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REVIEW

The effects of feeding fresh forage and silage on some nutritional attributes of beef: an overview

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Abstract
Consumers are increasingly concerned with the amount and composition of fat present in foods. The nutritional image of cattle fat has suffered because of the association of a high proportion of saturated fatty acids with coronary heart disease. This is leading to a shift in the way milk and beef are produced. Extensive research data from the last decade show that beef from animals finished on green fodder and silages (except for maize silage) has a lower content of intramuscular fat, but a higher proportion of nutritionally favourable n-3 polyunsaturated fatty acids (PUFAs), ratio n-6:n-3 PUFAs, vitamin E and ß-carotene, than meat from animals fed on grain-based rations. The differences in beef cholesterol content between the feeding systems are not nutritionally significant.

Key words: beef; muscular fat; fatty acid composition; cholesterol; tocopherol; ß-carotene; herbage; silage; concentrate

Abbreviations:

ALA	α-linolenic acid
CLA	conjugated linoleic acids
DM	dry matter
FA(s)	fatty acid(s)
MUFA(s)	monounsaturated fatty acid(s)
PUFA(s)	polyunsaturated fatty acid(s)
RA	rumenic acid
SFA(s)	saturated fatty acid(s)
TVA	*trans*-vaccenic acid
UFA(s)	unsaturated fatty acid(s)

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INTRODUCTION

Consumers have perceived differences in the sensory properties of beef such as colour, texture and flavour. In the developed countries, "green image beef", originating from cattle grazing natural swards of varied botanical composition is preferred to meat from cattle fed with preserved forages. Consumers traditionally feel hay to be superior to silage. Nevertheless, feeding with silage has exceeded hay considerably in many countries with a cold and wet climate, where the weather complicates the production of high quality hay. Grasses – particularly perennial ryegrass and Italian ryegrass – maize, lucerne, clovers and cereals have been the main ensiled forages in temperate areas. Various feeding regimes have been used, ranging from cattle grazed for many months in countries with mild climate, to year-round in-housed animals fed with rations based on silage and concentrates.

The effects of various forages feeding on beef composition have been studied for decades. Formerly, the interest was focused mainly on feeding efficiency, gross composition and sensory attributes of beef. During the last two decades, qualitative criteria started to be the main research topics. Among them, the composition of beef fat and the possibilities for its alteration have been extensively studied. Health professionals recommend a reduction in the overall consumption of saturated fatty acids (SFAs) and cholesterol, while emphasising the need to increase intake of long-chain n-3 polyunsaturated fatty acids (PUFAs). Moreover, the ratio of n-6:n-3 PUFAs consumed should be 2-5:1, while the long-term situation has been >10:1 in the developed countries. Such nutritional recommendations are largely due to numerous epidemiological studies showing a strong positive correlation between intake of SFAs and cardiovascular disease. The role of meat as a source of dietary insufficient n-3 PUFAs has been reviewed by Givens et al. (2006).

Besides fatty acid composition of intramuscular fat, the type of forage fed affects the level of some nutritionally desirable beef constituents (e.g. natural antioxidants). Moreover, the occurrence and content of volatiles affecting beef flavour have been of concern.

The aim of this review is to collate and evaluate the information from the last decade on the effects of cattle feeding with fresh herbage, silage and concentrates, on some qualitative parameters of beef. The article continues previous reviews on the effects of fresh forages and silage on cow's milk fat composition (Kalač and Samková 2010) and on some sensory and health attributes of cow's milk (Kalač 2011).

FATTY ACIDS IN FORAGE, RUMEN AND BEEF

Characteristics of fatty acids

The structural characteristics of the major saturated and *cis*-unsaturated FAs including their grouping are given in Table 1. Common names of the acids and the abbreviations ALA, EPA and DHA for α-linolenic acid, eicosapentaenoic acid and docosahexaenoic acid, respectively, will be used within the following text.

Table 1. Main saturated and *cis*-unsaturated fatty acids (FAs) occurring in forages and intramuscular fat of beef. For abbreviations see their list.

Group and its abbreviation		Common name of acid	Designation[1]	Double bond position(s)[2]
Saturate	SFA	Lauric	C12:0	–
		Myristic	C14:0	–
		Palmitic	C16:0	–
		Stearic	C18:0	
Monounsaturated	MUFA	Palmitoleic	C16:1n-7	9
		Oleic	C18:1n-9	9
Polyunsaturated (with two and more double bonds)	PUFA			
n-6 Family		Linoleic	C18:2n-6	9, 12
n-3 Family		α-Linolenic (ALA)	C18:3n-3	9, 12, 15
		EPA	C20:5n-3	5, 8, 11, 14, 17
		DHA	C22:6n-3	4, 7, 10, 13, 16, 19

[1] Symbols of fatty acids: CX:Yn-Z X – number of carbons; Y – number of double bonds; Z – position of the first double bond numbered from the methyl end of the carbon chain (ω-Z has been also often used).
[2] Positions of double bonds numbered from carboxylic group with number 1.

Beef usually contains 2–5% of intramuscular crude fat from muscle weight. The predominant FAs in beef fat are saturated palmitic and stearic acids together with monounsaturated acids (MUFAs), among which oleic acid prevails. The usual proportion of PUFAs, occurring preferably as linoleic, ALA and conjugated linoleic acids, is low. According to recent knowledge on the undesirable effect of the individual dietary SFAs on the level of serum cholesterol, lauric and myristic acids have a greater increasing effect than palmitic acid. Stearic acid is assessed as neutral.

The proportion of various *trans*-unsaturated FAs in beef fat varies between 2% and 3% of total FAs. Among them, the isomeric acids C18:1 with various positions of double bond are common. *Trans*-vaccenic acid (TVA; C18:1 acid with a double bond between carbons 11 and 12) is present in the highest proportion. Great interest has been focused on conjugated linoleic acids, designated commonly as CLA (in total, 28 positional and geometric isomers). Rumenic acid (RA; 9-*cis*, 11-*trans*-C18:2 acid as frequently reported), the most abundant isomer, and 10-*trans*, 12-*cis*-C18:2 acid were proved as anticarcinogenic in a range of human cell lines and animal models. These *trans*-fatty acids are not associated with coronary heart disease. The negative finding is valid for *trans*-FAs present in hardened fats produced by the traditional catalysed hydrogenation from plant oils. In contrast, TVA and RA may possess anti-atherogenic properties, and RA, moreover probably has a role in the prevention of mammary tumorigenesis.

For the evaluation of the literature data, there were some snags to be taken into consideration. FA composition, including that of CLA isomers, varies among various muscles within an animal (Lorenzen et al. 2007). Thus, only the same muscles should be compared. Moreover, various units are used to express FA composition, for example the % of the individual acids of total fatty acids, the % of methyl esters of the individual acids of total fatty acid methyl esters or mg per g of fat, and sometimes separated as neutral and polar lipids. Counts of FAs detected vary widely in individual reports.

Fatty acids in fresh and ensiled forages

General information will be given in this section. For more information see the review of Kalač and Samková (2010) and numerous references therein.

Fatty acids in fresh, wilted and dried herbage

The usual content of total FAs in various forages varies in the range of 20–50 g kg^{-1} dry matter (DM); even lower in silage maize. This is still a relatively low level, however, forages have often been the major and also the cheapest and safest source of FAs in ruminant diets. Fatty acid content and composition are affected by numerous factors such as plant species and variety, climate, day length, rainfall, fertilisation and stage of growth.

ALA is the prevailing acid in forages with the usual proportion of about 40–60% from total FAs, followed by palmitic and linoleic acids. Red clover (*Trifolium pratense*) and white clover (*T. repens*) seem to have a higher total level of FAs than grasses.

Under conditions in the Netherlands, maximum PUFA content in silage maize was observed 56 days after flowering or at ear dry matter content of 440 g kg^{-1}, which was before the onset of rapid senescence. Any further delay in harvesting caused a rapid decline in ALA content in maize silages (Khan et al. 2011).

According to Dewhurst et al. (2003), forage breeding to increase delivery of beneficial FAs from plants into ruminant products is an important long-term strategy. However, the situation is complicated by the large genotype × management interactions.

Forage wilting prior to ensiling and drying for hay production are technological operations causing mechanical damage of plant tissues combined with air access. Such conditions enable extensive oxidation of PUFAs. The processes are started by lipolysis catalysed by plant lipases. The PUFAs released from membranes are then oxidised by air oxygen under the catalysis with lipoxygenases. Many of the products participate in emissions of volatile organic compounds. The detrimental effects of prolonged wilting and field drying on both total FA and PUFA content have been proved repeatedly. Plant lipids are mainly associated with the thylakoid membranes of chloroplasts. An alternative strategy for reducing losses is to produce more resilient chloroplasts, e.g. “stay-green” varieties.

Fatty acids during ensiling and feed out period

An extensive lipolysis of about 85–90% membrane lipids occurs during ensiling of various forages. A somewhat lower level was reported in red clover due to the activity of an enzyme, polyphenol oxidase, through deactivation of lipolytic enzymes and/or through formation of protein-phenol-lipid complexes (for further information see a review by Van Ranst et al. 2011). The majority of the FAs thus occur as free fatty acids in silage as opposed to fresh herbage.

Compared with prolonged wilting, the application of additives, either chemical preservatives or lactic acid bacteria inoculants, seems to have only a limited effect on the changes in FAs composition.

An anaerobic reductive environment of silage protects the released FAs from oxidation. Nevertheless, the situation is markedly changed after silo opening, preferably at its front part. The free fatty acids are exposed to air and light and their oxidisation is induced. Khan et al. (2009) reported a lowered proportion of PUFA and an increased proportion of palmitic acid in both maize and grass silages exposed to air for 24 h. The relative decrease in total FA was higher in maize silages with low DM and progressively decreased with increasing DM content.

Overall, forage wilting and silage aeration during the feeding out period increase losses of unsaturated FAs and total FAs. The losses increase furthermore in hay, which is exposed to the long-term effect of air oxygen.

Changes of dietary lipids in the rumen

Recent knowledge of the transformation of dietary lipids in the rumen by the activity of microbial population has been reviewed by Jenkins et al. (2008) and Kim et al. (2009).

Dietary lipids entering the rumen in fresh herbage are mostly triglycerides together with a limited amount of polar phospho- and galactolipids, while the proportion of free fatty acids can be high in silage and hay. The initial transformation of glycerides is lipolysis, releasing free FAs by the hydrolysis of ester linkages catalysed by lipases of ruminal bacteria, e.g. by *Anaerovibrio lipolytica* or *Butyrivibrio fibrisolvens*. Lipolysis is considered to be rate limiting for following biohydrogenation.

The released unsaturated FAs, mostly ALA and linoleic acid, are then rapidly hydrogenated by the rumen microbes and saturated FAs, principally stearic acid (18:0), are produced. The saturation pathway in biohydrogenation is carried out almost exclusively by rumen bacteria. The biohydrogenation pathway of linoleic acid proceeds via rumenic acid, an intermediate *trans*-vaccenic acid to stearic acid. The pathway of ALA with three double bonds naturally has more steps.

At the same time, an isomerisation reaction converts *cis*-12 double bond of linoleic acid to a *trans*-11 isomer of conjugated linoleic acids (CLA). The abbreviation CLA is a collective term used for all positional and geometric isomers of linoleic acid with conjugated double bonds. Among them, two isomers are predominant: i) *cis*-9, *trans*-11-CLA (rumenic acid), and ii) *trans*-10, *cis*-12-CLA, occurring in ruminant meats in proportions of about 75–90% and 10–25% of total CLA, respectively. The isomers 10, 12-CLA are synthesised by a different mechanism than 9, 11-isomers.

The major factors affecting biohydrogenation are ruminal pH, forage:concentrate ratio and level of FAs intake. For instance, low ruminal pH showed a significant protective effect on linoleic acid and ALA. For more information see reviews of Schmidely et al. (2008) and Glasser et al. (2008).

Overall, extensive biohydrogenation of dietary unsaturated FAs in the rumen results in the production of saturated FAs, particularly stearic acid. This is an important reason for the highly saturated nature of ruminant lipids, including intramuscular fat in beef. Nevertheless, an amount of desirable CLA is produced in the rumen.

The effects of forages on fatty acid composition of beef muscular fat

Besides forages, some further factors affect the fatty acid composition of muscular fat. The effects of cattle breed and gender should be borne in mind (e.g. Mir et al. 2003, Dymnicka et al. 2004, Garcia et al. 2008, Bartoň et al. 2010). In a three-factorial experiment, Warren et al. (2008a) observed by far the biggest effects of diet on FA composition in all age steer groups (slaughtered at 14, 19 and 24 months). However, muscle fat levels greatly increased with age and the proportion of PUFA decreased. The effect of breed was only subtle.

Time of feed was shown to have only a low effect on the FA composition of intramuscular fat of bulls as compared to feeding intensity (Sami et al. 2004). Under the conditions of north Finland, beef of outdoor housed bulls had a higher PUFA:SFA ratio than tethered animals in an insulated barn (Huuskonen et al. 2010b).

Thus, the FA composition of beef intramuscular fat is affected by several factors and an assessment of the literature data on the effects of various forages cannot provide a comprehensive view.

Fresh herbage

This topic was thoroughly reviewed by Lourenço et al. (2008). They assessed extensive data in the literature, comparing particularly the main forages fed in western Europe: red clover vs. ryegrass based diets, red clover vs. white clover forages, and floristically diverse vs. grass based diets. Feeding of floristically diverse forages affects FA metabolism in the rumen, producing a higher rumen outflow of RA and TVA proportions. These FAs are further reflected in the higher RA proportions in beef fat. PUFA content in forages is not the only factor affecting FA metabolism in the rumen. Among other factors, some plant secondary metabolites are probably of concern. Rumen lipolysis is particularly affected by the activity of polyphenol oxidase present in red clover, resulting in higher proportion of ALA in the fat of ruminants fed with red clover. Other plant compounds, e.g. terpenes, saponins and flavonoids, in white clover and some herbs may exert similar effects.

Overall, feeding herbage to ruminants increases the n-3 PUFA content in meat and milk. Thus, the ruminant products from organic farming systems with a high forage proportion, particularly containing clovers, have improved the FA profile in terms of human nutritional recommendations in comparison with the products from conventional systems. Moreover, the FA profile of beef and milk from animals fed with floristically diverse forage is superior to that from animals fed with pure swards.

In a recent report, Dierking et al. (2010) did not detect significant changes in the FA composition of *m. longissimus* fat of Angus steers grazing only tall fescue, or tall fescue combined with either red clover or lucerne. The respective n-6:n-3 ratios were 5.05, 4.12 and 4.75.

Fresh herbage vs. concentrates

Daley et al. (2010) also recently reviewed this topic.

Former pastoral beef was produced mainly from cattle produced on grass. Since about the 1950's, the efficiency of beef production has increased by feeding high-energy grains and concentrates. Days on feed decreased and beef marbling (i.e. intramuscular fat) improved. Nevertheless, changing consumer demands and new views on health attributes of dietary fat restore the concept of "grass-finished beef". Such an attitude has scientific support. As reported by McAfee et al. (2011), meat from grass-fed animals compared with concentrate-fed animals can significantly increase consumer plasma and platelet status of n-3 PUFAs.

A comparison of FA content and composition in the intramuscular fat of steers fed with grasses or with concentrates is given in Table 2. The total fat content in the beef of grass-finished cattle is lower than from their grain-fed counterparts. There is no consistent difference in total SFAs content and also in undesirable palmitic acid proportion (and similarly in myristic acid; data not shown in Table 2). The proportion of stearic acid seems to be higher in grass-finished steers than in grain-fed animals. Grass-fed beef produces a lower content of MUFAs, particularly of oleic acid, but a higher level of TVA. However, some papers reported the reverse. The contents of PUFAs are not univocally different between the two feeding systems. Nevertheless, a grass-feeding regimen shows a higher content of n-3 PUFAs and hence a more favourable n-6:n-3 ratio than in grain-fed steers. The reported proportions of EPA and DHA are very low, usually below 0.5% of total FAs, in both the feeding regimes.

Raising Angus crossbred steers on forage and pasture with no grain supplements increases CLA content in both intramuscular and adipose tissues as compared to animals fed on a total mixed ration (Poulson et al. 2004). The nutritionally desirable composition of muscular fat composition improves with increasing duration of the grazing period prior to slaughter (Noci et al. 2005a).

Overall, grass-finished beef has a higher content of n-3 PUFAs than beef from grain-fed cattle, while n-6 PUFAs level is not affected. This results in a more favourable n-6:n-3 ratio. Moreover, grass-fed cattle showed a higher CLA proportion than their counterparts.

Fresh herbage vs. silage

The data collated in Table 3 should be considered with respect to different experimental designs. Various amounts of different concentrates were fed with silage and sometimes even within the pasture period. Nevertheless, some conclusions can be drawn.

Grass-finished beef has a higher proportion of n-3 PUFAs, thus an improved n-6:n-3 ratio, and a higher total CLA (or RA) proportion than beef finished on silage and concentrate.

Various silages

Wilting of grass with predominant perennial ryegrass prior to ensiling from initial 21.1% to 42.3% DM increased RA content in *m. longissimus* of Friesian steers from 41.9 to 49.6 mg 100 g^{-1} in animals fed silages from unwilted and wilted grass, respectively. Ratio n-6:n-3 PUFA was not affected (3.89 and 3.72, respectively) (Noci et al. 2007).

Table 2. The effects of steer finishing feeding (grass-fed or concentrate-fed) on total lipids content (g 100 g^{-1} muscle) and fatty acid composition (% of total FA) of *musculus longissimus*.
Upper line: grass-fed; lower line: grain-fed.
For abbreviations see their list.

Breed	Total lipids	Total SFA	Total PUFA	Ratio n-6:n-3 PUFA	Fatty acid								Reference
					Palmitic	Stearic	Oleic	Linoleic	ALA	Total *trans* 18:1	Total CLA	RA	
Alentejano	0.98	38.8	29.0	1.77	18.4	17.5	20.5	12.6	5.53	1.87	–	–	Alfaia et al. 2009
	1.30	39.3	19.1	8.99	20.8	15.0	28.6	12.0	0.48	2.81	–	–	
Angus cross	2.34	44.2	6.09	1.65	24.3	17.4	30.9	2.75	1.08	3.38	0.98	0.78	Duckett et al. 2009
	4.07	43.4	4.50	4.84	26.7	14.0	37.9	2.97	0.37	1.83	0.46	0.36	
Angus, Charolais x Angus, Holstein Argentine	2.86	38.4	7.95	1.72	23.1	13.1	31.2	3.41	1.30	3.22	–	–	Garcia et al. 2008
	3.85	35.3	9.31	10.4	22.1	10.8	32.8	6.19	0.28	4.35	–	–	
German Holstein	2.30	45.6	9.71	1.94	23.3	18.3	34.1	4.32	1.67	4.37	–	0.84	Nuernberg et al. 2005
	2.67	43.6	7.47	6.49	25.1	14.6	39.3	4.11	0.34	2.83	–	0.75	
German Simmental	1.51	43.9	14.3	2.04	22.6	17.6	31.7	6.56	2.22	4.28	–	0.87	Nuernberg et al. 2005
	2.61	44.5	9.07	8.34	24.3	16.8	37.3	5.22	0.46	3.19	–	0.72	
Hereford	1.68	49.1	10.0	1.44	21.6	17.7	31.5	3.29	1.34	–	0.53	0.41	Realini et al. 2004
	3.18	47.6	6.0	3.00	24.3	15.8	37.3	2.84	0.35	–	0.25	0.23	
Crossbred	4.36	42.8	5.4	2.33	22.8	14.7	40.6	2.11	1.13	–	1.08	–	French et al. 2000
	3.41	48.1	4.9	4.15	27.4	16.0	38.6	2.96	0.72	–	0.37	–	

Table 3. The effects of cattle feeding (grass-fed or based on silage) on total lipids content (g 100 g^{-1} muscle) and fatty acid composition (% of total FA) of *musculus longissimus*.
For abbreviations see their list.

Cattle	Variant	Total lipids	Total SFA	Total PUFA	Ratio n-6:n-3 PUFA	Fatty acid							Reference
						Palmitic	Stearic	Oleic	Linoleic	ALA	TVA	Total CLA	
Hereford steers	Grazed timothy	–	41.9	16.0	–	20.1	18.7	34.1	8.4	2.00	–	0.42[a]	Huuskonen et al. 2010a
	Timothy silage	–	42.6	13.7	–	21.4	17.9	34.6	6.9	1.53	–	0.28[a]	
Limousin heifers	Grazed meadow	2.60	46.2	4.1	7.8	25.7	16.5	39.8	–	-	1.91	0.16	Cozzi et al. 2010
	Maize silage + meadow hay	2.80	45.0	3.7	10.7	26.1	14.9	41.4	–	-	1.71	0.10	
Crossbred steers	Grazed pasture	–	48.9	7.9	1.26	30.7	15.6	31.3	3.1	1.74	–	0.33[a]	Fredriksson Eriksson and Pickova 2007
	Grass silage	–	46.2	5.7	1.20	30.8	13.1	36.9	2.0	1.13	–	0.22[a]	
Rubia Galega steers	Grazed pasture	–	42.4	11.8	1.82	17.1	19.4	35.2	5.1	2.39	–	–	Varela et al. 2004
	Maize silage	–	42.8	12.6	2.85	20.0	18.0	34.4	6.0	1.58	–	–	
Crossbred steers	Grazed grassland	4.36	42.8	5.4	2.33	22.8	14.7	40.6	2.1	1.01	–	1.08	French et al. 2000
	Perennial ryegrass silage	4.08	47.7	4.1	3.61	26.6	16.0	39.5	2.6	0.71	–	0.47	

[a] – rumenic acid

As reported by Dymnicka et al. (2004), the content of n-3 PUFAs was significantly higher in the beef fat of steers fed on grass silage rather than on maize silage. Similarly, the fat of Limousin steers fed silage from wilted meadow grass had a higher proportion of n-3 PUFAs, a lower level of linoleic acid and thus an improved n-6:n-3 ratio over steers fed maize silage. Moreover, the total CLA content was higher in grass silage fed animals (Bilik et al. 2009). Similar trends were reported by Bartoň et al. (2010). Steers fed a diet based on a legume-cereal silage and lucerne silage vs. those fed maize silage had a lower intramuscular fat content (1.04 and 1.47 g 100 g^{-1}, respectively), a higher percentage of n-3 PUFAs (2.47 and 1.23% of total FAs, respectively) and a more favourable n-6:n-3 ratio (3.28 and 5.27, respectively).

Similar results were reported also for perirenal fat. The n-6:n-3 ratio was >11 in bulls fed with maize silage while ~2 in animals fed with grass silage. However, shelf-life was twice as long with maize silage compared to grass silage. Four tested supplements, tannins, garlic, maca or lupins, did not improve carcass fat of maize silage fed bulls (Staerfl et al. 2011).

A comparison of the effects of feeding grass silage vs. whole crop wheat silages with 38% or 52% DM on fat content and FA composition in beef of crossbred heifers was reported by Noci et al. (2005b). The proportion of ALA was 50.4, 23.2 and 9.0% of total FAs in grass silage and wheat silages with lower and higher DM, respectively. The respective fat contents in *m. longissimus* were 2.70, 3.80 and 2.91 g 100 g^{-1}. While the type of silage insignificantly affected the contents of SFAs, PUFAs and RA; the proportions of n-3 PUFA were 1.18, 0.83 and 0.96% of the total FAs, respectively, and the ratios n-6:n-3 were 5.19, 7.73 and 7.90, respectively. Grass silage thus seems to be superior to ensiled whole crop wheat.

Investigation of the FA changes of grass silage, white clover silage and red clover silage in the rumen and duodenum of cannulated steers showed a lower rate of linoleic acid and ALA biohydrogenation in red clover silage than in the other silages (Lee et al. 2003, 2006). These results correspond with the favourable effects of red clover silage on FA composition of cow‘s milk fat (for a review see Kalač and Samková, 2010 and references therein).

Overall, it seems from the available data that the desirable FA composition of beef fat is affected in the order red clover silage > grass silage > maize silage.

Silage vs. concentrates

Increasing the proportion of concentrates based on barley/soybean meal from 0.20 to 0.80 of total DM of the diets containing unwilted perennial ryegrass silage decreased significantly the content of n-3 PUFAs and increased n-6 PUFAs in muscle. Perennial ryegrass silage of high digestibility thus showed the potential to improve the nutritional value of beef fat as compared to the diet with a high proportion of concentrates (Steen et al. 2002). Similar results were observed by Elmore et al. (2006). The n-6:n-3 ratios of PUFAs were 1.1 and 15.7 in Aberdeen Angus steers and 1.0 and 8.2 in Holstein-Friesian steers fed diets containing grass silage or a concentrate (based on barley and full-fat soya), respectively.

As reported by Warren et al. (2008a), feeding an unwilted perennial ryegrass silage diet rich in ALA increased the level of this FA in *m. longissimus* neutral lipids about three times compared with a diet based on concentrate (barley + molassed sugarbeet pulp + fullfat soybean meal). In contrast, both levels and proportions of linoleic acid were higher in steers fed the concentrate diet. Silage feeding resulted in beneficially low n-6:n-3 PUFAs ratio of about 1.2 compared with 12.0 in the concentrate diets. These values were very similar in animals slaughtered at 14, 19 or 24 months.

Thus, the effects of silage vs. concentrates feeding are similar to those of fresh herbage vs. concentrates (Section 2.4.2.).

CHOLESTEROL

Finishing systems of pasture vs. a high-concentrate ration did not affect cholesterol content (57.3 and 56.3 mg 100 g^{-1}, respectively) in *m. longissimus* of Angus-cross steers (Duckett et al. 2009). Similar results were determined by Descalzo et al. (2005) in crossbred steers: 49±4.0 and 52±4.0 mg 100 g^{-1}, respectively. Garcia et al. (2008), however, reported a significantly lower cholesterol content in pasture-finished beef than in the meat of concentrate-fed steers of three breeds (40.3 and 45.8 mg 100 g^{-1}, respectively). Meat of Limousin steers fed silage of wilted meadow grass had a significantly lower content of cholesterol in *m. longissimus* than the beef of steers fed maize silage or grazed on pasture (Bilik et al. 2009).

The effects of breed on cholesterol content in beef seem to be limited. Chambaz et al. (2001) compared six breeds and determined mean contents 47 and 51 mg 100 g^{-1} in *m. longissimus* and *m. biceps femoris*, respectively, with little difference among the breeds. In contrast, Garcia et al. (2008) reported significant differences among three breeds, whereas the interaction effect of breed × finishing system was insignificant.

Certain differences in cholesterol content among muscles were observed in feedlot steers (Rule et al. 2002), namely 52.7, 53.4 and 61.4 mg 100 g^{-1} in *m. longissimus dorsi*, *m. semitendinosus* and *m. supraspinatus*, respectively. The respective values in beef of pastured cows (4 to 7 years of age) were 52.3, 48.7 and 52.7 mg 100 g^{-1}.

Available data show that cholesterol content in beef is affected only to a limited extent by breed, sex and nutrition. All the mentioned differences seem to be of low nutritional consequence because dietary cholesterol increases the plasma cholesterol level only at greatly differing contents.

FAT-SOLUBLE VITAMINS

Tocopherols

The evaluation of published data is somewhat complicated by varying information on tocopherols. Some authors have reported values for α-tocopherol, others for several tocopherol isomers and others for vitamin E.

Beeckman et al. (2010) determined 156±11.3, 74.3±5.7 and 49.3±0.7 mg kg^{-1} DM of vitamin E in fresh perennial ryegrass, red clover and white clover. These differences remained after wilting and ensiling. Preservation with formic acid or lactic acid bacteria at ensiling had no significant effect on vitamin E content. The contents of 52±35, 4.5±1.7 and 7.1±3.8 mg kg^{-1} DM in grass-clover silage, hay and grain, respectively, demonstrate great differences among various feeds. O'Sullivan et al. (2002) reported 105 and 20.8 mg kg^{-1} fresh matter of vitamin E for grass silage and maize silage, respectively.

Available data on the effects of pasture vs. grain-based feeding on α-tocopherol content in beef from steers are collated in Table 4. Similar contents of 0.25 and 0.12 mg 100 g^{-1} were determined in meat from heifers on pasture or concentrate-fed, respectively (Vasta et al. 2011). Herbage feeding is obviously superior to concentrate feeding.

Table 4. The effects of steers feeding (grass-fed or concentrate-fed) on α-tocopherol and β-carotene contents in beef (mg 100 g^{-1})

Breed	α-Tocopherol		β-Carotene		Reference
	Grass	Concentrate	Grass	Concentrate	
Angus-cross	0.77	0.20	0.044	0.029	Duckett et al. 2009
British x Indicus crossbred	0.21	0.08	0.074	0.017	Insani et al. 2008
Crossbred steers	0.31	0.15	0.045	0.015	Descalzo et al. 2005
Hereford cross	0.45	0.18	0.016	0.001	Yang et al. 2002

Fredriksson Eriksson and Pickova (2007) reported mean α-tocopherol contents of 0.10, 0.12 and 0.11 mg 100 g^{-1} in beef of steers finished on pasture, grass silage and silage + grain, respectively. Mean vitamin E contents in beef of Angus crossbred steers were 0.53 and 0.13 mg 100 g^{-1} of fresh meat for finishing rations based on lucerne hay and high-grain diet, respectively (Poulson et al. 2004).

The beef of dairy cull cows had somewhat higher vitamin E content from animals fed grass silage than from those fed red clover silage (Lee et al. 2009). Considerable differences in vitamin E content were determined (O'Sullivan et al. 2002) in beef produced on rations based on grass silage or maize silage (0.38 and 0.21 mg 100 g^{-1}, respectively). Warren et al. (2008b) reported significant differences in vitamin E contents in the meat of half-Holstein-Friesian steers fed grass silage or a concentrate. The values were 0.32, 0.31 and 0.34 mg 100 g^{-1} in silage-finished steers of 14, 19 and 24 months of age, respectively, whereas the counterpart contents were 0.13, 0.14 and 0.16 mg 100 g^{-1}.

As the above data and further papers reviewed by Daley et al. (2010) indicate, cattle finished on pasture or on ensiled grass and/or clovers produce higher tocopherol levels in the final meat than cattle fed high concentrate diets. Tocopherols are required not only as vitamin E for human nutrition, but also as the antioxidants delaying oxidative deterioration of myoglobin which results in a darkened colour of retail beef (e.g. Descalzo et al. 2005).

An analytical procedure determining stereo-isomers of α-tocopherol makes it possible to discriminate between beef from animals raised at pasture or fed concentrates containing synthetic vitamin E (Röhrle et al. 2011a). Doctoring of meat marketed as pasture-fed beef can be thus revealed.

β-Carotene

Cattle produced under extensive herbage-based production systems generally have more yellow carcass fat than concentrate-fed counterparts. This is caused by a higher content of carotenoids originating from green or ensiled forages.

Available data for steers from the last decade for ß-carotene, a pro-vitamin A, are collated in Table 4. Comparable results were reported by Röhrle et al. (2011b) for subcutaneous adipose tissue of Charolais × Limousine crossbred heifers. The contents of ß-carotene were 0.054, 0.049 and 0.009 mg 100 g^{-1} in animals fed pasture, grass silage followed by pasture, and a barley-based concentrate, respectively. The respective contents of lutein were 0.013, 0.010 and 0.004 mg 100 g^{-1}. Thus, as for α-tocopherol, herbage feeding is obviously superior to concentrate feeding.

The usual required daily allowance of ß-carotene for adults is 3 mg.

As results from a previous review (Kalač 2011), fresh forage is the richest source of ß-carotene and generally of carotenoids, whereas silages are more favourable than hay. Maize silage is a poor source of carotenoids.

IMPLICATIONS

Increasing PUFA content and proportion in cattle products is a recent tendency for consumer health. Forages, such as grass and legumes, are rich in n-3 PUFAs and are a useful natural strategy in improving the nutritional value of ruminant products. Ensiled forages have a somewhat lower n-3 PUFAs content.

A low-input feeding regime with a high proportion of green fodder or silage (except maize silage) and limited intake of concentrates allows beef production with a lower overall fat content and n-6:n-3 PUFAs ratio meeting the nutritional requirements. Such meat has a higher vitamin E and ß-carotene content than that produced on grain-based rations, whereas differences in cholesterol level seem to be of low significance.

Nevertheless, further viewpoints have to be taken under consideration. Different feeding systems affect beef quality parameters such as texture, colour and its stability and finally flavour and palatability of the cooked meat. Both consumer demands and the economic aspects naturally present the causal factors.

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