



REVIEW

Fatty Acid Composition of Grain- and Grass-Fed Beef and Their Nutritional Value and Health Implication

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OPEN ACCESS

Received September 20, 2021

Revised December 7, 2021

Accepted December 9, 2021

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Abstract Beef contains functional fatty acids such as conjugated linoleic acid and long-chain fatty acids. This review summarizes results from studies comparing the fatty acid composition of beef from cattle fed either grass or grain-based feed. Since functional lipid components are contributed through dietary consumption of beef, the fatty acid composition is reported on mg/100 g of meat basis rather than on a percentage of total fat basis. Beef from grass-fed contains lesser total fat than that from grain-fed in all breeds of cattle. Reduced total fat content also influences the fatty acid composition of beef. A 100 g beef meat from grass-fed cattle contained 2,773 mg less total saturated fatty acids (SFA) than that from the same amount of grain-fed. Grass-fed also showed a more favorable SFA lipid profile containing less cholesterol-raising fatty acids (C12:0 to C16:0) but contained a lesser amount of cholesterol-lowering C18:0 than grain-fed beef. In terms of essential fatty acids, grass-fed beef showed greater levels of trans-vaccenic acid and long-chain n-3 polyunsaturated fatty acids (PUFA; EPA, DPA, DHA) than grain-fed beef. Grass-fed beef also contains an increased level of total n-3 PUFA which reduced the n-6 to n-3 ratio thus can offer more health benefits than grain-fed. The findings signify that grass-fed beef could exert protective effects against a number of diseases ranging from cancer to cardiovascular disease (CVD) as evidenced by the increased functional omega-3 PUFA and decreased undesirable SFA. Although grain-fed beef showed lesser EPA, DPA, and DHA, consumers should be aware that greater portions of grain-fed beef could also achieve a similar dietary intake of long-chain omega-3 fatty acids. Noteworthy, grain-fed beef contained higher total monounsaturated fatty acid that have beneficial roles in the amelioration of CVD risks than grass-fed beef. In Hanwoo beef, grain-fed showed higher EPA and DHA than grass-fed beef.

Keywords beef, fatty acids, health, grain, grass

Introduction

The fatty acid composition of intramuscular fat (IMF) of beef has received considerable interest in light with the association and implication of beef fats to the risk of cardiovascular disease (CVD; Briggs et al., 2017), and its positive relationship to the sensory characteristic of the beef meat such as aroma, flavor, juiciness, and tenderness (Listrat et al., 2020). The amount of beef IMF and the composition of the fatty acids have been reported to be impacted by the cattle breed or genetic variation (Pitchford et al., 2002), fat deposition (Hwang and Joo, 2016), and alterations in the feeding strategy either by grass or grain feeding (Hwang and Joo, 2017; Van Elswyk and McNeill, 2014). In South Korea, the feeding system can be classified under grain-feeding. To produce marbled beef, the raising of the Korean native cattle (Hanwoo) is fed with grass only in the first 6 months of age and primarily relies on concentrate or grain diet from growing to the fattening stage (Chung et al., 2018). In the USA, Australia, New Zealand, and countries with abundant grass growing seasons, the grass-feeding of beef cattle is recognized and practiced. The diet of the grass-feeding system is derived solely from annual and perennial grass, legumes, Brassica, hay, haylage, silage, crop residue without grain, or pre-grain state cereal crop and is given from birth to slaughter with the exception of providing milk prior to weaning (USDA-AMS, 2007). Whether feeding is based on the use of grains and formulated feedlot rations (grain-feeding) or reducing or eliminating grains from the diet (grass-feeding), these two feeding systems have resulted in changing concentrations of functional lipids, and saturated and trans fatty acids in beef. With the increasing demands of consumers on healthier beef, it is necessary to understand the fatty acid composition in beef that is beneficial for human health. When considering the health implications of beef fat, it is important to consider not only the effect of the individual fatty acid but the combined effects of the related group of fatty acids. Health claims have reported that grass-fed beef showed 62% lower fat content, 65% lower SFA, and greater concentrations of omega-3 fatty acids and conjugated linoleic acid (CLA) compared to grain-fed beef (Ziehl et al., 2005). Grass-based diets have also been shown to enhance the total CLA (C18:2) isomers, *trans* vaccenic acid (TVA, C18:1 t11), and omega-3 fatty acids on a g/g fat basis while grass-finished beef has tended to increase saturated fatty acids (SFA) such as myristic (C14:0), palmitic (C16:0), and stearic (C18:0) fatty acids (Daley et al., 2010). Grass-feeding or grain-feeding shows influences on the alteration of the fatty acid composition in beef. However, the recommendation to reduce red meat consumption due to its association with human heart diseases has led to criticisms over the Hanwoo beef industry in Korea. Hence, this review aimed to emphasize the fatty acid composition in Hanwoo beef but due to the lack of numerous publications about Hanwoo fatty acids, some other breeds of beef cattle were included. The review summarized the fatty acid composition of beef as reported from the limited number of studies comparing grass-fed and grain-fed, and to view the standing of Hanwoo fatty acid composition with other beef breeds. Furthermore, since these functional lipid components are contributed through dietary consumption of red or beef meat, the fatty acid composition will be reported on a mg/100 g of meat basis rather than on percentage of total fat basis.

An Overview of the Feeding System in Korea, Australia, and the USA

Grain-feeding system: Calves intended for beef production in South Korea are typically fed with grass, forage, hay, and some feed supplements until six months of age in which calves will undergo a finishing period with high concentrate to reach the desired weight for slaughter. Hanwoo beef cattle are typically fed with a high-energy diet from 6 to 29 months. During the growing stage (6 to 11 months) and early fattening period (12 to 20 months), cattle are fed with a concentrate that has 71% total digestible nutrient (TDN) and 13% crude protein (CP) combined with *ad libitum* rice straw. This diet is slightly changed

to 73% TDN and 11% CP combined with *ad libitum* rice straw as the final fattening period approaches. During the final fattening stage (21 to 29 months), cattle are fed with a combination of 10% rice straw and 90% concentrate to maximize IMF development (Jo et al., 2012). High TDN content in diet steadily increased marbling scored at 28 and 30 months of age and it was reported that the most suitable feeding period for Hanwoo is until 29 months (Chung et al., 2015) to avoid an increase of inedible fat that could negatively influence beef grade and yield. In the USA, breeds of beef cattle are mostly Angus and Hereford and are typically fed with grain diets. As reported, young steers and heifers in the beef industry of the USA are fed with grain diets on average for 5 months and slaughtered at 15 to 28 months to produce marbled beef (Drouillard, 2018). Backgrounding or stocker calves are mostly grown using forage-based diets and are transferred to feedlots (grain-feeding) when they reach a year or more of age and are fattened on high-concentrate diets in later years of their lives before marketing or slaughtering. Grain-feeding in Australian beef cattle has assumed more importance just recently to resolve the decline in the quality of pasture and forage due to the varying climate of Australia, and also to measure up with the increasing demand for marbled beef within Australia and the exports in Korea and Japan (Greenwood et al., 2018). Feedlot diets or grain-feeding in Australia are formulated using wheat, barley, and sorghum grains to provide high energy to beef cattle.

Grass-feeding: Grass-feeding system in South Korea and Australia is not as well-established as the grass-feeding system in the USA. Beef cattle fed with grass in the USA should strictly follow the rule defined by the USDA Agricultural Marketing Service that animals cannot be fed grain or grain byproducts and must have continuous access to pasture during the growing season (USDA-AMS, 2009). In Australia, beef production were cow-calf systems based on pasture and rangeland, backgrounding or grow-out period on pasture, and finishing on pasture or forage (Greenwood et al., 2018).

Saturated Fatty Acid Composition of Grass-Fed and Grain-Fed Beef

SFA are made up of a carbon chain with no double bonds, and high consumption of this fatty acid has long been associated with CVD risks. According to Nurse's Health Study (NHS) and Health Professionals Follow-Up Study (HPFS), consumption of long-chain SFA from C12:0 (lauric acid) to C18:0 (stearic acid) increased coronary heart disease (CHD) risks (Hu et al., 1999; Zong et al., 2016). Lauric acid (C12:0) has the greatest raising effect on high-density lipoprotein (HDL) cholesterol, consequently decreasing the total cholesterol: HDL ratio (Mensink et al., 2003; Micha and Mozaffarian, 2010). Myristic (C14:0) and palmitic (C16:0) acids comparably influence the low-density lipoprotein (LDL) and LDL, and both have a small influence on the total cholesterol: HDL ratio (Micha and Mozaffarian, 2010). Stearic acid (C18:0) showed neutral impact (Williamson et al., 2005; Yu et al., 1995) to little lowering-effect on the plasma LDL cholesterol and did not show an effect on HDL cholesterol (Hunter et al., 2010; Mensink, 2005). Due to desaturation of stearic acid (C18:0) in part to oleic acid (C18:1 n-9) during metabolism (Sampath and Ntambi, 2005), stearic acid (C18:0) is the only SFA that does not appear to adversely increase CVD risks.

Studies on the influence of grass-feeding and grain-feeding on the fatty acid composition of beef cattle normally report comparable total SFAs between the two feeding strategies when presented on a percentage of total fatty acid. However, finishing or feeding beef cattle in the grass instead of concentrates typically results in leaner carcasses or beef with lower fat content (Duckett et al., 2007, Duckett et al., 2009a; Garcia et al., 2008; Leheska et al., 2008; Neel et al., 2007; Nuernberg et al., 2005) as also shown in Table 1 where grass-fed beef showed lower overall fat content. The percentage of total fatty acids does not necessarily translate to human dietary intake of fatty acids due to the difference in the total fat content of grass-fed and grain-fed beef. The eight collected studies on the influence of grass-feeding and grain-feeding on the fatty acid

Table 1. Comparison of mean saturated fatty acid composition expressed as mg/100 g of meat between grass-fed and grain-fed beef

Author (publication year)	Feeding system	Breed	Beef cut/muscle location	Fat content	Saturated fatty acid (mg/100 g meat)					
					C12:0	C14:0	C16:0	C18:0	C20:0	Total SFA
Najar-Villarreal et al. (2019)	Grass-fed	NR	Ground beef	15.7 (% crude fat)	11.5*	457.3*	3,746.3	1,784.7*	372.5*	6,322.0*
	Grain-fed	Angus	Ground beef	19.8 (% crude fat)	16.3*	623.9*	4,771.8	2,562.7*	551.4*	8,431.8*
Hwang and Joo (2017)	Grass-fed	Hanwoo	Sirloin	5.94 (% crude fat)	3.8*	142.6*	1,593.7*	724.7*	7.6*	2,569.8*
	Grain-fed	Hanwoo	Sirloin	25.39 (% crude fat)	14.0*	565.2*	6,098.0*	2,088.5*	25.6*	9,223.8*
	Grass-fed	Australian beef	Sirloin	5.15 (% crude fat)	3.3*	126.0*	1,442.1*	742.0*	8.0*	2,415.3*
	Grain-fed	American beef	Sirloin	10.22 (% crude fat)	4.7*	239.7*	2,579.1*	1,339.6*	11.2*	4,332.5*
Turner et al. (2015)	Grass-fed	NR	Ribeye	38.26 (mg/g muscle)	NR	86.9	911.2*	602.8	NR	1,671.7
	Grain-fed	NR	Ribeye	84.90 (mg/g muscle)	NR	213.1	2,107.5*	1,228.7	NR	3,701.8
Duckett et al. (2013)	Grass-fed	Angus	Ribeye, strip	2.6 (% total fat)	NR	57.9	606.1	401.5	NR	1,064.6
	Grain-fed	Angus	Ribeye, strip	6.7 (% total fat)	NR	171.9	1,657.5	812.9	NR	2,642.9
Aldai et al. (2011)	Grass-fed	Asturian valley cattle	Ribeye/ L. thoracis	NR	0.014 (%)*	0.60 (%)*	15.82 (%)*	15.85 (%)	0.11 (%)	197.2*
	Grain-fed	Asturian valley cattle	Ribeye/ L. thoracis	NR	0.024 (%)*	1.36 (%)*	20.97 (%)*	15.31 (%)	0.09 (%)	447.6*
Alfaia et al. (2009)	Grass-fed	Alentejano purebred	Sirloin/ L. lumborum	9.76 (mg/g muscle)	0.4*	11.1*	164.7*	133.7*	2.2*	346.5
	Grain-fed	Alentejano purebred	Sirloin/ L. lumborum	13.03 (mg/g muscle)	0.7*	22.0*	248.1*	209.3*	2.3*	468.7
Ponnampalam et al. (2006)	Grass-fed	Angus	Sirloin/ L. lumborum	2.12 (% of muscle)	NR	56.9*	508.0	272.8	NR	900.0*
	Grain-fed	Angus	Sirloin/ L. lumborum	3.61 (% of muscle)	NR	103.7*	899.0	463.3	NR	1,568.0*
Realini et al. (2004)	Grass-fed	Hereford	Ground beef	11.43a (% total fat)	NR	304.7*	2,498.1	2,035.3*	NR	5,037.1*
	Grain-fed	Angus-Hereford	Ground beef	24.57b (% total fat)	NR	724.7*	5,448.7	3,294.9*	NR	9,891.4*

Between grass-fed and grain-fed beef studies followed by asterisk (*) indicates significant difference (at least $p < 0.05$); NR, not reported; C12:0, lauric acid; C14:0, myristic acid; C16:0, palmitic acid; C18:0, stearic acid; C20:0, arachidic acid; SFA, saturated fatty acid.

composition of beef cattle have consistently reported a decrease in the total SFAs in response to grass-feeding. Because of the lower total fat content in grass-fed beef, consumption of 100 g beef provides 1.58 to 4.85 g less total SFAs than consuming 100 g grain-fed beef (in various cattle breeds except for Hanwoo). In terms of the Korean native cattle, Hanwoo, 100 g grass-fed beef contained 6.65 g less total SFAs than grain-fed beef. Regardless of beef cuts and cattle breed, total SFAs are found abundantly in grain-fed beef (2,773 mg/100 g meat higher). Individual SFAs that are considered detrimental to serum cholesterol levels and pose higher risks of CVD such as lauric (C12:0), myristic (C14:0), and palmitic (C16:0) acids have also been consistently reported elevated in grain-fed beef. Stearic acid (C18:0), on the other hand, has been reported to be

greater in grass-fed beef than in grain-fed beef (Daley et al., 2010; Van Elswyk and McNeill, 2014). In the current review, studies collected have consistently reported a lesser amount of stearic acid along with the other individual SFAs (C12:0, C14:0, C16:0, C20:0) as computed in mg per 100 g in grass-fed beef (Table 1). The difference in the reported results might be due to the unit used in the presentation of the fatty acid composition. Despite the lower stearic acid, it would appear that grass-fed beef posed a more favorable SFA composition as shown by the lower contents of cholesterol-raising fatty acids (C12:0 to C16:0) than grain-fed beef.

Monounsaturated Fatty Acid Composition of Grass-Fed and Grain-Fed Beef

Monounsaturated fatty acids (MUFA) are fatty acids containing one double bond. Common dietary MUFA are myristoleic (C14:1n-5), palmitoleic (C16:1n-7), and oleic (C18:1n-9) acids in which oleic acid represents approximately 90% of MUFAs in the diet (Kris-Etherton, 1999). Epidemiological studies on the association of MUFA and CVD have shown mixed results. Meta-analyses found no significant association between MUFA and CHD (Chowdhury et al., 2014; Skeaff and Miller, 2009) but a systematic review showed a strong association between dietary intake of MUFA and lower CHD risks (Mente et al., 2009). Despite this, several mechanisms were reported showing the beneficial role of MUFA in ameliorating CVD risk factors which includes the inactivation of sterol regulatory element-binding protein (SREBP, a transcription factor that regulates cholesterol synthesis), an increase of hepatic LDL receptor expression by stimulating Acyl-CoA: cholesterol acyltransferase, and the increased production of acylcarnitines to shift in fat catabolism (Hammad et al., 2016; Kien et al., 2014). MUFA also showed a greater fat oxidation rate compared to SFA (Krishnan and Cooper, 2014), and replacement of SFA with MUFA showed a reduction of total cholesterol, LDL, and HDL cholesterol, and triglycerides (Mensink and World Health Organization, 2016).

As expected, eight out of the eight studies collected in this review showed an elevated concentration of the total MUFA in grain-fed beef (Table 2). Grain feeding decreases ruminal pH that causes reductions in the population of bacteria responsible for rumen biohydrogenation of unsaturated fatty acids to SFAs (Fukuda et al., 2006; John Wallace et al., 2006), hence contributing to the increase MUFA in beef. The reduction in the total MUFA of grass-fed beef ranged from 0.2 g to 6.2 g per 100 g less than the grain-fed beef in various breeds and as much as 10.6 g per 100 g beef less MUFA in grass-fed Hanwoo than grain-fed one. Regardless of the breeds, the decreased total MUFA in grass-fed beef could be due to the depression of the expression of sterol carnitine desaturase (SCD) (Chung et al., 2007; Duckett et al., 2009b; Hilmia et al., 2017) decreasing the desaturation of SFA to their respective MUFA. Concomitantly, all individual MUFAs such as myristoleic (C14:1), palmitoleic (C16:1), and oleic (C18:1) acids were elevated in grain-fed beef except TVA (C18:1 t-11) as shown in Table 2. It is worthy to take note, that three out of five studies that reported TVA concentration showed an increased TVA as influenced by grass-feeding. Desaturation of TVA synthesizes the CLA (C18:2 c-9, t-11), which has drawn significant attention for its various beneficial health effects such as reduction of body fat, reduction of risk factors to CVD and cancer, and modulation of the immune and inflammatory responses (Dilzer and Park, 2012).

Polyunsaturated Fatty Acid Composition of Grass-Fed and Grain-Fed Beef

Polyunsaturated fatty acids (PUFA) are hydrocarbon chains containing two or more double bonds and can be characterized as either n-3 PUFA or n-6 PUFA referring to the position of the first double bond relative to the methyl end of the fatty acid. Of particular interest in the n-6 PUFA are the CLA (C18:2) and arachidonic acid (C20:4, AA), while in the n-3 PUFA are the

Table 2. Comparison of mean monounsaturated fatty acid composition expressed as mg/100 g of meat between grass-fed and grain-fed beef

Author (publication year)	Feeding system	Breed	Beef cut/muscle location	Fat content	Monounsaturated fatty acid (mg/100 g meat)				
					C14:1	C16:1	C18:1 t11	C18:1 n-9	Total MUFA
Najar-Villarreal et al. (2019)	Grass-fed	NR	Ground beef	15.7 (% crude fat)	165.4*	671.6*	162.5	6,073.2*	7,436.5*
	Grain-fed	Angus	Ground beef	19.8 (% crude fat)	177.7*	892.3*	195.9	7,338.1*	8,888.8*
Hwang and Joo (2017)	Grass-fed	Hanwoo	Sirloin	5.94 (% crude fat)	24.5*	188.8*	NR	2,380.5*	2,669.9*
	Grain-fed	Hanwoo	Sirloin	25.39 (% crude fat)	139.5*	1,023.3*	NR	11,772.8*	13,282.2*
	Grass-fed	Australian beef	Sirloin	5.15 (% crude fat)	20.3*	167.0*	NR	1,891.2*	2,136.0*
	Grain-fed	American beef	Sirloin	10.22 (% crude fat)	46.8*	413.8*	NR	4,133.1*	4,712.6*
Turner et al. (2015)	Grass-fed	NR	Ribeye	38.26 (mg/g muscle)	16.8	93.9	67.6*	1,153.0*	1,474.4*
	Grain-fed	NR	Ribeye	84.90 (mg/g muscle)	40.4	232.5	74.7*	2,838.5*	3,599.9*
Duckett et al. (2013)	Grass-fed	Angus	Ribeye, strip	2.6 (% total fat)	10.0	63.8	83.1	785.5	1,064.6
	Grain-fed	Angus	Ribeye, strip	6.7 (% total fat)	41.7	226.7	9.3	2,591.2	2,859.6
Aldai et al. (2011)	Grass-fed	Asturian valley cattle	Ribeye/ L. thoracis	NR	0.063 (%)*	0.804 (%)*	2.41 (%)	18.85 (%)	156.4
	Grain-fed	Asturian valley cattle	Ribeye/ L. thoracis	NR	1.171 (%)*	1.546 (%)*	1.841 (%)	23.17 (%)	355.9
Alfaia et al. (2009)	Grass-fed	Alentejano purebred	Sirloin/ L. lumborum	9.76 (mg/g muscle)	0.9*	10.5*	12.1	183.2*	220.7*
	Grain-fed	Alentejano purebred	Sirloin/ L. lumborum	13.03 (mg/g muscle)	3.1*	26.5*	11.0	341.8*	417.6*
Ponnampalam et al. (2006)	Grass-fed	Angus	Sirloin/ L. lumborum	2.12 (% of muscle)	NR	NR	NR	836.0*	930.0*
	Grain-fed	Angus	Sirloin/ L. lumborum	3.61 (% of muscle)	NR	NR	NR	1,582.0*	1,729.0*
Realini et al. (2004)	Grass-fed	Hereford	Ground beef	11.43a (% total fat)	45.0*	246.0*	NR	3,707.4*	3,998.4*
	Grain-fed	Angus-Hereford	Ground beef	24.57b (% total fat)	189.1*	695.4*	NR	9,358.0*	10,242.5*

Between grass-fed and grain-fed beef studies followed by asterisk (*) indicates significant difference (at least $p < 0.05$); NR, not reported; C14:1, myristoleic acid; C16:1, palmitoleic acid; C18:1 t11, trans vaccenic acid; C18:1 n-9, oleic acid; MUFA, monounsaturated fatty acid

linolenic (C18:3), eicosapentanoic (C20:5, EPA), docosapentanoic (C22:5, DPA), and docosahexanoic (C22:6, DHA) acids. The PUFA in beef particularly in the IMF ranged from 4% to 5% of the total fatty acids (Scollan, 2003; Scollan et al., 2006). In this review (excluding the 2004 and 2006 studies), the total estimated PUFA concentration in grass-fed beef is 151 mg/100 g meat which is lower than in the total PUFA content of grain-fed beef due to its lower total fat content as influenced by grass-feeding. As presented in Table 3, the primary fatty acid among the individual PUFA in grass-fed and grain-fed beef is the n-6 fatty acid linoleic acid (LA), one of the two essential fatty acids in human nutrition. Seven out of the eight studies collected in

Table 3. Comparison of mean unsaturated fatty acid composition expressed as mg/100 g of meat between grass-fed and grain-fed beef

Author (publication year)	Feeding system	Breed	Beef cut/muscle location	Fat content	Polyunsaturated fatty acid (mg/100 g meat)									
					C18:2 n-6	C18:3 n-3	C20:4 n-6	C20:5 n-3	C22:5 n-3	C22:6 n-3	Total PUFA	Total n-6	Total n-3	n-6/n-3 ratio
Najar-Villarreal et al. (2019)	Grass-fed	NR	Ground beef	15.7 (% crude fat)	372.5*	40.3	50.3*	5.8*	17.3*	1.7*	621.3	451.6*	66.2*	1,127.5*
	Grain-fed	Angus	Ground beef	19.8 (% crude fat)	551.4*	38.1	43.5*	1.8*	12.7*	9.1*	814.3	623.9*	58.0*	1,976.9*
Hwang and Joo (2017)	Grass-fed	Hanwoo	Sirloin	5.94 (% crude fat)	105.0*	52.8*	9.2	6.5*	NR	4.4*	201.3*	134.9*	66.4*	110.5
	Grain-fed	Hanwoo	Sirloin	25.39 (% crude fat)	523.3*	39.5*	48.8	11.6*	NR	7.0*	748.9*	686.1*	62.8*	2,542.0
	Grass-fed	Australian beef	Sirloin	5.15 (% crude fat)	79.7*	42.9*	10.4	3.3*	NR	3.8*	166.1*	113.7*	52.4*	102.4
	Grain-fed	American beef	Sirloin	10.22 (% crude fat)	194.7*	44.0*	20.6	1.9*	NR	4.7*	316.4*	264.0*	52.4*	471.8
Turner et al. (2015)	Grass-fed	NR	Ribeye	38.26 (mg/g muscle)	113.9	37.5*	37.5*	11.6*	23.8*	2.1*	243.9*	168.6	75.3*	86.2*
	Grain-fed	NR	Ribeye	84.90 (mg/g muscle)	203.8	19.4*	49.0*	4.7*	15.6*	1.6*	324.3*	283.1	41.2*	695.2*
Duckett et al. (2013)	Grass-fed	Angus	Ribeye, strip	2.6 (% total fat)	61.2	28.1	20.7	12.9	20.0	20.7	147.7	81.9	63.1	31.0
	Grain-fed	Angus	Ribeye, strip	6.7 (% total fat)	166.3	14.9	32.4	5.6	13.1	1.9	236.7	198.1	34.9	374.4
Aldai et al. (2011)	Grass-fed	Asturian valley cattle	Ribeye/L. thoracis	NR	14.6 (%)	3.5 (%)*	3.2 (%)	1.0 (%)	1.3 (%)	0.1 (%)	130.5	99.2	31.2*	3.3*
	Grain-fed	Asturian valley cattle	Ribeye/L. thoracis	NR	11.3 (%)	1.3 (%)*	2.3 (%)	0.7 (%)	0.9 (%)	0.1 (%)	158.1	130.6	27.5*	4.9*
Alfaia et al. (2009)	Grass-fed	Alentejano purebred	Sirloin/L. lumborum	9.76 (mg/g muscle)	112.2	49.4*	36.1*	19.0*	22.9*	1.8*	259.2*	160.7*	93.1*	15.8*
	Grain-fed	Alentejano purebred	Sirloin/L. lumborum	13.03 (mg/g muscle)	142.6	5.7*	45.4*	5.6*	10.9*	1.3*	227.5*	203.9*	23.5*	107.3*
Ponnampalam et al. (2006)	Grass-fed	Angus	Sirloin/L. lumborum	2.12 (% of muscle)	108.8*	32.4*	NR	24.5*	36.5*	4.2	NR	191.6*	97.6*	2.0
	Grain-fed	Angus	Sirloin/L. lumborum	3.61 (% of muscle)	167.4*	14.9*	NR	13.1*	31.6*	3.7	NR	253.8*	63.3*	3.6
Realini et al. (2004)	Grass-fed	Hereford	Ground beef	11.43a (% total fat)	185.3*	64.9*	8.4*	NR	NR	NR	4.4*	NR	NR	NR
	Grain-fed	Angus-Hereford	Ground beef	24.57b (% total fat)	335.3*	40.5*	24.8*	NR	NR	NR	2.6*	NR	NR	NR

Between grass-fed and grain-fed beef studies followed by asterisk (*) indicates significant difference (at least $p < 0.05$); NR, not reported; C18:2n-6, linoleic acid; C18:3n-3, linolenic acid; C20:4n-6, arachidonic acid; C20:5n-3, eicosapentanoic acid; C22:5n-3, docosapentanoic acid; C22:6n-3, docosahexanoic acid; n-6, omega-6 fatty acids; n-3, omega-3 fatty acids; PUFA, polyunsaturated fatty acids.

this review reported that grain-fed beef contained higher LA (285 mg/100 g meat) than grass-fed beef (142 mg/100 g meat). The total n-6 PUFA concentration in grain-fed beef was also found 155 mg/100 g meat higher than grass-fed beef. High n-6 PUFA promotes the production of eicosanoids such as prostaglandins, thromboxane, leukotrienes generated from the arachidonic acid (AA) at the expense of EPA (Simopoulos, 1991), and the increase of these eicosanoids could result in allergic and inflammatory responses (Simopoulos, 2008). These potentially harmful effects of n-6 PUFA on human health remains unsettled (Calder et al., 2010). The α -linolenic acid (ALA), an n-3 PUFA and also one of the two essential fatty acids, was found 16.40 mg per 100 g higher in grass-fed beef compared to grain-fed beef. In Hanwoo beef, grain-fed contained 418 mg per 100 g higher LA than in grass-fed, while ALA was 13 mg per 100 g lower in grain-fed than in grass-fed beef. Other n-3 PUFA such as EPA, DPA, and DHA were found higher in grass-fed in various breeds and beef cuts. Consequentially, total n-3 PUFA concentration was found elevated in grass-feeding. It has been reported that low intake of n-3 PUFA contributes to the risk factors for disease and disability identified according to The Global Burden of Disease Study (Lim et al., 2012). Globally, the recommended dietary intake of n-3 PUFA is at least 250 mg EPA+DHA per day (European Food Safety Authority, 2010; U.S. Department of Agriculture and U.S. Department of Health and Human Services, 2010). In this review, the EPA concentration in grass-fed beef is estimated on average of 11.94 mg and 6.33 mg per 100 g meat on grain-fed beef (Table 4). The concentration of DHA, on the other hand, is at 5.53 mg and 4.19 mg per 100 g meat in grass-fed and grain-fed beef, respectively (Table 4). The most common and abundant n-3 PUFA in beef is DPA averaging 24.10 mg/100 g grass-fed beef and 16.76 mg/100 g grain-fed beef (Table 4). Although reports on the beneficial health effect of DPA are scarce and limited, DPA is readily converted to EPA and DHA (Miller et al., 2013). The long-chain n-3 fatty acids are higher in grass-fed beef than grain-fed beef but in Hanwoo beef, grain-fed showed 5.1 mg/100 g meat higher EPA and 2.6 mg/100 g meat DHA compared to grass-fed beef (Table 3). Only traces of n-3 PUFA concentrations are synthesized in beef due to the rumen biohydrogenation of PUFA. Microbes use rumen biohydrogenation as a coping mechanism to continue normal rumen function, where the PUFA present in the dietary lipids are converted to less toxic fatty acids (Jenkins et al., 2008; Scollan et al., 2006). The significance of the PUFA on human health and nutrition is clearly shown by the individual concentration of the n-6 and n-3 fatty acids, but the interference of the two with the metabolism of the other could reduce the deposition of the specific n-6 and n-3 PUFA in the tissue lipids and thus, may alter the overall biological effects (Ruxton et al., 2004). Hence, it is important to describe the PUFA composition through one of the two important nutritional indices, the ratio of the n-6 to n-3 PUFA which is usually expressed as the ratio of the two essential fatty acids LA and ALA or could be expressed as the ratio of the total n-6 to total n-3 (Scollan, 2003). Studies collected for this review consistently reported an increased concentration of n-3 PUFA in grass-fed beef compared to grain-fed beef showing that grass-feeding contained a more favorable n-6 to n-3 ratio. As evidenced, grass-fed beef contained lower n-6 to n-3 ratio compared to grain-fed beef. Studies have previously reported that cattle primarily fed with grass significantly elevated n-3 content in beef and produced desirable ratio of n-6 to n-3 (Duckett et al., 1993; French et al., 2000; Wood and Enser, 1997; Yehuda et al., 1996). The low ratio of n-6 to n-3 PUFA promotes suppressive effects from CVD and arthritis to cancer (Simopoulos, 2006) and ameliorate atherogenesis (Lawrence, 2013).

Regulation of Fatty Acid Composition according to Grass- and Grain-Feeding System

Modifying the amount of fat in beef and the composition of the fatty acid can be primarily affected by the feeding strategy and diet of beef cattle. Grain-feeding of beef cattle leads to fatter carcasses and greater deposition of IMF into meat tissue.

Table 4. Summary and a simple average and SD of the observations of the fatty acids expressed as mg/100 g of meat found in grass-fed and grain-fed beef regardless of the muscle location and cattle breed

Fatty Acids	Grass-fed beef			Grain-fed beef		
	Observations	Average	SD	Observations	Average	SD
C12:0	3	6.20	4.60	3	11.67	6.14
C14:0	8	139.04	149.38	8	333.03	264.66
C16:0	8	1,275.36	1,211.35	8	2,976.21	2,187.36
C18:0	8	745.06	709.25	8	1,499.99	1,069.67
C20:0	4	97.58	183.30	4	147.63	269.35
Total SFA	8	2,259.44	2,141.55	8	5,032.61	3,655.39
C14:1	7	40.41	56.78	7	91.19	75.46
C16:1	7	205.94	220.31	7	501.50	375.01
C18:1 t11	4	85.90	74.96	4	72.07	107.25
C18:1 n-9	7	2,310.57	1,941.40	7	5,481.93	4,115.59
Total MUFA	7	2,714.36	2,406.98	7	6,286.17	4,605.15
C18:2 n-6	8	142.33	99.69	8	285.60	166.14
C18:3 n-3	8	43.54	11.87	8	27.13	14.90
C20:4 n-6	7	24.66	16.71	7	37.79	11.77
C20:5 n-3	7	11.94	7.64	7	6.33	4.42
C22:5 n-3	7	24.10	7.39	7	16.78	8.45
C22:6 n-3	7	5.53	6.79	7	4.19	2.97
Total PUFA	6	252.86	169.35	6	403.74	264.87
Total n-6	8	175.28	117.60	8	330.44	206.54
Total n-3	8	68.16	21.34	8	45.45	15.85
n-6/n-3 ratio	8	184.84	383.46	8	772.01	960.62

C12:0, lauric acid; C14:0, myristic acid; C16:0, palmitic acid; C18:0, stearic acid; C20:0, arachidic acid; SFA, saturated fatty acid; C14:1, myristoleic acid; C16:1, palmitoleic acid; C18:1 t11, trans vaccenic acid; C18:1 n-9, oleic acid; MUFA, monounsaturated fatty acid; C18:2n-6, linoleic acid; C18:3n-3, linolenic acid; C20:4n-6, arachidonic acid; C20:5n-3, eicosapentanoic acid; C22:5n-3, docosapentanoic acid; C22:6n-3, docosahexanoic acid; n-6, omega-6 fatty acids; n-3, omega-3 fatty acids; PUFA, polyunsaturated fatty acids.

Grass-feeding of beef cattle, on the other hand, leads to leaner carcasses and lower deposition of IMF into meat tissue. Some of the mechanisms on how grass-feeding and grain feeding were reported. Grain-feeding may contribute to an increase in MUFA in response to alteration in the ruminal environment. Grain-feeding lowers the rumen pH sufficient enough to decrease protozoal populations that have high levels of TVA and palmitic acid (Devillard et al., 2006; Or-Rashid et al., 2007). Grain-feeding also depresses the isomerization of LA to cis-9, trans-11 CLA, and hydrogenation of cis-9, trans-11 CLA to TVA, and to stearic acid, which is reflected in tissue fatty acid composition (Chung et al., 2007). Meanwhile, grass-feeding could increase the duodenal flow of stearic and α -linolenic acids, and decrease the duodenal flow of oleic and LAs (Kucuk et al., 2001). Grass-feeding may also depress SCD activity by increased absorption of the α -linolenic acid (Waters et al., 2009). Efforts to alter and establish the fatty acid profile of beef that would be beneficial to human health have been made but, the complexity of the fatty acid in beef fat stems from the rumen biohydrogenation of the dietary lipids of the beef cattle. Continued research is necessary to successfully establish the feeding strategy that would practically reach the required levels

of fatty acids beneficial to human health. In South Korea, the current grain-feeding system proved to increase intramuscular lipid and MUFAs in the adipose tissue of the beef cattle. Due to increasing demands of consumers for beef with healthy beef in regards with fatty acids, beef producers may opt to consider grass-feeding system which tends to produce lower fat content for consumers preferring to reduce overall fat consumption. This move, however, could sacrifice the marbling competitiveness of Hanwoo. Hence, beef producers and animal scientists should emphasize to beef consumers in South Korea the awareness that greater portions of grain-fed beef could also achieve similar dietary intake of long-chain omega-3 fatty acids. It also worthy to be noted that grain-fed Hanwoo was reported to contained higher EPA (11.6 mg/100 g meat) and DHA (7.6 mg/100 g meat) than grass-fed (Table 3) although more studies should be conducted to establish this finding.

On-going Debate on Grass-Fed and Grain-Fed Beef

Attention had been geared towards the feeding system of beef cattle with the uprising concern on animal health and well-being, environmental impact of livestock production, and health-related concerns of beef fat consumption (Table 5). Aside from the nutrition and health standpoint of grass-fed beef, discussion on shifting to grass-fed beef or grain-fed beef has also covered the environmental impact, the welfare of the animal, and the price and sensory quality of the beef. Cattle are naturally designed to consume a diet that is based on grass that is not edible to humans but to secure the increasing need for meat protein of humans, cattle are finished on grain-based diets. Grass-fed cattle eat from pasture and grassland and should not be finished on grains and supplements (USDA-AMS, 2009), while grain-fed cattle eats on pasture for the first 6 months and finishes at feedlots that are sometimes supplemented with growth hormones and antibiotics (Chung et al., 2018). Due to the lesser efficiency of feed conversion ratios of grass, grass-fed cattle reach the market weight slower than cattle fed on

Table 5. Major differences between grass-fed and grain-fed beef

	Grass-fed beef	Grain-fed beef
Feeding method or production system	Cattle eat from pasture and are not finished on grains and supplements (USDA-AMS, 2009)	Cattle graze on pasture for the first 6 months to a year and finishes at a feedlot of a concentrated mix of corn, soy, grains, and other supplements like hormones and antibiotics (Chung et al., 2018; Drouillard, 2018; MFAFF, 2007)
Growth period	Reach the market weight slower than cattle fed on grain due to lesser efficiency of feed conversion ratios of grass (Pethick et al., 2001)	Grows to target slaughter weight a year faster than grass-fed beef cattle (Chung et al., 2018; Drouillard, 2018; MFAFF, 2007)
Environment impact	Grass-feeding could increase nitrogen oxidation from manure and leguminous forages (Hayek and Garrett, 2018)	Requires significantly less land and produces less methane per unit of meat produced (Nijdam et al., 2012; Poore and Nemecek, 2018)
Animal welfare	Beef cattle are primarily provided with grass and forages that are not supplemented with growth hormones and are raised in their natural environment (USDA-AMS, 2009)	Require the use of frequent antibiotic and growth hormone, located in areas that are prone to heat exhaustion, do not allow the beef cattle to perform natural activities such as grazing or pasturing in rangeland or open pasture (Grandin, 2016)
Price	Prices for grass-fed beef are 47% greater by weight than conventional beef or cattle finished on grain diets (Hayek and Garrett, 2018)	Less expensive than grass-fed beef due to larger scale of production (Hayek and Garrett, 2018)
Sensory	Steaks from grass-fed cattle are less tender (Sitz et al., 2005); lack beef flavor, and presents off-flavor than grain-fed beef (Duckett et al., 2013)	Similar juiciness between grass-fed and grain-fed beef (Duckett et al., 2013)

grains (Pethick et al., 2001). Aside from the higher feed efficiency of grain, cattle fed in grain grow to target market weight faster than grass-fed due to the use of growth hormones and the lesser locomotion activities. The cattle in the grain-feeding system are normally contained in areas where they are limited to move and are sometimes prone to heat exhaustion (Grandin, 2016), which sacrifices the welfare and the well-being of the animals. While grass-feeding permits the beef cattle to conduct their activities naturally, there are environmental impacts that are contributed negatively. Grass-feeding could increase the nitrogen oxidation from manure and leguminous forages (Hayek and Garrett, 2018), and increase methane conversion rates due to their slower growth rates. Grain-feeding system requires significantly lesser land and produces lesser methane per unit of meat (Nijdam et al., 2012; Poore and Nemecek, 2018). The environmental impact of grass-feeding also remains debatable as grain-feeding has been shown to leave a lower carbon footprint than grass-feeding (Capper, 2012). In terms of price, grass-fed beef is more expensive because of its smaller production. Compared to grain-fed beef, prices for grass-feed beef are 47% greater by weight (Hayek and Garrett, 2018). In grass-fed beef producers, shortage of processors, limited clear marketing system, pasture management problems, and the longer period of time needed to raise the cattle are some of the important challenges. Finally, the sensory of grass-fed and grain-fed beef is under continuous arguments. Grain-fed beef consumers maintain the argument on the marbling and overall sensory and palatability satisfaction of the cattle fed with grain. Studies have reported that steaks from grass-feeding have less tender meat (Sitz et al., 2005), lack the flavor of beef, present an off-flavor, and have significantly increased yellowness of external fat than cattle fed in grains (Duckett et al., 2013). The comparison of grass-fed and grain-fed beef largely varies depending on the needs of consumers and the objectives of the beef producers.

Conclusion

The results of this review revealed that beef cattle fed on a grass-feeding diet contained less total fat than the beef from the cattle fed on grain-feeding. The reduction of the total fat content had notably influenced the fatty acid composition of beef for human consumption. A 100 g beef meat from grass-fed cattle contained 2,773 mg less total SFA than from the same 100 g beef meat from grain-fed beef. Grass-fed beef also showed a more favorable SFA lipid profile containing less cholesterol-raising fatty acids (C12:0 to C16:0) but also contained a lesser amount of cholesterol-lowering C18:0 fatty acid in comparison to grain-fed beef. In terms of fatty acids that are essential to human health, grass-fed beef showed higher TVA, total omega-3, and long-chain n-3 PUFA than grain-fed beef. Increased long-chain n-3 PUFA in grass-fed beef are EPA, DPA, and DHA. In Hanwoo, grain-fed showed higher EPA and DHA than grass-fed beef. The increased n-3 PUFA in grass-fed beef also reduced the n-6 to n-3 ratio as compared to grain-fed beef. The net effect of grass-feeding increased the n-3 PUFA but decreased MUFA due to the decreased total fat content. Grass-fed beef increased functional lipid components (omega-3 PUFA) while decreasing undesirable SFA in comparison to grain-fed beef, and thus could exert protective effects against several diseases ranging from cancer to CVD. Although grain-fed beef showed decreased long-chain n-3 PUFA, consumers should be aware that greater portions of grain-fed beef could also achieve a similar dietary intake of long-chain omega-3 FAs. Noteworthy, grain-fed beef contained higher total MUFA that have beneficial roles in ameliorating CVD risks than grass-fed beef.

Conflicts of Interest

The authors declare no potential conflicts of interest.

Acknowledgements

This research was funded by National Research Foundation in Korea (grant number NRF-2018R1D1A3B07048219) and the Technology Innovation Program (20012411, Alchemist Project) funded by the Ministry of Trade, Industry and Energy (MOTIE).

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Ethics Approval

This article does not require IRB/IACUC approval because there are no human and animal participants.

References

- Aldai N, Dugan MER, Kramer JKG, Martínez A, López-Campos O, Mantecón AR, Osoro K. 2011. Length of concentrate finishing affects the fatty acid composition of grass-fed and genetically lean beef: An emphasis on trans-18:1 and conjugated linoleic acid profiles. *Animal* 5:1643-1652.
- Alfaia CPM, Alves SP, Martins SIV, Costa ASH, Fontes CMGA, Lemos JPC, Bessa RJB, Prates JAM. 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 Chem* 114:939-946.
- Briggs MA, Petersen KS, Kris-Etherton PM. 2017. Saturated fatty acids and cardiovascular disease: Replacements for saturated fat to reduce cardiovascular risk. *Healthcare* 5:29.
- Calder PC, Dangour AD, Diekman C, Eilander A, Koletzko B, Meijer GW, Mozaffarian D, Niinikoski H, Osendarp SJM, Pietinen P, Schuit J, Uauy R. 2010. Essential fats for future health. Proceedings of the 9th Unilever Nutrition Symposium, 26–27 May 2010. *Eur J Clin Nutr* 64:S1-S13.
- Capper JL. 2012. Is the grass always greener? Comparing the environmental impact of conventional, natural and grass-fed beef production systems. *Animals* 2:127-143.
- Chowdhury R, Warnakula S, Kunutsor S, Crowe F, Ward HA, Johnson L, Franco OH, Butterworth AS, Forouhi NG, Thompson SG, Khaw KT, Mozaffarian D, Danesh J, Di Angelantonio E. 2014. Association of dietary, circulating, and supplement fatty acids with coronary risk: A systematic review and meta-analysis. *Ann Intern Med* 160:398-406.
- Chung KY, Chang SS, Lee EM, Kim HJ, Park BH, Kwon EG. 2015. Effects of high energy diet on growth performance, carcass characteristics, and blood constituents of final fattening Hanwoo steers. *Korean J Agric Sci* 42:261-268.
- Chung KY, Lee SH, Cho SH, Kwon EG, Lee JH. 2018. Current situation and future prospects for beef production in South Korea: A review. *Asian-Australas J Anim Sci* 31:951-960.
- Chung KY, Lunt DK, Kawachi H, Yano H, Smith SB. 2007. Lipogenesis and stearoyl-CoA desaturase gene expression and enzyme activity in adipose tissue of short- and long-fed Angus and Wagyu steers fed corn- or hay-based diets. *J Anim Sci*

85:380-387.

- Daley CA, Abbott A, Doyle PS, Nader GA, Larson S. 2010. A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutr J* 9:10
- Devillard E, McIntosh FM, Newbold CJ, Wallace RJ. 2006. Rumen ciliate protozoa contain high concentrations of conjugated linoleic acids and vaccenic acid, yet do not hydrogenate linoleic acid or desaturate stearic acid. *Br J Nutr* 96:697-704.
- Dilzer A, Park Y. 2012. Implication of conjugated linoleic acid (CLA) in human health. *Crit Rev Food Sci Nutr* 52:488-513.
- Drouillard JS. 2018. Current situation and future trends for beef production in the United States of America: A review. *Asian-Australas J Anim Sci* 31:1007-1016.
- Duckett SK, Neel JPS, Fontenot JP, Clapham WM. 2009a. Effects of winter stocker growth rate and finishing system on: III. Tissue proximate, fatty acid, vitamin, and cholesterol content. *J Anim Sci* 87:2961-2970.
- Duckett SK, Neel JPS, Lewis RM, Fontenot JP, Clapham WM. 2013. Effects of forage species or concentrate finishing on animal performance, carcass and meat quality. *J Anim Sci* 91:1454-1467.
- Duckett SK, Neel JPS, Sonon RN Jr, Fontenot JP, Clapham WM, Scaglia G. 2007. Effects of winter stocker growth rate and finishing system on: II. Ninth–tenth–eleventh-rib composition, muscle color, and palatability. *J Anim Sci* 85:2691-2698.
- Duckett SK, Pratt SL, Pavan E. 2009b. Corn oil or corn grain supplementation to steers grazing endophyte-free tall fescue. II. Effects on subcutaneous fatty acid content and lipogenic gene expression. *J Anim Sci* 87:1120-1128.
- Duckett SK, Wagner DG, Yates LD, Dolezal HG, May SG. 1993. Effects of time on feed on beef nutrient composition. *J Anim Sci* 71:2079-2088.
- European Food Safety Authority. 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 J* 8:1461.
- French P, Stanton C, Lawless F, O’Riordan EG, Monahan FJ, Caffrey PJ, Moloney AP. 2000. Fatty acid composition, including conjugated linoleic acid, of intramuscular fat from steers offered grazed grass, grass silage, or concentrate-based diets. *J Anim Sci* 78:2849-2855.
- Fukuda S, Suzuki Y, Murai M, Asanuma N, Hino T. 2006. Augmentation of vaccenate production and suppression of vaccenate biohydrogenation in cultures of mixed ruminal microbes. *J Dairy Sci* 89:1043-1051.
- Garcia PT, Pensel NA, Sancho AM, Latimori NJ, Kloster AM, Amigone MA, Casal JJ. 2008. Beef lipids in relation to animal breed and nutrition in Argentina. *Meat Sci* 79:500-508.
- Grandin T. 2016. Evaluation of the welfare of cattle housed in outdoor feedlot pens. *Vet Anim Sci* 1-2:23-28.
- Greenwood PL, Gardner GE, Ferguson DM. 2018. Current situation and future prospects for the Australian beef industry: A review. *Asian-Australas J Anim Sci* 31:992-1006.
- Hammad S, Pu S, Jones PJ. 2016. Current evidence supporting the link between dietary fatty acids and cardiovascular disease. *Lipids* 51:507-517.
- Hayek MN, Garrett RD. 2018. Nationwide shift to grass-fed beef requires larger cattle population. *Environ Res Lett* 13:084005.
- Hilmia N, Noor RR, Sumantri C, Gurnadi RE, Priyanto R. 2017. Polymorphism of stearoyl-CoA desaturase (SCD1) gene in Indonesian local cattle. *J Indones Trop Anim Agric* 42:1-5.
- Hu FB, Stampfer MJ, Manson JE, Ascherio A, Colditz GA, Speizer FE, Hennekens CH, Willett WC. 1999. Dietary saturated fats and their food sources in relation to the risk of coronary heart disease in women. *Am J Clin Nutr* 70:1001-1008.

- Hunter JE, Zhang J, Kris-Etherton PM. 2010. Cardiovascular disease risk of dietary stearic acid compared with trans, other saturated, and unsaturated fatty acids: A systematic review. *Am J Clin Nutr* 91:46-63.
- Hwang YH, Joo ST. 2016. Fatty acid profiles of ten muscles from high and low marbled (quality grade 1++ and 2) Hanwoo steers. *Korean J Food Sci Anim Resour* 36:679-688.
- Hwang YH, Joo ST. 2017. Fatty acid profiles, meat quality, and sensory palatability of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle. *Korean J Food Sci Anim Resour* 37:153-161.
- Jenkins TC, Wallace RJ, Moate PJ, Mosley EE. 2008. Board-invited review: Recent advances in biohydrogenation of unsaturated fatty acids within the rumen microbial ecosystem. *J Anim Sci* 86:397-412.
- Jo C, Cho SH, Chang J, Nam KC. 2012. Keys to production and processing of Hanwoo beef: A perspective of tradition and science. *Anim Front* 2:32-38.
- John Wallace R, Chaudhary LC, McKain N, McEwan NR, Richardson AJ, Vercoe PE, Walker ND, Paillard D. 2006. *Clostridium proteoclasticum*: A ruminal bacterium that forms stearic acid from linoleic acid. *FEMS Microbiol Lett* 265:195-201.
- Kien CL, Bunn JY, Stevens R, Bain J, Ikayeva O, Crain K, Koves TR, Muoio DM. 2014. Dietary intake of palmitate and oleate has broad impact on systemic and tissue lipid profiles in humans. *Am J Clin Nutr* 99:436-445.
- Kris-Etherton PM. 1999. Monounsaturated fatty acids and risk of cardiovascular disease. *Circulation* 100:1253-1258.
- Krishnan S, Cooper JA. 2014. Effect of dietary fatty acid composition on substrate utilization and body weight maintenance in humans. *Eur J Nutr* 53:691-710.
- Kucuk O, Hess BW, Ludden PA, Rule DC. 2001. Effect of forage: Concentrate ratio on ruminal digestion and duodenal flow of fatty acids in ewes. *J Anim Sci* 79:2233-2240.
- Lawrence GD. 2013. Dietary fats and health: Dietary recommendations in the context of scientific evidence. *Adv Nutr* 4:294-302.
- Leheska JM, Thompson LD, Howe JC, Hentges E, Boyce J, Brooks JC, Shriver B, Hoover L, Miller MF. 2008. Effects of conventional and grass-feeding systems on the nutrient composition of beef. *J Anim Sci* 86:3575-3585.
- Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. 2012. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: A systematic analysis for the Global Burden of Disease study 2010. *Lancet* 380:2224-2260.
- Listrat A, Gagaoua M, Andueza D, Gruffat D, Normand J, Mairessec G, Picard B, Hocquetta JF. 2020. What are the drivers of beef sensory quality using metadata of intramuscular connective tissue, fatty acids and muscle fiber characteristics? *Livest Sci* 240:104209.
- Mensink RP. 2005. Effects of stearic acid on plasma lipid and lipoproteins in humans. *Lipids* 40:1201-1205.
- Mensink RP, World Health Organization. 2016. Effects of saturated fatty acids on serum lipids and lipoproteins: A systematic review and regression analysis. World Health Organization, Geneva, Switzerland.
- Mensink RP, Zock PL, Kester ADM, Katan MB. 2003. Effects of dietary fatty acids and carbohydrates on the ratio of serum total to HDL cholesterol and on serum lipids and apolipoproteins: A meta-analysis of 60 controlled trials. *Am J Clin Nutr* 77:1146-1155.
- Mente A, de Koning L, Shannon HS, Anand SS. 2009. A systematic review of the evidence supporting a causal link between dietary factors and coronary heart disease. *Arch Intern Med* 169:659-669.
- Micha R, Mozaffarian D. 2010. Saturated fat and cardiometabolic risk factors, coronary heart disease, stroke, and diabetes: A

- fresh look at the evidence. *Lipids* 45:893-905.
- Miller E, Kaur G, Larsen A, Loh SP, Linderborg K, Weisinger HS, Turchini GM, Cameron-Smith D, Sinclair AJ. 2013. A short-term *n*-3 DPA supplementation study in humans. *Eur J Nutr* 52:895-904.
- Ministry for Food, Agriculture, Forestry, and Fisheries [MFAFF]. 2007. Processing standard for meat products act, grading, fabrication and cutting of beef carcass. Ministry for Food, Agriculture, Forest and Fisheries, Seoul, Korea. p 82.
- Najar-Villarreal F, Boyle EAE, Danler RD, O'Quinn TG, Houser TA, Gonzalez JM. 2019. Fatty acid composition, proximate analysis, and consumer sensory evaluation of United States retail grass-fed ground beef. *Meat Muscle Biol* 3:389-398.
- Neel JPS, Fontenot JP, Clapham WM, Duckett SK, Felton EED, Scaglia G, Bryan WB. 2007. Effects of winter stocker growth rate and finishing system on: I. Animal performance and carcass characteristics. *J Anim Sci* 85:2012-2018.
- Nijdam D, Rood T, Westhoek H. 2012. The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy* 37:760-770.
- Nuernberg K, Dannenberger D, Nuernberg G, Ender K, Voigt J, Scollan ND, Wood JD, Nute GR, Richardson RI. 2005. Effect of a 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* 94:137-147.
- Or-Rashid MM, Odongo NE, McBride BW. 2007. Fatty acid composition of ruminal bacteria and protozoa, with emphasis on conjugated linoleic acid, vaccenic acid, and odd-chain and branched-chain fatty acids. *J Anim Sci* 85:1228-1234.
- Pethick DW, Harper GS, Oddy VH. 2001. Growth, development and nutritional manipulation of marbling in cattle. *Aust J Exp Agric* 44:705-715.
- Pitchford WS, Deland MPB, Siebert BD, Malau-Aduli AEO, Bottema CDK. 2002. Genetic variation in fatness and fatty acid composition of crossbred cattle. *J Anim Sci* 80:2825-2832.
- Ponnampalam EN, Mann NJ, Sinclair AJ. 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 Pac J Clin Nutr* 15:21-29.
- Poore J, Nemecek T. 2018. Reducing food's environmental impacts through producers and consumers. *Science* 360:987-992.
- Realini CE, Duckett SK, Windham WR. 2004. Effect of vitamin C addition to ground beef from grass-fed or grain-fed sources on color and lipid stability, and prediction of fatty acid composition by near-infrared reflectance analysis. *Meat Sci* 68:35-43.
- Ruxton CHS, Reed SC, Simpson MJA, Millington KJ. 2004. The health benefits of omega-3 polyunsaturated fatty acids: A review of the evidence. *J Hum Nutr Diet* 17:449-459.
- Sampath H, Ntambi JM. 2005. The fate and intermediary metabolism of stearic acid. *Lipids* 40:1187-1191.
- Scollan N. 2003. Strategies for optimising the fatty acid composition of beef. *Iger Innov* 42-45.
- Scollan N, Hocquette JF, Nuernberg K, Dannenberger D, Richardson I, Moloney A. 2006. Innovations in beef production systems that enhance the nutritional and health value of beef lipids and their relationship with meat quality. *Meat Sci* 74:17-33.
- Simopoulos AP. 1991. Omega-3 fatty acids in health and disease and in growth and development. *Am J Clin Nutr* 54:438-463.
- Simopoulos AP. 2006. Evolutionary aspects of diet, the omega-6/omega-3 ratio and genetic variation: Nutritional implications for chronic diseases. *Biomed Pharmacother* 60:502-507.
- Simopoulos AP. 2008. The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. *Exp Biol Med* 233:674-688.

- Sitz BM, Calkins CR, Feuz DM, Umberger WJ, Eskridge KM. 2005. Consumer sensory acceptance and value of domestic, Canadian, and Australian grass-fed beef steaks. *J Anim Sci* 83:2863-2868.
- Skeaff CM, Miller J. 2009. Dietary fat and coronary heart disease: Summary of evidence from prospective cohort and randomised controlled trials. *Ann Nutr Metab* 55:173-201.
- Turner TD, Jensen J, Pilfold JL, Prema D, Donkor KK, Cinel B, Thompson DJ, Dugan MER, Church JS 2015. Comparison of fatty acids in beef tissues from conventional, organic and natural feeding systems in western Canada. *Can J Anim Sci* 95:49-58.
- United States Department of Agriculture AMS [USDA-AMS]. 2007. United States standards for livestock and meat marketing claims, grass (forage) fed claim for ruminant livestock and the meat products derived from such livestock. *Fed Regist* 72:58631-58637.
- United States Department of Agriculture AMS [USDA-AMS]. 2009. United States standards for livestock and meat marketing claims, naturally raised claim for livestock and the meat and meat products derived from such livestock. *Fed Regist* 74:3541-3545.
- U.S. Department of Agriculture, U.S. Department of Health and Human Services. 2010. Dietary guidelines for Americans, 2010. 7th ed. U.S. Government Printing Office, Washington, DC, USA.
- Van Elswyk ME, McNeill SH. 2014. Impact of grass/forage feeding versus grain finishing on beef nutrients and sensory quality: The U.S. experience. *Meat Sci* 96:535-540.
- Waters SM, Kelly JP, O'Boyle P, Moloney AP, Kenny DA. 2009. Effect of level and duration of dietary *n*-3 polyunsaturated fatty acid supplementation on the transcriptional regulation of Δ^9 -desaturase in muscle of beef cattle. *J Anim Sci* 87:244-252.
- Williamson CS, Foster RK, Stanner SA, Buttriss JL. 2005. Red meat in the diet. *Nutr Bull* 30:323-355.
- Wood JD, Enser M. 1997. Factors influencing fatty acids in meat and the role of antioxidants in improving meat quality. *Br J Nutr* 78:S49-S60.
- Yehuda S, Rabinovitz S, Carasso RL, Mostofsky DI. 1996. Essential fatty acids preparation (Sr-3) improves Alzheimer's patients quality of life. *Int J Neurosci* 87:141-149.
- Yu S, Derr J, Etherton TD, Kris-Etherton PM. 1995. Plasma cholesterol-predictive equations demonstrate that stearic acid is neutral and monounsaturated fatty acids are hypocholesterolemic. *Am J Clin Nutr* 61:1129-1139.
- Ziehl A, Thilmany DD, Umberger WJ. 2005. A cluster analysis of natural beef product consumers by shopping behavior, importance of production attributes, and demographics. *J Food Distrib Res* 36:209-217.
- Zong G, Li Y, Wanders AJ, Alsema M, Zock PL, Willett WC, Hu FB, Sun Q. 2016. Intake of individual saturated fatty acids and risk of coronary heart disease in US men and women: Two prospective longitudinal cohort studies. *BMJ* 355:i5796.