	4.43	0.00	0.00	0.00	n.e	n.e.
Sulfur compounds									
Cyclooctasulphur	2030	MS	+ LRI	5.31	4.92	5.40	5.07	0.196	0.789
Others									
Caprolactam	1253	MS	+ LRI	4.69	4.28	4.27	4.55	0.135	0.647

[a,b,c]: differences between treatments on the row $P \leq 0.05$.

[1] LRI: Linear retention indices calculated from the n-alkanes (C7-C30) run under the same GC-MS conditions as kidney fat sample.

[2] MS: mass spectrum identified using NIST Mainlib Mass Spectral Database; LRI: in agreement with Kondjoyan and Berdagué (1996) and NIST Mass Spectral Data Center.

[3] Values are expressed as log10 specific ions peak area units.

* Compound found only in one experimental group. SEM and P-value non-estimated (n.e.).

In accordance with the volatile profile reported for muscle, aldehydes were the most representative class of volatile compounds in fat. Moreover, as previously observed for muscle, a general limited effect of the dietary treatments on volatile profile was noted. Indeed, among the 45 compounds detected, only six were significantly affected by treatments ($P < 0.05$), five of which (tetradecanal, 2- heptadecanone, 1-octanol, octadecane and γ-dodecalactone) were lipid oxidation products, and one, the *p*-cresol (4-methylphenol), which derive from tyrosine metabolism in the rumen. Tetradecanal and 2-heptadecanone were detected at the lowest levels in perirenal fat from CON fed lambs ($P < 0.05$; Table 4). Moreover, 1-octanol, within alcohols, and octadecane, within hydrocarbons, were detected at the highest levels in fat from TA group. As for γ-dodecalactone, which derives from the oxidation of dietary oleic and linoleic acid (Gargouri, Drouet, & Legoy, 2003), it was detected at the lowest levels in fat from the group added with CH extract ($P < 0.05$). Among those tested, this extract had the highest content of

non-tannic polyphenols that may have contributed to the protection of oleic and linoleic acids from oxidation (Valenti et al., 2019). Previous studies reported a limited or no effect of tannins on lipid oxidation. Brogna et al. (2014) did not observe an effect on lipid oxidation following the inclusion of 80 g/kg diet of quebracho extract (*Aspidosperma quebracho*; CT) to lambs' diet. Also Leick et al. (2012) reported that supplementing goat diets with increasing levels of dietary pine bark (0, 15 and 30%), rich in condensed tannins, had no effect on lipid stability.

In a sensory context, when present at levels that exceed its odour perception, tetradecanal is reported to confer "buttery", "fruity" and "green" odour notes (Zhan et al., 2017) while 2-heptadecanone has been reported to have "floral type" connotations (Verma et al., 2018). Lactones have been reported to confer "fruity" and "oily" odour notes in meat (Arshad et al., 2008), while alcohols and hydrocarbons are generally considered not to be important contributors to the flavors of lipid-based foods (Ho & Chen, 1994; Bianchi et al., 2007).

The phenolic compound *p*-cresol (4-methylphenol) was detected only in fat from CON-fed lambs. The reason for that could be linked to the possible inhibitory action of tannins in rumen degradation of tyrosine (and a consequence of tannin-protein complex formation), thus reducing the occurrence of *p*-cresol in fat. Having a low threshold value, this compound has been regarded as one of the main volatile contributors to the "pastoral" odour which includes sheep and barnyard odour notes, strongly perceived in fat provided by CON-fed lambs.

Short and medium-chain branched fatty acids

In order to reach a deeper knowledge of those compound that may have actively contributed to odour perception in perirenal fat, BCFA content was investigated. Results are reported in Table 5. Among treatments, perirenal fat from the CON group exhibited the highest content of 8-methylnonanoic acid ($P < 0.05$). The same group showed a numerically higher content of the total BCFAs detected compared to tannin fed groups (88.08 vs 70.54 μg/g fat on average respectively, data not tabulated).

Table 5. Concentration (μg/g fat) of short and medium branched chain fatty acids (BCFA) in kidney fat from lambs fed control diet (CON) or diet integrated with mimosa (MI), tara (TA) or chestnut (CH) tannin extracts.

Odour attributes	Dietary treatment				SEM	P-value[1]			
	CON	MI	TA	CH		DT	CvsT	CTvsHT	TAvsCH
4-methyloctanoic	3.60	3.09	2.90	2.79	0.217	0.601			
8-methylnonanoic	10.97	8.58	7.49	7.15	0.429	0.020	0.004	0.223	0.779
2-methylundecanoic	23.14	20.90	19.63	15.94	1.481	0.405			
4-methyldodecanoic	19.10	15.48	14.13	13.83	1.287	0.493			
10-methyldodecanoic	31.27	25.88	27.22	26.62	1.024	0.289			

[1] DT: diet treatment; CvsT: control vs. tannins contrast; CTvsHT: condensed tannin vs. hydrolysable tannins contrast; TAvsCH: tara vs. chestnut, hydrolysable tannins, contrast

These compounds are mainly synthesized when propionate levels exceed liver capacity to metabolize it through gluconeogenesis (Garton et al., 1972). The inhibitory effect of tannins on ruminal metabolism may have reduced the propionate production and consequently the occurrence of BCFAs in fat. The effectiveness of tannins in limiting BCFAs occurrence may have been further enhanced by the saponins provided by alfalfa included in the basal diet. Indeed, the effect of tannins and saponins was found to be additive in decreasing microflora fermentation in rumen (Makkar et al., 1995). In addition, tannins with low molecular weight have been reported to have greater inhibitory effects on rumen bacteria (Patra & Saxena, 2011). HT are characterized by a lower molecular weight than the CT (500-3000 Da compared to 1000-20000 Da, respectively; Frutos et al., 2004) and this may explain the numerically lower content of BCFAs in kidney fat provided from lambs fed TA and CH compared to the fat from MI group. The effectiveness of HT from chestnut was also noted by Buccioni et al. (2015) who reported lower concentration of several branched chain fatty acids in milk from ewes fed a diet added with chestnut HT (80 g/kg as diet). Together with 4-MOA, 4-MNA and 4-EOA, commonly regarded as key compounds responsible for mutton and sheep flavours and odours, 8-methylnonanoic acid is also reported to confer “sheepy” odour notes (Brennand & Lindasay; 1992) when occurring at a concentration of 10 μg/g. The sheep odour intensity in kidney fat from CON group, perceived at a significantly higher level than tannins treatments, may have been enhanced by the 8-methylnonanoic content that reached a concentration of 10.97 μg/g fat (Table 5). In addition, short chain fatty acids are reported to be also responsible for the

presence of certain off-flavours, described as pungent (Rius et al., 2005), an attribute clearly distinguished in CON-fed lambs.

Indole and skatole

Data relating to the indole and skatole content in perirenal fat are shown in Table 6. Fat from all dietary treatments was characterized by a numerically higher indole content compared to skatole, a finding in line with previous study in which a decreased skatole, but not indole level, was observed in the caudal fat of lambs supplemented with CT from quebracho (40 g/kg DM of tannic acid equivalents) (Priolo et al., 2009). Similarly, Girard et al. (2015) showed an effect of CT from sainfoin (*Onobrychis viciifolia*) in reducing skatole but not indole content in lamb perirenal fat. Indoles arises from tryptophan degradation, and its decarboxylation in the rumen forms indole and indole acetic acid, which is then converted to skatole (Prache et al., 2005).
Dietary treatments did not significantly influence ($P > 0.05$) skatole, indole nor their total amount in kidney fat. However, in comparison with CON group, an overall numerically less skatole and indole content in fat from lambs fed MI, TA and CH diet was observed. A subtle effect of tannins may be at play, limiting the pathway that leads to the formation of indole, and its successive conversion to skatole, by forming complexes with tryptophan and thus preventing its ruminal degradation. In addition, tannins with a low molecular weight, are reported to have a higher interaction capacity to form complexes with proteins (Frutos et al., 2004; Patra and Saxena, 2011) and the indoles trend observed for TA and CH group seemed to be in line with this statement.

Table 6. Indole, skatole and total indoles concentration (ng/g fat) in kidney fat from lambs fed control diet (CON) or diet integrated with mimosa (MI), tara (TA) or chestnut (CH) tannin extracts.

	Dietary treatment					
	CON	**MI**	**TA**	**CH**	**SEM**	**P-value**
Indole	25.41	19.12	14.16	15.78	1.802	0.163
Skatole	9.58	9.83	10.43	10.35	2.208	0.999
Total indoles	34.99	28.95	24.59	26.13	3.130	0.676

The basal diet of the animals can further contribute to explaining the overall results found for the concentration of indole and skatole. Indole content is generally reported to be low in the

concentrate-based diet, characterized by a low protein/non fibrous-carbohydrate ratio (Priolo et al., 2005). In fat from all dietary treatments, skatole concentration was lower than 50 ng/g which is considered as a critical threshold for the perception of the pastoral flavour (Watkins et al., 2014). It is therefore plausible that indoles had a limited effect on fat odour in this study.

5.4 Conclusions

An inclusion rate of 4% tannin extracts has reduced pastoral odour perception in perirenal fat of lambs the meat of which was characterized by a very low perception of this attribute.
It may be assumed that *p*-cresol and 8-methylnonanoic acid were the volatile compounds that mostly contributed to pastoral odour expression in the concentrate-based diet, without addition of condensed or hydrolysable tannins. Further research efforts could be addressed to investigate the effect on volatile compounds of tannins added to different basal diets, such as those based on forages or enriched with lipids.

6. General conclusions and implications

Small ruminants can be an important resource for satisfying the growing demand of products of animal origin, mainly in developing countries where there will be the greatest growth of the world population in the next years. Moreover, sheep and goat are not competitive with humans for food, they can exploit forage of low nutritional value and marginal areas, and are particularly resilient and adaptable to the environment, which is an interesting characteristic in light of possible future scenarios of climate change. Their meats have characteristics that can meet the expectations of a consumer who is ever more aware of the health and nutraceutical aspects of food. Indeed, the meat from small ruminants is an important source of protein of high biologic value and contains some compounds that are considered bioactive such as taurine, carnosine, coenzyme Q, creatine, and creatinine. The meat fat is rich in essential fatty acids such as α-linolenic and, within the meats of different species, small ruminants show the higher levels of conjugated linoleic acids thanks to the frequent use of pasture. Moreover, these meats are an important source of minerals and vitamins with particular regards to iron, which is also highly available for humans, and Vitamin B12, which is synthesized by ruminal bacteria.

However, small ruminant meat, particularly sheep, has several characteristics that clearly differentiate it from meat provided from other species, including a distinctive "pastoral" flavour that may be considered as unpleasant by some consumers.

In the experimental section of the thesis, the influence of cardoon meal and tannins extracts on pastoral flavour were investigated.

Cardoon meal is an agro-industrial by-product that, in line with a circular bio-economy approach, may be successfully exploited as an ingredient in lamb diets. We demonstrated that the inclusion of this by-product, in substitution of dehydrated alfalfa, reduced the "animal/barnyard odour" perceived in the kidney fat, which could be linked with the aromatic compound *p*-cresol detected only in in fat from lamb fed with the control diet. This result suggest that cardoon meal may successfully be added to lambs' diet in order to ameliorate the sensory quality of their meat.

As found using cardoon meal, also dietary inclusion of tannin extracts reduced pastoral odour perception in kidney fat of lambs the meat of which was characterized by a very low perception of this attribute. Together with the odour - active compound *p*-cresol, also the short-branched fatty acid 8-methylnonanoic has been assumed as the main responsible for the pastoral odour clearly perceived in the fat provided from lambs fed a diet without tannins. Nevertheless, the effects of tannins are not always predictable, since the chemically and physically characteristic of the basal diet appear to be discriminant for ensure secondary compound activity. Thus, further research effort could be addressed to investigate the effect of tannins added to different basal diets such as those based on forages or enriched with lipids.

7. Publications

International journals

Del Bianco, S., Natalello, A., Luciano, G., Valenti, B., Monahan, F., Gkarane, V., Rapisarda, T., Carpino, S. & Piasentier, E. (2020). Influence of dietary cardoon meal on volatile compounds and flavour in lamb meat. Meat Science, 163, 108086.

Corazzin M., Del Bianco S., Bovolenta S., Piasentier E., 2019. Carcass characteristics and meat quality of sheep and goats. In: J.M. Lorenzo, P.E.S. Munekata, F.J. Barba and F. Toldra (Eds) More than Beef, Pork and Chicken - The Production, Processing, and Quality Traits of Other Sources of Meat for Human Diet. (Springer, Springer Nature Group, Cham, Switzerland), 119-165.

Submitted

Del Bianco, S., Natalello, A., Luciano, G., Valenti, B., Campidonico, L., Biondi, L., Monahan, F., Gkarane, V., Favotto, S., Sepulcri, A. & Piasentier, E. Influence of dietary inclusion of tannin extracts from mimosa, chestnut and tara on volatile compounds and flavor in lamb meat. Submitted to Meat Science.

Others

Piasentier, E., Corazzin, M., Del Bianco, S., Favotto, S., Foletto, V., Saccà, E., Sepulcri, A. Qualità della carne della Pezzata Rossa. In: La Pezzata Rossa in Friuli Venezia Giulia: Innovazione di processo e di prodotto per sviluppare la filiera della carne di qualità. A cura di E. Piasentier. Sozooalp editore, Udine, 2019, 66-84.

Favotto, S., Del Bianco, S., Piasentier, E. Qualità dell'hamburger di Pezzata Rossa. In: La Pezzata Rossa in Friuli Venezia Giulia: Innovazione di processo e di prodotto per sviluppare la filiera della carne di qualità. A cura di E. Piasentier. Sozooalp editore, Udine, 2019, 114-122.

International conferences

Del Bianco, S., Favotto, S., Sepulcri, A., Piani, B., Campidonico, L., Salami, S., Valenti, B., Luciano, G., Filoso, F., Piasentier, E., 2017. Effect of tannins on indoles content and pastoral flavor of lamb meat. In: Proceedings of FAO-CIHEAM Network on sheep and goats. 3-5 October, Vitoria-Gasteiz, Spain.

Favotto, S., Del Bianco, S., Sepulcri, A., Piani, B., Campidonico, L., Salami, S., Valenti, B., Luciano, G., Filoso, F., Piasentier, E., 2017. Effetto dell'integrazione alimentare con tannini di diversa natura sul contenuto di scatolo e indolo e sul profilo sensoriale del grasso e della carne di agnello. In: Atti del VI convegno nazionale della Società Italiana di Scienze Sensoriali.30 novembre-01dicembre 2016, Bologna, Italy.

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