Content is avaliable at SCOPUS

Meat Technology — Special Issue 64/2

www.meatcon.rs ▪ www.journalmeattechnology.com

UDK: 637.5:636.2

ID: 126616329

https://doi.org/10.18485/meattech.2023.64.2.34

Review paper

Nutritional approaches to enhance fatty acid composition of beef: a review

Mirjana Lukić[a], Sara Simunović[a] and Stefan Simunović[a]*

[a] *Institute of Meat Hygiene and Technology, Kaćanskog 13, 11000 Belgrade, Serbia*

A R T I C L E   I N F O

Keywords:
Beef
Fatty acids
Forage feeding
Oilseed/oil supplementation

A B S T R A C T

Intramuscular fat content and fatty acid composition are important factors contributing to the nutritional value of meat. Beef meat is characterized by a high content of saturated fatty acids (SFA) which can contribute to elevated serum cholesterol levels and coronary heart disease in humans. Consumer concerns regarding the association between beef consumption and chronic cardiovascular diseases have motivated increased interest in developing strategies for reducing the lipid content and improving the fatty acid (FA) composition of beef. Although beef fat quality is determined by many factors, such as breed, gender, age, live weight, fatness degree, but the bovine diet has a key role in enhancing the nutritional quality of beef lipids. Nutritional strategies to improve the FA composition of beef focussed mainly on reducing the SFA and the n-6:n-3 poly-unsaturated fatty acid (PUFA) ratio, simultaneously increasing the PUFA of beef fat.

1. Introduction

Beef is a high-quality source of protein and essential micronutrients, but consumers recognize it as red meat with a high content of SFA (*McAfee et al*., 2010). The processes of microbial lipolysis and biohydrogenation in the rumen, which result in the conversion dietary PUFA to more saturated end products, are major reasons why beef fats are highly saturated. A high intake of SFA and a high ratio n-6:n-3 PUFA are typical of Western and, increasingly, global diets and is associated with an increased risk of cardiovascular disease, obesity, type 2 diabetes and several form of cancer, especially in people with genetic predispositions (*Trbović et al.*, 2020). The feeding system has important effects on beef quality since the nutrient composition and energy intake of the diet affect commercial quality attributes of the carcass and the nutritional composition of the meat, particularly the amount of intramuscular fat and FA composition (*Liu et al.*, 2022). In comparison to new breeding strategies, manipulation of beef quality through feeding is cost-effective and more practical, and a variety of nutritional interventions have been successfully implemented in feedlots (*Weeb*, 2006). Growing demand for foods with potentially beneficial effects on consumer health has motivated increased interest in developing strategies for improving the nutritional quality of beef and producing meat more desirable for the consumers.

This paper reviews nutritional strategies for improving the lipid composition of beef by increasing its content of PUFA.

***Corresponding author:** Mirjana Lukić, *mirjana.lukic@inmes.rs*

Paper received Jun 13th 2023. Paper accepted Jun 30th 2023.
Published by Institute of Meat Hygiene and Technology — Belgrade, Serbia

2. Forages and fatty acid composition of beef

Grass, either fresh or conserved, is usually the cheapest and most important source of cattle feed in temperate climates. Typical ruminant diet mainly consists of carbohydrates, (up to 70% of dry matter). Lipids from grasses and legumes, mainly present in the form glycolipids, are important components of the ruminant diet even though they constitute only small fraction of dry matter (up to 8 %). Forages such as grass and clover contain a high proportion α -linolenic acid (ALA, 18:3n-3) (~70%) and linoleic acid (LA, 18:2n-6) (~20%). In contrast, cereal (maize, barley, sorghum) grain lipids are richer in LA (~60%) compared to ALA (~4%) (*Davis et al.*, 2022). Ruminants are generally supplied with unsaturated fatty acids (UFA) from the forage portion of their diet. The findings of available studies conducted in Europe and South America are generally consistent and showed differences in meat FA composition from pasture- and grain-fed animals, and higher PUFA content, especially ALA in pasture-fed groups (*Alfaia et al.*, 2009, *De la Fuente et al.*, 2009, *Leheska et al.*, 2008, *Garcia et al.*, 2008). Pasture-based feeding of beef cattle results in increased ALA content in muscle lipids, but also in increased content long chain n-3 PUFA, eicosapentaenoic acid (EPA 20:5n-3), docosapentaenoic (DPA 22:5n-3), and docosahexaenoic acid (DHA 22:6n-3), due to the elongation and desaturation of ALA in body tissue. *Alfaia et al.* (2009) reported that pasture and feedlot beef contain 21.3 mg and 4.7 mg EPA/100g and 20 mg and 1.1 mg DHA/100g, respectively. Consuming pasture-fed beef could be considered as an adequate method for increasing dietary intake of n-3 PUFA, including EPA, DPA and DHA, in humans (*Butler et al.*, 2021). Higher protection of FA in fresh grass from the ruminal biohydrogenation, relative to that of grain, could be explained by the presence of secondary plant metabolites (PSM) in pasture (*Alfaia et al.*, 2009). Some PSM have the potential to modulate the microbial population in the rumen and modify ruminal fermentation, leading to increased PUFA availability for incorporation into

Table 1. Effect of forage type, oilseed and oil supplementation on the PUFA content of beef muscle (mg/100g muscle)

Diet	C18:2n-6 Linoleic	C18:3n-3 Linolenic	C20:5n-3 EPA	C22:6n-3 DHA	Total PUFA	Reference
Pasture	12.55	5.53	2.13	0.20	28.99	*Alfaia et al.* (2009)
2-Month concentrate after pasture	11.38	1.96	1.28	0.14	19.84	
4-Month concentrate after pasture	10.07	0.84	0.77	0.12	16.31	
Mixed pasture	2.59	1.17	0.54	0.09	6.11	*Duckett et al.* (2013)
Alfalfa	2.85	1.32	0.60	0.10	6.71	
Pearl millet	2.27	1.06	0.49	0.07	5.47	
Oilseed						*Mapiye et al.* (2013)
Hay + flaxseed	3.72	1.09	0.21	0.02	6.59	
Hay + sunflower-seed	4.47	0.49	0.10	0.02	6.70	
Red clover silage + flaxseed	3.73	1.38	0.26	0.03	6.99	
Red clover silage + sunflower-seed	5.17	0.39	0.10	0.02	7.63	
Oil supplementation						*González et al.* (2014)
Concentrate + linseed oil	4.70	1.59	0.44	0.08	9.02	
Concentrate + sunflower oil	5.03	0.55	0.22	0.04	7.75	
Concentrate + soybean oil	4.94	0.75	0.29	0.04	8.12	

animal muscle tissue. It has been reported that the enzyme polyphenol oxidase (PPO), which is present in red clover, may reduce the activity of plant lipases and as a result, reduce ruminal biohydrogenation of ALA. Some other plant species such as chicory, perennial ryegrass and meadow fescue, also contain a range PSM such as tannins, saponins and proanthocyanins, which can enhance protection of PUFA in the rumen and provide higher concentrations of beneficial PUFA that can be incorporated into the meat (*Kearns et al*., 2023). Generally, the impact of fresh grass on n-3 and n-6 PUFA levels in beef depends on plant species, phenological stage, plant maturity and senescence, temperature, light exposure, seasonality and time spent on pasture (*Pethik et al.*, 2021). With regard to the type of forage, *Duckett et al.* 2013 (Table 1**)** reported a difference in the proportion of ALA in muscles from steers that grazed alfalfa, pearl millet or a mixed pasture, with the highest concentration ALA found in steers grazing alfalfa. Moreover, the FA profile of beef from animals fed with botanically diverse pasture shows a higher content of n-3 PUFA than that from animals fed with pure swards (*Kalač*, 2011). The FA composition of intramuscular fat in grass-finished beef significantly improves with increasing duration of the grazing period prior to slaughter. Steers grazing perennial ryegrass for 158 days display higher n-3 PUFA (as a proportion of total FA) and lower n-6:n-3 PUFA ratios, compared to steers grazing perennial ryegrass pasture for 44 days and 99 days (*Noci et al.*, 2005a). Feeding concentrates in the finishing period to animals reared on pasture causes depletion of ALA and higher accretion of LA and a longer finishing period on concentrate, significantly attenuating all beneficial characteristics achieved by grass feeding (*Ponnampalam et al.*, 2006). Roughage conservation methods such as haying or silage production reduce the initial concentrations of antioxidants and PUFA. Consequently, proportions of ALA and long chain n-3 PUFA in meat lipids are higher from the animals fattened on fresh grass (pasture) compared to those fattened on grass silage (*French*, 2000). Feeding with wholecrop wheat silage or maize silage resulted in a low proportion of n-3 PUFA in muscles of finishing cattle, compared with those fed grass silage (*Noci et al.*, 2005b, *Dymnicka et al.*, 2004). Replacing, maize silage with a legume-cereal mixture and lucerne silage increased the concentration ALA in intramuscular fat of bulls by 2.2 times (0.63 and 1.39g/100g FA, respectively) (*Bartoň et al.*, 2010). The high dietary proportion of grass silage improved the beef FA profile, and the proportion valuable long-chain n-3 PUFA, EPA and DHA in intramuscular fat increases linearly with increased grass silage proportion in the beef cattle diet (*Keller et al.*, 2021).

3. Dietary lipid sources and fatty acid composition of beef

Dietary supplementation with oilseed improves the FA composition of beef despite ruminal biohydrogenation, because a proportion of dietary PUFA bypasses the rumen intact and is absorbed and deposited in body fat. The proportion of PUFA in meat increases linearly with PUFA levels in the diet up to 80 g/kg of dry matter intake, above which rumen function is compromised, meaning that the capacity to manipulate the fatty acid composition by use of ruminally-available fatty acids is limited. Many studies (*Marino et al*., 2019, *Fiorentini et al*., 2018, *González et al.*, 2014, *Juárez et al.*, 2011) show that supplementation of bovine diet with oilseeds, such as linseed, soybean, sunflower-seed or their oils, can improve the FA composition of beef. The FA profile of these oilseeds is various, with LA comprising 16–66 g/100 g and ALA 7–54 g/100 g of total FA. Linseed contains the highest proportion of ALA (around 54% of the total FA), and as a consequence, a low n-6:n-3 PUFA ratio. Accordingly, supplementation with linseed or linseed oil (rich in ALA) can increase the concentration of ALA in muscle tissue with desirable decrease in the n-6:n-3 PUFA ratio. Sunflower-seed (rich in LA) can increase the concentration of LA in tissue but with an associated undesirable increase in the n-6:n-3 PUFA ratio (*Scollan et al.*, 2014). In the study by *Mapiye et al.* (2013), steers fed high forage diet, with either grass hay or red clover silage (70% forage: 30% concentrate), in combination with flaxseed had higher proportions of total n-3 PUFA, ALA, EPA and DHA, than steers fed high forage diet in combination with sunflower-seed, and the authors noted the influence of dietary PUFA supplements is strongly influenced by the composition of the basal diet, especially by the amount and type of forages. *Mach et al.* (2006) offered whole canola seed (ALA content 10.6 g/100 g of total FA) or whole linseed (ALA content 54.2 g/100 g of total FA), at three lipid levels (50, 80 and 110 g/kg dry matter) to 54 Holstein bulls and noted that the concentration of n-3 PUFA in the *longissimus dorsi* muscle increased linearly with lipid level. Nevertheless, the n-6:n-3 PUFA ratio was significantly lower in whole linseed supplemented beef (15.6, 8.8 and 6.3), compared to whole canola seed supplemented beef (26.2, 21.0 and 26.4) at increasing levels of supplementation, respectively. Dietary flaxseed elicits substantial changes in the intramuscular beef FA composition (*Kim et al*., 2009). Proportions of PUFA in the intramuscular fat of steers fed 10% and 15% flaxseed were increased by 42.4 % and 57.1% respectively, compared with the control group (*Kim et al.*, 2009). The physical form in which linseed is provided to animals has little to no impact on the FA composition of beef. In a study by *Raes et al*. (2004), the effects feeding of extruded or crushed linseed on intramuscular and subcutaneous FA composition was investigated, and the authors reported that both physical forms of linseed in the finishing diet of young bulls (for approximately 120 days) increased ALA supply equally. Due to costs related to oilseed supplementation, it is useful to evaluate the optimal duration of oilseed inclusion in the bovine diet. The effect of the duration of dietary supplementation with linseed on the level incorporation of n-3 PUFA into beef muscle was reported by *Marino et al.* (2019). Results of this study suggest that supplying 10% linseed for 75 days before slaughter is sufficient for the incorporation of a significant quantity of n-3 PUFA into meat from steers. *González et al.* (2014) (Table 1) compared the effect of supplementation with linseed, sunflower and soybean oils, added at 4.5 % to a commercial concentrate, on the FA composition of young beef cattle. Feeding linseed oil diet led to a doubling Σn-3 PUFA, ALA and DHA compared to feeding sunflower and soybean oil diets. Expressed quantitatively per 170 g of beef serving, this amounts to n-3 PUFA increasing from 52 mg to 110 mg and long-chain PUFA increasing from 21 mg to 39 mg, i.e., to a level that provides 16% of the recommended intake of long-chain n-3 PUFA (250mg EPA+DHA per day) suggested by the European Food Safety Authority (*EFSA*, 2010).

4. Conclusion

Despite biohydrogenation of lipids in the rumen by the ruminal microbiota, diet has a key role in enhancing the FA composition of beef. The most effective method for increasing n-3 PUFA and reducing the n-6:n-3 PUFA ratio in beef fat is inclusion of dietary ingredients that are rich in n-3 PUFA. Feeding fresh or ensiled forages, whole oilseeds or plant oil results in beneficial changes in FA composition and higher nutritional quality of the beef.

Disclosure statement: No potential conflict of interest was reported by authors.

Funding: This study was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, and based on the Contract on the implementation and financing of scientific research work in 2023 (No 451-03-47/2023-01/200050 dated 03.02.2023).

References

Alfaia, C. P. M, Alves, S. P., Martins, S. I. V., Costa, A. S. H., Fontes, C. M. G. A., Lemos, J. P. C., Bessa, R. J. B. & Prates, J. A. M. (2009). Effect of the feeding system on intramuscular fatty acids and conjugated linoleic acid isomers of beef cattle, with emphasis on their nutritional value and discriminatory ability. *Food Chemistry*, 114, 939–946.

Bartoň, L., Bureš, D. & Kudrna, V. (2010). Meat quality and fatty acid profile of the musculus longissimus lumborum in Czech Fleckvieh, Charolais and Charolais x Czech Fleckvieh bulls fed different types of silages. *Czech Journal Animal Science*, 55, 479–487.

Butler, G., Mohamed, A. A., Oladokun, S., Wang J. & Davis H. (2021). Forage-fed cattle point the way forward for beef. *Future Foods* 3, 100012, https://doi.org/10.1016/j.fufo.2021.100012

Davis, H., Magistrali, A., Butler, G. & Stergiadis, S. (2022). Nutritional benefits from fatty acids in organic and grass-fed beef. *Foods*, 11, 646.

De la Fuente, J., Díaz, M. T, Álvarez, I., Oliver, M. A., Font i Furnols, M., Sañudo, C., Campo M. M, Montossi, F., Nute G. R. & Cañeque, V. (2009). Fatty acid and vitamin E composition of intramuscular fat in cattle reared in different production systems. *Meat Science*, 82, 331–337.

Duckett S. K., Neel, J. P. S, Lewis, R. M., Fontenot, J. P. & Clapham W. M. (2013). Effects of forage species or concentrate finishing on animal performance, carcass and meat quality. *Journal of Animal Science*, 91, 1454–1467, doi:10.2527/jas2012-5914.

Dymnicka, M., Klupczyński, J., Lozicki, A., Miciński, J. & Strzetelski, J. (2004). Polyunsaturated fatty acids in *M. longissimus thoracis* of fattening bulls fed silage of grass or maize. *Journal Animal Feed Science*, 13, 101–104.

European Food Safety Authority (EFSA), (2010). Panel on dietetic products, nutrition, and allergies (NDA); scientific opinion on dietary reference values for fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans fatty acids, and cholesterol. *EFSA Journal*, 8(3), 1461 (Available online: www.efsa. europa.eu).

Fiorentini, G., Santanaa, M. O., Messanaa, J. D. Valentea, A. L. S., Härtera, C. J., Rabeloa, C. H. S, French, P., Stanton, C., Lawless, F., O'Riordan, E. G., Monahan, F. J., Caffrey, P. J., Moloney, A. P., Barberoa R. P., Lannab, D. P. D, Reisa, R. A. & Berchiellia, T. T. (2018). Effect of lipid sources on fatty acid profiles of meat from pasture- and feedlot-finished Nellore bulls. *Livestock Science,* 211, 52–60.

French, P., Stanton, C., Lawless, F., O'Riordan, E. G., Monahan, F. J., Caffrey, P. J. & Moloney, A. P. (2000). Fatty acid composition, including conjugated linoleic acid, of intramuscular fat from steers offered grazed grass, grass silage, or concentrate-based diets. *Journal of Animal Science*, 78, 2849–2855.

Garcia, P. T., Pensel, N. A., Sancho, A. M., Latimori, N. J., Kloster, A. M., Amigone, A. A. & Casa, J. J (2008). Beef lipids in relation to animal breed and nutrition in Argentina. *Meat Science*, 79, 500–508.

González, L., Moreno, T., Bispo, E., Dugan, M. E. R. & Franco, D. (2014). Effect of supplementing different oils: Linseed, sunflower and soybean, on animal performance, carcass characteristics, meat quality and fatty acid profile of veal from "Rubia Gallega" calves. *Meat Science*, 96, 829–836.

Juárez, M., Dugan, M. E. R., Aalhus, J. L, Aldai, N., Basarab, J. A, Baron, V. S. & McAllister T. A. (2011). Effects of vitamin E and flaxseed on rumen-derived fatty acid intermediates in beef intramuscular fat. *Meat Science*, 88, 434–440.

Kalač, P. (2011). The effects of feeding fresh forage and silage on some nutritional attributes of beef: an overview. *Journal of Agrobiology*, 28(1), 1–13.

Kearns, M., Ponnampalam, E. N., Jacquier, J. C., Grasso, S., Boland, T. M., Sheridan, H. & Monahan, F. J. (2023). Can botanically-diverse pastures positively impact the nutritional and antioxidant composition of ruminant meat? — Invited review. *Meat Science*, 197, 109055.

Keller, M., Reidy, B., Scheurer, A., Eggerschwiler, L., Morel, I. & Giller, K., (2021). Soybean Meal Can Be Replaced by Fava Beans, Pumpkin Seed Cake, Spirulina or Be Completely Omitted in a Forage-Based Diet for Fattening Bulls to Achieve Comparable Performance, Carcass and Meat Quality. *Animals*, 11, 1588, https://doi.org/10.3390/ani11061588

Kim, C., Kim, J., Oh, Y., Park, E., Ahn, G., Lee, G., Lee, J. & Park, K. (2009). Effects of Flaxseed diets on performance, carcass characteristics and fatty acid composition of Hanwoo steers. Asian-Aust. *Journal of Animal Science*, 22(8), 1151–1159.

Leheska, J. M., Thompson, L. D., Howe, J. C., Hentges, E., Boyce, J., Brooks, J. C., Shriver, B., Hoover, L. & Miller M. F. (2008). Effects of conventional and grass-feeding systems on the nutrient composition of beef. *Journal of Animal Science*, 86(12), 3575–3585.

Liu, J., Ellies-Oury, M. P., Stoyanchev, T. & Hocquette, J. F. (2022). Consumer Perception of Beef Quality and How to Control, Improve and Predict It? Focus on Eating Quality. *Foods*, 11, 1732.

Mach, N., Devant, M., Dıaz, I., Font-Furnols, M., Oliver, M. A., Garcıa, J. A. & Bach, A. (2006). Increasing the amount of n-3 fatty acid in meat from young Holstein bulls through nutrition. *Journal of Animal Science,* 84, 3039–3048.

Mapiye, C., Turner, T. D., Rolland, D. C., Basarab, J. A., Baron, V. S., McAllister, T. A., Block, H. C., Uttaro, B., Aalhus J. L. & Dugan, M. E. R. (2013). Adipose tissue and muscle fatty acid profiles of steers fed red clover silage with and without flaxseed. *Livestock Science,* 151, 11–20.

Marino, R., della Malva, A., Caroprese, M., de Palo, P., Santillo, A., Sevi, A. & Albenzio, M. (2019). Effects of whole linseed supplementation and treatment duration on fatty acid profile and endogenous bioactive compounds of beef muscle. *Animal*, 13(2), 444–452.

McAfee, A. J., McSorley, E. M., Cuskelly, G. J., Moss, B.W., Wallace, J. M. W., Bonham, M. P. & Fearon, A. M. (2010). Red meat consumption: an overview of the risks and benefits. *Meat Science*, 84, 1–13.

Noci, F., Monahan, F. J., French, P. & Moloney, A. P. (2005a). The fatty acid composition of muscle fat and subcutaneous adipose tissue of pasture fed beef heifers: Influence of the duration of grazing. *Journal of Animal Science,* 83, 1167–1178.

Noci, F., O'Kiely, P., Monahan, F. J., Stanton, C. & Moloney, A. P. (2005b). Conjugated linoleic acid concentration in m. longissimus dorsi from heifers offered sunflower-based concentrates and conserved forages. *Meat Science,* 69, 509–518.

Ponnampalam, E. N., Mann N. J. & Sinclair, A. J., (2006). Effect of feeding systems on omega-3 fatty acids, conjugated linoleic acid and *trans* fatty acids in Australian beef cuts: potential impact on human health. *Asia Pacific Journal Clinical Nutrition*, 15(1), 21–29.

Raes, K., Fievez, V., Chow, T., Ansorena, D., Demeyer, D. & De Smet, S. (2004). Effect of diet and dietary fatty acids on the transformation and incorporation of C18 fatty acids in double-muscled Belgian blue young bulls. *Journal of Agricultural and Food Chemistry*, 52, 6035–6041.

Scollan, N. D, Dannenberger, D., Nuernberg, K., Richardson, I., MacKintosh, J., Hocquette J-F. & Moloney A. P. (2014). Enhancing the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Science*, 97, 384–394.

Trbović, D., Lukić, M., Petronijević, R., Lakićević, B., Rašeta, M., Branković Lazić I. & Parunović, N. (2020). Evaluation of n-3 polyunsaturated fatty acid content in various foods: health impact assessment. *Meat Technology*, 61(2), 174 –178.