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Fatty acid profile of meat and milk from small ruminants: a review

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ABSTRACT - Increased knowledge of fatty acid metabolism and signaling capabilities of such molecules led researchers to identify specific FA that are capable of diminishing the risk for occurrence of some pathological states. Some fatty acids naturally occurring in ruminant products, such as vaccenic acid and CLA were shown to exert positive impact on human health. Dietary source of fatty acids and production systems are the main factors affecting the fatty acid profile of ruminant products. The biological effect of such molecules is FA specific and, therefore, not all *trans* fatty acids produce the same biological response - ruminant products are correlated with a profile of *trans* fatty acids not detrimental to humans. Grass-based diets increase the percentage of CLA and *n*-3 fatty acids, which ultimately result in lower *n*-6/*n*-3 ratio. Supplemental lipids are other alternative, and more efficient, to increase polyunsaturated fatty acids in meat and milk. The organoleptic properties of ruminant products may decrease as the percentage of long chain polyunsaturated fatty acids increases. Future research should characterize feedstuff from semiarid regions that are capable of improving the profile of fatty acids in meat and milk from small ruminants.

Key Words: goat, lamb, genotype, semiarid, pasture

Perfil de ácidos graxos no leite e na carne de pequenos ruminantes: revisão

RESUMO - O avanço do conhecimento sobre o metabolismo de ácidos graxos e suas capacidade de agir como mensageiros moleculares levou pesquisadores a identificar os ácidos graxos capazes de diminuir o risco de estados patológicos. Alguns ácidos graxos encontrados naturalmente no leite e na carne de ruminantes são benéficos à saúde humana. Fontes dietéticas de ácidos graxos e sistemas de produção são os principais fatores que afetam o perfil de ácidos graxos do leite e carne de ruminantes. O efeito biológico dessas moléculas é específico a cada ácido graxo e, portanto, nem todos os ácidos graxos *trans* exercem o mesmo efeito no metabolismo — produtos oriundos de ruminantes estão correlacionados com um perfil de ácidos graxos *trans* não deletérios à saúde humana. Dietas a pasto aumentam a porcentagem de isômeros de CLA e ácidos graxos *n*-3, consequentemente diminuindo a relação *n*-6/*n*-3. Fontes de lipídio suplementar são outra forma de aumentar mais eficientemente os ácidos graxos poliinsaturados no leite e carne. As propriedades organolépticas desses alimentos podem diminuir com o aumento do teor de ácidos graxos poliinsaturados de cadeia longa. Pesquisas futuras deveriam caracterizar os alimentos oriundos do semiárido capazes de melhorar o perfil de ácidos graxos da carne e leite de pequenos ruminantes.

Palavras-chave: caprino, ovino, genótipo, semiárido, pasto

Introduction

The increased knowledge of the implication of some minor compounds in the diet, such as vitamins, fatty acids (FA), and flavonoids, on health has led consumers to demand for naturally enriched food products. Fatty acids (FA) are one of these nutrients that were shown to improve human health, particularly some FA that only occur naturally on ruminant products. Additionally, the identification of FA as signaling molecules, capable of triggering metabolic pathways that ultimately could result in changes in the risk for occurrence of disease has created an enormous interest in enriching food with such molecules.

The biohydrogenation (BH) of dietary FA by ruminal microorganisms results in a wide variety of FA that reaches the small intestine for absorption, which are ultimately incorporated into meat and milk. Ruminant products are characterized by higher content of saturated fatty acids (SFA) and moderate to lower concentration of monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA). Ruminant lipids are among the richest natural sources of *trans*-octadecenoic acids and

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conjugated linoleic acid (CLA) isomers; also, some of these FA were shown to decrease cholesterol and may affect sensory attributes of meat.

Milk and meat of small ruminants can be an important source of food in many countries, particularly in some regions of Brazil. Brazilian goat and sheep herd sized 7.1 and 13.8 million heads, respectively (IBGE, 2006), with greater social and economical impact in the South and the Northeast of Brazil. Many factors can be implicated in the FA composition of small ruminants, such as breed, sex, live weight, environment, diet, degree of fatness and interaction between these factors (Juárez et al., 2008). Diet was shown to be the main factor influencing FA composition of lamb fat (Wood et al., 2004; Schmid et al., 2006). Research data on factors affecting meat FA composition in small ruminants have already been reviewed (Banskalieva et al., 2000; Wood et al., 2008; Wood et al., 2004). The parameters used to determine a desirable FA composition are mainly the percentage of *trans* FA, CLA, PUFA, essential FA (EFA), long chain polyunsaturated *n*-3 fatty acids (LC*n*-3PUFA), and the *n*-6/*n*-3 ratio.

The metabolism of *n*-3 and *n*-6 series FA in ruminants is different from non-ruminants because of ruminal BH and the requirement for essential FA (EFA). Describing the tissue (muscle or adipose tissue), lipid class - neutral or polar - from which the FA profile was determined is critical in scientific research.

Supplements and/or production systems are the factors most studied since they seem to have the greatest impact on meat FA. Scientific data regarding neutral and polar lipids of goat meat raised in semiarid regions is very limited. Because the profile of FA affects meat and milk quality, this review will address the main factors affecting FA and lipids subclasses of small ruminant products.

Extraction and derivatization of fatty acids

Precise and accurate quantification of the FA profile from biological samples is extremely challenging, and relies in a multistep process: adequate storage, therefore FA are well preserved, lipid extraction, derivatization (methylation, for instance) of FA, identification and quantification of the derivatized molecules.

These chemical molecules are seldom present in biological samples as free FA (FFA), they are much more often found in other lipid structures, such as triacylglycerides (TAG; storage), phospholips (PL), glycolipids (GL), and others. In milk, the percentage of total FA found as TAG is large and relatively constant, about 98% (Jensen, 1996). On the other hand, the same is not true for muscle (without subcutaneous fat), in which FA are distributed mainly between PL and TAG fractions, but the percentage of total FA in each fraction is very variable (Insausti et al., 2004). Genotype, muscle type, and nutrition that impacts degree of marbling can therefore change the distribution of FA across lipid structures in muscle.

The first challenge is to efficiently separate FA that are present in the different lipid molecules, neutral (TAG) and polar lipids (PL, FFA, esfingolipids). Because, for most biological samples, the distribution of FA within each lipid structure is unknown and variable, the ideal method should be equally efficient in extracting all of these fractions. Therefore, the solvent must be polar enough to remove lipids from cell membranes and tissue, but not excessively polar that nonpolar lipids, such as TG, are not dissolved (Iverson et al., 2001). In order to accomplish such task, mixture of solvents has been utilized in most extraction methods; traditionally, the chloroform/methanol/water phase systems have been widely and successfully used by most laboratories to extract lipids from tissues and milk. The Folch and Bligh and Dyer methods are by far the most utilized protocols for lipid extraction (Bligh & Dyer, 1959; Folch et al., 1957). These methods are based on the principle of forces available in a ternary system, in which, depending on the ratio of solvents, monophasic or biphasic systems are produced and, therefore, extraction and separation of molecules can be accomplished.

The second challenge is to efficiently and equally derivatize FA that are present in different lipid structures. Briefly, methylation (main derivatization method) of FA can be accomplished by utilizing alkaline or acid catalyzing solutions; however, these solutions are selective towards the lipid structure in which the FA is available. Acid catalyzed methylation has the advantage of being efficient in methylating FA present in any lipid structure, such as FFA, TG, PL and others. Although, it has the disadvantage of producing double bond migration (e.g., isomerization of conjugated dienes), particularly when high temperatures are utilized and, hence misrepresenting the FA profile of a sample. Base catalyzed methylation does not esterified FFA (only transesterifies), working well in FA moieties from TAG and PL molecules (Kramer et al., 1997), as well as it preserves to the best way possible the original structure of conjugated dienes. Because the conjugated dienes and other *trans*-isomers have been the focus of most scientific researches lately, base catalyzed methylation or a combination of base-acidic methylation (Kramer et al., 1997) for samples rich in FFA are preferred. The use of internal standard is not widely common, but it is desirable so quantification of FA can be accomplished. The ideal internal standard should resemble the original lipid structure as much as possible, because it will behave similarly during extraction, and it is particularly important during the methylation process. Therefore, FFA are not the ideal internal standard for quantification of FA in oils, meat, and milk. Most of FA are in the TAG or PL fractions in these materials, therefore internal standard in the TAG form are recommended.

Once FA methyl esters (FAME) are obtained utilizing a reliable methylation method, separation and quantification of FAME needs to be accomplished. The use of standard mixtures of FAME with known concentration is necessary for identification of peaks and for correction of detector response. Not all FA generates the same response in a detector. Even though the concentration is the same, because response is different, so will be the area of the chromatogram. If correction is no properly performed, underestimation of FA concentration in the biological sample will result.

Human dietary fat intake

Some FA found in milk TAG have been shown to exert positive impact on human health such as a cardioprotective effects through a direct vascular antiatherogenic action (Castro et al., 2009). As a consequence, there is much current interest in adding value to meat, milk, and dairy products by increasing levels of specific FA, which are thought to be beneficial for human health (e.g., CLA). Moreover, consuming a greater proportion of these beneficial FA as part of an everyday diet may be appealed to the public (Bernard et al., 2009).

Dietary intake of unsaturated fatty acids (UFA) can be associated with a reduction of risk for cardiovascular diseases (CVD), decrease incidence for some type of cancers, diabetes, and other conditions. Although ruminant products are important sources of nutrients, their relative high content of SFA has been criticized and linked with an increase in on totalcholesterol and, consequently, associated with CVD.In fact, 12:0, 14:0 and 16:0 are associated with an increased risk for CVD (Ulbricht & Southgate, 1991).

Mensink et al. (2003) did a meta-analysis with 60 controlled trials evaluating 159 diets with 1672 total volunteers and different classes of FA: SFA, *cis*-monounsaturated FA (*c*-MUFA), *cis*-polyunsaturated FA (*c*-PUFA) and *trans*-monounsaturated FA (*t*-MUFA). This study evaluated the effects of isocaloric substitution of carbohydrates (1% of the dietary energy) by SFA, *c*-MUFA, *c*-PUFA, and *t*-MUFA on serum cholesterol fractions (Figure 1). There were almost no effect of SFA and it is clear the anti-CHD effect of *c*-MUFA and PUFA, but there was an increased risk factor for CHD by *trans*-FA (*t*-MUFA). However, within the SFA group, there was an effect of individual FA on the risk of cardiovascular diseases. The main SFA found in milk fat (12:0, 14:0, 16:0 and 18:0) doesn't seem to increase risk fact or for CHD (Figure 2).

A higher concentration of PUFA and a lower *n*-6/*n*-3 ratio are related to a reduction on CVD risk factor (Givens et al., 2006; Wood et al., 2004), while CLA is associated to a lower risk of diabetes, heart attack, and cancer (Givens et al., 2006; Mourão et al., 2005). Webb et al. (2005) and Nuernberg et al. (2004) reported that the recommended *n*-6/*n*-3 should be lower than 5:1. Feeding strategies and dietary factors can affect the CLA and *trans*18:1 isomers of meat and milk fat. Given that CLA is produced naturally in ruminant animals, a rational approach to increase milk fat CLA levels may be to increase the dietary intake of UFA, the substrates for CLA synthesis in the rumen (Gomez-Cortes et al., 2008). Supplementation with plant oils and oilseeds with a high linoleic acid content has been confirmed as an effective nutritional strategy to enrich ruminant milk fat with *cis*-9, *trans*-11 18:2 - the biologically most active CLA

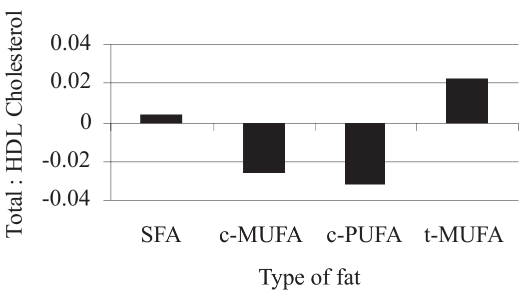

Figure 1 - Predicted changes in serum total/HDL cholesterol ratio when carbohydrates (1% the energy of the diet) are replaced by different classes of fat. c-MUFA and c-PUFA (P<0.001), t-MUFA (P<0.01). Adapted from Mensink et al. (2003)

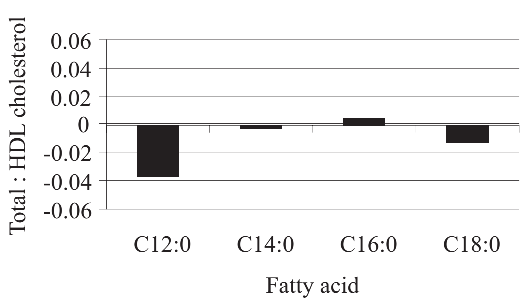

Figure 2 - Predicted changes in the serum ratio of total to HDL cholesterol ratio when carbohydrates (1% the energy of the diet) are replaced by individual fatty acids. 12:0 (lauric acid, P<0.001). Adapted from Mensink et al. (2003).

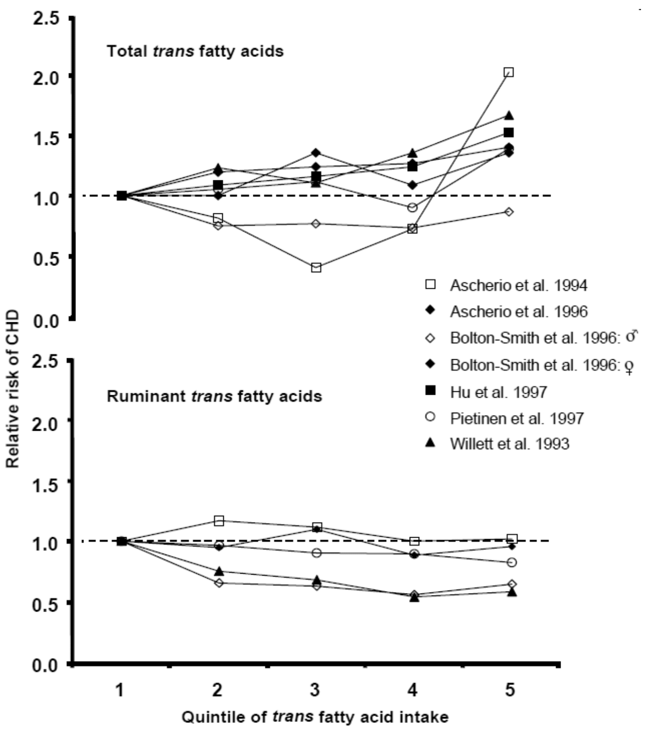

Figure 3 - Relative risk of coronary heart disease (CHD) with increasing relative intake of total or from ruminant products *trans* fatty acids. Adapted from Lock et al. (2005).

isomer - and *trans*-11 18:1 (vaccenic acid), its precursor in the mammary gland (Palmquist et al., 2005).

Milk fat contains mainly monounsaturated 18:1 isomers and also *trans*-octadecadienoic acids as CLA isomers. The detrimental effects of *trans* FA to human health are intensively covered in the media and well known by consumers; one scientific data that supports such statements is shown on Figure 1. However, as pointed by Lock et al. (2005), most epidemiological studies that shown *trans* FA unhealthy to humans made no distinction regarding the source of fat (hydrogenated vegetable oils or ruminant fat). Figure 3 shows that, depending on the source (industrial or ruminant products) of *trans* FA, they have differences regarding their relative risk of CHD.

Also, essential fatty acids (EFA), especially the LC*n*-3PUFA are advocated to be deficient in western diets and; hence, their intake should be increased by humans (Simopoulos, 2002). However, those FA are biohydrogenated in the rumen, leading to a lower concentration in ruminant products compared to nonruminants. Despite that, meat and milk of small ruminants may be a good source of healthy FA. However, more research is need to evaluate the biological effects of individual FA on parameters and variables used as markers involved on the risk of cardiovascular diseases.

Background on rumen metabolism

Several factors are known to affect the BH pattern in the rumen, including forage to concentrate ratio, level and type of lipid supplementation, ionophores etc (Bessa et al., 2005; Bessa et al., 2000; Daley et al., 2010; Jenkins, 1993). The main PUFA in ruminant diets are linoleic acid (18:2 *n*-6) and linolenic acid (18:3 *n*-3), usually available in grains and forages. Both FA are extensively biohydrogenated in the rumen, resulting in a higher outflow of 18:0 to the duodenum than the actual intake of 18:0 as well FA intermediates of BH. The 18:1 *trans*-11 (vaccenic acid; VA) and the 18:2 *cis*-9, *trans*-11 (rumenic acid) are the main *trans*-octadecenoic and conjugated dienes in ruminant

Table 1 - Effect of oil supplementation on fatty acid profile of milk from goat and ewes

References	Species	Oil supplemented	% inclusion	% of change							
				12:0	14:0	16:0	CLA[1]	18:3 *n*-3	SFA	UFA	UFA/SFA
Gómez-Córtes et al. (2008)	Ewes	Soybean	6	-42.0	-31.3	-20.3	230	31.4	-21.0	71.1	117
Gómez-Córtes et al. (2011)	Ewes	Olive	3	-35.5	-15.4	-20.4	185	-13.3	-16.0	54.4	83.8
		Soybean	3	-39.3	-20.0	-20.4	648	11.1	-19.0	64.4	103
		Linseed	3	-30.4	-10.9	-24.2	380	106.7	-14.5	49.3	74.7
Castro et al. (2009)	Ewes	Soybean	1.2	5.52	3.22	-1.22	29.1	31.3	-0.71	1.94	2.67
Bernard et al. (2009)											
	Goat	Sunflower	6.3	-45.5	-32.9	-37.1	423	-21.1	-25.2	84.7	147
Bernard et al. (2005)											
Goat		Formaldehyde linseed	11.2	-37.6	-26.1	-28.0	41.6	138.5	-12.6	36.9	56.6
		Oleic sunflower	3.5	-41.3	-26.8	-30.5	16.9	-28.1	-13.2	40.8	62.1
Bouattour et al. (2008)	Goat	Soybean	6	-31.8	-23.2	-17.8	199	-10.1	-11.5	31.9	49.0
Matsushita et al. (2007)											
	Goat	Soybean	3	-14.9	-4.50	6.34	-	62.9	-2.51	7.22	10.0
		Canola	3	-15.1	6.89	-2.54	-	-37.6	3.74	-6.33	-9.70
		Sunflower	3	-15.1	9.19	-0.13	-	49.2	-0.43	0.80	1.24

[1] *cis*-9, *trans*-11 18:2.

fat, respectively (Bessa et al., 2005). The VA is the main precursor of rumenic acid (Palmquist et al., 2005), a CLA isomer known to have anticarcinogenic properties (Givens et al., 2006; Mourão et al., 2005).

The biological function of FA in meat and milk are quite different; the later is a source of energy and EFA. Both, the profile of FA and enzyme activity related to FA synthesis, are also different. Therefore, nutritional management and the most important FA in milk and meat will be discussed separately.

Milk fatty acids

Milk fat represents the major energetic component of milk; it is an important component that contributes to the physical, organoleptic, and manufacturing properties of dairy products (Chilliard et al., 2003; Shingfield et al., 2010). In the last decades, consumers became more aware about the links between nutrition and health, and the importance of ruminant fatson development and/or prevention of cardiovascular disease, cancer, insulin resistance, and Alzheimer, was extensively highlighted by many media sources.

The fat content and FA composition of ruminants' milk can be modified through the diet (Table 1); therefore, the understanding of ruminant's digestive system, milk fat synthesis and regulation are critical for development of feeding strategies that can be useful for the production of milk with a healthier nutritional composition. In the following sections, we will address how rumen metabolism and dietary management can be used to alter milk composition and FA profile in lactating goats and ewes.

Table 2 - Fatty acid composition of bovine, caprine, and ovine milk fat

	Composition (g/100g fatty acids)		
Fatty acid	Bovine	Caprine	Ovine
4:0	3.88	2.64	2.18
6:0	2.49	2.11	2.39
8:0	1.39	2.41	2.73
10:0	3.05	9.35	9.97
12:0	4.16	5.35	5.00
14:0	11.4	12.0	9.81
14:1 *cis*-9	1.11	0.24	0.18
16:0	29.4	27.5	28.2
16:1 *cis*-9	1.94	0.76	1.43
18:0	11.4	6.92	8.88
18:1 *cis*-9	21.9	16.4	17.2
18:1 *trans*-11	0.28	0.72	0.78
18:2 *cis*-9, *cis*-12	1.94	1.99	3.19
18:3 *cis*-9, *cis*-12, *cis*-15	0.55	0.96	0.42
Saturated	70.1	74.7	72.4
Monounsaturated	25.8	20.4	22.0
Polyunsaturated	3.32	2.93	4.31

Adapted from Shingfield et al. (2008).

Goat milk composition

The regulation of "*de novo*" FA synthesis and elongation in the mammary is different between goats and cows. Goat milk has a higher percentage of medium chain FA (i.e., 8:0 and 10:0; MCFA) and less butyric acid (4:0) than cow's milk (Table 2), and the UFA may contain one or more *trans* double bonds (Chilliard et al., 2003).

Mammary lipogenesis

Caprine and ovine milk contain around 3 to 5% and 4 to 11% fat, respectively, (Givens & Shingfield, 2006; Pulina et al., 2006). Milk fat globules are comprised mainly by TAG that has saturated FA with chain lengths with 4 to 18 carbon atoms, palmitoleic acid (16:1 *cis*-9), oleic acid (18:1 *cis*-9), *trans*-18:1 FA , and linoleic acid (18:2*n*-6) being the most abundant (Jensen, 2002). Milk FA are derived from two sources: synthesized by the mammary gland mainly from acetate (short to medium chain - 4:0 to 16:0) or incorporated in the TAG preformed from the blood stream (16:0 and < 16:0; Figure 4).

The esterification of FA to glycerol during the TAG synthesis is not random. The stereospecificity of acyl moieties in the TAG molecule may play a role on the percentage of esterified FA in milk (TAG) and meat fat (polar and neutral lipids). As pointed by Jensen (2002), 56 and 62% of medium to long chain SFA (10:0 to 18:0) are esterified at the *sn*-1 and *sn*-2 positions, while 18:0 is preferentially esterified at the *sn*-1. The FA 8:0, 10:0, 12:0 and 14:0 are, preferentially, esterified at the *sn*-2 position, and the SCFA (4:0, 6:0, 8:0) and oleic acid (18:1 *cis*-9) at the *sn*-3 position in the TAG molecule. According to Hawke & Taylor (1995), the distribution of FA between *sn*-1 to *sn*-3 positions is related to regulation of milk fat fluidity.

Effect of fatty acid supplementation on milk fatty acids of goats and ewes

Chilliard et al. (2003) summarized the effects of fat supplementation in diets naturally low in lipids (alfalfa hay and hay plus beet pulp) with different fat sources (saturated free FA, calcium salts, animal fat, vegetable oils, free or encapsulated oils, oilseeds - whole, crushed, extruded or formaldehyde-treated) in early, mid and late lactating goats. Most of the studies showed that milk fat content was increased by fat supplementation, which differs from the responses observed in cows. Bernard et al. (2009) supplemented dairy goats fed a corn silage base diet with 6.3% of DM as sunflower oil and found an increase in milk fat content (0.6%) and larger output of 18:0 (96.7%), 18:1

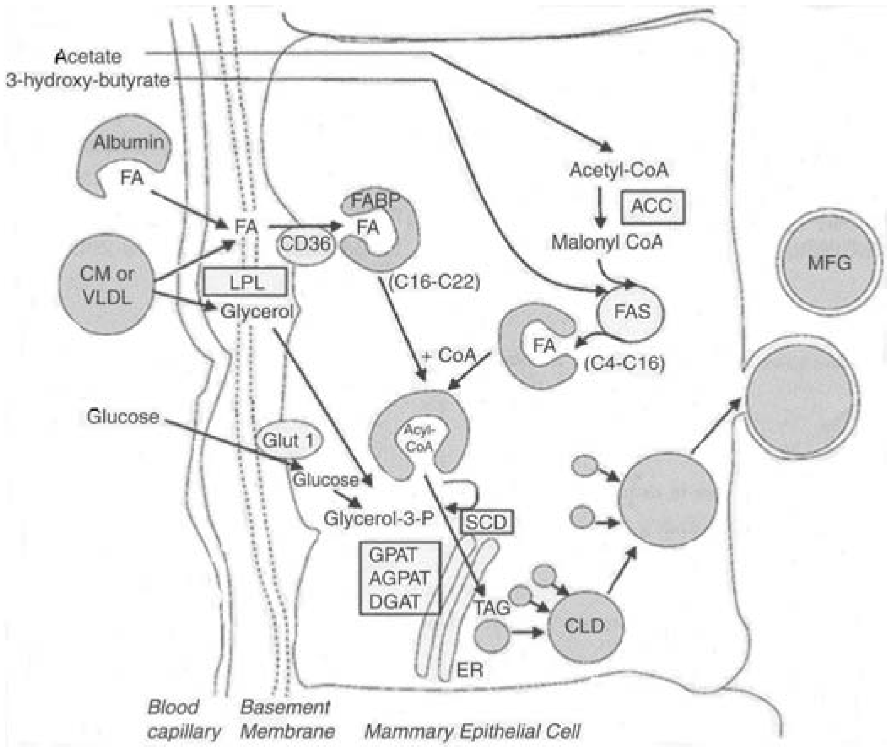

Figure 4 - Milk fat synthesis in bovine mammary gland, were: ACC, acetyl-CoA carboxylase; AGPAT, 1-acylglycerol 3-phosphate acyl transferase; CD36, cluster of differentiation 36; CLD, cytoplasmic lipid droplet; CoA, coenzyme A; CM, chylomicron; DGAT, diacylglycerolacyltransferase 1; ER, endoplasmic reticulum; FA, fatty acid; FABP, fatty acid binding protein; FAS, fatty acid synthase; GLUT 1, glucose transporter 1; GPAT, glycerol-3-phosphate acyl transferase; LPL, lipoprotein lipase; MFG, milk fat globule; SCD, stearoyl-CoA desaturase; TAG, triacylglyceride; VLDL, very low density-lipoprotein. (Adapted from Shingfield et al., 2010).

(22.0%), 18:1 *trans*-10 (682%), 18:1 *trans*-11 (674%), CLA *cis*-9, *trans*-11 (422.7%) and CLA *trans*-10, *cis*-12 (1,500%) into milk.

Supplementation of lactating ewes fed an alfalfa hay based diet with 6.0% of DM as sunflower oil increased the yield of fat in milk by 10% compared to a control group that received no supplemental fat (Hervas et al., 2008). The output of 14:0 (1.3%), 18:0 (62.8%), 18:1 (55.7%), 18:1 *trans*-10 (622%), 18:1 *trans*-11 (374%), CLA *cis*-9, *trans*-11 (282.9%) and CLA *trans*-10, *cis*-12 (600%) were increased into milk. Lactating dairy ewes fed alfalfa hay and supplemented with 6.0% of DM as soybean oil produced milk with 5.9% more fat (Gomez-Cortes et al., 2008), but the secretion of 14:0 (28.3%) and 16:0 (16.7%) were reduced, while secretion of 18:0 (63.3%), 18:1 (31.3%), 18:1 *trans*-10 (233%), 18:1 *trans*-11 (211%), CLA *cis*-9, *trans*-11 (230.7%), and CLA *trans*-10, *cis*-12 (700%) were increased.

In bovines, diets rich in PUFA, mainly oleic and linoleic acid, and fermentable carbohydrates can result in an increase of intermediates of BH, such as 18:1 *trans*-10 and *trans*-10, *cis*-12 CLA. Baumgard et al. (2002)demonstrated that abomasum infusion of small amounts of *trans*-10, *cis*-12 CLA reduced the mammary lipogenesis in lactating cows. De Veth et al. (2004) showed that the milk fat synthesis decrease in a curvilinear manner (dose dependent) in cows with *trans*-10, *cis*-12 CLA infused abomasally and the maximum reduction in milk fat yield (around -50%) was achieved when the *trans*-10, *cis*-12 CLA concentration in milk fat was 0.8%. The use of unprotected CLA supplements in dairy ewes showed no relationship between CLA dose and milk fat content (Oliveira, unpublished data; Figure 5).

We observed similar response in lactating goats (Figure 6), no relationship between the concentration of *trans*-10, *cis*-12 CLA in milk fat and changes in milk fat yield in goats fed corn silage based diets.

Lock et al. (2007) infused *trans*-10 18:1 isomer in lactating cows for 4 days which increased the concentration of this isomer in the milk fat but with no effect on milk fat content, suggesting no anti-lipogenic effect on the mammary gland. Recently, post-ruminal infusion of higher doses of *trans*-10 18:1 showed 21.3% of reduction on milk fat content (Shingfield et al., 2009).

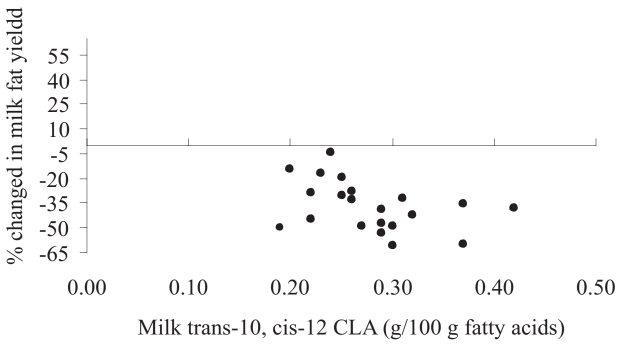

Figure 5 - Relationship between increase in milk fat *trans*-10, *cis*-12 CLA content and changes in milk fat yield in lactating ewes (●, n= 22). Source: Oliveira, unpublished data.

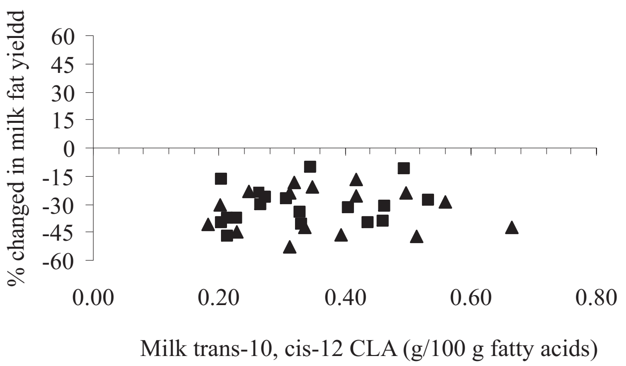

Figure 6 - Relationship between increases in milk fat *trans*-10, *cis*-12 CLA content and changes in milk fat yield in lactating goats (■, forage + concentrate, n = 19; ▲, TMR, n = 16). Source: Oliveira, unpublished data.

Although there is not as many data on flow of FA to duodenum on small lactating ruminants as on dairy cows, the limited data available suggests that 18:1 *trans*-10 does not cause reductions on the milk fat content from goats and sheep. On the same range of concentration of18:1 *trans*-10 in milk fat, diets that could caused reduction in milk fat content from cows do not cause changes in concentration of fat in milk from lactating goats and ewes (Figure 7).

According to Figure 7, higher concentrations of *trans*-10 18:1 in milk fat of goats and ewes does not decrease milk fat, as observed in cows, suggesting that the mammary gland of caprines and sheep are much less responsive to the anti-lipogenic effects of *trans* FA and/or the ruminal metabolism BH pathways are different between lactating cows, goats and ewes.

Small ruminant meat fatty acids

Although goat meat is leaner than beef and lamb, meat fat from both species respond similarly to dietary management. The FA profile of meat lipids (polar and neutral) has a greater impact on its quality, sensorial characteristics, consumer acceptance, and healthy benefits for humans. Consequently, many studies have focused on the effect of nutritional management on FA profile of muscle and fat depots in ruminants. Among the parameters used to determine a desirable FA composition, the percentage of CLA and PUFA, *n*-6/*n*-3 ratio, UFA/SFA ratio, and LC*n*-3PUFA (i.e., DHA and EPA) are the most widely researched.

Beneficial fatty acids in meat

An important question is whether the essential and/or beneficial FA content, expressed in mg/g of intramuscular fat, can be increased by specific feeding strategies or dietary components. As previously mentioned, the BH process allows ruminants to absorb and store many different FA that cannot be found in feedstuff and, therefore, are not ingested. In virtue of that, ruminants have a unique profile of FA in their tissue when compared to nonruminant species: more saturated, higher percentage of odd chain FA, *trans*-octadecenoic acids and CLA isomers. According to Schmid et al. (2006), the highest CLA concentrations were found in lamb (4.3-19.0 mg/g lipid) and slightly lower concentration in beef (1.2-10.0mg/g lipid). The content of pork, chicken, and meat from horses is usually lower than 1 mg/g lipid. Additionally, the ratio of *n*-6/*n*-3 is beneficially lower in ruminant meats, with reported values of 7.2, 2.1, and 1.3 for loin muscles of pork, beef, and lamb, respectively (Enser et al., 1996), although feed source and production system will both modify the magnitude of those values. The concentration of the LCPUFA are much lower in ruminant meat than fish; however, maintaining high *n*-3 levels in ruminant meat through grass feeding may be advantageous for human health (Enser et al., 1998).

Even so dietary FA are the major player determining the FA profile of small ruminant muscles, there is variation regarding muscle and fat depot within animal. Moreover, genotype, age, production system, and species (lamb and goat) have also an effect on the FA content. For instance, the content of 18:3*n*-3 as a percentage of total FA (lamb value followed by beef) was: *triceps brachi* 2.3 and 1.4; *gluteobiceps* 2.3 and 1.5 and *longissimus*1.9 and 1.2 (Enser et al., 1998).

Juárez et al.(2008) quantified the influence of interactions among anatomical depot location, fat depot, breed, feeding system, and fatness effects on the FA composition of five Spanish light lambs breeds based on descriptive statistical analyses. They concluded that the factors outlined above explain more than 60% of the

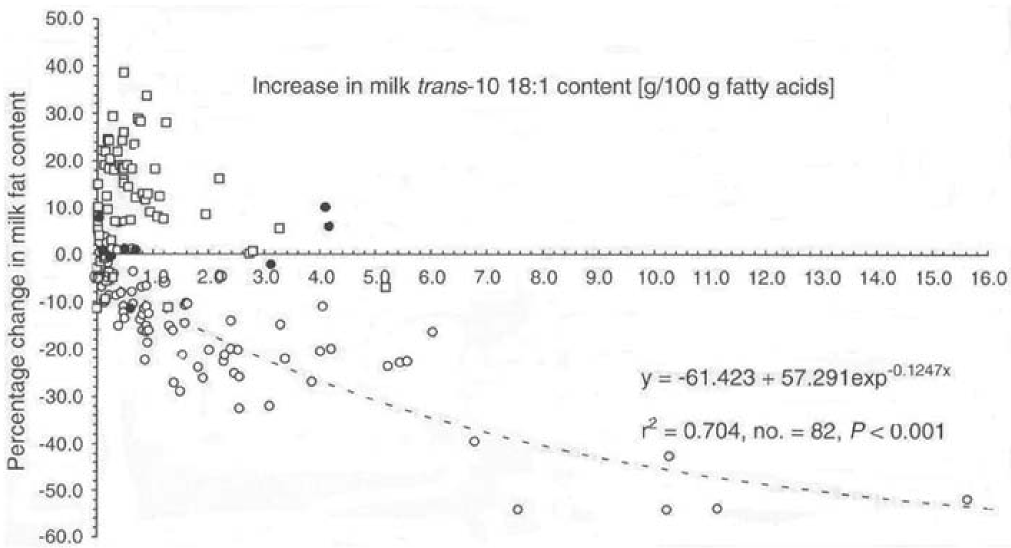

Figure 7 - Relationship between increase in milk fat *trans*-10 18:1 content and changes in milk fat content in lactating cows (○, n= 82), goats (□, n= 63) and ewes (●, n= 9). Fitted dotted line is the relationship between increases in 18:1 *trans*-10 content and relative changes in milk fat content in lactating cows. Adapted from Shingfield et al. (2010).

variation in most of the FA monitored. In addition, the production system as a combination of breed and diet was the main feature to elucidate variations in the FA profile. On the other hand, Werdi Pratiwi et al. (2006) demonstrated that the FA composition had no influence of breed on muscles of goats from different breeds (Boer and Australian feral goats), and similar observation with sheep (Pelegrini et al., 2007). These studies may suggest that FA profile is not directly related to breed or species, but species and breeds that generate leaner meat may increase PUFA as a percentage of total FA in meat (as discussed later).

Pasture and supplementation with vegetable oils and oilseeds provide, quantitatively and qualitatively, different FA being absorbed in the small intestine, altering the FA profile and sensorial characteristics of meat by increasing CLA, total PUFA, EFA, and LC*n*-3PUFA. Despite that, diets affecting an overall change in muscle and adipose tissue FA composition can be grouped in 3 major nutritional managements: pasture-based diets, grain-based, and grain-based diets supplemented with a source of FA.

Grass feeding versus grain/concentrate feeding

The overall effect of pasture on the profile of muscle FA is similar for both, caprine and ovine. Higher levels of CLA, linoleic and linolenic acids, and lower *n*-6/*n*-3 ratio were observed for grazing compared to grain-fed lambs (Nuernberg et al., 2008). Also, Bas et al.(2005) reported higher percentage of *n*-3 and PUFA for goats on pasture.However, the type of forage fed must be considered, because conserved forages have reduced levels of PUFA and *n*-3 FA (Atti & Mahouachi, 2009; Dewhurst & King, 1998).

Several studies have demonstrated significant differences in tissue FA profile when animals went from a concentrate-based to a pasture-based diet (Bessa et al., 2005; Daley et al., 2010; Pelegrini et al., 2007; Rhee et al., 2000; Ryan et al., 2007; Valvo et al., 2005). Grass-based diets lead to higher concentrations of *n*-3 intramuscular PUFA (Dewhurst et al., 2003; Dewhurst et al., 2006) and grain-fed diets (without oil supplementation) lead to higher concentrations of *n*-6 PUFA (Sanudo et al., 2000). Feeding pasture is more prone to improve *n*-3 and EFA because leaf tissues can have more than 75% of 18:3 *n*-3 (Ribeiro & Eastridge, 2006) esterified as GL (Hawke, 1973) and a *n*-6/*n*-3 ratio lower than 4:1 (Figure 8). Also, grazing ruminants have higher levels of EPA and DHA in their meat (Demirel et al., 2006; Scollan et al., 2006), what can be better achieved by fish oil/meal supplementation (Kouba & Mourot, 2011; Noci et al., 2007).

Meat of grazing cattle tends toward a higher proportion of 18:0 and less shorter SFA, such as 14:0 and 16:0, higher total CLA isomers, VA (18:1 *trans*-11), and *n*-3 FA on a g/g fat basis, as reviewed by Daley et al. (2010). In addition, the increase in meat CLA levels of grazing ruminant may even be greater with oil supplementation (Bessa et al., 2005; Santos-Silva et al., 2004). Furthermore, grazing also increases the antioxidant content of meat, albeit with variable impacts on overall

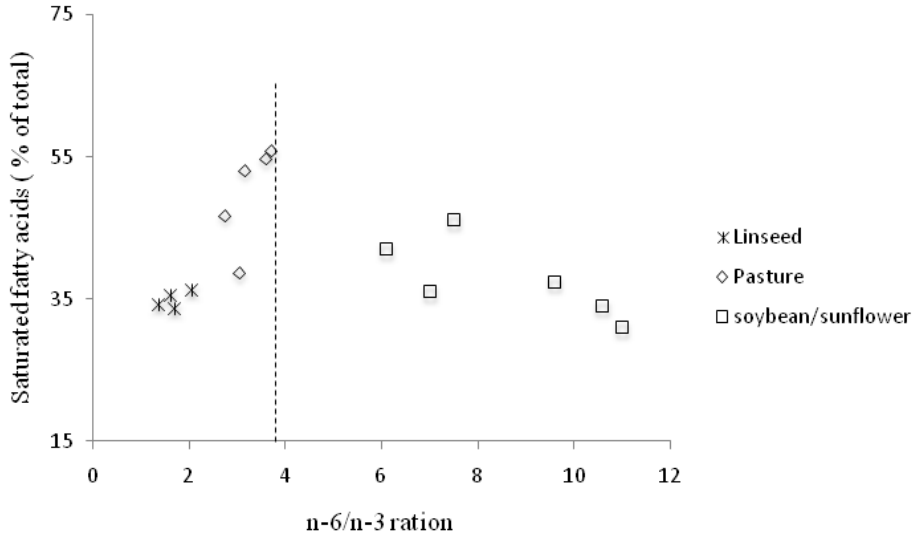

Figure 8 - Relationship between the *n*-6/*n*-3 ratio and the percentage of saturated fatty acids in meat from lambs fed different sources of fatty acids (pooled data from the literature; n=15). The dashed line represents the *n*-6/*n*-3 ratio of 4:1.

palatability (Bessa et al., 2005; Daley et al., 2010; Garcia et al., 2008; Schmid et al., 2006).

Lipid extracts from lean meat of range goats raised on multiple species of grasses and forbs (with no supplement) were more saturated than the corresponding extracts from goats fed grain-based diets (Rhee et al., 2000). The authors commented that the higher percentage of SFA for grass-based compared to grain-based diets seems to generally reflect the higher percentage of SFA observed in the range plants (mean of 34.9%) versus the grain diet (18.6%). In addition, finishing dietary regiment duration influencing meat FA is apparently limited just by the dietary strategy (Aurousseau et al., 2007). The authors investigated the time effect on pasture or feedlot on raising and/or finishing treatments and have shown that, independently of time (22 or 41 days), the real influence on FA composition was exerted by the dietary system (pasture or feedlot). Also, the authors reported decreases in 18:3 *n*-3 percentage in muscle neutral lipids observed after changing from grass feeding to feedlot feeding for both periods, and a decrease in proportions of conjugated 18:2 *cis*-9, *trans*-11 was obtained after the long period of concentrate feeding.

As also observed for milk fat, grass-fed ruminant species have been shown to store more *cis*-9, *trans*-11 18:2 in muscle fat than ruminants fed high grain diets.The VA absorbed by the enterocytes account for most of the 18:2*cis*-9,*trans*-11CLA isomer - by endogenous synthesis through stearoyl-CoA desaturase (SCD) activity- found in meat TG; hence, dietary management that increases VA flowing out of the rumen will provide a greater percentage of *cis*-9, *trans*-11 18:2 in milk and meat fat. A few hypotheses have been proposed to explain why VA is more absorbed by grazing ruminants, such as the role of protozoa delaying complete BH (Ribeiro et al., 2005), and the higher ruminal pH favoring *Butyrivibrio fibrisolven* (Daley et al., 2010) or, more likely, groups of bacteria related to the first step of BH. However, a discussion about this topic is beyond the scope of this review.

Comparing the quality traits and FA in lamb and goat meat from animals raised on similar dietary conditions (pasture supplemented with grain), Lee et al. (2008) found no significant differences in moisture, protein, and fat percentages in goat and lamb meat (*longissimus* muscle). However, the goat meat contained less concentration of SFA (49.2% versus 53.6%) than lamb. Although the authors concluded that goat (crossbred Boer x Spanish) may be healthier than lamb meat, the only significant difference observed in intramuscular fat was on oleic acid percentage, which should not be used alone as an indicator of a beneficial FA profile. Additionally, different breeds and production systems than the ones studied may contrast to the inference made by the authors.

Fatty acid supplementation

Concentrate-based diets supplemented with FA sources (oilseed or vegetable oil) may increase the percentage of PUFA in lamb and goat meat compared to grass-fed animals. Both, vegetable oils and oilseeds, show similar effects on FA content (Schmid et al., 2006). The addition of oilseeds to the diet has also proven to be an efficient method to increase CLA and PUFA in muscle total lipids (Table 3); nevertheless, the effects of oilseeds may differ. Additionally, the amount of the FA source supplemented may not be sufficient to alter the profile of FA stored in the tissue and/or the BH process may not be saturated. Santos-Filho et al. (2005) assessed the effect of 13% cashew nut bran supplementation in goat diet and did not observe an increase in the 18:1 *cis*-9 concentration (44.8%) in intramuscular (*Longissimus dorsi*) fat when compared to the control treatment (46.2%). The amount of supplemental oil must be considered to avoid decrease in DMI. Oil source, animal species, and forage source may determine the maximum amount of FA supplementation without adverse effect on the ruminal microbial ecosystem. Diets containing around 6% supplemental oil have been published for lambs (Boles et al., 2005; Jeronimo et al., 2010, 2009; Mir et al., 2000) and goats (Santos-Filho et al., 2005) without detrimental effect on growth. Also, Bessa et al. (2005) and Santos-Silva et al. (2004) added 8 and 10% soybean oil (between 10 and 14% EE) in lamb diets and did not observe decrease in animal performance.

In conclusion, feeding vegetable oil or oilseed has been shown to be the most effective dietary management to increase CLA and EFA in ruminant products. The profile and magnitude of change will depend mostly on level of inclusion, FA source, sources interaction, and feeding system. However, the increase in muscle CLA percentage is also a consequence of absorptive (BH process) and post-absorptive (SCD activity) factors.

Conjugated linoleic acid isomers

Comparing CLA levels in meat and milk with oilseed supplementation, enhancement the CLA content in meat is relatively low. For instance, Bolte et al. (2002) and Kelly et al. (1998) reported up to 0.98% and 2.44% of CLA (% of total fat) in meat of lambs fed safflower and milk of Holstein cows fed sunflower oil, respectively. This difference in CLA percentage between meat and milk may be associated to a lower amount of VA outflow from the rumen and/or a lower activity of the SCD in the intramuscular fat. However, supplementation of linoleic acid-rich sources, such as sunflower, in the diet of ruminants appears to be the most effective way to increase CLA concentration in meat (Khanal and Olson, 2004; Schmid et al., 2006). Dietary oilseed supplementation does not only increase CLA content, but also alters the FA composition of tissues. Concentrations of 18:1, 18:2, and 18:3 FA are increased as the intake of these FA also increases (Casutt et al., 2000). Supplementation with 6% of safflower oil increased 134% (Mir et al., 2000) and 306% (Boles et al., 2005) the CLA percentage in lamb muscle. Also, 8% to 10% addition of soybean oil to the diet promoted a 181% to a 331% increase in CLA of lamb muscle (Bessa et al., 2005; Santos-Silva et al., 2004).

Depending on tissue and lipid class, the percentage of CLA isomers can be quite different. Cooper et al. (2004) reported percentage of CLA two times greater for neutral lipids in comparison with PL in lambmuscle. However, the CLA content was similar between muscle neutral lipids and subcutaneous adipose tissue.

Table 3 - Effect of dietary fatty acids on lamb meat fat

Lipid source	Results	Author
Safflower oil	Increased CLA in various tissues of lamb	Mir et al. (2000), Boles et al. (2005)
Linseed oil	Increased *n*-3 fatty acids and decreased *n*-6/*n*-3 ratio in muscle of growing lambs	Kim et al. (2007)
Soybean and linseed oil	Did not increase CLA in muscle fat of lambs, but increased *n*-6 and PUFA levels	Radnuz et al. (2009)
Soybean oil	More effective in increasing CLA in lamb muscle	Bessa et al. (2005), Santos-Silva et al. (2004)
Sunflower and linseed oil	Both increased CLA in lamb muscle lipids but higher increase with sunflower oil.	Bessa et al. (2007)
Sunflower and linseed oil	Replacement of sunflower oil with linseed oil reduced CLA but increase *n*-3 levels in fat depots of lambs	Jerónimo et al. (2009)
Fish oil	Increased long chain polyunsaturated fatty acids (EPA and DHA) levels in lamb muscle	Cooper et al. (2004), Demirel et al. (2004)
Palm oil	Increased undesirable fatty acids in lamb muscle.	Solomon et al. (1992), Castro et al. (2005)

Essential fatty acids

Supplementation with FA sources high in 18:2 *n*-6 will increase CLA levels in meat, but also decrease *n*-3 FA and, thus, increase the *n*-6/*n*-3 ratio. However, supplemental *n*-3 FA sources have the opposite effect on the *n*-6/*n*-3 ratio (Figure 8). Therefore, a mixture of sources may be an alternative to increase CLA and *n*-3 FA in ruminant meat (Alfaia et al., 2007; Bessa et al., 2007; Jeronimo et al., 2010; Jeronimo et al., 2009).

Bas et al. (2007) studied the effect of three levels of linseed supplementation (3, 6 and 9%) on a high concentrate diet fed to lambs. The authors observed an increased in 18:3 *n*-3 concentration from 0.47g/100g of FA (mean of control group without linseed) to 1.34g/100g (mean of group 9% linseed). The 18:2 *n*-6 was no affected by linseed supplementation when compared to the control group and the *n*-6/*n*-3 ratio ranged from 5.8 in the control group to 2.8 in 9% linseed treatment. Comparing total muscle lipid from linseed supplementation to grazing sheep (Enser et al., 1998), there appeared to be higher amounts of 18:3 *n*-3, 18:2 *n*-6, and 18:1 *n*-9 for the linseed-fed animals. Apart from these differences, the results for grass and unprotected linseed were similar. Díaz et al. (2011) studied the effect of different *n*-3 FA sources on meat FA of lambs supplemented with fish oil, extruded linseed, and extruded linseed plus microalgae. Meat from lambs fed the fish oil treatment had the highest percentage of LC*n*-3 PUFA while the linseed treatment had the highest percentage of 18:3 *n*-3 in total fat. Fish oil and the extruded linseed plus microalgae diet increased the most CLA levels. The increase in 18-3 *n*-3, as a percentage of total FA in muscle, will generally be higher when animals are fed a linolenic acid-rich source (linseed); the same rationale applies for LC*n*-3PUFA dietary sources.

LCn-3PUFA and lipid class

Among the *n*-3 FA, the LC*n*-3PUFA (mainly *n*-3 EPA and DHA) are the most beneficial to human health (Givens et al., 2006) and researchers have studied ways to increase those FA in ruminant products without adverse effects. Because ruminants — as well as humans (Williams & Burdge, 2006) — have limited ability to convert 18-3 *n*-3 to 20:5 *n*-3 and, mainly, to 22:6-*n*3 (Cooper et al., 2004; Kouba & Mourot, 2011; Scollan et al., 2001), linseed supplementation — rich in 18-3 *n*-3 - is not be the best FA source when the objective is to increase LC*n*-3PUFA in ruminant meat. Consequently, the most efficient form to increase percentage of DHA and EPA in meat is to add fish oil to the diets (Cooper et al., 2004; Demirel et al., 2004; Kouba & Mourot, 2011; Noci et al., 2007) or other source of pre-formed LC*n*-3PUFA. However, higher levels of PUFA may be detrimental to organoleptic characteristics and product shelf life, because those FA are more susceptible to oxidation (Priolo et al., 2001; Vatansever et al., 2000; Wood et al., 2004).

Preferably esterified at the *sn*-2 position of phospholipids, polyenoic FA functionas structural constituent of biological membranes. Additionally, ruminants biohydrogenate most of the dietary UFA, incurring in lower amounts of EFA reaching the duodenum compared to non-ruminants. Therefore, EFA are rather used for many metabolic functions — such as components in lipoproteins of active membranes and precursor of prostaglandins — than oxidized for energy purpose. For instance, the ruminant mitochondrial carnitine acyltransferase has lower specificity to 18:2 *n*-6 than 16:0, when compared to rats (Reid & Husbands, 1985). Thus, ruminants have relatively more PUFA in PL than TAG, up to 7.7 times greater (Popova, 2007), what is not so evident in non-ruminants species. Despite that, young small ruminants and lean meat have higher percentage of PUFA in muscle total lipid.

Cooper et al. (2004) studied the effect of different FA sources and their interaction on the FA profile of PL and TAG in lambs. The authors reported that, on average, the muscle PL had 14.2% and the neutral lipid had only 3.3%of total FA as *n*-3 FA. Also, the fish oil plus algae treatment had the higher percentages of DHA in both lipid fractions, but the percentage of DHA was 10-fold higher for the PL compared to neutral lipids in muscle.

An implication of the higher percentage of PUFA in the polar lipid fraction is reflected in the FA profile of older animals. The older the animal, the higher the TAG/PL ratio; thus, decreasing the percentage of PUFA and EFA in meat with no significant variation on the percentage of 18:0 (Figure 9). The same reasoning may be applied when comparing the FA profile of leaner versus fatter meat; the latter has lower PUFA as a percentage of total lipids. In fact, older animals or genotype that lead to fatter meat may incur in this rationale.

Genotype

Reducing carcass fatness has been one of the major breeding goals for farm animals for many years. More recently, the effect of breed on carcass FA has been received more attention. Research data evaluating the effect of breed on the profile of FA on meat has shown that FA deposition is inversely correlated with the concentration of FA beneficial to humans. Fisher et al. (2000) studied the effect

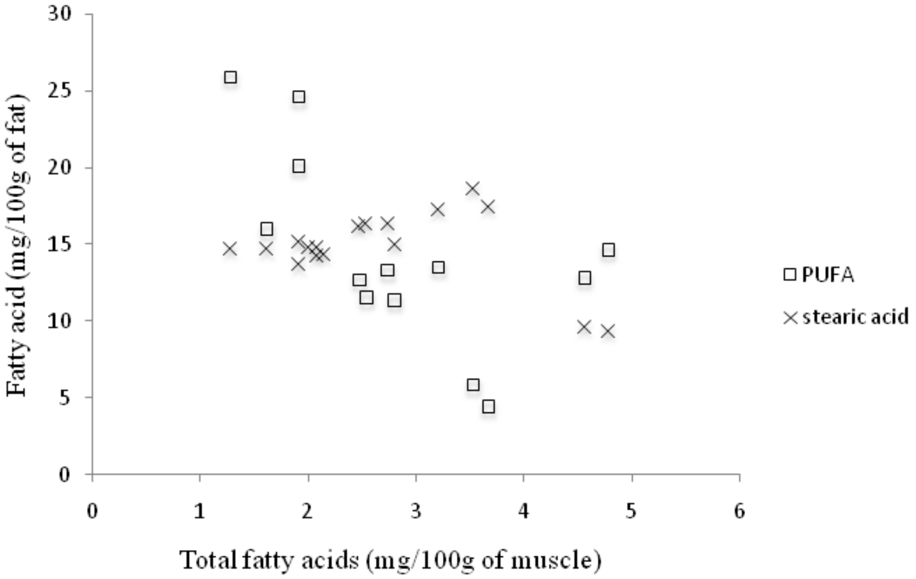

Figure 9 - Relationship among the percentage of fatty acids in muscle withthe percentages of polyunsaturated fatty acids and stearic acid in the total fat from lamb meat (pooled data from the literature; n=30).

of different lamb breeds on meat quality and carcass characteristics. The authors reported that the Soay breed had leaner carcasses with higher concentration of *n*-3 FA (mg/100 of total FA). Demirel et al. (2006) observed the same relationship between carcass fatness and FA profile when comparing the effect of lamb breeds; the Sakiz animals had leaner carcasses and higher percentage of *n*-3 FA (1.75%) than the Kivircik breed.

The effect of breed is similar between and within species. Tshabalala et al. (2003) evaluated the effect of 2 genotypes in ovines and caprines on meat FA. They showed that goats, which have less percentage of FA in muscle, have a healthier profile of FA for human consumption. Among the breeds studied, Indigenous goats shown leaner carcasses and higher percentage of PUFA.

Goats have lower SFA/UFA ratio (healthier fatty acid profile) and less fat than sheep (Sheridan et al., 2003; Tshabalala et al., 2004; Lee et al., 2008). Leaner meat has a higher percentage of polar lipids and PUFA are preferably esterified in the polar lipid fraction (e.g., phospholipids) compared to neutral lipids. As a result, thinner animals — either by genotype or age — could have relatively high proportions of PUFA (mg/100g of FA) compared with fatter animals in which the amount of phospholipid (and, consequently, PUFA) is diluted by higher levels of neutral storage lipid (Demirel et al., 2006; Fisher et al., 2000). Additionally, when studying the effect of genotype on meat fat is relevant to consider the units that the values are expressed: mg of FA per 100g of muscle or mg of FA per 100g of FA (or lipid). For instance, fat animals may have higher amount of 18:3 *n*-3 in meat (mg/100g muscle) and lower percentage of 18:3 *n*-3 in total FA.

Tannin

Researchers are investigating compounds that are able to alter the final stages of the ruminal BH with the purpose of increasing the concentration of FA intermediates flowing out of the rumen. A few studies indicated that tannins primarily disrupt the final step of BH, which promotes an increase in levels of 18:1 isomers (Khiaosa-Ard et al., 2009; Vasta et al., 2009b). This disruption is related to selective inhibition of microorganisms responsible for the final stages of the BH process (Durmic et al., 2008). Vasta et al. (2009c) showed that feeding tannin to sheep increased the expression of SCD in muscle. Generally, tannins are added to the diet through feeding forages that are rich in these compounds, such as Sainfoin (*Onobrychis viciifolia*), Sulla (*Hedysarum coronarium*), and quebracho (*Schinopsis lorentzii*) or purified tannins, fromblack wattle (*Acacia mearnsii*) for example, obtained from aqueous extracts (Cabiddu et al., 2009; Khiaosa-Ard et al., 2009; Vasta et al., 2009a). Vasta et al. (2009c) reported that the addition of tannins to sheep diets increased the concentration of CLA in the rumen and increased concentrations of polyunsaturated fatty acids in muscle. On the other hand, Vasta et al. (2007) reported lower levels of CLA in meat from sheep fed forage rich in tannin, but the diets fed in this study had less than 3% ether extract, which suggests that the dietary pool of PUFA may have been too small for an effect to be observed. Nonetheless, the use of such technology should take into account to negative effect of tannins on digestibility of nutrients (Cortés et al., 2009).

Dry areas and meat fatty acids

The unique flora biodiversity located in dry areas has not been fully studied by researchers regarding their impact on meat FA profile. In addition, different palm oils with a lower iodine value (commonly found in semiarid regions) are usually fed to small ruminants as a cheap source of energy in the Northeast of Brazil. Manso et al. (2009) reported that palm oil did not affect and sunflower oil improved FA composition of fattening lambs without affecting animal performance. Palm oils and their by-product derivatives, lower in UFA and higher in MCFA, are auseful feed alternative in semiarid regions to increase energy density of ruminant diets (Borja et al., 2010; Silva et al., 2010). However, those FA sources may reduce meat quality (Manso et al., 2009; Silva et al.; 2011) by decreasing the percentage of PUFA in total meat compared to the most common oil sources (soybean and sunflower oils).

Goats fed spineless cactus (*Opuntiaficus-indica*) had lower lipid content in meat and higher proportion of CLA, PUFA, and PUFA/SFA ration (Atti et al., 2006). Unfortunately, we are not aware of any research studying the effect of vegetable oils and plants from semiarid regions on the profile of FA from neutral and polar lipids of goat meat. We speculate that small ruminants fed mixed pasture in extensive and semi-extensive systems in the semiarid regions of Brazil may produce ruminant products (milk and meat) with a beneficial profile of FA, rich in EFA with a lower *n*-6/*n*-3 ratio.

Sensorial characteristic of meat

Palatability is a multifaceted concept that includes tenderness, flavor, residue, and succulence. Each of these criteria is dependent on a long list of other factors, such asanimal age, gender, physiological state, biochemistry of the post-mortem muscle, carcass composition, fat, and connective tissue. In addition to the effect of feed characteristics on flavor, protein and fat depot, as well as genetics, are important in determining characteristics of tissues and metabolism (Webb et al., 2005). Meat tenderness and flavor appear to be the most important sensory features concerning meat quality (Tshabalala et al., 2003). Both attributes can be influenced by the percentage and type of fat, which may be originated from feed-derived substances in lipid or non-lipid compounds, or from oxidative off-flavors; the latter may be developed during processing or storage of meat (Ponnampalam et al., 2002; Wood et al., 2004). The degree of SFA is one of the most important factors affecting the palatability of meat, because SFA solidify at room temperature, and the physical aspect of fat can decrease meat palatability (Webb et al., 2005). Sensory evaluations with trained assessors, consumer acceptability tests or consumer preference tests are useful tools to evaluate whether meat quality meets the palatability standards of a specific consumer population.

Sensory aspects of goat meat showed that intensive (concentrate plus perennial peanut) or semi-intensive (pasture plus cracked corn) nutrition regimes had no effect on juiciness, flavor, tenderness, connective tissue or occurrence of off-flavors. Despite the fact that goat meat produced in an intensive feeding system had higher percentages of saturated and polyunsaturated FA (54.9 and 2.8 versus 53.3 and 2.4 for semi-intensive system) and lower levels of 18:1 (40.4 versus 42.3), sensory evaluation was not affected (Johnson & McGowan, 1998). On the other hand, Díaz et al. (2011) reported a significant effect of diet on flavor and aroma in lamb meat when they compared supplementation with linseed (12,5%), fish oil (3,3%), and linseed (10,7%) plus microalgae (4%) into basal concentrate diet (control group) offered to lambs. The sensory analyses showed that lambs fed the control diet had the highest scores for lamb characteristic aroma and flavor, while lambs fed fish oil had high scores for fish and rancid odor and flavor, yielding the lowest overall liking meat. The fishy flavor was most likely associated to the higher content EPA in all lipid fractions in meat of lambs supplemented with fish oil. According to Nute et al. (2007), 20:5 *n*-3 and 22:6 *n*-3 reduced the lamb flavor and tended to increase fish flavor in lamb meat. The increase in the content of PUFA in muscle may be nutritionally desirable; however, poor sensory quality may result, if incorporation of PUFA is excessive. Elmoreet al. (2005) reported that the addition of 4% marine algae in the diet resulted in the highest scores for abnormal flavor and rancid flavor in sensory evaluation profile. The authors assessed the volatile aroma compounds in lamb and reported that those were associated with high levels of 22:6 *n*-3 in meat from animals fed algae. However, lambs fed linseed were preferred, they scored high for lamb characteristic flavor but the lowest for abnormal flavor, and had low levels of 22:6 *n*-3. In conclusion, feeding a high linoleic acid-rich source will acquire the most desirable meat quality, assuming solely an increase of *n*-3 FA, without adverse effect on flavor and consumer acceptance.

Ryan et al. (2007) studied distinct concentrate levels (50, 70 or 90%) and their effect on goat meat composition and quality. The sensory evaluation revealed that grass-fed goats had more off-flavor intensity than concentrate-fed goats. The authors concluded that low levels of concentrate (50%) are sufficient to reduce off-flavors when compared to grass-fed goats. Plain grain or pasture plus supplement typically result in lamb meat with more acceptable flavors than only pasture. Finishing lambs on pasture increases lamb flavor and off-flavors (Duckett & Kuber, 2001). Also, grassy flavor was reported as a consequence of the addition of protected lipid supplement, rich in 18:2 *n*-6 and 18:3 *n*-3, which was probably related to the high levels of hexanal (Elmore et al., 2005). However, Ponnampalam et al. (2002) described that lamb meat with increased levels of LC*n*-3PUFA can be produced without altering the sensory quality, such as flavor and aroma. Significant increase in muscle LC*n*-3PUFA was reported by the authors with fish meal (9%), fish oil (1.5%), and *n*-6 FA from protected canola seeds (6%). These traits were not detrimental to sensory panel evaluations of flavor and aroma of lamb meat LC*n*-3PUFA when compared to the control diet.

Diets supplemented with *n*-6 FA sources seem to have a less significant effect on sensory attributes when compared to sources rich in LC*n*-3PUFA. Supplementation with 8% soybean oil on alfalfa-based diets (hay or pelleted) altered the meat FA profile without significant changes in sensory attributes (Santos-Silva et al., 2004); although consumers detected the oil inclusion by tasting lamb meat, consumers had no clear preference for meat between oil supplemented and non-supplemented animals. Similarly, Bessa et al. (2005) studied the effect of soybean oil on alfalfa-based diets and reported similar findings, in which consumers could differentiate between oil supplemented and non-supplemented lamb meat, but did not show a clear preference between the two feeding system.

Final Considerations

Production of nutrient-enriched food can be a useful alternative to marketing differentiation for the livestock industry. The scientific knowledge in which relates to fatty acid composition of meat and milk from small ruminants advanced considerably in the last decade, and focused mainly on processes to improve the content of UFA, PUFA, *n*-3 FA and CLA isomers. Caprine and ovine have similar profile of FA when fed in similar dietary management, but total carcass fatty acid (g FA/g meat) can differ. Grazing and supplemental dietary sources of UFA seem to be the most applicable practice to ensure an increase in levels of PUFA and beneficial FA in milk and meat (applicable, because the feeding protected FA is economically prohibitive in Brazil). However, LC*n*-3FA rich products may be more likely to oxidize and, therefore, have a shorter shelf life. Further research should focus on effects of tannins in controlling ruminal BH, as well as the potential of indigenous pastures, including plants from semiarid regions, to improve the FA composition of meat and milk from small ruminants.

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