Feeding modulation of the fatty acid composition in lamb meat

Klir[1], Ž., Z. Antunović[1], V. Halas[2], M. Domaćinović[1], M. Šperanda[1], J. Novoselec[1]

review

Summary

Various science researches have shown that meat of ruminants has more desirable fatty acid composition and a ratio between ω-6 and ω-3 fatty acids (lower than 4.0) because of lower content of linoleic, and a higher content of ω-3 polyunsaturated fatty acids, especially linolenic fatty acid. The aim of the present study is to examine researches about feeding modulation of the fatty acid composition in lamb meat. The fatty acid composition in tissues of suckling lambs can be modified by fatty acid composition of ewes´ milk. Numerous investigations have shown that lambs on pastures have increased content of ω-3 fatty acids, especially eicosapentaenoic and docosahexaenoic fatty acids in m. longissimus thoracis and m. semimembranosus. Addition of 10% flax oil in lambs´ diet significantly increased the content of linoleic acid in m. longissimus lumborum (4.5 times), while fish oil stimulated deposition of intramuscular fat in shoulder, leg and abdomen. The fatty acid content of intramuscular and subcutaneous tissues of suckling lambs is influenced by fatty acid composition of ewes´ milk, and depends on rearing and feeding systems of ewes. One of the advantages in feeding of ruminants is the addition of rich linoleic source and source of linolenic acid in combination with fish oil in diets of lambs that increases the content of conjugated linoleic acid (CLA) in different tissues. It is clear from the above mentioned data that fatty acid composition of lamb meat may be modeled with the aim to decrease the content of saturated fatty acids and increase the content of polyunsaturated fatty acids in fat and muscle tissues of lambs.

***Keywords**: feeding of lambs, lamb meat, polyunsaturated fatty acids, conjugated linoleic acid.*

Introduction

The popular perception of fats is that they increase the risk of a number of health problems such as heart diseases, stroke, diabetes, and some cancers. However, fats are very important for human health. Nutritionists have also focused on increasing the consumption of the important n-3 fatty acids; particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) that could have a large influence on human health. Many researches have been carried out in feeding fish oil, a rich source of DHA, to animals in attempts to transfer the long chain fatty acids present in the fish, to the meat (Demirel et al., 2004a; Ponnampalam et al., 2001). Omega-3 fatty acids are essential fatty acids and they are necessary for human health, but the body cannot produce them. Omega-3 fatty acids can be found in fish, such as salmon, tuna, and halibut, other seafood including algae, some plants, and dietary oils. Healthy benefits of these fatty acids are in reducing inflammation and contribution in lowering the risk of chronic diseases such as heart disease, cancer, and arthritis. Omega-3 fatty acids are highly concentrated in the brain and appear to be important for cognitive behavioural function (University of Maryland, 2009). Omega-3 fatty acids assist in reducing inflammation, whilst most omega-6 fatty acids tend to promote inflammation. Therefore, it is important to have the balance of omega-3 and omega-6 in the diet. Omega-3 fatty acids are called "good fats" because they play a vital role in every cell and system in the body.

The fatty acid composition in muscle and adipose tissues of ruminants is much more variable than in non-ruminants. The reason for this is presence of *trans* fatty acids, fatty acids with an odd number of carbon atoms, branched fatty acids and fatty acids with conjugated double bonds. These variations are the result of microbial enzymes presented in rumen, which degrade plant structure and fatty acids from the diet. Previous studies suggest that fatty acid composition of ruminant meat can be influenced by diet (Enser et al., 1998). However, the greater susceptibility to oxidation and flavour defects of animal products enriched in polyunsaturated fatty acids (PUFA) must also be considered (Vatansever et al., 2000). When oxidative rancidity starts to develop, the products of this process give rise to unpleasant odours and tastes which reduces the acceptability of the meat to consumers. Oxidation of the lipids in meat and meat by-products can be effectively controlled with antioxidants. Many recent studies have dealt with the use of synthetic antioxidants. On the other hand, vitamin E proved to be an effective solution for that. Pasture feeding, due to high content of α-linolenic acid and vitamin E in grass, provides more acceptable way of increasing the n-3 unsaturation of meat (Enser et al., 1998).

The aim of the study was to collect and analyse scientific literature that elaborates influence of different factors on the fatty acid composition in lamb meat with a special regard to the feeding modulation.

[1] **Željka Klir, MSc.**, BSc (Agri); **Zvonko Antunović, PhD**, Full Professor; **Matija Domaćinović, PhD**, Full Professor; **Marcela Šperanda, PhD**, Full Professor; **Josip Novoselec**, BSc - Department of Animal Science, Faculty of Agriculture in Osijek, Trg Sv. Trojstva 3, HR-31000 Osijek, Croatia email: zklir@pfos.hr

[2] **Veronica Halas, PhD** - University of Kaposvár, Faculty of Animal Science, Department of Animal Nutrition, P. O. Box 16, H-7400 Kaposvár, Hungary

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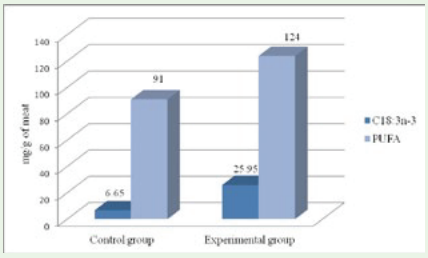

Figure 1 **The content of fatty acids (mg/g of meat) in *m. longissimus lumborum* of lambs fed flaxseed supplemented diets, compared with lambs fed no supplement (Gruszecki et al., 2006)**

Fat content and fatty acid composition of meats from different species

Fatty acids are very important source of energy for many organisms. Excess glucose can be stored efficiently as fat. All cell membranes are made of phospholipids, each of them containing two fatty acids. Catabolic processes generate energy and primary metabolites from fatty acids, while anabolic processes create biologically important molecules from fatty acids and other dietary carbon sources. Triglycerides are storage form of fatty acids in an organism, therefore, an important source of energy. The energy yield from a gram of fatty acids is approximately 9.3 kcal (39 kJ/g), compared to 3.7 kcal (15.5 kJ/g) for carbohydrates (Kulier, 1990). Besides, fats decrease rapidity of digested food flow that may enable better absorption of nutrients.

Fats are classified as saturated (containing no double bonds in their chemical structure) or unsaturated (containing at least one double bond). Saturated fats are less disturbing to the microbes present in rumen. The role of the rumen microbes is converting or hydrogenating unsaturated into saturated fats.

Body fat can be synthesized from different sources in ruminants i. e. (1) from glucose, (2) from volatile fatty acids as a metabolite of rumen fermentation, particularly from acetic acid and (3) from long chain fatty acids.

In non-ruminant animals, glucose derived from dietary carbohydrate is the main precursor for the synthesis of lipids (Hanson and Ballard, 1967). The situation is different in ruminants, where dietary carbohydrate is converted into various short-chain intermediates before absorption. The available glucose in ruminants is synthesized in liver and kidney and the obvious premium on this source of carbohydrate suggests that the products of rumen metabolism, such as acetate and butyrate, are the major precursors for lipogenesis in these animals (Hanson and Ballard, 1967).

There is a big difference between ruminant and non-ruminant species in their proportions of PUFA in tissues and meat. These are greatly changed by digestion in pig and poultry and are incorporated directly in adipose tissue. While ruminants consume forage, fatty acids are hydrogenated by microorganisms in the rumen. This microbial action results in generally low levels (10% or less) of dietary PUFAs being available for absorption into body tissues after passing through the rumen. However, the fatty acids may be absorbed in the small intestine as monoglycerol and free fatty acids. Those fatty acids can be used for body fat synthesis in sheep without any change.

In ruminants, most of esterified plant lipids are hydrolysed after consumption by microbial lipases, causing release of fatty acids. *Anuerovibrio lipolytica*, which is best known for its lipase activity, produces esterase and lipase. This lipase hydrolyzes acylglycerols completely to fatty acids and glycerol. Glycerol is fermented rapidly, yielding propionic acid as a major end product.

Unsaturated fatty acids have a relatively short half-life in ruminal

SCIENTIFIC AND PROFESSIONAL SECTION

Feeding modulation of the fatty acid composition in lamb meat

contents because they are rapidly hydrogenated by microbes to more saturated end products. The initial step in biohydrogenation is an isomerization reaction that converts the *cis*-12 double bond in unsaturated fatty acids to a *trans*-11 isomer. The extent to which *trans*-11 C18:1 is hydrogenated to C18:0 depends on conditions in the rumen. For example, complete hydrogenation to stearic acid is promoted by the presence of cell-free ruminal fluid and feed particles but it is inhibited irreversibly by large amounts of linoleic acid.

Polyunsaturated fatty acids are formed by sequential desaturation and elongation reactions. The position of further desaturation depends very much on the organism. Animal enzymes insert new *cis*-double bonds towards the carboxyl group (mammalian systems dispose Δ9-, Δ6-, Δ5-, and Δ4-desaturases, a minimum chain length of 16–18 carbons is required), but never beyond C-9. Besides, plant and fungal enzymes tend to insert additional *cis*-double bonds between the existing double bond and the methyl terminus (Δ12- and Δ15-desaturases). Accordingly, oleic acid is further desaturated to octadeca-6,9-dienoic acid (Δ6-desaturase) in mammals, but in plants and fungi to octadeca-9,12-dienoic (linoleic) acid (Δ12-desaturase, plastidal oleate desaturase), and further to linolenic (*α*-linolenic) acid, octadeca-9,12,15-trienoic acid (Δ15-desaturase, plastidal linoleate desaturase). The inability of animal systems to desaturate closer to the methyl terminus than C-9 renders them unable to convert palmitic acid to linoleic or α-linolenic acids. Accordingly, linoleic and *α*-linolenic acids are referred to as essential fatty acids since they cannot be synthesised *de novo* and must be obtained from the plant materials in the diet.

A study by Wood and Enser (1997) showed the fat content of steaks

Table 1 **Influence of feeding on the fatty acid composition in *MLD* of lambs (Rowe et al., 1999)**

Fatty acids	Pasture	Feed mixture	Significance
C18:0 stearic	30.11±0.42	23.51±0.36	p<0.01
C18:1ω9 oleic	30.73±0.40	38.21±0.44	p<0.01
C18:2ω6 linoleic	2.63±0.14	3.85±0.13	p<0.01
C18:3ω3 α-linolenic	1.14±0.04	0.20±0.02	p<0.01
C20:4ω6 arachidonic	0.32±0.05	0.21±0.03	p<0.01
SFA[a]	55.07±0.43	49.36±0.54	p<0.01
MUFA[b]	31.37±0.35	40.68±0.49	p<0.01
PUFA[c]	5.36±0.40	4.74±0.40	NS
P/S[d]	0.10	0.10	NS

[a]saturated; [b]monounsaturated; [c]polyunsaturated fatty acids; [d]polyunsaturated/saturated fatty acids ratio.; NS-not significant

from loin in beef, lamb and pork. The results showed that the lean meat (muscle) is low in fat of all three species (20-50g/kg), but particularly pork. While the fat contents in beef, lamb and pork were 156, 302 and 211 g/kg, respectively. The fatty acid composition of total lipid extracted from the lean meat showed clear differences between the species. Beef and lamb had a low polyunsaturated: saturated fatty acids (P: S) ratio compared with pork due mainly to the high linoleic acid content of pork. However, this also caused beef and lamb to have a more favourable n-6/n-3 fatty acids ratio. Recommended values are 0.45 for P: S and below 4.0 for n-6/n-3 (Wood and Enser, 1997). On the basis of results like these, researchers have particularly focused on ways to increase the P: S ratio of ruminant meats and correct the imbalance between n-6 and n-3 fatty acids in pork and also in poultry.

The total fatty acid composition of the *m. longissimus* was the highest in lamb and lowest in pork. The most obvious difference in fatty acid composition was that linoleic acid, C18:2, was higher in pork, causing a higher P: S ratio. This is due to the high content of C18:2 in the cereal-based diets consumed by meat animals and this produced an undesirably high n-6:n-3 ratio. The ruminant meats had a more favourable n-6: n-3 ratio, due to less C18:2 than in pork and relatively high levels of n-3 PUFA, especially C18:3. The study also showed that the long chain (C20–C22) n-3 PUFA were at low but significant levels in pork subcutaneous fat, reflecting a relatively greater deposition of long chain derivatives of C18:3 in pig neutral lipids (triacylglycerols). Similar results weren´t detected in beef and lamb. In ruminant muscle and adipose tissue, PUFA are restricted to the phospholipid fraction. The relative content of C18:2 in *m. longissimus* phospholipids was 12 times greater than in neutral lipids of steers and 3 times greater in pigs. Differences in muscle fibre type between muscles are reflected in differences in fatty acid composition. "Red" muscles have a higher proportion of phospholipids than "white" muscles and therefore a higher content of PUFA. Studies on poultry meat have shown similarities with pork, i.e. the meat fatty acids are relatively unsaturated although C18:2 is at a higher level (Enser, 1999).

Feeding with voluminous forage and concentrates

Demirel et al. (2006) studied the influence of feeding systems on the content of fatty acids in *m. longissimus thoracis* of Kivircik and Sakiz breeds. The results showed that the amount of stearic fatty acid (C18:0) in *m. longissimus thoracis* was higher for the lambs fed hay. Bas and Morand-Fehr (2000) reported that a concentrate without any voluminous forage diet gave the highest relative content of oleic fatty acid (C18:1n-9). The content of n-3 polyunsaturated fatty acids (PUFA) weights were higher in meat from lambs fed hay-based diets. The high level of linolenic acid (C18:3) in *m. longissimus thoracis* from grass-based diets probably results from the high C18:3 content in hay (Demirel et al., 2006). The content of eicosapentaenoic (EPA, C20:5n-3), docosapentaenoic (DPA, C22:5n-3) and docosahexaenoic acid (DHA, C22:6n-3) was 2.5 times higher in *m. longissimus thoracis* of lambs fed hay-based diets. In the study of Fisher et al. (2000) lambs of Soay breed fed grass had the highest concentration of EPA (29 mg) in *m. semimembranosus*. Similar to EPA, the DHA content of lambs fed hay was 2.5 times higher than of lambs fed concentrate-based diets. Soay lambs also contained higher amounts of C18:3n-3 as well as other n-3 PUFA, although they had the lowest total fatty acid content (1668 mg/100 g) in *m. semimembranosus*. The contents of linoleic (C18:2 n-6) and arachidonic fatty acid (C20:4 n-6) in *m.longissimus thoracis* of concentrate fed lambs were higher compared to lambs fed hay (Demirel et al., 2006). Mentioned authors emphasise that the reason for this is high level of C18:2n-6 and C20:4n-6 fatty acids in seeds.

In the *m. longissimus lumborum* and *m. semimembranosus*, the rearing systems influenced the relative content of phospholipids polyunsaturated fatty acids (Popova, 2007). In the study of Popova (2007) phospholipids of *m. longissimus lumborum* and *m. semimembranosus* in pasture lambs, contained more C18:3 (p<0.001) and less C18:2 (p<0.01). The relative contents of EPA and DHA were significantly greater (p<0.001) than those of animals fed on concentrate diet. Therefore, PUFA (n-6)/PUFA (n-3) ratio in phospholipids of grass fed lambs decreased by 50% (p<0.01) and 59% (p<0.01) respectively for the *m. longissimus lumborum* and *m. semimembranosus.* Lower n-6/n-3 ratio, found in muscles of grass fed animals, is more desirable for human health. The higher amount of C18:3 in both muscles, in grazing animals, shows that despite the hydrogenating effect of the rumen microorganisms, a part of the essential linolenic acids originating from the grass escaped the saturation (Popova, 2007).

The quality of forage is very important in the meaning of modelling the fatty acid composition of body fat in lamb meat. The fatty acid composition of the forage is the main determinant in this respect. The amount of α-linolenic acid in forages is variable according to a number of factors including species, cutting date, growth stage, fertilisation and conservation methods (Dewhurst et al., 2001). Clapham et al. (2005) recorded that fatty acids composition varied between different fresh grasses, legumes and forbs but α-linolenic acid was the predominant fatty acid throughout, and that both total fatty acid and α-linolenic acid contents tended to decrease as plants matured. Kliem et al. (2006) studied influence of cutting date on the total lipid and α-linolenic acid content in plants like red and white clover, plantain, yarrow, dandelion. Mentioned authors concluded that lipid and α-linolenic contents in plants were higher in September than in June. These authors suggested that this observation may reflect the effect of differences in leaf/stem ratio of the species studied. Preventing or reducing biohydrogenation is more challenging as fibrolytic bacteria tend to be powerful biohydrogenators. One of the solutions is the use of "stay green" grasses that are deficiency in chlorophyll degradation enzyme and they resist lipid degradation during leaf seasoning (Harwood et al., 1982). Therefore in lambs it leads to increase concentrations of plasma total fatty acids and conjugated linoleic acid compared with conventional grass (Traill et al., 2008).

Ray et al. (1975) investigated different levels of corn and alfalfa (0 to 100% with increase of 5%) in the diet of lambs. They reported the changes in fatty acid content of depot fat. As the level of corn increased in the ration, the relative content of palmitic (C16:0) and linoleic (C18:2n-6) acids increased, whereas stearic (C18:0) acid decreased. Also, oleic (C18:1) acid increased and *α*-linolenic acid (C18:3n-3) decreased as the level of corn increased in the ration. Jenkins (1992) reported that the presence of C18:2 in high levels in diets may prevent complete hydrogenation from C18:1 to C18:0. That may explain the increase of oleic acid in muscles of lambs fed concentrates. Clarke et al. (1977) studied lambs fed different diet composition. Lambs were fed diets based on barley and alfalfa pellets with or without 3.4% corn oil addition. Authors observed that feeding barley increase the C18:2n-6 acid content and reduced C18:0 acid content of the subcutaneous fat. Addition of oil to barley diet further increased linoleic acid and reduced stearic acid, whereas oil addition to alfalfa pellet diet did not alter fatty acid composition. This suggests that grain feeding reduce ruminal biohydrogenation and increase the deposition of unsaturated fatty acids in tissues.

Solomon et al. (1991) investigated the influence of rapeseed meal, soybean meal and whole rapeseed-soybean meal addition in the diets on the content of muscle and fat lipids. *M. longissimus dorsi* (MLD), *m. semimembranosus* and *m. triceps brachii*

SCIENTIFIC AND PROFESSIONAL SECTION

of lambs fed rapeseed meal addition had higher content of palmitic, but lower of stearic acid, compared with lambs of other groups. St. John et al. (1987) investigated feeding of steers based on high energy corn based with 20% rapeseed addition for period of 100 days on the fatty acid content in muscle of steers and observed that rapeseed lowered palmitic acid (C16:0) in the lean tissue by as much as 10%. Solomon et al. (1991) found out the increase in C16:0 in the MLD for 9% as a result of feeding with 6.5% rapeseed meal in diet. In the same trial authors did not find any significant results of feeding influence on the content of saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids in the investigated samples of muscles. Similar results were reported in the trial by St. John et al. (1987) that observed decreased content of SFA while steers were fed 20% of rapeseed oil in the diet.

Scerra et al. (2007) investigated pregnant Italian Merino ewes that were divided in two groups. The first group of ewes was allowed to graze a natural pasture, while the second group was penned indoors and fed hay (*ad libitum*) and concentrates. Both groups of lambs were fed maternal milk. In the same trial it was concluded that content of monounsaturated fatty acids (MUFA) such as palmitoleic (C16:1*cis*-9) and oleic (C18:1*cis*-9) were higher in the intramuscular fat of lambs´ mother fed concentrates. The content of linoleic (C18:2n-6) and arachidonic (C20:4) fatty acids in *m. longissimus lumborum* of lambs did not show significant differences among groups depending on different feeding. These results are in contrast with other studies that investigated lambs´ mothers fed pasture or with high amounts of grass silage (Valvo et al., 2005; Velasco et al., 2001 and 2004; Rowe et al., 1999). Scerra et al. (2007) reported significant influence

Table 2 **Fatty acid composition (%) of lambs´ leg fed on diets enriched with conjugated linoleic acid (CLA) and safflower oil (Mir et al., 2000)**

Fatty acids	Diets				Significance	
	Control (C)	CLA	Safflower oil (S)	SE	C/ S	C/S
16:0	27.5	29.3	29.7	0.45	NS	NS
18:0	14.7	12.5	16.9	0.47	NS	NS
18:1	47.9	48.2	39.7	0.62	NS	p<0.001
18:2	8.6	8.6	12.4	0.49	NS	p<0.001
18:3	1.1	1.3	1.7	0.06	NS	p<0.001

NS-not significant ; SE-standard error

of feeding on the content of linolenic (C18:3n-3) acid in *m. longissimus lumborum* of lambs, whereby they didn´t observe the influence on the content of linoleic and arachidonic (C20:2n-6) acids. In the lambs from ewes fed pasture, the content of linolenic acid in meat increased two times by comparison with lambs from ewes fed concentrates.

The content of linolenic acid in milk fat was two times higher from ewes fed pasture. The increased content of linolenic acid is a result of its presence in young meadow pastures (Chillard et al., 2001). The content of eicosapentaenoic (C20:5n-3, EPA) and docosahexaenoic (C22n-6, DHA) acids were higher in intramuscular fat of lambs from ewes that were grazing on the pastures in comparison with lambs from ewes fed concentrates. Therefore, intramuscular fat from lambs of ewes fed pasture had higher content of n-3 polyunsaturated fatty acids (PUFA). The content of PUSA, and PUFA: SFA ratio was higher in lambs from ewes grazing on pasture, while the content of saturated fatty acids (SFA) was higher in lambs from mothers fed concentrates.

The fatty acid composition of the various adipose depots also varies according to the length of lactation and the feed consumed. Therefore, the fat composition of suckling animals is related to that of maternal milk that may be modified by the supplementary feedstuffs consumed (Velasco et al., 2001). Whole cereals can be used to provide an energy supplement for lambs fed grass. That favours grass digestibility and increase intake and digestion of pasture that contents high level of C18:3, precursor of omega-3 fatty acids (Rhee, 1992). Diet composition affects the rumen fermentation model. Therefore, diets rich in concentrates affect decrease in acetic/propionic acid ratio in rumen (Velasco et al., 2004). Berthelot et al. (2001) confirmed the role of propionic acid as important precursor of fatty acid with odd number of carbon atoms.

Modelling of fatty acid composition with the aim to reduce saturated fatty acids and/or increase polyunsaturated fatty acids in tissues of ruminants is more difficult than in non-ruminants. The influence of feeding on the fatty acid composition of the adipose and muscle tissues of ruminants has been established in samples of lambs´ *m. longissimus dorsi* (MLD) in the trial by Rowe et al. (1999). There are two fattening systems, drylot and grazing systems that had influence on the chemical composition of lamb meat. Animals fattened in the grazing system presented higher contents of saturated long-chain fatty acids, in the form of stearic and arachidic (C20:0) acids, α-linolenic (C18:3n-3), γ-linolenic (C18:3n-6) and arachidonic (C20:4n-6), but lower contents of oleic and linoleic (C18:2n-6) acids (Table 1.). These data are a very important factor from a nutrition as-

pect. When feeding pasture, rich in omega-3 fatty acids ends, and lambs are transported in feedlot, where diets are based on the concentrates that are poor in omega-3 fatty acids, lambs begin to lose depots of good fats. With each day that lambs spend in a feedlot, a supply with omega-3 fatty acids decrease.

Feeding on fish and flaxseed oil supplement

In recent years the subject of many investigations was addition of fish oil in diets of domestic animals. In the meat of cattle and sheep, significant influence on the fatness, fat content, increasing content of n-3 PUFA (polyunsaturated fatty acids) was observed as well as lowering n-6/n-3 ratio, which is recommended for human nutrition (Ponnampalam et al., 2001).

Popova et al. (2008) investigated the influence of fish oil supplement in the diets of lambs on the fatty acid composition of fat tissues. Relative content of subcutaneous tissue of carcass did not change in the lambs fed diets supplemented with the addition of fish oil, but in comparison with lambs that had no addition of fish oil, increased content (16%) of intramuscular fat was reported. Mentioned data indicates that addition of fish oil leads to increased deposition of intramuscular fat. Fish oil supplemented diet results in different changes in fatness of the carcass cuts of lambs. Subcutaneous fat tended to increase in the leg and abdomen, but in the leg, shoulder and neck of the fish oil fed animals, the subcutaneous fat significantly decreased by 40% (p<0.05), 16% and 28%, respectively, as compared to control lambs. Fish oil supplement significantly stimulated deposition of more intermuscular fat in the shoulder by 30% (p<0.05), leg by 10% and abdomen by 18%, but did not change the amount of intermuscular fat in the neck. In the leg, not only the subcutaneous, but also the intermuscular fat was significantly decreased. Despite of the different anatomical locations of the fat depots, the major fatty acids of the triacylglycerols of both groups of lambs were palmitic (C16:0), stearic (C18:0) and oleic (C18:1) fatty acids in lamb meat. The content of linoleic (C18:2) and linolenic (C18:3) in the triacylglycerols in control group of lambs were between 3.20% and 4.42%, and between 0.6% and 0.75%, respectively. Fish oil did not change the content of C18:2 in the perirenal and intermuscular fat, whereas C18:2 content tended to decrease in the triacylglycerol fraction of the subcutaneous fat over *m. longissimus dorsi* (MLD) and at the base of the tail. Higher PUFA content of thymus fat, abdominal caul and fat around the breast is the result of a higher content of C18:2 and C18:3. Probably the increased flow of PUFA from fish oil blocked the complete dehydrogenation of C18:2 in the rumen and may have caused different accumulation of more C18:2 in the triacylglycerols of the adipose tissue (Popova et al., 2008). The addition of fish oil in diet of lambs significantly increased the content of C16:1 in perirenal fat depot (p<0.001), abdominal caul (p<0.01), and over *m. longissimus dorsi* (p<0.05). The content of the saturated fatty acids (SFA) in triacylglycerols in most of the fat depots was reduced, accompanied with higher content of monounsaturated fatty acids (MUFA). Mentioned data displays that fish oil had influence on lipid metabolism in lambs fed diets supplemented with fish oil. The increase of the MUFA content suggest that fish oil had an effect on the lipid metabolism of the lambs fed fish supplemented diets. In the same group of lambs contents of C16:1, C18:1 and C18:0 were changed, because fish oil affects the activity of steroyl-CoA-desaturase. It was observed that composition of the diet and location of fat depot influence the activity of enzyme steroyl-CoA-desaturase which index was increased. Authors concluded that addition of fish oil in diets of lambs increased the storage of intermuscular and internal fat, compared with subcutaneous fat of lambs (Popova et al., 2008).

Except fish oil, flax oil also presents good source of ω-3 fatty acids of which influence on the content of fatty acids in lamb meat was investigated in the trial by Gruszecki et al. (2006). In the experimental diet part of soy meal was substituted with 10% of crushed flax seeds. Significant differences among the groups were in the content of linolenic acid (C18:3n-3) and total amount of PUFA (Figure 1.). *M. longissimus lumborum* of lambs fed flax seeds supplemented diet had 4.5 times higher content of C18:3, whereas the difference in the content of other fatty acids was not significant. The content of PUFA was significant higher in the *m. longissimus lumborum* of the same group of lambs, whereas content of SFA and UFA (unsaturated fatty acids) was not significant.

Conjugated linoleic acid (CLA) in lamb meat

Food products derived from ruminant animals are the major source of CLA in human diets (Chin et al., 1992). Many investigations found dietary CLA to be able to reduce the incidence of tumors in animal models for mammary, colon, and skin tumor (Belury and Kempa-Steczko, 1997; Banni and Martin, 1998). Many positive health effects associated with CLA in experiments have been extended to include reduction in body fat increasing and altered nutrient partitioning, antidiabetic effects, reduction of atherosclerosis development, enhanced bone mineralization, and modulation of the immune system (Belury and Kempa-Steczko, 1997; Banni and Martin, 1998). The main isomer is *cis*-9, *trans*-11 that is presented in food which originates from biohydrogenation of linoleic acid to stearic acid by rumen bacteria or from Δ9-desaturation of *trans*-11 vaccenic acid (Kepler et al., 1966).

Food products from ruminants fed grass are good sources of CLA, and contain much more of it than those from animals fed grain (Dhiman et al., 2000). Therefore, meat products from grass fed animals can produce 300-500% more CLA than those of animals fed the usual diet of 50% hay and silage, and 50% grain (Dhiman, 2001). Rumenic acid has been proposed as the common name for this specific CLA isomer (Kramer et al., 1998). The CLA found in fat from ruminants´ milk and meat originates from two sources (Griinari and Bauman, 1999). One source is CLA formed during ruminal biohydrogenation of linoleic acid, while the second source is CLA synthesized by the animal's tissues from *trans*-11 C18:1, another intermediate in the biohydrogenation of unsaturated fatty acids. Therefore, the uniqueness of CLA in food products derived from ruminants relates to the incomplete biohydrogenation of dietary unsaturated fatty acids in the rumen. According to Dugan et al. (1997) supplementation of ruminants´ diets with CLA, is not possible because CLA would be rapidly hydrogenated in the rumen to stearic acid. In order to avoid this biohydrogenation, the addition of CLA in diets has to occur when the animals are not ruminating; it means prior to weaning when they are identical to non-ruminants.

In the trial by Mir et al. (2000), a comparison of conjugated linoleic acid (CLA) content in lamb meat relating to different feeding treatment was investigated for 21 days. In that trial all lambs were fed milk replacer with addition 5 ml of olive oil. Experimental group of lambs was fed 0.33 g of CLA supplement dissolved in 5 ml of olive oil, after weaning lambs received diets with 6% of safflower oil. Safflower oil constituted 78% of linoleic acid and 0.7 mg CLA/g of fat. Dietary supplementation with safflower oil increased fat content of subcutaneous adipose tissue only, whereas the CLA content of all the tissues was increased (p<0.05) by more than 200%. However, the content of CLA in tissues wasn´t under the impact by CLA content in lambs´ diets before weaning. In the trial by Mir et al. (2000), dietary supplement of safflower oil significantly increased the content of linoleic acid in leg of lambs (Table 2.). Results indicated that addition of linoleic acid source was a successful method of increasing CLA content of tissues. In the first feeding treatment, CLA supplement was added to diets of unweaned lambs for direct deposition into the tissues. In the second treatment diet was supplemented with linoleic acid rich safflower oil to enhance ruminal bacterial activity for the conversion of linoleic acid to CLA isomers. Direct feeding of CLA to unweaned lambs did not increase the CLA content in any of the examined tissues. The CLA was probably metabolized for energy by the growing lambs (Mir et al., 2000). The change in configuration of C18:2 may disable the system to actuate fibroblasts to differentiate into adipocytes and may be the reason for the lower fat content in mature adipose tissue in lambs fed CLA prior to weaning (Mir et al., 2000). In weaned lambs, supplemented with safflower oil, the availability of CLA from rumen did not decrease fat content of adipose tissue, suggesting that CLA is not effective in restricting lipid accumulation once fibroblast differentiation into adipocytes has occurred. The content of CLA in muscle samples from control lambs ranged from 0.64 to 3.13 mg CLA/g lipid and was within the range of values reported for various muscle tissue from lambs (Hansen and Czochanska, 1976). However, values for muscle from control lambs in the present study were lower than the value of 5.6 mg CLA/g lipid in lambs (Chin et al., 1992). Mentioned authors established that safflower oil supplement increased the CLA content in rib muscle to 8.4 mg CLA/g lipid, which was 1.7 higher than in the rib muscle from control animals. In this study the average content of CLA for leg and rib muscle for lambs in control and safflower oil treatment was 76.6 and 178.6 mg/100 g tissue, respectively. Content of CLA in liver and adipose tissue from lambs fed safflower oil were not as high as the values of 12.6 and 16.9 mg CLA/g lipid reported by Banni et al. (1996) in liver and adipose, respectively. That was perhaps due to the differences in the age of the animals and dietary conditions. In the study of Mir et al. (2000), the average age was about 3.5 months and the lambs received milk replacer and high concentrate diets, while the suckling lambs in the study by Banni et al. (1996) were one month of age and were nursed by ewes grazing on grass pasture.

Kott et al. (2010) investigated the influence of diets supplemented with safflower seeds and vitamin E on the content of fatty acids in lamb meat. *M. longissimus dorsi* (MLD) from lambs fed safflower seed supplemented diets had higher contents of the conjugated linoleic acid (CLA), polyunsaturated fatty acids (PUFA), total unsaturated fatty acids (TUFA) and higher ratio among polyunsaturated and saturated fatty acids (PUFA:SFA), compared with lambs received diets with no safflower supplement. Influence of safflower supplementation on total fatty acid composition in lamb muscle was variable. Authors from previous experiments concluded that supplementation with safflower oil or seeds increased the contents of linoleic acid, CLA, and C18:1 isomers in lamb muscle, whereas content of oleic acid decreased (Mir et al., 2000; Kott et al., 2003).

Feeding modulation of fatty acid composition in lamb meat with special regard on the content of conjugated linoleic acid was investigated by Demirel et al. (2004 b). During trial lambs were also fed supplements that constituted different source of fat for 60 days. Lambs were divided into three groups from which the first group received Megalac supplement (high content of palmitic fatty acid), the second flaxseed (high content of linolenic fatty acid), and the third group received addition of flaxseed and fish oil (high content of n-3 fatty acid) in diets. Influence of different feeding treatment on the content of conjugated linoleic fatty acid (CLA) in liver of lambs did not display significant results. Lambs fed flaxseed and fish oil supplement had significant increased (p<0.01) content of CLA in *m. semimembranosus* in comparison with lambs fed other mentioned supplements. In *m. semimembranosus* of lambs fed equal feeding treatment significantly increased (p<0.01) the content of *trans* C18:1, fatty acid which is one of metabolites from incomplete biohydrogenation from which CLA originates. Noble et al. (1974) observed that long-chain fatty acids from fish oil inhibits microbial reductase activity in rumen and therefore prevent complete biohydrogenation from unsaturated to saturated fatty acids. Consequently, incomplete biohydrogenation of fatty acids in rumen results in development of intermediate trans C18:1 that is absorbed in small intestine of lambs. In present trial, the combination of fish oil and flaxseed rich in linolenic acid (C18:3n-3) indicated as the best feeding treatment with the aim to increase CLA content in *m. semimembranosus* of lambs.

Conclusion

Fatty acid composition, as well as n-6/n-3 ratio in adipose and muscle tissues of lambs, is influenced by feeding. The ratio below 4 is desirable, and may be expected towards feeding animals with pasture, whereas n-6 polyunsaturated fatty acids (PUFA) supply is lower. Hay and pasture, as well as the addition of flaxseed and fish oil in diets increase the content of n-3 PUFA in lambs´ muscle tissue, compared to diets based on concentrates. Therefore, feeding modulation of fatty acid composition should be focused on composition of diets that decrease saturated fatty acids and increase polyunsaturated fatty acids in lamb meat.

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SCIENTIFIC AND PROFESSIONAL SECTION

Modellierung der fettsäuerlichen Zusammensetzung von Lammfleisch durch die Fütterung

Zusammenfassung

Verschiedene wissenschaftliche Untersuchungen haben gezeigt, dass das Fleisch von Wiederkäuern eine günstige fettsäuerliche Zusammensetzung hat, und ein Verhältnis ω-6/ω-3 unter 4,0 wegen des geringeren Anteils der Linolsäure und des relativ hohen Gehalts ω-3 poliungesägtigter Fettsäuren, besonders Linolensäure, vorzeigt. Das Ziel dieser Arbeit ist, die Untersuchungen über die Möglichkeiten der Modellierung der fettsäuerlichen Zusammensetzung von Lammfleisch durch die Fütterung zu studieren. Durch die Fütterung der Lämmer und deren Mütter vor dem Abstillen ist es möglich, fettsäuerliche Zusammensetzung und deren Verhältnis in Lammfleisch zu modellieren. Zahlreiche Untersuchungen haben gezeigt, dass das Weiden der Lämmer auf der Weide den Gehalt von ω-3 Fettsäuren erhöht, besonders bezieht sich das auf Eikozapentaensäuren und Dokozaheksaensäuren in m. longissimus thoracis und m. semimembranosus . Der Zusatz von 10% Leinöl in Portionen hat bei den Lämmern den Gehalt der Linolensäure in m. Longissimus lumborum (sogar 4,5 mal) bedeutend vergrößert, während der Zusatz von Fischöl die Lagerung des Zwischenmuskelfettes im Vorderschinken, in der Keule und im Abdomen stimmuliert. Die fettsäuerliche Zusammesetzung des Zwischenmuskelfettes und des Unterhautfettgewebes von Lämmern, die noch gestillt werden, steht unter dem Einfluss des fettsäuerlichen Gehaltes in Muttermilch und hängt somit von der Haltung und Fütterung der Mutter ab. Einer der Vorteile bei Fütterung von Lämmern ist der Zusatz von Linolsäurenquelle und Linolensäurenquelle in Kombination mit Fischöl, wobei es zu bedeutender Vergrößerung des Gehaltes der konjugierten Linolsäure (CLA) in verschiedenen Geweben kommt. Aus angeführten Angaben geht hervor, dass man durch die Fütterung die fettsäurleiche Zusammensetzung von Lammfleisch modellieren kann, mit dem Ziel der Verminderung des Gehaltes von gesättigten Fettsäuren und Vergrößerung des Gehaltes von poliungesättigten Fettsäuren im Fett- und Muskelgewebe der Lämmer.

Schlüsselwörter: *Fütterung von Lämmern, Lammfleisch, poliungesättigte Fett*

Aggiustamento della composizione di acidi grassi di carne d'agnello tramite l'alimentazione

Somario

Varie ricerche scientifiche hanno rivelato che la carne di ruminanti ha una composizione gradevole di acidi grassi e la percentuale ω-6/ω-3 sotto il 4,0 a causa della minore quantità di acido linolico e di una quantità relativamente alta degli ω-3 acidi grassi polinsaturi, specialmente del linoleico. Lo scopo di quest'articolo era esaminare le ricerche che esaminano la possibilità di aggiustamento della composizione di acidi grassi di carne d'agnello tramite l'alimentazione. Alimentando gli agnelli o loro madri prima di svezzamento è possibile aggiustare la composizione chimica di acidi grassi e la loro percentuale in tessuti di agnelli. Le numerose ricerche hanno dimostrato che pascendo gli agnelli al pascolo aumenta la percentuale degli ω-3 acidi grassi, soprattutto l'eikozapentaenoico e quel dokozaessaenico nei m. longissimus thoracis e m. Semimembranosus. Con l'aggiunta del 10% di olio di lino negli alimenti previsti per agnelli è notevolmente aumentata la percentuale di acido linoleico nel m. longissimus lumborum (4,5 volte), mentre con l'aggiunta di olio di pesce è stato stimolato l'immagazzinamento del grasso intramuscolare di spalla, coscia e addome. Sulla composizione di acidi grassi del grasso intramuscolare e del tessuto subcutaneo di agnelli allattati influisce la percentuale di acidi grassi nel latte di madre e dipende dall'allevamento e alimentazione di madre. Uno dei vantaggi nell'alimentazione di agnelli è l'aggiunta di sorgente di acido linolico e quel linoleico combinando l'olio di pesce, al contempo con l'aumento notevole di percentuale di acido linolico coniugato (CLA) in vari tessuti. Da questi dati si può concludere che tramite l'alimentazione è possibile aggiustare la composizione di acidi grassi nella carne di agnello allo scopo di far diminuire la percentuale di acidi grassi saturi e far aumentare la percentuale di acidi grassi polinsaturi nel tessuto grasso e muscolare di agnelli.

Parole chiave: *alimentazione agnelli, carne di agnello, acidi grassi polinsaturi, acido linolico coniugato*

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