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Chapter

Cis/Trans-Fatty Acid Content of Red Meats and the Related Effects on Meat Quality and Human Health

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Abstract

Red meats are often criticized as unhealthy based on their perceived high-fat content and saturated fatty acid composition. Uncertainties about the fatty acid composition and trans-fatty acid contents may discourage consumers to eat red meat, especially those living with non-communicable diseases such as cardiovascular diseases, hypertension and obesity (e.g. the metabolic syndrome). Previous studies have investigated the factors that influence the fat content and fatty acid composition of red meats, including the effects of species, age, nutrition, sex, production systems and growth promotants in animals, but the trans-fatty acid content of red meat has not been well studied to date. The purpose of this chapter is to review the fat content and fatty acid composition of red meats, with specific reference to its cis/trans-fatty acid content. Representative samples of beef sirloin steaks (n = 60) and lamb loin chops (n = 80) (the lumbar part of the longissimus dorsi muscle) were collected from carcasses from several randomly selected abattoirs in the Gauteng region of South Africa for proximate and fatty acid analyses. Results from this study confirm that the intramuscular fat content of red meats is low compared to most fat-containing processed foods. The lean component of beef and lamb contain a trivial proportion of TFA's, consisting of vaccenic acid, rumenic acid and conjugated linoleic acid (CLA) isomers. The CLA's in red meat are beneficial due to their antioxidant and anti-carcinogenic properties, so they should not strictly be considered in the TFA definition. This means that the TFA's in red meats are negligible and pose no harm to human health. Labelling of red meats should be improved to convey this information to consumers.

Keywords: Red meat, animal fat, saturated fatty acids, unsaturated fatty acids monounsaturated fatty acids, polyunsaturated fatty acids, cis-, trans-fatty acids, conjugated linoleic acid, CLA

1. Introduction

Red meats are tarnished as unhealthy due to their perceived high-fat content and saturated fatty acid composition [1]. Uncertainties about the trans-fatty acid content of red meats may deter consumers to eat red meat, especially those living with non-communicable diseases such as obesity, hypertension and cardiovascular

diseases. Much of the criticism against fats in red meats is unfounded and usually poorly understood. Some of these paradoxical issues and perceptions about animal fats and their related effects on meat quality, human health and consumer perceptions have been reviewed in detail previously [1]. However, there is little scientific information about the trans-fatty acids in beef and lamb or the factors that affect its content.

Trans-fatty acids (TFA) are the sum of all unsaturated fatty acids that contain one or more isolated, non-conjugated double bond in the trans geometric configuration [2], (excluding CLA's, which are conjugated). According to the European Food Safety Authority (EFSA), TFA's do not serve any vital functions in the human body because they are neither synthesized nor required by the human body [3]. Health professionals recommend a reduction in overall consumption of saturated fatty acids (SFA), TFA and cholesterol, while increasing intake of n-3 polyunsaturated fatty acids (PUFAs) [4, 5].

The harmful health effects related to TFA intake are specifically those associated with Coronary Heart Disease (CHD), Cardiovascular Disease (CVD) and related diseases [3, 6, 7]. Intake of TFA that exceeds 5 grams per portion (100 g) is associated with an increased risk of CHD [8]. The TFA's in the human diet generally originate from either the partial hydrogenation of vegetable oils and to some extent fish oils, such as deep-fat frying cooking techniques and other heat treatments used in the fast-food industry, or from a small number of natural types of TFA's which are synthesized from polyunsaturated fatty acids (PUFA) by anaerobic bacteria in the rumen of cloven-hoofed animals [9–11].

The TFA content of some industrial foods is reportedly as high as 60% of total fatty acid content and sometimes even higher [11]. In comparison, the ruminant derived TFA's found in ruminant fat, seldom exceed 6%, e.g. the TFA content of milk fat range from 4–6% [11]. In ruminant fat, up to 20% of the TFA content may consist of the C16:1 trans-isomer range, which is not found in industrial TFA profiles [12]. The most common TFA-isomers are elaidic acid (C18:1), vaccenic acid (C18:1 t-11) and rumenic acid (C18:2) [11, 13].

Vaccenic acid and rumenic acid are the trans isomers that are specific to ruminant derived fats [2]. Research indicates that ruminant derived trans vaccenic acid is not associated with an increased risk of CHD or CVD, because it is readily converted to CLA isomers which have numerous health benefits [14, 15]. Trans unsaturated fatty acids when consumed in excessively large amounts cause elevated plasma LDL cholesterol and a reduced HDL cholesterol state, which is associated with CVD, CHD and Type II diabetes mellitus [16, 17].

Little information is available about the trans-fatty acid content of red meats. The purpose of this chapter is to provide an overview of the composition of fats in red meats (beef, lamb, goat (chevon)) in Section 2, and to present new results about the trans-fatty acid composition of red meats in Section 3 in this chapter.

2. Review of the lipid composition of animal fats

The fats in animal tissues are a subgroup of lipids, which consist mostly of triacylglycerols. Animal fats are stored in different adipose tissue (fat) depots, at different physiological stages of animal growth and development. The predominant adipose tissue depots in animals include the subcutaneous fat (underneath the skin), intramuscular fat and a variety of internal fat depots such as perirenal, cardiac, omental and pelvic fat depots.

The growth of animals is characterized by an allometric accumulation of bone, muscle and fat, in that order, with fat accumulating and maturing slower and later

than the other tissues. Different adipose depots mature at different rates, with the intramuscular and subcutaneous fat depots maturing slower and later compared to the internal tissues depots.

Red meat has erroneously being labelled as high in fat, especially saturated fatty acids (SFA) which can be associated with many non-communicable human diseases like the metabolic syndrome, but frankly, lean meat only contains 2–3% intramuscular fat in lean beef [18–20], 5–7% in conventional beef [21–23] and as high as 15% in marbled beef. The intramuscular fat content of lamb varies between 8 to 14% [24, 25]. The predominant saturated fatty acids (SFA) in red meats are C14:0 (myristic acid), C16:0 (palmitic acid) and C18:0 (stearic acid). The intramuscular fat contents of red meats are respectively 80% and 40% lower in conventional and marbled beef, compared to the average fat content of processed foods [26] in the USA. The importance of animal fats is highly underestimated, especially in terms of its source of essential fatty acids, serving as a carrier of fat-soluble vitamins A, D, E and K, synthesis of steroidal hormones, role as metabolic energy source, and contribution to sensory properties such as flavor, aroma and texture in meat [1, 18].

2.1 The nutritional value of fat in meat

The lean component of red meat is a highly digestible and high biological value protein source in the human diet, e.g. the digestibility value of red meat is appreciably higher (94%), compared to whole wheat (86%) or beans (78%) [27]. Red meat has a relatively low fat and sodium content, but with high contents of antioxidants and several other nutritionally important bioactive substances such as taurine, carnitine, carnosine, ubiquinone, glutathione and creatine [27], which are physiologically important because of their antioxidant and anti-inflammatory effects, and immunological, neurological, muscular and retinal functions [28]. Taurine, carnitine, carnosine and creatine are abundant in beef, but do not occur in plant-sourced foods [28].

The nutritional value of fats in meat depends essentially on the ratio between saturated (SFA), monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA), as well as the balance between the n-6 and n-3 fatty acids [29]. Conventional wisdom suggests that the fat composition of red meats is all saturated. Several research groups in Australia [30], Europe [18–20], the United Kingdom [21, 31], and in South Africa [1, 23–25] have studied animal fats extensively. All concur that animals fats in red meat species are certainly not all saturated. This represents perhaps one of the most incorrect perceptions about red meats.

A summary of the composition of SFA, MUFA and PUFA previously reported for meat from cattle, sheep and goats are presented in **Table 1**. These results demonstrate that neither beef, lamb nor goat meat are all saturated. Normal saturation levels of these red meats generally vary between about 45 to 54%, with significant proportions of the mono-unsaturated fatty acid oleic acid, ranging from ca. 38 to 44%. Overall the SFA content of beef is less than 3 g per 100 gram edible portion of raw red meat.

Previous recommendations by medical professionals were to reduce the total fat intake to decrease obesity and lower the risk of coronary heart disease (CHD). However, the recommendations have shifted to the fatty acid composition instead of quantity [1]. For example, it is stressed that the MUFAs and PUFAs are more important than total fat ingestion to reduce the risk of cardiovascular heart disease in middle-aged men [34].

Much of the internal carcass fat is removed during the slaughter process, but subcutaneous and intramuscular fat depots remain part of the meat sold to consumers. The removal of carcass fat is regarded as a wasteful process, but its

Meat species	Fatty acid fraction (w/w%)			Reference
	SFA	MUFA	PUFA	
Beef				
Feedlot steers[#]	49.6 ± 4.4	38.5 ± 3.4	8.7 ± 1.5	[23]
Belgian white blue[*]	46.5 ± 4.2	38.4 ± 4.1	15.0 ± 3.9	[19]
Sheep				
Dorper sheep	52.8 ± 1.9	43.9 ± 1.3	3.3 ± 0.5	[32]
Damara sheep	51.8 ± 1.8	44.3 ± 1.3	3.9 ± 0.2	[32]
Dorper sheep	50.8 ± 2.9	42.7 ± 3.7	4.7 ± 0.9	[24, 25]
Merino sheep	52.2 ± 3.9	40.0 ± 3.2	5.21 ± 1.1	[24, 25]
Dorper (Karoo grass)	52.9 ± 4.5	43.1 ± 3.6	3.6 ± 0.9	[33]
Dorper (Karoo browse)	54.7 ± 2.9	41.3 ± 1.9	3.7 ± 1.5	[33]
Goats				
Boer goats	54.7 ± 2.2	41.9 ± 0.9	3.4 ± 0.4	[32]
Indigenous goats	53.6 ± 2.8	42.5 ± 1.1	3.9 ± 0.4	[32]

SFA-Saturated fatty acids; MUFA-Monounsaturated fatty acids; PUFA-Polyunsaturated fatty acids.
[#]*Conventionally raised beef cattle.*
[*]*High lean beef breed.*

Table 1.
Summary of saturated and unsaturated fatty acids previously reported for meat from cattle, sheep and goats.

accumulation in the carcass is an inevitable consequence of finishing livestock to the required body condition (grade) to yield the most acceptable and flavorsome meat.

Several methods and biotechnologies have been employed to optimize the fattening of livestock, whilst minimizing the accumulation of excess internal carcass fat [1, 23, 29, 35, 36] and improving production efficiency. The methods include the manipulation of age, sex and production systems, and the use of biotechnologies such as improved animal feeding, ration formulation, steroidal hormone implants and feed additives such as probiotics, prebiotics and repartitioning agents (beta-adrenergic agonists). The latter molecules repartition energy away from fat accretion to protein (muscle) accretion, by stimulating muscle anabolism and decreasing its catabolism [23, 35]. These molecules are gaining popularity because of the effective repartitioning of energy towards lean gain (muscle growth) and considerable reductions in carcass fat content. Moreover, these molecules improve the use of natural resources through large improvements in animal growth and efficiency, which reduces the environmental impact of animal production systems.

2.2 Fatty acid composition of red meats

Neutral lipids also known as triacylglycerol's which are the major lipid class in animal fats, while phospholipids occur mostly in cell membranes and muscle tissue [20]. Triacylglycerol's serve as a concentrated energy source for the body [36]. Phospholipids contain much higher levels of PUFA and lower SFA content for the subsequent function as a constituent of cellular membranes [20, 31]. Oleic acid (C18:1c-9) is formed from stearic acid (C18:0) by stearoyl CoA desaturase and is a major component of neutral lipids [31]. In ruminant animals, lipids accumulate mainly as triacylglycerol's in adipocytes (fat cells) which are located in subcutaneous, intermuscular and intramuscular adipose tissue depots, as well as abdominal

fat depots such as omental and perirenal adipose tissue [36]. Dietary n-6 and n-3 PUFA are incorporated into adipose and muscle tissues despite rumen biohydrogenation. Ruminant animals preferentially incorporate essential fatty acids into muscle tissues rather than into adipose tissue [31].

In ruminant animals, the diet has a small but significant effect on the fatty acids in triacylglycerol's due to rumen biohydrogenation. By contrast, higher proportions of PUFAs are located in the phospholipids than triacylglycerol's, and they are less affected by diet [1]. The PUFAs in phospholipids consist of essential fatty acids such as C18:2n-6 and C18:3n-3 as well as their long-chain derivatives namely ecosapentaenoic acid (C20:5n-3; EPA) and decosahexaenoic acid (C22:6n-3; DHA) [37]. The fatty acid composition determines the firmness and oiliness of adipose tissue as well as the oxidative stability of muscle tissues, which influences the flavor and color of the meat product [24, 25, 31].

The ratio of PUFA/SFA and the n-6/n-3 ratio influence the nutritional value of lipids in red meats. Fats containing a lower SFA content and higher PUFA and CLA content are regarded as ideal [29, 37]. The PUFA/SFA (also referred to as P:S) as well as the n-6/n-3 fatty acid ratios are primary values used to measure the nutritional quality of foods for human nutrition [29]. The recommended benchmark value for the PUFA:SFA (or P:S) ratio is >0.7, and for the n-6/n-3 ratio < 5 [38].

Lean red meat is an excellent source of long-chain omega-3 PUFAs [39]. The PUFA in beef range from 14 to 24%, and C18:1 trans-fatty acid content about 3% of the total fatty acid profile [27, 40]. Conjugated linoleic acid (CLA) occurs naturally in meat and dairy products and is credited for beneficial effects on type II diabetes, weight loss and muscle accretion. CLA's are omega 6-fatty acids which occur in either the cis or trans configuration, with a total of about 28 isomers. CLA's are conjugated fatty acids which means that the two "conjugated" double bonds are not separated by a methylene group, so they are excluded from the TFA's.

2.3 Overview of trans-fatty acids in food

Trans-fatty acids (TFA's) are the sum of all unsaturated fatty acids that contain one or more isolated, non-conjugated double bond in the trans geometric configuration [2]. According to the European Food Safety Authority [3], TFA's are not vital in the human body because they are neither synthesized nor required by the human body. Health professionals worldwide recommend a reduction in the overall consumption of SFA's, TFA's and cholesterol, while increasing the intake of n-3 polyunsaturated fatty acids (PUFAs) [4, 5]. Unfortunately no "Population Reference Intake (PRI)", "Average Requirement (AR)" or "Adequate Intake (AI) value" have been established for TFA's yet [3].

The adverse health effects associated with the consumption of TFA's to date relate specifically to non-communicable diseases such as cardiovascular diseases (CHD and CVD) [3, 6, 7]. It was estimated that CHD is the number one cause of death globally and the consumption of TFA that exceeds five grams per portion is associated with increased risk of CHD [8, 41]. A positive association was confirmed between industrial TFA intake and increased CHD risk [42]. Industrial TFA are produced during partial hydrogenation of vegetable fats and fish oils and are common to products such as margarines, spreads and shortenings, baked goods and deep-fried foods such as those in fast food outlets [11, 43].

There is relatively little information about TFA's in livestock as well as the specific factors that influence TFA concentrations in red meat. The purpose of this section is to present new data about the cis/trans-fatty acid composition of typical beef and lamb meat.

2.4 Effects of production systems on fat and fatty acid composition of red meats

Cattle are frequently fattened on either rangelands or concentrate diets. Different combinations of pasture-based systems together with intensive systems are used to raise livestock and the degree to which these are used rely on resources available as well as climatological conditions [44]. Pasture feeding has gained popularity because of the favorable effects on the fatty acid profile of meat, although the effects are small and at the expense of increased production efficiency [1].

The essential fatty acid alpha-linolenic acid (C18:3n-3) is a prominent fatty acid found in grasses, and therefore a consistent concentration occurs in muscle tissue, despite rumen biohydrogenation [31, 45]. Concentrate fed cattle accumulate slightly less C18:3n-3, which may decrease the n-6/n-3 ratio marginally [18]. A lower n-6/n-3 ratio is obtained when grass and pasture feeding is employed [31]. Grass-fed animals produce meat products that exhibit better oxidative stability due to higher concentrations of natural antioxidants such as vitamin E, which stabilizes the PUFAs [34, 46]. Linoleic acid (C18:2n-6) is a major fatty acid in concentrate feeds (grains and oilseeds). It is degraded into MUFAs and SFAs in the rumen, and incorporated into adipose and muscle tissue in relatively high concentrations [31].

The main benefit of concentrate feeding of livestock is the higher growth rates and feed efficiency achieved, which yield carcasses of high value at a younger age than those from extensive (pasture-based) production systems [44]. This depends typically on better use of feed resources due to meticulous feed formulation and mixing. Concentrate fed cattle generally have better carcass characteristics i.e. a heavier carcass weight, better dressing percentage and conformation scores, and carcass grading or classification compared to steers finished on pasture [45, 47, 48]. Pasture finished cattle yield darker meat with fat which has a more yellow color [45]. The differences in fatty acid content of concentrate fed cattle compared to those raised on pastures are small due to rumen biohydrogenation.

Similar results were reported for lamb and mutton on pasture versus concentrate feeding in France [49, 50] and South Africa [1, 24, 25, 51]. Concentrate fed lambs produced heavier carcasses with better muscular conformation scores and they were fatter than those from grass-fed lambs. The meat from concentrate fed lambs are superior in juiciness as well as in tenderness relative to those from grazing natural pastures. The subcutaneous fat from pasture-fed lambs is yellower and harder, while the meat is darker compared to grain-fed lamb [1, 51]. Meat from grass-fed lambs contain marginally lower triacylglycerol's and a higher phospholipids content [50]. The triglyceride fraction contain marginally higher proportions of C18:0, C18:3n-3, CLA and lower proportions of C16:0, MUFAs, C18:2n-6 and other n-6 PUFAs. The phospholipids contain lower MUFAs, C18:2n-6 and other n-6 PUFAs and higher levels of C18:3n-3. Backgrounding feeding before the onset of concentrate feeding is a relatively new practice. Research indicate that backgrounding strategies have beneficial residual effects on lipid profiles and CLA content of meat from Angus heifers [52].

2.5 Effects of exogenous growth-regulating molecules on fat and fatty acid content of red meats

Red meat producers have been using growth-promoting agents for over 50 years to improve muscle leanness, increase average daily weight gain, stimulate feed intake, and enhance the feed efficiency of animals [35]. Hormonal growth implants and feed additives such as anabolic steroids and beta-adrenergic agonists are used in the beef industry (excluding the European Union) to obtain improved growth rates

and feed efficiency during the fattening phase, and subsequently superior carcass composition and quality [44]. The use of these exogenous growth modifiers has improved the effectiveness of red meat production by producing meat that complies more closely with consumer demands in terms of optimizing carcass fat accumulation and thus producing a leaner product [44]. This has resulted in significant improvements in the efficiency of animal production with major benefits to beef producers, retailers and consumers in terms of the relative price competitiveness of beef relative to other dietary protein sources [35, 44].

Beta-adrenergic agonists are compounds similar to naturally occurring endogenous catecholamines (norepinephrine and epinephrine) which are used as feed additives to improve feed efficiency at the end of the fattening phase by placing focus on more protein synthesis rather than fat accretion [23, 35]. These synthetic products such as ractopamine hydrochloric acid and zilpaterol hydrochloric acid provide comparable production benefits as steroid implants but differ in the application as well as mode of action [36]. The results of such treatments during the final 20–25 to 30–42 days of the fattening period are leaner carcasses with improved conformation [23, 35, 53]. The use of beta-adrenergic agonists (L-644,969) improved the proportion and distribution of lean meat [54]. Zilpaterol hydrochloride was shown to decrease carcass fat content and had beneficial effects on fatty acid composition of beef [23, 51]. Higher proportions of oleic acid (C18:1) and lower proportions of C14:0 and C16:0 were deposited in tissues of steers supplemented with zilpaterol hydrochloride, and hence decreasing the saturated fatty acid content of meat [23, 51].

3. Analysis of cis/trans-fatty acid composition of red meats

3.1 Cis/trans fatty acid content of beef and lamb

The purpose of this research was to determine the fat and fatty acid content of beef and mutton, with specific reference to the cis/trans-fatty acid composition. The cis/trans-fatty acid content of South African beef and lamb from range and conventional production systems were analyzed. Representative samples of beef sirloin steaks (n = 60) and lamb loin chops (n = 80) (the lumbar part of the longissimus dorsi muscle) were collected from carcasses from several randomly selected abattoirs in the Gauteng region in South Africa for proximate and fatty acid analyses. The samples were reasonably representative of beef and lamb available from meat retailers in South Africa, with the beef originating from feedlot systems and the lamb from extensively reared lamb production systems.

3.2 Materials and methods

Proximate analysis of beef sirloins and lamb loin chops, as well as medium- and long-chain fatty acid analyses were conducted as previously explained [23, 25]. The fatty acid methyl esters from beef and lamb samples were analyses using gas chromatography. All visible fat was removed from meat samples using a scalpel, followed by mincing and blending of each sample separately into a homogenous mixture using a BUCHI Mixer B-400.

The intramuscular fat content within the muscle tissue was analyzed to determine its nutritional contribution to the human diet. The equipment used to dissect the meat samples (i.e. glass cutting board, scalpel and mixer beaker and blades) were thoroughly cleaned with warm soapy water. All blended meat samples were stored overnight in air-tight containers in the fridge for subsequent proximate

analyses and lipid extraction [55]. The remainder of the samples were freeze-dried and then milled for approximately 10 seconds into a fine powder form using a Hamilton Beach Commercial blender. The milled samples were placed into large plastic containers with screw caps and labelled.

Determination of fat content by ether extract was performed using the Soxtec method with the Tecator Soxtec System 1040 Extraction unit, at a temperature setting of 80°C [55]. Ether extraction was done in duplicate by using sub-samples of the freeze-dried, minced meat samples (ca. 2 g). Fatty acid analyses were performed by extracting the lipids from the freeze-dried meat samples using the chloroform: methanol (2:1, v/v) method [56], with modifications as described previously [24]. Saponification and methylation of the fatty acids were done using 14% BF3/CH3OH, followed by analysis with a Varian 3300 FID gas chromatograph fitted with a 100-meter WCOT fused silica capillary column (CP-Sil 88, 100 m x 0.25 mm DF 0.2 μm).

Fatty acids were identified based on the retention times of known fatty acid methyl ester standards obtained from Nu Chek Prep.Inc., Elysim, Minesota (USA). Helium was used as the carrier gas at a flow rate of 50 ml/min, and the gas chromatograph program used was the same as that previously described [24]. Fatty acids were expressed both in terms of the proportion of total medium- and long-chain fatty acids (w/w, %) and in gravimetric concentrations (mg/g of tissue sample) [24, 25].

The raw data was recorded in an excel spreadsheet and all statistical procedures were carried out with the IBM SPSS Statistics Windows software package, version 26 (SPSS Inc., Chicago, IL, USA). Quantitative analysis of the beef and lamb samples were conducted and the means and standard deviations of each lipid fraction, as well as molar proportions (w/w%) and gravimetric content (mg/g meat) of identified fatty acids were determined.

3.3 Composition of cis/trans-fatty acids in beef and lamb

The results of cis/trans-fatty acid analysis of beef and lamb in South Africa are presented in **Tables 2–5** respectively. The results presented in **Table 2** indicate that the fatty acid composition of conventional beef contains about 70% less TFA's (e.g. 1.4 g/100 g beef; **Table 2**) than the recommended threshold of 5 g per 100 g portion, which is the threshold for increased risk of CHD. It should be emphasized that these TFA values were obtained in beef from cattle in conventional production systems in South Africa, i.e. weaner production on extensive grazing, followed by concentrate feeding for about 120 days to the desired carcass composition to meet market requirements, namely carcasses containing about 15–18% carcass fat and 5–7% intramuscular fat (measured in the longissimus dorsi (loin) muscle).

Lipid fraction	Content (%)
IMF	6.5%
SFA	49.61%
MUFA	46.96%
PUFA	3.41%
TFA	4.19%
TFA/100 g meat	1,4 g

MUFA, monounsaturated fatty acids (C18:1 t-11 + C18:1c-9); PUFA, polyunsaturated fatty acids (sum of C18:2 isomers + sum of C18:3 isomers); SFA, saturated fatty acids (C14:0 + C16:0 + C18:0); TFA, trans-fatty acids.

Table 2.
The lipid composition of beef sirloin (Longissimus dorsi samples) from conventional production systems in South Africa (n = 60).

Fatty acid	Molar % (w/w%; n = 60)	Gravimetric content (mg /g meat; n = 60)
C14:0	3.2 ± 0.569	6.36 ± 2.69
C16:0	25.97 ± 3.205	51.67 ± 21.900
C18:0	20.44 ± 5.589	40.01 ± 17.285
C18:1(n-9)t	4.82 ± 1.930	9.32 ± 4.8
C18:1(*n-9*)c	40.71 ± 8.793	83.06 ± 44.641
C18:2 (*n-6*)	3.02 ± 0.955	5.98 ± 3.057
C18:2 (t-9,t-12)	0.14 ± 0.134	0.29 ± 0.206
C18:2 (c-9,t-12)	0.12 ± 0.097	0.27 ± 0.270
C18:2 (t-9,c-12)	0.01 ± 0.029	0.03 ± 0.109
C18:2 (c-9,c-12)	3.75 ± 0.923	7.35 ± 2.724
C18:3 (*n-3*)	0.39 ± 0.183	0.86 ± 0.594
C18:3 (t-9,t-12,t-15)	0.09 ± 0.098	0.20 ± 0.159
C18:3 (c-9,t-12,c-15)	0.07 ± 0.059	0.17 ± 0.179
C18:3 (t-9,c-12,c-15)	0.12 ± 0.094	0.27 ± 0.241
C18:3 (c-9,c-12,c-15)	0.09 ± 0.064	0.22 ± 0.153
CLA (*n-6*)	1.43 ± 0.234	0.90 ± 0.738

CLA, conjugated linoleic acid (C18:2c-9,t-11); MUFA, monounsaturated fatty acids (C18:1 t-11 + C18:1c-9); PUFA, polyunsaturated fatty acids (sum of C18:2 isomers + sum of C18:3 isomers); SFA, saturated fatty acids (C14:0 + C16:0 + C18:0); TFA, trans-fatty acids.

Table 3.
The molar (w/w%) and gravimetric (mg/g) content of cis-and trans-fatty acids in beef sirloin (Longissimus dorsi samples) from conventional production systems in South Africa (w/w%) (n = 60).

Lipid fraction	Content (%)
Intramuscular fat%	13.95 ± 4.18%
SFA	52.13 ± 1.22%
MUFA	38.98 ± 2.65%
PUFA	3.24 ± 0.857%
CLA	0.70 ± 0.148%
TFAs	4.65 ± 1.284%
TFA's/100 g lamb	0.22 g

CLA, conjugated linoleic acid; MUFA, monounsaturated fatty acids (C18:1 t-11 + C18:1c-9); PUFA, polyunsaturated fatty acids (sum of C18:2 isomers + sum of C18:3 isomers); SFA, saturated fatty acids (C14:0 + C16:0 + C18:0); Trans FAs, trans-fatty acids.

Table 4.
The lipid composition of lamb loin chops (Longissimus dorsi samples) from conventional production systems in South Africa (n = 80).

The regression of TFA accumulation with increasing carcass fat content in beef carcasses is presented in **Figure 1** ($r2$ = 0.64, $P < 0.05$). This illustrates that TFA concentrations accumulate slowly with increasing carcass fat content, but reach a turning point at about ca. 25% carcass fat content. Although the proportions of fatty acids generally remain relatively unchanged in ruminant fats due to rumen biohydrogenation, it seems that the concentration of TFA's reach a turning point

Fatty acid composition	Molar % (w/w%)	Gravimitric content (mg/g meat)
C12:0	0.146 ± 0.057	0.081 ± 0.040
C14:0	3.368 ± 0.673	1.742 ± 0.710
C14:1	0.084 ± 0.024	0.050 ± 0.024
C16:0	24.23 ± 1.788	16.612 ± 4.562
C16:1	1.023 ± 0.192	0.908 ± 0.279
C17:0	1.774 ± 0.525	0.545 ± 0.152
C18:0	22.30 ± 3.321	10.740 ± 2.373
C18:1 (n-11 t)	3.910 ± 1.256	1.735 ± 0.584
C18:1 (n-9c)	33.27 ± 2.809	24.348 ± 5.668
C18:l(n-11c)	0.631 ± 0.114	0.608 ± 0.124
C18:2 (n-6 t)	0.046 ± 0.014	0.019 ± 0.007
C18:2(n-6c)	2.029 ± 0.772	1.918 ± 0.385
C18:2 (n-10 t, n-12c)	0.592 ± 0.133	0.314 ± 0.147
C18:2 (n-10c,n-12c)	0.006 ± 0.001	0.003 ± 0.001
C18:2 (n-9c,n-11 t)	0.013 ± 0.008	0.008 ± 0.006
C18:3(n-6)	0.026 ± 0.005	0.022 ± 0.004
C18:3(n-3)	0.331 ± 0.069	0.176 ± 0.056
C20:0	0.131 ± 0.026	0.052 ± 0.011
C20:1(n-9)	0.060 ± 0.016	0.034 ± 0.006
C20:2	0.029 ± 0.007	0.030 ± 0.006
C22:0	0.011 ± 0.004	0.018 ± 0.004
C20:4(n-6)	0.081 ± 0.020	0.520 ± 0.147

CLA, conjugated linoleic acid (C18:2c-9,t-11); MUFA, monounsaturated fatty acids (C18:1 t-11 + C18:1c-9); PUFA, polyunsaturated fatty acids (sum of C18:2 isomers + sum of C18:3 isomers); SFA, saturated fatty acids (C14:0 + C16:0 + C18:0); Trans FAs, trans-fatty acids.

Table 5.
The molar (w/w%) and gravimetric (mg/g) content of cis-and trans-fatty acids in lamb shops (Longissimus dorsi samples) from conventional production systems in South Africa (w/w%) (n = 80).
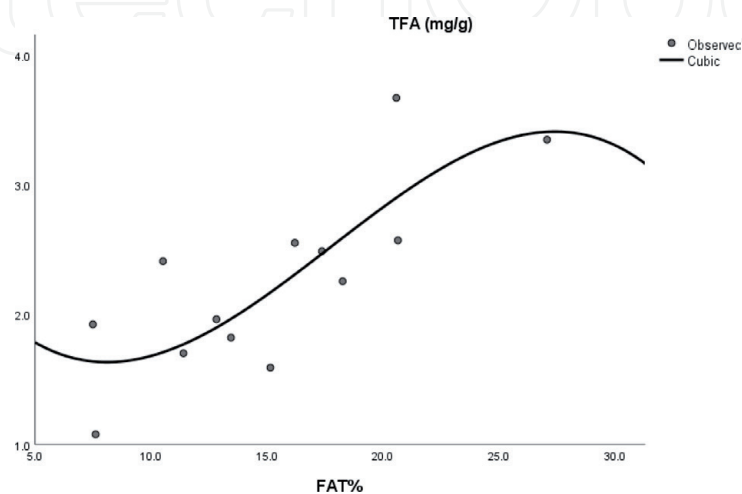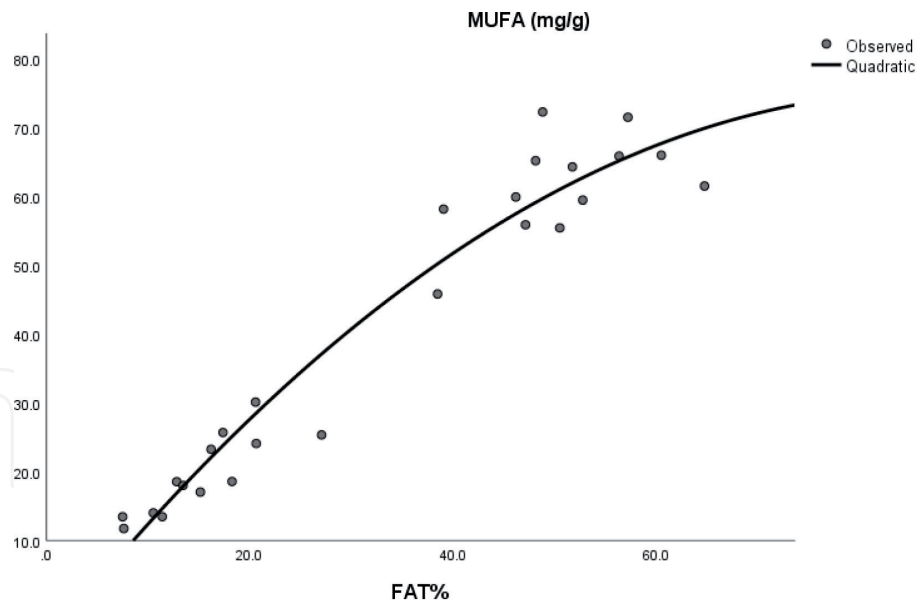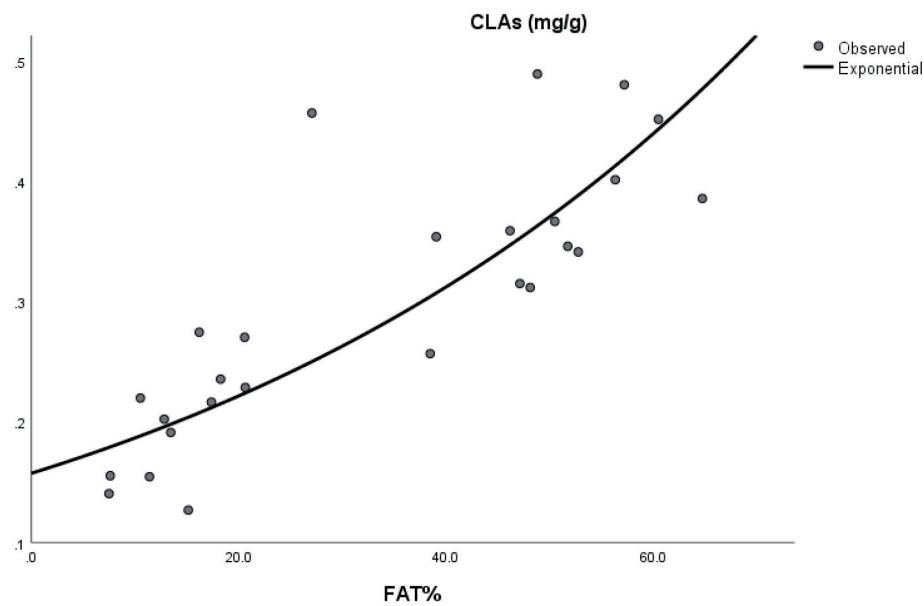

Figure 1.
Regression of trans-fatty acid content of beef loin samples (mg/g) with increasing carcass fat content in conventionally fed cattle.

(a)

(b)

Figure 2.
Regression equations of (a) mono-unsaturated fatty acid content (MUFA, w/w%) of beef loin muscle with increasing carcass fat content, and (b) conjugated linoleic acid content (CLA, w/w%) of beef loin muscle with increasing carcass fat content.

perhaps due to the preferential incorporation other dominant fatty acids such as MUFA and CLA metabolism and absorption in ruminants (see **Figure 2a** and **b**).

The molar composition of fatty acids of beef produced in conventional production systems contain less than 50% saturated fatty acids, while the balance of the fatty acids consist of heart-healthy MUFAs and PUFAs. The trans-fatty acid component of beef is ca. 4.19%, of which a large portion comprise the essential conjugated linoleic acid isomers.

Assessment of the specific medium and long-chain fatty acids in beef (**Table 3**) indicate that the SFAs consist of a small proportion of myristic acid (<3.5% C14:0), about 25% of palmitic acid (C16:0) and 20% of stearic acid (C18:0). It follows that the medium-chain fatty acids (MCFA; C14:0 and C16:0) comprise less than a third of the fatty acid content of beef, which is beneficial from a heart health perspective, as MCFA's have been associated with a slight elevation in low-density lipoprotein
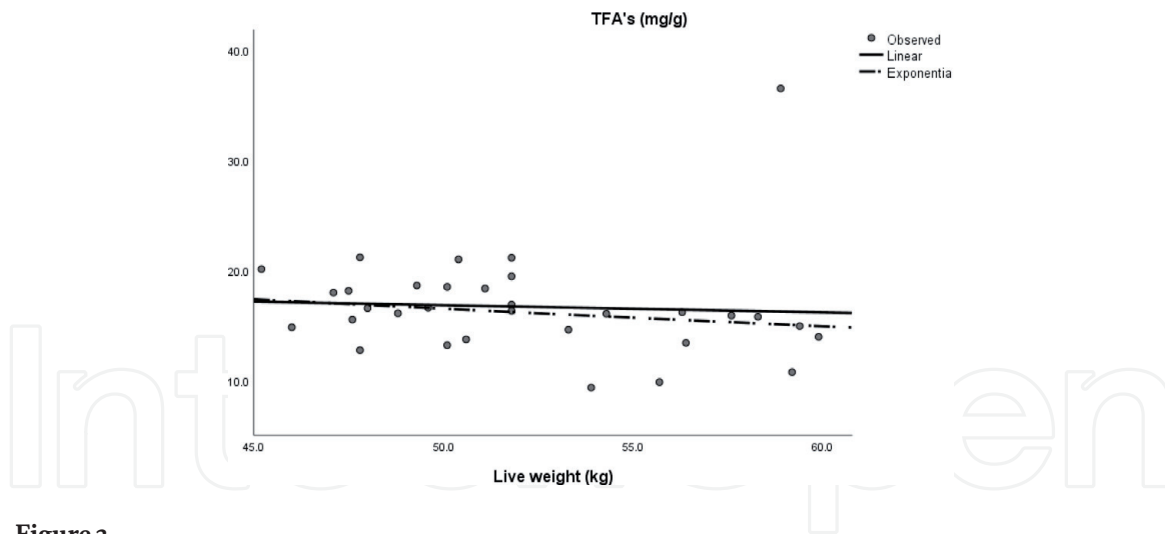
Figure 3.
Trans-fatty acid content (TFA, mg/g) of lamb loin muscle with increasing live weight.

(LDL) cholesterol values [57]. Stearic acid is known as a cholesterol neutral fatty acid and therefore beneficial in terms of essential fat ingestion. Recent research indicate that stearic acid decreases both cardiac and cancer risk in humans [58]. This beneficial fatty acid is also credited with signaling the mitochondria in cells and stimulate fatty acid beta-oxidation. The MUFAs in beef consist predominantly (40%) of the LDL cholesterol lowering oleic acid (C18:1) which therefore has no adverse effects on CHD or CVD. A large portion of the PUFAs also consist of CLA isomers, which are known to occur predominantly in milk and meat from ruminant livestock such as cattle and sheep.

Oleic acid (C18:1) has a well-known reputation of lowering the risk of cardio-vascular disease [59]. In this review, it is emphasized that the replacement of 5% of SFA's with oleic acid, may reduce the risk of coronary heart disease by 20–40%. The C18:1-component of beef is almost 45%, and it is important to know that concentrate feeding and dietary supplementation of cattle diets with zilpaterol hydrochloride increases the oleic acid content of beef by ca. 2% [23].

Figure 2(a) indicates the highly significant correlation between the accumulation of MUFA's in beef loin muscle with increasing carcass fat percentage (r^2 = 0.94, P < 0.001). Similarly, the CLA content of beef loin muscle (mg/g of loin muscle) correlates significantly (r^2 = 0.709, P < 0.001) with increasing carcass fat content in beef carcasses, as illustrated in **Figure 2(b)**.

This implies that the accumulation of both MUFA's and CLA's in beef muscle is significantly influenced by the increasing maturity and fat accumulation in cattle, in addition to the known dietary effects on beef CLA's. Beef carcasses are generally fed to about 18–25% carcass fat in European countries, Australia and South Africa and to about 25 to 35% carcass fat in the USA. Backgrounding on pastures combined with intensive concentrate feeding have beneficial effects on the CLA content of beef.

Lamb meat contains more intramuscular fat (ca. 14%; **Table 4**) compared to beef. However, the fat is not all saturated as commonly believed, with SFA's seldom exceeding 53%, and about 40% MUFA's, 3,2% PUFA's and low trans-fatty content (**Tables 4** and **5**). The data from typical mutton sheep breeds raised mainly on extensive pasture systems in South Africa indicate a low TFA content of 0.22 g/100 g meat, which is much lower than the threshold value of 5 g / 100 g portion.

It has been postulated that ruminant derived trans vaccenic acid may not be associated with an increased risk of CHD or CVD, because it is converted to CLA isomers, which hold several health benefits [14, 15]. Vaccenic acid in adipose tissues is converted to CLA by the stearoyl-CoA desaturase enzyme [31]. This enzyme is also responsible for converting oleic acid (C18:1c-9) to stearic acid (C18:0).

Figure 3 confirms that the TFA content of lamb loin muscle remains consistently low during the normal popular target weights at slaughter namely between 40 to 55 kg live weight.

4. Discussion

It is accepted that the consumption of excess red meat and alcohol, may adversely affect the life expectancy of humans [60]. Nonetheless, almost all lipid-containing foods in Western diets contribute to n-6 PUFA and alpha-linolenic acid intake, while only meat, eggs and seafood contribute to beneficial n-3 PUFA intake in the human diet [61]. Results of published epidemiological studies are conflicting concerning the effects of TFA's on blood cholesterol homeostasis [53, 62–66]. Unfortunately, most dietary trials on TFA's are based on industrial TFA's with the assumption that those trans isomers have the same metabolic effects as TFA's from natural sources such as those from red meat. The latter assumption is incorrect because trans vaccenic acid (C18:1 t-11) is unique of TFA's in ruminant adipose tissue, while elaidic acid (C18:1 t-9) occurs specifically in industrial TFA's [68].

The most important trans isomers in human biology are the mono-unsaturated and di-unsaturated fatty acids which contain sixteen and eighteen carbon atoms, namely C16:1 trans, C18:1 trans and C18:2 trans-fatty acids [67]. C18:1 trans isomers encompass 80–90% of total TFA content in foods. The importance of different tertiary structures relay to the different crystalline packing which ultimately result in differing melting points of these fatty acids [67]. The melting points of the trans isomeric fatty acids are generally much higher compared to their corresponding cis-isomers, i.e. oleic acid (C18:1 cis) has a melting point of 10–11°C, while its trans-isomer, elaidic acid (C18:1 trans) has a melting point of 44.5–45.5°C [67].

Based on the data from the present study, the TFA content of beef and lamb is low, and tend to peak early in the growth curve, after which the relative concentration starts to decrease slowly. This is associated with a slow but consistent increase in CLA's in ruminant muscle tissues. The current data also indicate that the growth curve and carcass fat content affect the accumulation of TFA's and CLA's in addition to the known effects of nutrition on their accumulation. Conjugated linoleic acid (CLA) is not included in the definition of TFA as it has conjugated double bonds [3], which means that the two double bonds are "conjugated" or continuous or not separated by a methylene group. CLA is a collective term used for all conjugated geometric and positional isomers of C18:2 (linoleic acid) [68, 69]. It is less well known that meat and milk from ruminant livestock are excellent sources of CLA's, which are synthesized in the rumen by the microbial isomerisation and biohydrogenation of mostly linoleic and alpha-linolenic acids (e.g. 18 carbon PUFAs), and the desaturation of trans-fatty acids in their adipose tissue and mammary glands. Rumenic acid (C18:2 c9,t11) comprises about 90% of the total CLA isomer range [70]. More recently the CLA-isomer (C18:2 t7,c9) has been detected in milk, cheese, beef, human milk as well as human adipose tissue.

CLA's are nutritionally beneficial due to their antioxidant and anti-carcinogenic properties [70, 71]. CLA's also have beneficial effects on non-communicable diseases such as cancer, cardiovascular diseases, diabetes, and positive effects on the immune system and bone health [70].

5. Conclusions

Red meats constitute an important source of high-quality protein and fatty acids in the human diet. Accordingly, red meat forms a critical part of a balanced

diet, along with moderate food intake and healthy habits such as physical activity and not smoking. The intramuscular fat content of red meats range between 3 and 14%, which is low compared to most fat-containing processed foods (25%). More importantly, the fats in red meats are not all saturated, with a SFA content of 45 to 53%, consisting predominantly of stearic acid which has proven health benefits. Animal fats contain several other beneficial fatty acids (including MUFA's, PUFA's, and CLA's) that have either no, or an LDL-cholesterol lowering effect, which may reduce the risk of coronary heart diseases.

TFA's are neither synthesized nor required by the human body. Although health professionals recommend a reduction in the consumption of SFA and TFA, animal fats contribute a very small portion of the overall TFA intake, most of which originate from other sources such as the partial hydrogenation of vegetable and fish oils. The lean component of beef and lamb contains a trivial proportion of TFA's, consisting of vaccenic acid, rumenic acid and CLA-isomers. CLA's in red meat are beneficial due to their antioxidant and anti-carcinogenic properties, so they should not strictly be considered in the TFA definition. This means that the TFA's in red meats are negligible and pose no harm to human health. Better labelling of red meats is recommended, to ensure that consumers understand the nutritional value of red meats, as part of a balanced diet.

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Conflict of interest

There is no conflict of interest.

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References

[1] Webb , E.C. & O'Neill, H.A. The animal fat paradox and meat quality, Meat Science, 2008; 80, 28-36.

[2] Albuquerquea, T.G., Costa, H.S., Castilho, M.C. & Sanches-Silva, A., Trends in the analytical methods for the determination of trans fatty acids content in foods. Trends in Food Science & Technology. 2011; 22, 543-560.

[3] EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA)., 2010. 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, 1-107.

[4] Griel, A.E. & Kris-Etherton, P.M. Beyond saturated fat: The importance of the dietary fatty acid profile on cardiovascular disease. Nutrition Reviews. 2006; 64, 257-262.

[5] Kris-Etherton, P.M. & Innis, S. Dietary Fatty Acids – Position of the American Dietetic Association and Dietitians of Canada. Journal of the American Dietetic Association. 2007; 107, 1599-1611.

[6] Judd, J.T., Clevidence, B.A., Muesing, R.A., Wittes, J., Sunkin, M.E. & Podczasy, J.J. Dietary trans fatty acids: Effects on plasma lipids and lipoproteins of healthy men and women. American Journal of Clinical Nutrition. 1994; 59, 861-868.

[7] Mensink, R.P. & Katan, M.B. Effect of dietary trans fatty acids on high-density and low-density lipoprotein cholesterol levels in healthy subjects. The New England Journal of Medicine. 1990; 23, 439-445.

[8] Wagner, K., Plasser, E., Proell, C. & Kanzler, S. Comprehensive studies on the trans fatty acid content of Austrian foods: Convenience products, fast food and fats. Food Chemistry. 2008; 108, 1054-1060.

[9] Ratnayake, W.M. & Zehaluk, C. Trans fatty acids in foods and their labeling regulations. In: Healthful Lipids. Eds Akoh, C.C. & Lai, O.M., AOCS Press, 2005; pp 1-32.

[10] Richter, E.K., Shawish, K.A., Scheeder, M.R. & Colombani, P.C. Trans fatty acid content of selected Swiss foods: the TransSwissPilot study. Journal of Food Composition and Analysis. 2009; 22, 479-484.

[11] Stender, S., Astrup, A. & Dyerberg, J. Ruminant and industrially produced trans fatty acids: health aspects. 2008; Food & Nutrition Research.

[12] Fritsche, J. & Steinhart, H. Contents of trans fatty acids (TFA) in German foods and estimation of daily intake. Lipid. 1997; 99, 214-217.

[13] Weggemans, R.M., Rudrum, M. & Trautwein, E.A. Intake of ruminant versus industrial trans fatty acids and risk of coronary heart disease – what is the evidence? European Journal of Lipid Science and Technology. 2004; 106, 390-397.

[14] Huth, P.J. Do ruminant trans fatty acids impact coronary heart disease risk? Lipid Technology. 2007; 19, 59-62.

[15] Turpeinen, A.M., Mutanen, M., Aro, A., Salminen, I., Basu, S., Palmquist, D.L. & Griinari, J.M. Bioconversion of vaccenic acid to conjugated linoleic acid in humans. American Journal of Clinical Nutrition. 2002; 76, 504-510.

[16] Zock, P.L. & Mensink, R.P. Dietary trans fatty acids and serum lipoproteins in humans. Current Opinions of Lipidology.1996; 7, 34-37.

[17] Katan, M.B. Trans fatty acids and plasma lipoproteins. Nutrition Reviews. 2000; 58, 188-191.

[18] Nuernberg, K., Dannenberger, D., Nuernberg, G., Ender, K., Voigt, J., Scollan, N.D., Wood, J.D., Nute, G.R. & Richardson, R.I. Effect of grass-based and a concentrate feeding system on meat quality characteristics and fatty acid composition of longissimus muscle in different cattle breeds. Livest. Prod. Sci. 2005; 94, 137-147.

[19] De Smet, S., Webb, E. C., Claeys, E., Uytterhaegen, L., & Demeyer, D. I. Effect of dietary energy and protein levels on fatty acid composition of intramuscular fat in double-muscled Belgian Blue bulls. Meat Science, 2000; 56, 73-79.

[20] Webb, E. C., De Smet, S., Van Nevel, C., Martens, B., & Demeyer, D. I. Effects of anatomical location on the composition of fatty acids in double-muscled Belgian Blue cows. Meat Science, 1998; 50, 45-53.

[21] Enser, M., Hallett, K. G., Hewett, B., Fursey, G. A. J., Wood, J. D., & Harrington, G. Fatty acid content and composition of UK beef and lamb muscle in relation to production system and implications for human nutrition. Meat Science, 1998; 49, 329-341.

[22] Enser, M., Hallett, K., Hewitt, B., Fursey, G. A. J., & Wood, J. D. Fatty acid content and composition of English beef, lamb and pork at retail. Meat Science, 1996; 42(4), 443-456.

[23] Webb, E. C., & Casey, N. H. Fatty acids in carcass fat of steers treated with ß-adrenergic agonist individually or in combination with trenbolone acetate + oestradiol-17b. Meat Science, 1995; 41(1), 69-76.

[24] Webb, E. C., & Casey, N. H. Genetic differences in fatty acid composition of subcutaneous adipose tissue in Dorper and SA Mutton Merino wethers at different live weights. Small Ruminant Research, 1995; 18, 81-88.

[25] Webb, E. C., Casey, N. H., & Van Niekerk, W. A. Fatty acids in the subcutaneous adipose tissue of intensively fed SA Mutton Merino and Dorper wethers. Meat Science, 1994; 38, 123-131.

[26] Weaver, C.M., Dwyer, J.M., Fulgoni, V.L., King, J.C., Leveille, G.A., MacDonald, R.S., Ordovas, J & Schnakenberg, D., Processed foods: contributions to nutrition, Am J Clin Nutr 2014;99:1525-42.

[27] Williams, P. Key nutrients delivered by red meat in the diet. Nutrition & Dietetics. 2007; 64,113-119.

[28] Wu, G. Important roles of dietary taurine, creatinine, anserine and 4-hydroxyproline in human nutrition and health, Amino Acids, 2020; 52, 329-360.

[29] Warren, H.E., Scollan, N.D., Enser, M., Hughes, S.I., Richardson, R.I. & Wood, J.D. Effects of breed and a concentrate or grass silage diet on beef quality in cattle of 3 ages. I: Animal performance, carcass quality and muscle fatty acid composition. Meat Science. 2008; 78, 256-269.

[30] Droulez, V., William, P.G., Levy, G., Stobaus, T. & Sinclair, A. Composition of Australian red meat, Fatty acid profile. Food Australia. 2006; 58, 335-341.

[31] Wood, J. D., Richardson, R. I., Nute, G. R., Fisher, A. V., Campo, M. M., Kasapidou, E., et al. Effects of fatty acids on meat quality: A review. Meat Science, 2008; 78,343-358.

[32] Tshabalala, P. A., Strydom, P. E., Webb, E. C., & De Kock, H. L. Meat quality of designated South African indigenous goat and sheep breeds. Meat Science, 2003; 65, 563-570.

[33] Mostert, E. The effect of Karoo browse and veldt feeding on long-chain and volatile fatty acid components in lamb, [thesis]. University of Pretoria, 2020.

[34] Laaksonen, D. E., Nyyssonen, K., Niskanen, L., Rissanen & Salonen, J. T. Prediction of cardiovascular mortality in middle-aged men by dietary and serum linoleic and polyunsaturated fatty acids. Archives of Internal Medicine, 2005; 165, 193-199.

[35] Johnson, B.J., Ribeiro, F.J.B. & Beckett, J.L. Application of growth technologies in enhancing food security and sustainability. Anim. Frontiers 2013; 3, 8-13.

[36] Scollan, N. D., Choi1, N.-G., Kurt, E., Fisher, A. V., Enser, M., & Wood, J. D. Manipulating the fatty acid composition of muscle and adipose tissue in beef cattle. Meat Science, 2001; 85, 115-124.

[37] Zervas, G. & Tsiplakou, E. The effect of feeding systems on the characteristics of products from small ruminants. Small Ruminant Research 2011; 101, 140– 149.

[38] Raes, K., De Smet, S., & Demeyer, D. Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat: A review. Animal Feed Science and Technology, 2004; 113, 199-221.

[39] National Health and Medical Research Council., 2006. Nutrient Reference Values for Australia and New Zealand Including Recommended Dietary Intakes. Canberra: Commonwealth Department of Health and Ageing.

[40] Motard-Bélanger, A., Charest, A., Grenier, G., Paquin, P., Chouinard, Y., Lemieux, S., Couture, P. & Lamarche,

B. Study of the effect of trans fatty acids from ruminants on blood lipids and other risk factors for cardiovascular disease. American Journal of Clinical Nutrition. 2008; 87,593-9.

[41] World Health Organization (WHO). 2008-2013 action plan for the global strategy for the prevention and control of noncommunicable diseases: Prevent and control cardiovascular diseases, cancers, chronic respiratory diseases and diabetes. Geneva: Switzerland. 2008.

[42] Willett, W.C., Stampfer, M.J., Manson, J.E., Colditz, G.A., Speizer, F.E., Rosner, B.A., Sampson, L.A. & Hennekens, C.H. Intake of trans fatty acids and risk of coronary heart disease among women. Lancet. 1993; 341, 581-585.

[43] Ascherio, A., Katan, M.B., Stampfer, M.J. & Willett, W. C. Trans fatty acids and coronary heart disease. The New England Journal of Medicine. 1999; 340, 1994-1998.

[44] Webb, E.C. & Erasmus, L.J., (2013). The effect of production system and management practices on the quality of meat products from ruminant livestock, S. Afr. J. Anim. Sci., 43(3):413-423.

[45] Realini, C.E., Duckett, S.K., Brito, G.W., Dalla Rizza, M. & De Mattos, D. Effect of pasture vs. concentrate feeding with or D. Without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. Meat Science. 2004; 66, 567-577.

[46] Gatellier, P., Mercier, Y. & Renerre, M. Effect of diet finishing mode (pasture or mixed diet) on antioxidant status of Charolais bovine meat. Meat Science. 2004; 67, 385-394.

[47] Keane, M.G. & Allen, P. Effects of production system intensity on performance, carcass composition and

meat quality of beef cattle. Livestock Production Science. 1998; 56, 203-214.

[48] Muir, P.D., Beaker, J.M. & Brown, M.D. Effects of forage- and grain-based feeding systems on beef quality: A review. N. Z. J. Agric. Res. 1998; 41, 623-635.

[49] Priolo, A., Micol, D., Agabriel, J., Prache, S. & Dransfield, E. Effect of grass or concentrate feeding system on lamb carcass and meat quality. Meat Sci. 2002; 62, 179-185.

[50] Aurousseau, B., Bauchart, D., Calichon, E., Micol, D. & Priolo, A. Effect of grass or concentrate feeding systems and rate of growth on triglyceride and phospholipid and fatty acids in the *M. longissimus* thoracis of lambs. Meat Sci. 2004; 66, 531-541.

[51] Webb, E. C., & Casey, N. H. (1997). Influence of dietary presentation on the composition of fatty acids and sensory characteristics of meat from wethers. South African Journal of Food Science and Nutrition, 9, 69-76.

[52] Pordomingo, A.J., Garcia, T.P. & Volpi Lagreca, G. Effect of feeding treatment during the backgrounding phase of beef production from pasture on: II. Longissimus muscle proximate composition, cholesterol and fatty acids. Meat Science. 2012; 90, 947-955.

[53] Strydom, P.E., Hope-Jones, M, Frylinck, L. & Webb, E.C. The effects of a beta-agonist treatment, vitamin D3 supplementation and electrical stimulation on meat quality of feedlot steers, 2011; Meat Sci., 89:462-468.

[54] Moloney, A.P., Allen, P., Ross, D.B., Olson, G, & Convey, E.M. Growth, feed efficiency and carcass composition of finishing Friesian steers fed the beta-adrenergic agonist L-644,969. Journal of Animal Science. 1990; 68, 1269-1277.

[55] AOAC, Official methods of analysis of AOAC International by Patricia A Cunniff, AOAC International. Association of Official Analytical Chemists, Washington, DC, USA, 1995.

[56] Folch, J., Lees, M. & Stanley, H.S. A simple method for the isolation and purification of total lipids from animal tissues. Journal of Biological Chemistry. 1957; 226, 497-509.

[57] Temme, EH, Mensink, RP & Hornstra, G. Effects of medium chain fatty acids (MCFA), myristic acid, and oleic acid on serum lipoproteins in healthy subjects, J Lipid Res., 1997; 38(9):1746-1754

[58] Senyilmaz-Tiebe, D, Pfaff, D.H., Virtue, S, Schwarz, K.V., Fleming, T, Altamura,S, Muckenthaler, M.U., Okun,J.G. Vidal-Puig, A. Nawroth, P. & Teleman, A.E., Dietary stearic acid regulates mitochondria in vivo in humans, Nature Communication, DOI: 10.1038/s41467-018-05614-6

[59] Lopez-Huertas, E. Health effects of oleic acid and long chain omega-3 fatty acids (EPA and DHA) enriched milks. A review of intervention studies, Pharmacological Research 2010; 61, 200-207, DOI: 10.1016/j. phrs.2009.10.007

[60] Chhabi Lal Ranabhat, Myung-Bae Park & Chun-Bae Kim, Influence of alcohol and red meat consumption on life expectancy: Results of 164 Countries from 1992 to 2013, Nutrients, 2020; 12, 459; doi:10.3390/nu12020459.

[61] Meyer, B.J., Mann, N.J., Lewis, J.L., Milligan, G.C., Sinclair, A.J. & Howe, P.R.C. Dietary intakes and food sources of omega-6 and omega-3 polyunsaturated fatty acids. Lipids. 2003; 38, 391-397.

[62] Ascherio, A., Katan, M.B., Stampfer, M.J. & Willett, W. C. Trans fatty acids and coronary heart disease. The New

England Journal of Medicine. 1999; 340, 1994-1998.

[63] Aro, A. Complexity of issue of dietary trans fatty acids. The Lancet. 2001; 357, 732.

[64] Clifton, P.M., Keogh, J.B. & Noakes, M. Trans fatty acids in adipose tissue and the food supply are associated with myocardial infarction. Journal of Nutrition. 2004; 134, 874-879.

[65] Oomen, C.M., Ocke, M.C., Feskens, E.J., Erp-Baart, M.A., Kok, F.J. & Kromhout, D. Association between trans fatty acid intake and 10-year risk of coronary heart disease in the Zutphen Elderly Study: a prospective population-based study. Lancet. 2001; 357, 746 –751.

[66] Sun, Q., Ma, J., Campos, H., Hankinson, S.E., Manson, J.E., Stampfer, M.J., Rexrode, K.M., Willett, W.C. & Hu, F.B. A prospective study of trans fatty acids in erythrocytes and risk of coronary heart disease. Circulation. 2007; 115, 1858-1865.

[67] Aro, A., Kosmeijer-Schuil, T., van de Bovenkamp, P., Hulshof, P., Zock, P. & Katan, M.B., 1998. Analysis of C18:1 cis and trans fatty acid isomers by the combination of gas-liquid chromatography of 4,4-dimethyloxazolinederivatives and methyl esters. Journal of American Oil Chemistry Society. 75, 977-985.

[68] Koletzko, B & Decsi, T. Metabolic aspects of trans fatty acids. Clinical Nutrition. 1997; 16, 229-237.

[69] Schmid, A., Collomb, M., Sieber, R. & Bee, G. Conjugated linoleic acid in meat and meat products: A review. Meat Science. 2006; 73, 29-41.

[70] Yurawecza, M.P., Roacha, J.A.G., Sehata, N., Mossobaa, M.M., Kramerb, J.K.G., Fritschec, J., Steinhart, H. & Kua, Youh. A New Conjugated Linoleic Acid Isomer, 7 trans, 9 cis-Octadecadienoic Acid, in Cow Milk, Cheese, Beef and Human Milk and Adipose Tissue, Lipids. 1998; 33, 803-809.

[71] McDonald, H.B. Conjugated linoleic acid and disease preventions: A review of current knowledge. The American College of Nutrition. 2000; 19, 111-118.