New Nutritional Strategies for Improving the Quality of Meat

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Abstract

Few studies of using locally legume grains in lamb nutrition have been studied that their use had no negative impact on meat quality such as fatty acid composition. One of the strategies of increasing functional food availability is to increase polyunsaturated fatty acids, especially the ω-3 series, conjugated linoleic acid (CLA) level and reduce saturated fatty acids in animal products. The CLA isomers appear to be concentrated in intramuscular and subcutaneous fat of meat ruminants and the concentration of c9, t11-CLA being greater than the concentration of t10, and c12-CLA in all tissues. To increase the CLA yield in lamb meat, it is essential to provide lamb an appropriate substrate for the formation of CLA. The provision of source of dietary linoleic acid appears to increase the CLA concentration to the greatest extent. Regarding the recommended daily intake for the appreciation of health benefits in humans (3500 mg/d), this amount of CLA supplied to meat lamb will partially provide the CLA requirement for everyone under certain conditions; deposition of CLA in the tissues using the provision of modest amounts of locally legume grains is more conducive to CLA synthesis rather than high levels of grain.

Keywords: conjugated linoleic acid, local legume grains, meat quality, ruminants, nutrition manipulation, ruminal biohydrogenation

1. Introduction

The protein sources form the largest and most cost-effective part of animal feed, and large quantities of these resources are exported annually for use in animal feed production. Not only does this impose a heavy currency burden on the country, it also causes a lot of problems, in which case the quality of the purchased materials, the distances, transportation problems and the probability of their pollution can be pointed out [1]. Therefore, recognizing locally feedstuffs and replacing them with imported food sources have a significant contribution to economic self-sufficiency. The leguminous family is widely distributed globally, so that various species of chickling vetch are present in the Canary Islands, Germany, East Asia, Nepal, China, the Middle East, North Africa, southern Europe, North America and the Mediterranean, with moderate climates and moderate rainfall as a source of plant protein for animal nutrition [2].

In recent years, the limitations in the use of animal by-products, such as meat meal due to government regulations, and consumer demand have led to an increase in the use of plant protein sources. Soybean meal is the main plant protein source used in animal feeding and it is largely imported from Brazil, which has recently been questioned. In addition, in the livestock feeds industry, all efforts are made to reduce feed and feed costs; therefore, an important objective of world farmers has been to increase the use of plant protein sources preferably from local feedstuffs. Few studies of using locally legume grains in lamb nutrition have been studied. Several reports seemed to suggest that their use had no negative impact on meat quality such as fatty acid composition [3, 4]. Locally produced legumes as alternative protein sources in the diets of ruminants are commonly used worldwide like peas, field beans, types of vetch and rapeseed. Types of vetch, such as bitter vetch (*Vicia ervilia* L.), common vetch (*Vicia sativa* L.) and chickling vetch (*Lathyrus sativus* L.) grains, are the legume seeds available in the Mediterranean and Western Asia areas and especially in the west-north area of Iran and are comparatively cheap despite its relatively high nutritional value. One of the strategies of increasing functional food availability is to increase polyunsaturated fatty acids, especially the ω-3 series, conjugated linoleic acid (c9,t11-CLA) level and reduce saturated fatty acids in animal products [4, 5]. Although there is a vast amount of literature available about the CLA content of milk, a few research trials focusing on the CLA content of meat are limited. The CLA isomers appear to be concentrated in the intramuscular and subcutaneous fat of meat ruminants and the concentration of c9, t11-CLA being greater than the concentration of t10, c12-CLA in all tissues, but the proportion of the latter CLA isomer is greater in subcutaneous fat [6]. Of the many isomers identified, the cis-9, trans-11 CLA isomer (rumenic acid) accounts for up to 80–90% of the total CLA in ruminant products [7]. However, the amount of the CLAs found in milk and meat are small, relative to the recommended daily intake for the appreciation of health benefits in humans, which is 3500 mg/d [6]. There is little data available on the effects of feeding types of vetch grains on lamb intramuscular fatty acid composition. The objective of the present chapter is to evaluate the effect of totally replacing dietary soybean meal and nutrition manipulation of the diet of the livestock to produce high-quality and healthy meat.

2. Nutrition manipulation for the production of high-quality and healthy meat

New nutritional strategies for feeding livestock and poultry focus on the increase of unsaturated fatty acids (especially n-3) and conjugated linoleic fatty acids and the reduction of saturated fatty acids in animal food products [5, 8]. To increase the CLA in animal meat, it is essential to provide a suitable base for its formation. Therefore, the inclusion of the source of

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linoleic acid in the ruminant animal diet will be most effective in increasing the concentration of CLA in meat products. Forage foods such as grasses or legumes (alfalfa) are suitable for facilitating the accumulation of CLA and increasing the precipitate and forming it in the tissue of the animals. Therefore, the use of plant sources such as plants in the marine ecosystem and dry areas is one of the first and most important sources of unsaturated fatty acids. Aquatic plants have a special ability to produce fatty acids (18: 3 n-3), which are the building blocks for the production, refinement and nonsaturation of a series of fatty acids, which ultimately produce docosahexaenoic acid and eicosapentaenoic acid. These two fatty acids are consumed by fish from aquatic plants and can be used to produce a wide variety of fatty acids, especially in fish oil, in fish tissues [5]. Plant sources and dry forages such as clover have a high proportion of unsaturated fatty acids (75–50%), such as alpha linoleic acid, which can be considered as a suitable substitute for the supply of fatty acid in some regions. However, the transfer of this type of fatty acids in ruminant meat depends on two important processes for increasing the level of these fatty acids in fodder (resulting in the animal) and reducing the amount of ruminal bovine fermentation [5]. However, providing a moderate amount of granular material in the diet concentrate instead of high levels leads to more CLA synthesis. Specific breeds of cattle tend to have more fat storage in the muscle and more CLA in the adipose tissue that is suitable for offering to the consumer. CLA levels of muscle can be increased by increasing the consumption of food items such as fresh fodder, silage, rangeland nutrition and the use of vegetable oils and fish oils, all of which have high levels of linoleic acid [9]. The production of CLA in the ruminant tissue is such that in the pathway of unsaturated fatty acid biosynthesis, the increase in the activity of the delta-9-dosacharase enzyme occurs and ultimately leads to the production of trans-vaccenic acid (**Figure 1**), which is the acid of the domestic production source; CLA is in the tissue, so that a linear relationship is obtained between the concentration of CLA and trans-vaccenic acid [9]. According to researchers (**Table 1**), CLA levels in beef ranged from 2.1 to 5.12 mg/g of fat [10].

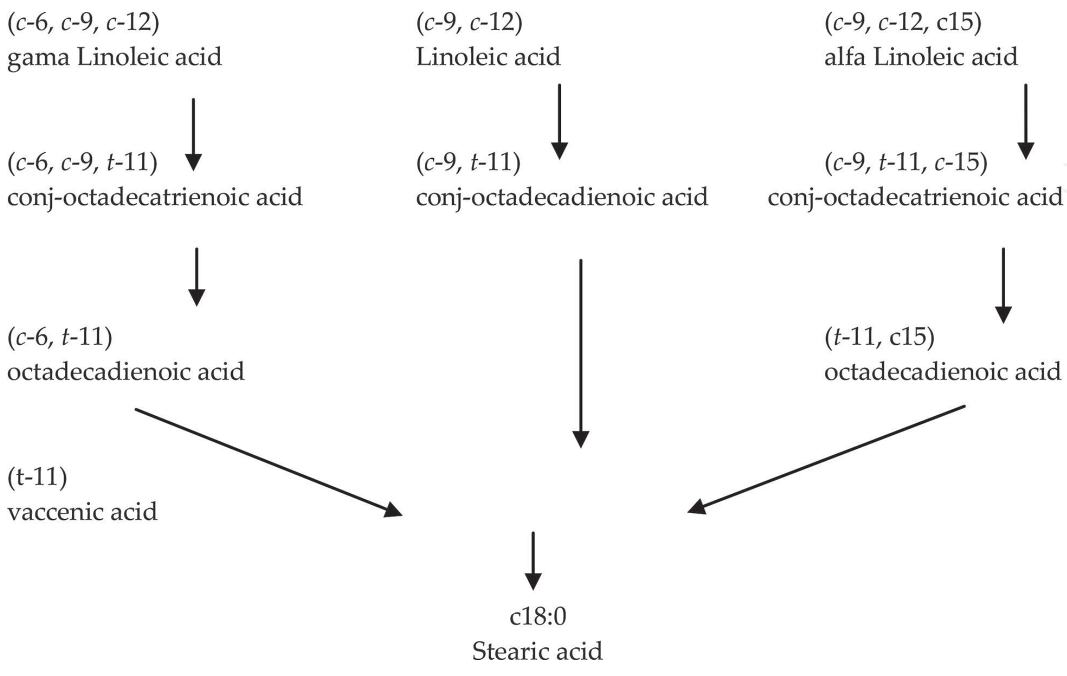

Figure 1. The major route of 18-carbon unsaturated fatty acid biohydrogenation [11].

These researchers have identified the variation in the concentration of CLA in beef, depending on the system used and the diet. In these reports, the factors affecting the content of CLA in beef have been compared with pasture forage and that the diet contains oil or whole grains, and even the composition of the fatty acid content of the grains and the ratio of the concentrate to the forage are also evaluated. Lanza et al. [3] in their research showed that the replacement of a variety of legumes with soybean meal and corn grain significantly increases the CLA in lamb meat. Scerra et al. [4] in their research examined the effects of some legume seeds on the composition of fatty acids and intramuscular CLA and showed that feeding some legumes over soybean meal saved omega 3, omega 6 and CLA fatty acids in muscle tissue. Abdollah et al. [12] in their study showed that the replacement of beet seed at different levels of 0, 5, 10 and 15% with soybean meal did not affect the characteristics, carcass traits and performance of lambs and it has been replaced without negative effects and has reduced the cost of the diet. At the 10% level, daily gain was higher than other levels and control group. The amount of crude protein, NDF, ADF and crude fat was estimated to be 23.1, 21.3, 6.9 and 1.6%, respectively, and researchers have proposed a 10% level for replacing soybean meal. In the study by Gül et al. [13] the authors used different levels of vetch (0, 15 and 25%) in the diet of avocado lambs and found that in 60 days of the feeding period, the daily gain and feed conversion ratio was 1.716, 0.26 and 6.06 kg for the level of 0 and 1.756, 0.28 and 6.27 kg for the level of 15% and 1.806, 0.29 and 6.23 kg for the level of 25% ration lambs. The growth traits, carcass quality and meat quality were approximately the same among treatments, and supplementation of up to 25% of levels of vetch did not have a significant effect on fattening performance and consumable carcass parts. However numerical improvement was observed in the food conversion ratio.

Diets	Country breeding system	CLA levels
Barley grain (800 g/kg diet)	Canada	1.7–1.8
Grass silage and concentrate	England	3.2–8.0
Corn grain (820 g/kg of diet)	America	3.9–4.9
Grain materials	America	5.1
Concentrate	Japan	3.4
Grass hey	America	7.4
Grass hey	Australia	2.3–12.5
Grass hey	Ireland	3.7–10.8
Corn and extruded soybean seeds	America	6.6–7.8
Pasture forage	America	3.5–5.6
Fattening diet	America	2.9–3.2
Fattening diet and soybeans seeds	America	3.2–3.6

As Ref. [10].

Table 1. CLA levels in cattle meat based on various breeding and feeding systems (mg/g fat).

2.1. Chemical composition and fatty acid composition of meat

The results of the chemical composition of the meat samples are reported in findings by Seifdavati and Taghizadeh [14]. The chemical composition of lamb samples fed with different diets showed a significant difference in crude fat and crude protein ($P < 0.01$). Unlike crude fats, the raw protein content of lamb meat was higher in soybean meal diet and slightly higher than in other groups. Although the crude protein content of common vetch was higher than the rest of the seeds, the lower carcase protein could be due to its low digestibility of undigested protein in the rumen, which is based on the results of digestion intestinal experiments from the methods of Gargallo et al. [15] and McNiven et al. [16], (for more details, refer to the references [17, 18]. However, there was no increase in the digestible protein content of the total gastrointestinal tract between the tested samples either in their raw state or autoclaved, except for common vetch grain. Even with the autoclave of the common vetch grain, its protein was too protected and was not digested. According to the findings of Seifdavati and Taghizadeh [14], the composition of their experimental diets containing bitter vetch seed and soybean meal, had higher C16: and C18:0 fatty acids compared to the diets of common vetch group and chickling vetch group. The diets of common vetch and chickling vetch group were rich in linoleic (C18:2) and linolenic (C18:3) as essential fatty acids, compared to bitter vetch diets and soybean meal diets. However, the total of these two fatty acids was in all their experimental diets ranging from 56.6 to 57.05 grams per gram of methylated fatty acids. The results according to Seifdavati and Taghizadeh [14] among the saturated fatty acids showed a significant difference in the C16:0 content of the meat samples of the groups and soybean meal group was higher in lamb meat group ($P < 0.05$). Also, among the soybean meal groups, the level of palmitic acid C16:0 in lamb meat was higher than soybean meal ($P < 0.01$). The most abundant fatty acid in meat was oleic acid among legumes and its amount was significantly different between treatments ($P < 0.01$). Linolenic acid was higher in common vetch group lamb meat than in dietary containing bitter vetch seed, chickling vetch seed and soybean meal ($P < 0.05$). Similar results for this fatty acid were observed by Lanza et al. [3], Wood et al. [8] and Scerra et al. [4] for other legumes used in the dietary concentrate section. Generally, linolenic acid in common vetch group lamb meat was higher than in dietary containing bitter vetch seed, chickling vetch seed and soybean meal group ($P < 0.01$). Lamb meat in dietary containing chickling vetch showed higher levels of linolenic acid than lamb meat in soybean meal group ($P < 0.01$). The fatty acid composition of the muscle of the lambs moderately reflects the composition of the fatty acid in the diet. Ruminants, unlike nonruminants, do not store fat in tissues as much as they receive in the diet. This is because ruminal microorganisms hydrolyze glycerides and subsequently cause hydrogen to combine with unsaturated fatty acids derived from dietary feeds [19, 20]. Therefore, ruminants have more ratios of saturated to unsaturated fatty acids compared to nonruminants. The reduction of palmitic acid and stearic acid in lamb meat with diets containing chickling vetch and common vetch, respectively, compared with other diets, showed the potential of these two diets to reduce harmful effects on health ($P < 0.01$). These two acids can be responsible for increasing total cholesterol and low-density lipoprotein in the plasma and increasing the risk of human health [5, 20]. In sheep and lamb meats, the ratio of these two fatty acids is more similar. There is a small variation in the ratio of fatty acids present in different body parts of the lamb. An alternative strategy to improve health indicators of humans in relation to consumption of lamb meat is reducing the level of stearic acid in the tissue by increasing the activity of the enzyme, stearoyl-CoA desaturase-Δ9, although the response of the animal to this manipulation is often relatively small [21]. In terms of fatty acid content, sheep meat is rich in saturated and poor fatty acids from unsaturated fatty acids, which is thought to be harmful for humans [21]. Despite the initial hypothesis [22], the effects of dietary lipids on human health, there were some issues and ambiguities in the concepts of saturated fatty acids that led to an increase in blood cholesterol and coronary artery disease. In a meta-analysis of Hunter et al. [23] on available scientific documentation from 2000 onwards, it resulted in a systematic review of all previous findings on the concepts of saturated fatty acids. The researchers, in a review with contributions from scientists, focused on the topic that the effect of stearic acid as saturated fatty acid on the risk of vascular disease in the heart depends on the fact that this fatty acid is to be replaced with other saturated fatty acids, trans-fatty acids, fatty acids with a double bond and fatty acids with multiple bonds or with sugary substances. One of the goals and main concern of advanced livestock nutrition research is the study of the possible nutritional manipulation of fatty acid composition of the lamb meat to reduce the concentration of saturated fatty acids and increase the concentration of fatty acids (C18:1, C18:2, C18:3), as cholesterol-lowering serum [20, 21]. However, in the study by Seifdavati and Taghizadeh [14], the concentration of palmitic saturated fatty acid in soybean and bitter vetch group meat was higher than other experimental groups ($P < 0.01$). The higher levels of these two fatty acids (palmitic and stearic acid) in the soybean and bitter vetch group meat can be attributed to the higher levels of these two fatty acids in their diets than those of diets containing chickling vetch and common vetch. The level of oleic fatty acid was lower in raw chickling vetch group than in other experimental groups. The amount of oleic fatty acid in the intramuscular fat was higher than that of the ration levels in the meat of all groups. Fortunately, farm animal cells are capable of synthesizing oleic acid and its derivatives from stearic acid. Oleic acid is obtained by unsaturation or loss of hydrogen in stearic acid. In farm animals especially ruminants, secretion of the Δ9-desaturase enzyme make stearic acid easily into oleic acid [24]. But linoleic acid in lamb fat was much less than its dietary fat [14]. This indicates that biohydrogenation is a major part of the rumen [25]. Larger amounts of linoleic acid in the fat of lamb in the chickling vetch group are likely to correlate with the high level of this acid in the chickling vetch group compared to the rest of the group. Among the remaining groups, the amount of linoleic acid in the fat of lamb meat was higher than soybean meal group. The internal biosynthesis of linolenic acid is shown in the studies of Zhou and Nilsson [26]. This acid is a precursor to omega-3 fatty acids that have a wide range of biological activities with beneficial effects on human health [27–29]. Linolenic acid level, similar to linoleic acid in lamb fat, was less than its dietary fat, indicating a major part of its transformation and hydrogenation in the rumen [25].

2.2. CLA of lamb's muscle

The CLA values in the muscles of the lambs in different groups are shown in findings of Seifdavati et al. [17]. According to these findings in the lamb meat samples of the diet group consisting of common vetch seed, chickling vetch seed, bitter vetch seed and soybean meal, the amount of CLA was 2.23, 1.41, 1.94 and 1.15 g per methylated fatty acid, respectively, and so CLA in the diet group containing common vetch seed was significantly more than lamb meat of others dietary groups ($P < 0.01$). However, except for the soybean meal group, CLA levels of meat were not significantly different between lambs fed with diets containing raw legumes and processed with autoclave moist heat ($P < 0.01$). It is likely that the difference between the dietary groups of the contents of the tested legumes and the soybean meal composition group (control) is related to the specific effect of common vetch, chickling vetch, bitter vetch seeds in expressing the gene and increasing the activity of the Δ9-desaturase enzyme for the production of CLA precursors. Priolo et al. [30] showed that farm animals, especially ruminants, by secreting this enzyme easily convert stearic acid into oleic acid. Priolo et al. [24] found that, by replacing some kind of legumes, the CLA increased in the meat of lambs than soybean meal in lamb diet. The findings of Seifdavati et al. [17] are consistent with the results of Priolo et al. [24]. French et al. [31] reported that CLA levels of calf meat fed with different levels of concentrate and basic forage were different. In this study, the amount of CLA in meat were in the diet of the group (4 kg of concentrate + free forage), 0.47 g per 100 g of muscle fatty acid, diet group (8 kg of concentrate +1 kg of hey), 0.37 g per 100 g of muscle fatty acid, diet group (6 kg of grass fodder +5 kg of concentrate), 0.54 g per 100 g of muscle fatty acid), diet group (12 kg of grass fodder +2.5 kg of concentrate), 0.66 g per 100 g of muscle fatty acid and finally diet group (Only 22 kg of grass fodder), 1.08 g per 100 g of muscle fatty acid. Franch et al. [31] concluded that by increasing the level of concentrate, the level of CLA in meat was reduced. De La Torre et al. [32] in a report showed that the base ration and supplementation with oily grains were one of the effective ways to increase the amount of CLA in meat and the use of flaxseed (22 to 36%) in the ration was increased the amount of CLA meat. The researchers explained that the basic forage with concentrates, especially whole grains in the ration of livestock, reduced the severity of the unsaturated fatty acid dehydrogenation in the rumen, and this resulted in the production of optimal trans-vaccenic acid for the synthesis of CLA and its accumulation in meat. McNiven et al. [20] showed that the use of toasted soybean seed instead of its crude soybean seed in feeding calves with base ration did not have an effect on the amount of CLA in meat, and its rate in this report was 0.32–0.35 g per 100 g of fatty acid muscle. Despite the negative effects of rumen metabolism on the intramuscular fat structure of the livestock, the process of biohydrogenation is often carried out incompletely and produces several intermediates that affect human health. One of these compounds is the rumenic acid known as CLA (one of the linoleic acid isomers). Increasing interest in this compound has been attributed to anticancer, coronary heart disease and anti-hyperglycemia and prevents lipid accumulation in the body [20, 33, 34]. In animal experiments, CLA has been shown to inhibit cancer, diabetes and atherosclerosis [35–38]. In addition, McGuire and his colleagues [39] reviewed some of the potential effects of CLA on human health. These researchers have recommended that the increase in the accumulation of CLA in human consumption is realized by manipulation of the dietary intake of ruminants, especially sheep, for the purpose of enriching meat, in order to show the beneficial effects of this compound on health. In the study of Seifdavati et al. [17], CLA levels in meat from lamb fed with the diet group containing common vetch seed were higher than soybean meal group ($P < 0.01$) and numerically higher than chickling vetch and bitter vetch seed groups. This can be attributed to a high level of linoleic acid in the content of common vetch seed diet. This fact is shown in the report by Scerra et al. [4], which investigated the effects of some legume seeds on intramuscular CLA, in their study. So these researchers found that the higher intracellular CLA in peas seed with 0.45 g per 100 g of methylated fatty acid compared with soybean meal (0.20 g per 100 g of methylated fatty acid) was associated with high levels of linoleic acid in the pea seed diet. As mentioned earlier, in nonruminants, the fatty acid structure of their meat is similar to the structure of fatty acid in the diet, both in terms of accumulation and in terms of its secretion and biosynthetics [40]. However, this is a beneficial and similar effect in ruminants by manipulating and benefiting from the biohydrogenation incomplete process of ruminal metabolism on the dietary fat content [41]. However, several studies have shown the difference in the structure of dietary fatty acids with ruminant body tissues (milk or meat) [42–44]. In the study of Seifdavati et al. [17], CLA levels in lamb meat were two to three times higher than those of other researchers, as reviewed by Khanal and Olson [45] and McNiven et al. [20]. The results of Seifdavati et al. [17], also coincided with the findings of Tilak et al. [46], Valvo et al. [47] and Lanza et al. [3]. In the study of Lanza et al. [3] reported that the use of pea grain and horse beans grain instead of soybean meal in the diet of lamb fattening did not change the amount of CLA in meat of lambs and its values for all treatments ranged from 0.78 to 0.93 g per 100 g of methylated fatty acids. Not only differences in CLA content of products in an animal but also among species have been reported and received. In general, CLA levels are higher in ruminants compared to nonruminants [6]. Differences in the total amount of CLA in lamb meat in the experiment of Seifdavati et al. [17], with other reports, can be due to several factors such as nutrition from pasture forage as compared to intensive feeding of the high grain content of rations, the nature of nutrient content of dietary concentrate (having intact and complete oily seeds), the composition of fatty acid supplementation, the proportion of concentrate and silage versus hay, seasonal differences, genetics and animal breed, the type and nature of the seed and the breeding system [6, 46]. In the study of Seifdavati et al. [17], wet-heating autoclave treatments of legume grains replacing soybean meal in lamb's diet had no effect on the results of CLA levels of lamb meat. This can be due to the inherent nature of the seeds and the difference in the processing method. The findings of McNiven et al. [20] regarding the effect of soybean heat treatment on CLA in meat contradicted Seifdavati et al. [17] conclusion. In contrast to McNeven et al. [20] findings and in accordance with the results of Seifdavati et al. [17] experiment, Mohammed et al. [48] study showed that the content of trans-fatty acid (C18:1) and CLA isomer of cow milk has a strong effect from the type and nature of the source of grain compared to the processing method, and these researchers have shown that intrinsic factors in the type of grain such as anti-nutritional factors like tannin are responsible for the difference and may not be affected by the processing method. Researchers have shown that tannin content of legume or legume seeds (such as common vetch, chickling vetch and bitter vetch seeds) causes the accumulation of trans-vaccenic acid in rumen in both cases, using the live animal and the laboratory methods [49, 50]. Because tannins have the ability to inhibit trans-vaccenic acid in rumen converting bacteria to stearic acid or, in other words, to reduce the action of biodehydrogenation by inhibiting the activity of mentioned bacteria [49, 50], as a result, this process of CLA production increases as an intermediate product of this route [49, 50]. Despite this, Vasta et al. [51] showed that the CLA of tannin (certainly in low-to-moderate concentrations) is less effective than vaccenic acid, which suggests the fact that CLA is also produced and synthesized in the muscle as endogenous. In the experiment of Vasta et al. [51], CLA levels in the control diet muscle (dried alfalfa with concentrate) were 0.73 g per 100 g of methylated fatty acids, and the diet containing tannin-rich carob pulp treated with and without polyethylene glycol was 0.63 and 0.48 g per 100 g of methylated fatty acid. Findings of Di La Torre et al. [32], Franch et al. [31] and Priolo et al. [24] and in results of Seifdavati et al. [17], lambs fed with whole legumes grains and with alfalfa hay as total mixed ration (TMR) and full oily seeds (more fatty common vetch seed compared to the rest of the seeds) mixed with alfalfa (especially the inclusion of common vetch seed instead of soybean meal) showed that it caused and led to an increase in CLA meat from 1.15 g per 100 g of methylated fatty acid (soybean meal ration) to 2.23 g per 100 g of methylated fatty acid (diet of common vetch seed). Based on the per capita consumption of sheep meat at 7.6 kg per year in Iran, 37 g a day is consumed [52]. According to these figures, based on the daily requirement of humans (3500 mg of CLA) and the amount CLA of sheep meat intake per day, it will range from 1.8 to 7 mg and depending on the marble fat inside the muscle and supplementation of diets of lambs with whole oily grains in fattening. The average value of CLA in the muscle fat of sheep in quantitative aspects are not justifiable and can not be interpreted, unless with for enrichment the lamb meat with CLA, it is used appropriate feed in the diet to form CLA. Preferably, these materials should be rich in linoleic acid. The forage in diet with the consolidation and proliferation of CLA productive and storage microorganisms and forage supplementation with medium amounts of full-fat high-grade whole-grain material in comparison with high levels of grains material for lambs leads to more CLA for accumulation in muscle tissue. Taking into consideration that the daily requirement per person (3500 mg) with regard to the CLA for the beneficial effects on health, part of these needs can be achieved by daily consumption of lamb meat and its inclusion in the food pyramid or food basket provided in each household.

2.3. The use of breeds with an increased capacity to deposit CLA in lambs muscle

Public health policies recommend population-wide decreases in the consumption of fat, saturated and trans-fatty acids (TFA), and higher intakes of polyunsaturated fatty acids such as increasing in the consumption of the long-chain n-3 polyunsaturated fatty acids (PUFAs), eicosapentaenoic acid (20:5n-3, EPA), and docosahexaenoic acid (22:6n-3, DHA) [54]. Another potential pathway to increase PUFAs in ruminant tissues is to utilize breeds with an increased ability to deposit these fatty acids or deposit n-3 PUFAs in preference to those of the n-6 fatty acid series [55]. According to findings of Wachira et al. [56] Suffolk and Soay lambs contained more α-linolenic acid (ALA) than the Friesland lambs, and Soay lambs had higher intramuscular levels for all the major n-6 PUFAs and CLA than Suffolk or Friesland lambs. The LA and ALA were higher in the Suffolk × Lleyn lambs than Scottish Blackface, as considered in the polar lipids of the semimembranosus muscle [54]. Lambs from Merino dams had about 2 mg/100 g higher levels of EPA + DHA than lambs from cross-bred dams, when the sire breed was Poll Dorset [57].

2.4. Protected fat as sources of n-3 fatty acids

Ferreira et al. [58] showed that stearic acid concentration decreased linearly when fish oil replaced soybean oil. Also, vaccenic acid concentration was higher for lamb-fed fat diets versus control diet with a 10:90 of forage to concentrate ratio. In addition, vaccenic acid increased linearly with fish oil inclusion. The conjugated linoleic acid (CLA) C18:2 cis-9, trans-11 showed a higher concentration in the meat of animal-fed diets containing fish oil compared to controlled diet, but it was not affected by soybean oil inclusion. However, if the fat used in the diet is somehow protected from rumen degradation, the result will be doubled, as shown in the research that the CLA content of lamb longissimus muscle improved 16.7% when 86.6 g of Megalac (as fat protected) per kg of diet DM was fed for 10 weeks [59]. It is the general opinion that inclusion of protected fat in diet increases the concentration of n-3 and n-6 fatty acids in muscle in some but not all researches [60, 61]. In these studies (as shown in **Table 2**), there was a higher amount of corn in the controlled diet as a replacement of protected fat diet and thus more LA [53]. It should also be noted that it is not obvious if the 18:3 shown is n-3, n-6 or the sum of both, in the study of Castro et al. [60]. In contradiction with the comment, Gómez-Cortés et al. [62] find the fatty acid composition of lamb muscle with a significant difference among diets containing calcium soap fatty acid (CSFA) compared with extruded linseed for 18:3n-3 (α-linolenic acid, ALA) but with no effect on 18:3n-6 (γ-linolenic acid, GLA). A significant difference among diets for the muscle level of ALA and no effect on GLA was found in research [63]. A recent research showed the ALA, EPA, DPA, DHA and the sum of PUFA levels, in IMF, were higher in lambs fed with extruded linseed than CSFA of palm oil [62]. This could be because of the higher level of ALA in extruded linseed than in calcium soap of palm oil (as shown in **Table 2**), which is the precursor of the n-3 long-chain PUFA.

	Unit	Oleic	Linoleic	Linolenic
Concentrate				
Soybean	%	23.3	52.2	5.6
Soybean	%	23.1	54.5	8
Corn	%	37	47.2	1.3
Sunflower	%	45.4	46	0.1
Sunflower	%	61.8	27.9	0.1
Mustard	%	38.2	25.3	11.3
Rapeseed	%	46.8	19.5	8.7
Canola	%	61.8	18.7	10.4
Linseed	%	18.5	17.3	53.2
Extruded linseed	%	15.1	18.2	54.3
Protected linseed	g/100 g	56.1	25	7.7
Palm	%	41.9	11	–
Palm	%	18	4	–
Palm olein	%	49.5	11.7	0.5
Red palm olein	%	44.6	10.4	0.3
Coconut	%	7.2	1.7	–
Coconut	%	5.8	1.3	–
Cotton seed	%	17	53.3	–
Oats	g/100 g	38.8	38.3	1.2
Barley	g/100 g	14.2	57.8	5.4

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	Unit	Oleic	Linoleic	Linolenic
Lupins	g/100 g	31.3	42.1	5.2
Flax seeds	%	22	18.3	48.2
Roughage				
Green maize fodder	g/100	4.7	17.1	38.9
Wheat straw	g/100 g	14.9	–	–
Perennial ryegrass	mg/g DW	0.4	2.73	15
Fresh grass perennial ryegrass	%	1.7	10.6	68.4
Fresh ryegrass	g/100 g	1.5	12.6	55.3
Silage perennial ryegrass	%	1.2	11.8	64.7
Silage ryegrass	g/100 g	1.6	11.2	51.3
Fresh corn (whole plant)	g/100 g	16.4	47.5	12
Silage corn	g/100 g	14.4	41.4	10.6
Lucerne hay	%	8	24.4	23.2
Corn silage	%	18.8	48.5	11.1
Supplementation				
Algae U. lactuca (flour)	%	27.4	8.3	4.4
Algae D. antarctica (leaves)	%	25.4	10.8	3.9
Algae D. antarctica (stem)	%	25.8	15.7	1.1
DHA Gold algae	%	0	0.01	0.1
Protected fat	g/100 g	26.4	32.7	2
Megalac	%	34.4	–	–
Calcium soap of palm oil	%	9.7	–	-
Fish oil	%	25.8	3.6	1.3
Fish oil	%	9.2	1.1	1.5

As reference [53].

Table 2. Sources of oleic, linoleic, and linolenic fatty acids in animal feeds.

3. Conclusion

Higher CLA values in the muscle tissue of intensively finished lambs are not easily explained. To increase the CLA yield in lamb meat it is essential to provide lamb an appropriate substrate for the formation of CLA. The provision of source of dietary linoleic acid appears to increase the CLA concentration to the greatest extent. Dietary forage such as grass or legume hay appears to facilitate the establishment of the micro-flora that enhances the formation and deposition of CLA in the tissues; also, the provision of modest amounts of grain is more conducive to CLA synthesis rather than high levels of grain. Regarding the recommended daily intake for appreciation of health benefits in humans (3500 mg/d), this amount of CLA supplied to meat lamb will partially provide the CLA requirement for everyone under conditions of this study.

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