CHANGES IN DIETARY REGIME IMPACT FATTY ACID PROFILE OF BEEF

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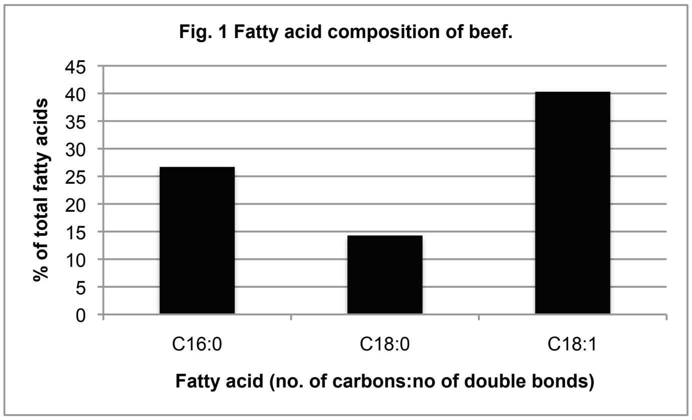
Introduction

Heart disease remains the leading cause of death in the US (CDC, 2011). In addition, over one-third of the US population is considered obese (CDC, 2012).



Obesity is a worldwide epidemic that increases the risk for developing insulin resistance and several chronic diseases such as diabetes, heart disease, stroke and non-alcoholic fatty liver disease. A dietary factor that contributes both to heart disease and obesity is dietary fat consumption. Of particular interest are the intake of saturated fatty acids (SFA), trans fatty acids (TFA), and total fat in the human diet. Concerns about dietary saturated fat content are related to consumption of diets high in specific SFA raise serum low-density lipoprotein (LDL) or bad cholesterol concentrations. The hypercholesterolemic or cholesterol-elevating SFA are: palmitic (C16:0) acid, myrisitic (C14:0) acid, and lauric (C12:0) acid (Mattson and Grundy, 1985; Grundy, 1986; Bonanome and Grundy, 1988; Mensink and Katan, 1989 & 1990; Denke and Grundy, 1992; Zock et al., 1994). In contrast, stearic (C18:0) acid, another SFA, does not raise serum cholesterol and is considered to be neutral (Bonanome and Grundy, 1988; Keys et al., 1965; Hegsted et al., 1965; Grande et al., 1970; Kris-Etherton et al., 1993). Estimates are that these three hypercholesterolemic fatty acids make up about two-thirds of the saturated fatty acids in the American diet and that dietary intake should be reduced to less than 7% of total energy (Grundy, 1997). The predominant fatty acids in beef longissimus muscle (LM) are: oleic (C18:1; 40%) acid, palmitic (C16:0; 27%) acid, and stearic (C18:0; 15%) acid (Fig. 1, Duckett et al., 1993). Consumption of beef does provide hypercholesterolemic fatty acids in the diet, namely palmitic acid, and therefore efforts to reduce its amount would be perceived as beneficial for human health.

Trans fatty acids are receiving attention lately and are even being banned from the menu in some U.S. cities. Trans fatty acids are produced during the hydrogenation of unsaturated vegetable oils (40-60% of total fatty acids as trans) and are found in margarines or processed products that list partially hydrogenated vegetable oil in the ingredient list. This process of hydrogenation increases shelf life of the oil by reducing polyunsaturated fatty acid levels. In this process, many short chain trans fatty acids are produced (trans bonds in 6-16 position) and consumption of these artificial trans fatty acids increases bad (LDL) cholesterol and decreases good (HDL) cholesterol. Results from the Nurses' Health Study found that women who consumed 4 teaspoons of margarine containing artificial trans fat had a 50% greater risk of heart disease than women who ate margarine only rarely (Willet et al., 1993). Mensink and Katan (1990) compared the effects of a trans or saturated fatty acid rich diet in humans and demonstrated that trans fats have a more negative effect on serum cholesterol levels than saturated fats. Clifton et al. (2004) reported high correlations (r = 0.66) between dietary trans fat intake from margarine and level of trans fat in adipose tissue, and that the level of trans fat in adipose tissue was associated with increased risk of coronary artery disease.

One strategy to limit SFA intake is to replace these fatty acids with dietary unsaturated fatty acids on an isocaloric basis. Certain unsaturated fatty acids are considered to be hypocholesterolemic or LDL-cholesterol lowering. These fatty acids include: monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). Mattson and Grundy (1985) showed that MUFA were as effective as PUFA in lowering LDL-cholesterol. Mensink and Katan (1987) compared high fat diets containing MUFA versus low fat diets. They found that high fat diets containing MUFA were as effective as low-fat diets in lowering LDL-cholesterol. Consumption of diets rich in monounsaturated fatty acids increases good, high-density lipoproteins (HDL) and lowers bad, LDL-cholester ol levels (Mensink and Katan, 1989; Wardlaw and Snook, 1990). Canola and olive oils contain predominately MUFA at levels of 58% and 72% of total fatty acids, respectively. Grundy (1997) recommend intakes of oleic acid, the predominant MUFA, at 16% of total energy.

Polyunsaturated fatty acids (PUFA) are subdivided into two categories, omega-6 and omega-3, based on location of the double bonds in the fatty acid chain. Omega-6 fatty acids are common in grains and vegetable oils. Omega-3 fatty acids are common in plant lipids and fish oils. Diets containing omega-6 or omega-3 fatty acids lower blood total and LDL-cholesterol; however, omega-6 PUFA also tend to lower HDL-cholesterol (Mensink and Katan, 1989). Consumption of diets high in omega-3 fatty acids is associated with reduced risk of heart disease, stroke and cancer (Kris-Etherton et al., 2002). Currently, Americans consume greater amounts of omega-6 PUFA than omega-3 PUFA, which has dramatically altered the omega-6 to omega-3 ratio in the human diet. Health professionals recommend that we consume a diet with a more balanced ratio (< 4:1) of omega-6 to omega-3 PUFA. The World Health Organization recommends a daily intake of 1.1 g/d of omega-3 fatty acids with approximately 0.8 g/d of linolenic acid and 0.3 g/d of EPA and DHA. McAfee et al. (2011) reported that consumption of grass-fed red meat products increases plasma and platelet n-3 PUFA status, which indicates that lower n-6:n-3 ratios typically observed in forage-finished beef can potentially impact human health.

The predominant fatty acids (70% or greater) in forages are PUFA; however, the predominant fatty acids in beef LM are MUFA and SFA due to the extensive biohydrogenation of PUFA to SFA by ruminal microbes (Duckett et al., 2002; Sackmann et al., 2003), and conversion of SFA to MUFA via adipose tissue desaturases (Duckett et al., 2009). Intermediates of ruminal biohydrogentation, trans-11 vaccenic acid (TVA) and conjugated linoleic acid (CLA), can be found in beef LM. However, the majority of CLA, cis-9 trans-11 isomer, in beef comes from desaturation of TVA to CLA in adipose tissues (Pavan and Duckett, 2007). Conjugated linoleic acid, cis-9 trans-11 isomer, has been shown to possess anticarcinogenic properties (Ha et al., 1987) that could be beneficial to human health. Recommendations are that we should consume about 300 mg of CLA, cis-9 trans-11 isomer, per day (Ip et al., 1994).

Dietary intake of specific fatty acids is important to human health. Health professionals recommend consuming a diet low in saturated and trans fatty acids. Limiting intake of animal fats is also typically recommended as a way to reduce total fat and saturated fat intake (AHA, 2014). Diet composition provided to the finishing animal can alter fatty acid composition of the LM to enhance healthfulness of beef products. This paper will review current research examining how finishing system alters fatty acid composition.

Grain vs. Grass Finishing Systems

Fatty acid composition as a percentage of total fatty acids of beef muscle from concentrate-finished versus pasture-finished beef is shown in Table 1. The results are from two experiments that evaluated finishing (final 150 d prior to slaughter) of Angus-cross steers (n = 326) on a high concentrate diet (82% concentrate:18% corn silage) versus pasture (mixed pastures consisting of bluegrass, orchardgrass, endophyte-free tall fescue and white clover; Duckett et al., 2009 & 2013). Steers were fed to an equal animal age endpoint in order to minimize confounding of treatments by animal age or environmental effects. The percentage of omega-6 PUFA did not differ between concentrate- and pasture-finished beef. Monounsaturated fatty acid percentage was greater for concentrate than grass-finished. Omega-3 PUFA percentage was greater for grass- than concentrate-finished. This resulted in a lower, more desirable for human health, ratio of omega-6 to omega-3 fatty acids in grass-finished beef (1.54) compared to concentrate-finished beef (5.01). The percentage of CLA, cis-9 trans-11 isomer, was greater for grass- than concentrate-finished. Trans-11 vaccenic acid percentage was also greater for grass- than concentrate-finished beef.

Fatty acid composition can be presented in two ways, 1) as a percentage of total fatty acids or 2) as the total amount per specific steak weight, estimated on a cooked basis (assume 25% cooking shrink). Table 1 showed the percentage of each fatty acid as part of the total fatty acid amounts. Table 2 shows the gravimetric content of total fatty acid types as amount per 18.7 oz. cooked serving. The American Heart Association recommends a 3-oz serving size of beef; however, most retail beef products available exceed this amount. Therefore, the estimates for fatty

Table 1. Fatty acid percentage of the longissimus muscle from steers finished on a high-concentrate diet or mixed pasture.

	CONCEN-TRATE	**PASTURE**
n	135	191
Total lipid content (TL), %	5.39^a	2.48^b
Total fatty acid content (TFA), %	4.56^a	2.25^b
Saturated fatty acids (SFA), %	43.23^b	44.48^a
C14:0, Myristic acid, %	2.76^a	2.46^b
C16:0, Palmitoleic acid, %	26.62^a	24.92^b
C18:0, Stearic acid, %	13.83^b	17.09^a
Monounsaturated fatty acids (MUFA), %	42.78^a	35.13^b
C14:1, Myristoleic acid, %	0.61^a	0.41^b
C16:1, Palmitoleic acid, %	3.49^a	2.71^b
C18:1, Oleic acid, %	39.68^a	32.02^b
Polyunsaturated fatty acids (PUFA), n-6, %	3.59	3.61
C18:2, Linoleic acid, %	2.89^a	2.67^b
C20:4, Arachidonic acid, %	0.70^b	0.94^a
Polyunsaturated fatty acids (PUFA), n-3, %	0.78^b	2.47^a
C18:3, Linolenic acid, %	0.36^b	1.13^a
C20:5, EPA, %	0.12^b	0.50^a
C22:5, DPA, %	0.26^b	0.76^a
C22:6, DHA, %	0.04^b	0.08^a
Ratio of n-6 to n-3 fatty acids	5.01^a	1.54^b
Trans-11 vaccenic acid (TVA), %	0.53^b	3.37^a
Conjugated linoleic acid (CLA), cis-9 trans-11, %	0.35^b	0.71^a

^{ab}Means in the same row with uncommon superscripts differ ($P < 0.05$).

acid content per ‘real-world’ serving is for 18.7-oz assuming that a 6.7-oz cooked hamburger (McDonalds Big Mac) and 12-oz ribeye steak (Longhorn’s Outlaw ribeye steak, 18 oz bone-in) were consumed per day. Based on these assumptions, beef from steers fed high- concentrate diet would provide about 47% more total fat and saturated fat content than beef from steers finished on pasture. Intake of MUFA would be 58% higher for beef from steers fed a high-concentrate diet than pasture. Intake of n-6 PUFA would be 48% greater and intake of n-3 PUFA would be 64% lower for beef from steers fed high-concentrates versus pasture. The actual amount of CLA provided from both beef sources would be similar and meet the recommended daily consumption levels. However, CLA can also be produced in

Forage Species for Finishing

Angus-cross steers (n = 60) from the Clemson University beef herd were used in this 2-yr grazing study (Schmidt et al., 2013). Each winter, 30 steers grazed cereal rye/ryegrass and tall fescue pastures prior to being blocked by BW and assigned randomly to 1 of 5 forage-finishing treatments of alfalfa (*Medicago sativa* L.), bermudagrass (*Cynodon dactylon*), chicory (*Cichorium intybus* L.), cowpea (*Vigna unguiculata* L.), and pearl millet (*Pennisetum glaucum* (L. R Br.). Finishing forage treatments started when forage growth for each individual forage species was adequate for grazing. Steers were slaughtered when there was either insufficient forage mass for continued steer gain or when steer live weight exceeded 568 kg. The steak from the 12th rib was trimmed of all exter

Table 2. Fatty acid amount per 'real-world' serving (18.7 oz; lunch = 6.7-oz hamburger cooked; dinner = 12-oz ribeye steak broiled) for beef finished on high-concentrate diet or mixed pasture.

	CONCEN-TRATE	PASTURE
Total fat content, g	99	51
Saturated fatty acids, g	42.8	22.7
Monounsaturated fatty acids, g	42.4	17.9
Polyunsaturated fatty acids, omega-6, g	3.55	1.84
Polyunsaturated fatty acids, omega-3, g	0.77	1.26
Trans-11 vaccenic acid, g	0.52	1.72
Conjugated linoleic acid, cis-9 trans-11, g	0.35	0.36

nal fat and epimysial connective tissue for subsequent fatty acid analysis.

Forage species utilized for finishing did not alter total lipid, fatty acid, saturated, monounsaturated or polyunsaturated fatty acid content of the LM. However, individual concentrations of certain fatty acids were altered. Most notably, trans-11 vaccenic (C18:1 trans-11; TVA) acid concentration in the LM was greater for BG than CH, CO and AL. Conjugated linoleic acid (CLA), cis-9 trans-11 isomer, concentration was greatest ($P < 0.05$) for BG and PM than AL, CH, and CO. Since the grasses (BG and PM) in this study had higher NDF content than did the legumes (AL, CO) or forbs (CH), this likely resulted in higher outflow of TVA at the duodenum, which corresponded to greater tissue deposition of TVA and CLA in these forage treatments.

Steers grazing CH, the forage species with a greater linolenic acid percentage, produced LM with the greater linolenic acid concentrations compared to AL, BG, and PM. In contrast, linolenic acid levels in PM forage were similar to CH but linolenic acid levels in the LM of PM steers were less than CH and CO. For CO, forage linolenic levels were less than CH and PM but LM linolenic acid concentrations were greater for CO than AL, BG, or PM. Due to the process of biohydrogentation in the rumen and desaturation in the adipose tissues, differences in forage fatty acid levels are not directly translated to similar changes in LM fatty acid composition. The n-6 to n-3 ratio was greater for CH and PM than AL, BG and CO. For AL, BG, and CO. Anticarcinogenic fatty acids, TVA and CLA cis-9 trans-11 isomer, concentrations were greater in beef finished on grasses (BG and PM) compared to other forage species. The highest ratios of n-6 to n-3 fatty acids were produced in LM when steers grazed CH and PM.

Corn Grain Supplementation on Grass or Legume Finishing

Thirty-two Angus x Hereford steers were used (BW = 461 ± 17.4 kg) to evaluate the effects of forage type (legumes [LG, alfalfa and soybeans] vs. grasses [GR, non-toxic tall fescue and sudangrass]) with or without daily corn supplementation (none [NONE] vs. 0.75 % BW/d of corn grain [CORN]) on animal performance and beef quality in a 2-yr study (Wright et al., 2014). The finishing period was 98 d in yr 1 and 105 d in yr 2. Fatty acid composition as a percent of the total fatty acids in the LM is presented in Table 4. All interactions between forage species and corn supplementations were non-significant ($P > 0.05$). Finishing on grasses increased stearic acid (C18:0) and trans-11 vaccenic acid concentrations compared to legumes. Grazing legumes increased linolenic acid and total n-3 fatty acid concentrations in the LM compared to grazing grasses. The concentration of other fatty acids in the LM was not altered by forage type.

Corn supplementation increased myristic (C14:0) and palmitic (C16:0) acid concentrations but did not alter total saturated fatty acid percentage. Oleic (C18:1 cis-9) and palmitoleic (C16:1 cis-9) acid concentrations tended to be increased with corn grain supplementation. As a result, the total monounsaturated fatty acid (MUFA) percentage in the LM was greater with corn supplementation. Linolenic (C18:3) acid concentration was reduced with corn grain supplementation; however, other individual and

Table 3. Fatty acid percentage of the longissimus muscle from steers finished on a five different forage species.

Forage Species[a]	**AL**	**BG**	**CH**	**CO**	**PM**
n					
TFA, %	2.35	2.82	2.18	2.38	2.16
SFA, %	43.59	43.12	43.42	44.46	41.54
C14:0, %	2.77	2.39	2.65	2.42	2.32
C16:0, %	26.63	25.42	25.84	26.19	24.54
C18:0, %	14.16^{d}	15.31^{bc}	14.92^{bcd}	15.54^{b}	14.68^{cd}
MUFA, %	39.67	39.20	37.46	38.08	39.50
C14:1, %	0.65	0.51	0.58	0.46	0.54
C16:1, %	3.28	3.11	3.07	3.10	3.36
C18:1, %	35.74	35.58	33.81	34.53	35.60
PUFA, n-6, %	4.14	3.60	5.37	4.22	4.41
C18:2, %	2.93^{c}	2.60^{c}	4.12^{b}	3.13^{c}	3.09^{c}
C20:4, %	1.22	1.00	1.24	1.09	1.33
PUFA, n-3, %	2.19	1.91	2.52	2.38	1.96
C18:3, %	1.03^{c}	0.90^{c}	1.46^{b}	1.32^{b}	0.86^{c}
C20:5, %	0.73	0.63	0.66	0.65	0.68
C22:5, DPA, %	0.73	0.63	0.66	0.65	0.68
C22:6, DHA, %	0.06	0.06	0.05	0.05	0.06
Ratio of n-6:n-3	1.88^{c}	1.90^{c}	2.11^{b}	1.80^{c}	2.26^{b}
TVA, %	2.01^{d}	3.03^{b}	2.35^{cd}	2.40^{cd}	2.84^{bc}
CLA, cis-9 trans-11, %	0.38^{c}	0.52^{b}	0.40^{c}	0.40^{c}	0.55^{b}

[a] Forage species: AL = alfalfa, BG = bermudagrass, CH = chicory, CO = cowpea, and PM = pearl millet.

[bcd] Means in the same row with uncommon superscripts differ (*P* < 0.05).

Table 4. Fatty acid percentage of the longissimus muscle from steers finished legume or grass pastures with or without corn grain supplementation (0.75% BW/d).

	Forage Type[a]		**Corn Gain Supplementation**[a]	
	GR	**LG**	**0**	**0.75%**
n	16	16	16	16
TFA, %	3.42^{c}	5.02^{b}	4.04^{c}	4.40^{b}
SFA, %	44.89	44.18	44.16	44.91
MUFA, %	39.69	40.53	39.34^{c}	40.89^{b}
PUFA, n-6, %	3.58	3.87	3.88	3.57
PUFA, n-3, %	0.99^{c}	1.25^{b}	1.20	1.04
Ratio of n-6:n-3	3.68	3.29	3.28	3.69
TVA, %	2.62^{b}	2.07^{c}	2.61	2.08
CLA, cis-9 trans-11, %	0.54	0.50	0.56^{d}	0.49^{e}

[a] Forage type = GR: grass (tall fescue + sorghum-sudan); LG: legumes (alfalfa + soybean)

[bc] Means in the same row with uncommon superscripts differ (*P* < 0.05).

[de] Means in the same row with uncommon superscripts differ (*P* < 0.10).

Table 5. Fatty acid percentage of the longissimus muscle from steers fed high concentrate diets or grazed pastures during phase 1 (30-d post weaning for 11 d) or phase 3 (final d to slaughter).

Phase 1[a]	**HC**	**HC**	**PA**	**PA**
Phase 3[a]	**HC**	**PA**	**HC**	**PA**
n	10	10	9	10
TFA, %	3.63	3.60	3.41	3.32
SFA, %	44.47	44.73	46.26	45.12
MUFA, % +	44.64	42.59	43.62	42.72
PUFA, n-6, % *	3.20	3.28	2.84	2.48
PUFA, n-3, % *+	0.98	1.57	1.57	1.82
Ratio of n-6:n-3 #	3.28^{b}	2.18^{c}	1.83^{d}	1.36^{e}
TVA, % #	0.84^{c}	1.49^{b}	1.29^{b}	1.43^{b}
CLA, cis-9 trans-11, % +	0.35	0.47	0.39	0.46

[a] Phase 1 (30-d postweaning for 111 d) or Phase 3 (final ~100 d before slaughter): HC = high concentrate diet; PA = pasture.
*Denotes Phase 1 effect ($P < 0.05$).
+Denotes Phase 3 effect ($P < 0.05$).
#Denotes interaction between Phase 1 and Phase 3 effect ($P < 0.05$).
[bcde] Means with uncommon superscripts differ ($P < 0.05$).

total n-3 fatty acid concentration were not altered by supplementation. Conjugated linoleic acid, cis-9 trans-11 isomer, concentration tended to be lower for corn supplemented than non-supplemented. The ratio of n-6 to n-3 fatty acids did not differ between CS and NS.

Timing of High Concentrate and Forage Finishing

Research was conducted to determine the timing of exposure to a high concentrate diet on subsequent beef quality and composition (Volpi Lagreca et al., 2014). Steers (n = 40) were backgrounded for 30-d post weaning and then randomly assigned to high concentrate diet (HC) or pasture (PA) in Phase 1 (111 d). After the completion of Phase 1, all steers grazed high-quality pastures for 98 d (Phase 2). At the end of Phase 2, steers were randomly divided based on Phase 1 treatments into two treatments of HC or PA for Phase 3. Phase 3 started when steers were about 454 kg BW and finished when steers reached 568 kg BW (live weight endpoint).

Total fatty acid content did not differ due to Phase 1 or Phase 3 treatments even though marbling scores did differ with Phase 1 and Phase 3 treatments. Total SFA percentage was not altered by Phase 1 or Phase 3 treatments. Exposure to HC in Phase 1 increased the concentration of n-6 PUFA and decreased the concentrations of n-3 PUFA. Exposure to HC in Phase 3 increased MUFA, and decreased PUFA n-3 and CLA cis-9 trans-11 isomer concentrations. Interactions between Phase 1 and Phase 3 feeding treatments were significant for ration n-6 to n-3 fatty acids and trans-11 vaccenic acid. The ratio of n-6 to n-3 was higher in longissmus muscle of steers that spent more time on a high concentrate diet (HC-PA-HC > PA-PA-PA). In addition, late exposure to HC resulted in lower ratios than early exposure to HC (HC-PA-PA > PA-PA-HC). Timing of exposure to HC or PA diets can alter fatty acid composition of the longissimus muscle. However, all ratios of n-6 to n-3 fatty acids, regardless of the length of time exposed to HC, were below the recommended 4:1 level for human health.

Summary

Animal nutrition can alter LM fatty acid composition. Finishing on high concentrate diets increases total fatty acid content and MUFA concentrations. The enzyme, stearoyl-CoA desaturase (SCD-1), is responsible for the conversion of SFA to MUFA, and is very responsive to energy content of the diet. Research comparing gene expression in subcutaneous fat from high-concentrate finished versus pasture finished cattle found that SCD-1 was up-regulated by

46-fold and MUFA increased concentration by 68% in high concentrate finished (Duckett et al., 2009). Even supplementation of corn grain, at a level of 0.75% of body weight, can also increase MUFA percentages in the LM. Finishing on forages typically increases n-3 PUFA and lowers total and saturated fat content. Finishing on different forage species results in minor changes in fatty acid composition of LM. However, finishing on grasses will increase TVA and CLA concentrations; whereas, finishing on legumes will increase n-3 PUFA and total lipid content. Concentration of n-3 PUFA decreases with the number of days cattle are fed a high-concentrate diet. Forages contain predominately n-3 PUFA (58% C18:3); in contrast to corn grain which contains predominately n-6 PUFA (58% C18:2). Therefore, finishing programs that utilize high concentrate diets for longer time periods will have lower n-3 fatty acid concentration. Finishing programs that combine periods of pasture and high concentrate finishing will provide higher levels of n-3 fatty acids than just high concentrate alone. With certain finishing strategies, fatty acid composition of beef can be altered to enhance specific fatty acids that consumers find desirable.

Literature Cited

AHA. 2014. The American Heart Association's Diet and Lifestyle Recommendations. Available at: ttp://www.heart.org/HEARTORG/GettingHealthy/NutritionCenter/HealthyEating/The-American-Heart-Associations-Diet-and-Lifestyle-Recommendations_UCM_305855_Article.jsp

Bonanome, A. and S. M. Grundy. 1988. Effect of dietary stearic acid on plasma cholesterol and lipoprotein levels. *N. Engl. J. Med.* 318:1244-8.

CDC. 2011. Leading Cause of Death, available at: http://www.cdc.gov/nchs/fastats/lcod.htm.

CDC. 2012. Adult obesity facts, available at: http://www.cdc.gov/obesity/data/adult.html.

Clifton, P. M., J.B. Keogh, and M. Noakes. 2004. Trans fatty acids in adipose tissue and the food supply are associated with myocardial infarction. *J. Nutr.* 134:874-879.

Denke, M. A. and S. M. Grundy. 1992. Comparison of effects of lauric acid and palmitic acid on plasma lipids and lipoproteins. *Am. J. Clin. Nutr.* 56:895-8.

Duckett, S.K., J. G. Andrae, and F. N. Owens. 2002. Effect of high oil corn or added corn oil or added corn oil on ruminal biohydrogenation and conjugated linoleic acid formation in beef steers fed finishing diets. *J. Anim. Sci.* 80:3353-3360.

Duckett, S. K., E. Pavan, and S. L. Pratt. 2009. Corn oil or corn grain supplement 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, S. K., D. G. Wagner, L. D. Yates, H. G. Dolezal, and D. R. Gill. 1993. Effect of time-on-feed on beef nutrient composition. *J. Anim. Sci.* 71:2079-2088.

Duckett, S. K., J. P. S. Neel, J. P. Fontenot, and W. M. Clapham. 2009. Effects if winter stocker growth rate and finishing system on: III. Tissue proximate, fatty acid, vitamin, and cholesterol content. *J. Anim. Sci.* 87:2961-2970.

Duckett, S. K., J. P. S. Neel, R. M. Lewis, J. P. Fontenot, and W. M. Clapham. 2013. Effects of forage species or concentrate finishing on animal performance, carcass and meat quality. *J. Anim. Sci.* 91:1454-1467.

Grundy, S. M. 1986. Comparison of monounsaturated fatty acids and carbohydrates for lowering plasma cholesterol. *N. Engl. J. Med.* 314:745-748.

Grundy, S. M. 1997. What is the desirable ratio of saturated, polyunsaturated and monounsaturated fatty acids in the diet? *Am. J. Clin. Nutr.* 66:988S-990S.

Ha, Y. L., N. K. Grimm and M. W. Pariza. 1987. Anticarcinogens from fried ground beef: heat-altered derivatives of linoleic acid. *Carcinogenesis* 8(12):1881-1887.

Hegsted, D. M., R. B. McGandy, M. L. Myers, and F. J. Stare. 1965. Quantitative effects of dietary fat on serum cholesterol in man. *Am. J. Clin. Nutr.* 17:281-95.

Ip, C., M. Singh, H. J. Thompson, and J. A. Scimeca. 1994. Conjugated linoleic acid suppresses mammary carcinogenesis and proliferative activity of the mammary gland in the rat. *Cancer Res.* 54:1212-1215.

Keys, A., J. T. Andreson, and F. Grande. 1965. Serum cholesterol response to changes in the diet. IV. Particular saturated fatty acids in the diet. *Metabolism* 14:776-87.

Kris-Etherton, P. M., J. Derr, and D. C. Mitchell. 1993. The role of fatty acid saturation on plasma lipids, lioproteins, and apolipoproteins. I. Effects of whole food diets high in cocoa butter, olive oil, soybean oil, dairy butter, and milk chocolate on the plasma lipids of young men. *Metabolism* 42:121-9.

Mattson, F. H., and S. M. Grundy. 1985. Comparison of effects of dietary saturated, monounsaturated, and polyunsaturated fatty acids on plasma lipids and lipoproteins in man. *J. Lipid Res.* 26:194-202.

Mensink, R. P. and M. B. Katan. 1989. Effect of a diet enriched with monounsaturated or polyunsaturated fatty acids on levels of low-density and high-density lipoprotein cholesterol in healthy women and men. *N. Engl. J. Med.* 321:436-41.

Mensink, R. P. and M. B. Katan. 1990. Effect of dietary trans fatty acids on high-density and low-density lipoprotein cholesterol levels in healthy subjects. *N. Engl. J. Med.* 323:439-45.

Pavan, E. and S. K. Duckett. 2013. Fatty acid composition and interrelationships among eight retail cuts of grass-fed beef. *Meat Sci.* 93:371-377.

Pavan, E. and S. K. Duckett. 2007. Corn oil supplementation to steers grazing endophyte-free tall fescue. II. Effects on longissmus muscle and subcutaneous adipose fatty acid composition and stearoyl-CoA desaturase activity and expression. *J. Anim. Sci.* 85:1731-1740.

Sackmann, J. R., S. K. Duckett, M. H. Gillis, C. E. Realini, A. H. Parks, and R. B. Eggelston. 2003. Effects of forage and sunflower oil levels on ruminal biohydrogenation of fatty acids and conjugated linoleic acid formation in beef steers fed finishing diets. *J. Anim. Sci.* 81:3174-3181.

Turpeinen, A. M., M. Mutanen, I. Salimen, S. Basu, D. L. Palmquist, and J. M. Griinari. 2002. Bioconversion of vaccenic acid to conjugated linoleic acid in humans. *Am. J. Clin. Nutr.* 76:504-10.

Volpi Lagreca, G., J. G. Andrae, and S. K. Duckett. 2014. Timing of exposure to high concentrate diets versus pasture on beef quality and composition. ICoMST Proc. (*Submitted*).

Wardlaw, G. M. and J. T. Snook. 1990. Effect of diets high in butter, corn oil or high-oleic sunflower oil on serum lipids and apolipoproteins in mean. *Am. J. Clin. Nutr.* 50:1382-1388.

Willet, W. C., M. J. Stampfer, J. E. Manson, G. A. Colditz, F. E. Speizer, B. A. Rosner, and C. H. Hennekens. 1993. Intake of trans fatty acid and risk of coronary heart disease among women. *Lancet* 341:581-585.

Wright, A. M., C. Fernandez Rosso, M. C. Miller, E. Pavan, J. G. Andrae, and S. K. Duckett. 2014. Effect of forage type with or without corn supplementation on beef fatty acid composition and palatability. *Meat Sci.* (*Submitted*).

Zock, P. L., J. H. M. de Vries, and M. B. Katan. 1994. Impact of myristic acid versus palmitic acid on serum lipid and lipoprotein levels in healthy women and men. *Arterioscler. Thromb.* 14:567-75.