Effect of Nutrition and Management Practices on Marbling Deposition and Composition

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Introduction

The amount of intramuscular fat or marbling deposited in longissimus muscle (cross-section of ribeye exposed between the 12th and 13th rib) is a major determinant of carcass value and predictor of palatability. Marbling fat is comprised of over 20 individual fatty acids; however, six major fatty acids contribute over 92% of the total fatty acid content (Table 1). These major fatty acids in beef marbling fat are: oleic, palmitic, stearic, linoleic, palmitoleic and myristic acids. Marbling also contains unique fatty acids as a result of ruminal biohydrogenation (hydrogenation of unsaturated fatty acids by rumen bacteria) of dietary lipid. One of these products is conjugated linoleic acid (CLA) which is a collective term used to describe one or more positional and geometric isomers of linoleic acid (cis-9, cis-12 octadecadienoic acid). Conjugated linoleic acid was first recognized as an anticarcinogen in experiments investigating compounds generated during the cooking of hamburger (13). Conjugated linoleic acid is produced in ruminant animals as the first intermediate in the biohydrogenation of dietary linoleic acid by rumen bacteria such as *Butyrivibrio fibrisolvens*. Chin et al. (14) reported levels of CLA in ground beef at 3.8 to 4.3 mg/g of lipid. Marbling also contains odd-chain fatty acids like pentadecylic (C15:0) and margaric (C17:0) acids due to the incorporation of propionate instead of acetate in *de novo* fatty acid synthesis.

Overall, the fatty acid composition of beef marbling fat is about 44% saturated fatty acids (SFA), 5% odd-chain fatty acids (OCFA), 45% monounsaturated fatty acids (MUFA), and 5% polyunsaturated fatty acids (PUFA) for beef marbling fat (Figure 1; 1). Human diets containing a high proportion of lipid as MUFA have been shown to be as effective as those containing high levels of PUFA at lowering serum cholesterol levels (2,3,4). Myristic and palmitic acids are saturated fatty acids and are considered to be hypercholesterolemic or cholesterol elevating (5, 6). Stearic acid is a saturated fatty acid; however, diets high in stearic acid have been shown to lower serum cholesterol compared to other saturated fatty acids (5,6,7,8). Stearic acid is believed to be converted to oleic acid after dietary ingestion which accounts for its different effect on serum cholesterol compared to other saturated fats (8). Several studies have been conducted to compare diets containing beef with those containing unsaturated oils (9), plant protein (10), or white meat (11,12). The results from these comparisons show that a diet containing lean beef has similar effects on serum lipids as other protein or oil sources.

The potential to alter marbling deposition and composition would be advantageous to both beef producers and consumers; however, most research evaluating the effect of nutrition and management systems on marbling content have shown only small to moderate changes. In order to alter marbling composition, dietary unsaturated fatty acids must escape ruminal biohydrogenation for subsequent absorption and deposition. Ruminal biohydrogenation of dietary unsaturated (eighteen carbon fatty acids) in steers consuming a high concentrate feedlot diet is about 64 to 69% of intake (15,16). Unsaturated fatty acid content of a typical feedlot diet, digesta from small intestine (duodenum), and marbling is 79%, 20%, and 49%, respectively (Table 2).

This paper will summarize the results from research examining nutrition and management effects on marbling deposition and composition.

Nutrition Effects

Pasture vs. Grain. In a comparison of forage versus grain finishing diets, Williams et al. (17) reported that consumption of the grain diet resulted in increased marbling scores, quality grades and percent grading Choice (Figure 2). The higher marbling content with grain feeding stemmed from a proportional increase in storage reservoirs (triglycerides) of the fat cells (adipocytes; 17,18). This increase in triglyceride content with grain-feeding also altered the fatty acid composition of the marbling fat. Grain feeding increased oleic acid and MUFA contents of marbling fat (Figure 3; 17,19,20,21,22). Forage-fed beef had higher concentrations of SFA and PUFA due to greater percentages of stearic, linoleic and linolenic acids (Figure 3; 17,20,22,23). Marmer et al. (23) found increased amounts of odd- and branched-chain fatty acids in marbling from cattle fed forage diets. The increase in PUFA content contribute to shorter shelf-life and off-flavors typically observed in forage-fed beef (22). Polyunsaturated fatty acids (PUFA) are very susceptible to oxidation during cooking and negatively correlated to sensory flavor ratings in comparisons between grass and grain-fed samples (1,22).

Time-on-Feed. Regardless of the age (calves (24) or yearlings (25,26,29)) or breed of the cattle used (Simmental sired, 25; Angus, 26; Angus x Hereford, 29; Hereford, 24), serial slaughter studies continue to demonstrate that marbling deposition proceeds in a non-linear manner across time-on-feed (Figure 4). These studies show a plateau in marbling score after about 112 d on a high concentrate diet. Duckett et al. (1) found that total lipid content in the longissimus doubled between 84 and 112 d on feed but did not differ from d 0 to 84 or from d 112 to 196 (Figure 5). The increase in marbling fat content with increased time-on-feed appears to be due to an enlargement of the fat (adipocyte) cell with storage reservoirs (triglycerides) versus an increase in fat cell number since the structural components of the cell (phospholipids) remained constant. Nash et al. (30) utilized real-time ultrasound to monitor changes in intramuscular lipid content and predict quality grade in 71 Angus-cross heifers across time-on-feed. The percent grading Choice increased from 20% at d 84 to 80% at d 100 and then remained constant to harvest at d 120 (Figure 6). The percentage estimated to qualify for Certified Angus Beef increased across time-on-feed from 2% at d 101 to 22% at d 120. Optimal time-on-feed for increased percentage of carcasses grading Choice appears to be around 112 d on feed; however, more research is needed to assess optimal time-on-feed for increased percentage of carcasses reaching the upper Choice grades in cattle with the genetic ability to marble.

Since the percent contribution of phospholipid fraction to total lipid declined greatly with advancing time-on-feed (1), this ultimately decreased the PUFA content of marbling fat with increased time-on-feed (Figure 7). Researchers (1,23,31,32) have found that the PUFA are almost exclusively located in the phospholipid fraction where they apparently serve as structural elements of the cells (33). However as the PUFA content in total lipid declined with time-on-feed, the MUFA content increased with the SFA being relatively unchanged. This increase in MUFA resulted from increased concentrations of oleic acid in the triglyceride fraction as time-on-feed increased. The increase in oleic acid concentration across time-on-feed would suggest changes in ruminal biohydrogenation and tissue desaturase activity with advancing time-on-feed.

Tallow and Yellow Grease. Addition of tallow to corn based finishing rations does not increase marbling scores (34,35,36); however, tallow addition to diets containing barley and milo was shown to increase marbling scores (37,38). In contrast, Bock et al. (39) and Brandt et al. (40) fed wheat or sorghum based finishing diets containing 0%, 3.5% or 4% added fat and observed no differences in marbling score. Addition of 4% tallow to corn based finishing diets has also decreased marbling scores (41). Small increases in marbling saturation, primarily as a result of increased stearic acid concentrations, have been observed when yellow grease and tallow are added to finishing rations (38,40,42).

Unsaturated oils. Addition of oil to the ration either as a free source (i.e. corn oil, soybean oil, soybean soapstock) or as a protected source (casein/formaldehyde protected oils or calcium soaps, i.e. Megalac) increases the supply of dietary unsaturated fatty acids. Free oils are more subject to hydrolysis and biohydrogenation by ruminal bacteria than protected fats (85 vs. 50%; 43,44). Roberts and McKirdy (45) reported lower SFA percentages in lipid of steers fed 5% added rapeseed or sunflower oil. This reduction in saturated fat was primarily the result of decreased palmitic acid content in both sunflower and rapeseed oil fed cattle and increased eicosenoic and erucic acid deposition in rapeseed oil fed steers. Eicosenoic and erucic acids are found in high levels in rapeseed oil and the presence of these lipids in tissue indicate that they escaped rumen biohydrogenation. Dryden and Marchello (46) evaluated adding 6% safflower oil or animal fat to finishing rations. Safflower oil fed steers had increased linoleic and linolenic acids in most of the external, internal and seam fat depots sampled but marbling composition remained unchanged. Bock et al. (39) found increased amounts of unsaturated lipids in the plasma of steers fed soybean soapstock compared to tallow; however, this did not translate to increased amounts of unsaturated fat deposited in marbling fat.

Less information is available on the effects of protected lipids on marbling and fatty acid composition of finishing steers. Garrett et al. (47) reported increased quality grades when rumen protected vegetable oils were fed to finishing steers consuming barley based diets. Ngidi et al. (48) fed increasing levels of rumen protected palm oil (Megalac; 0-6%) and observed no effects on marbling scores; however, ADG and carcass weight decreased linearly with addition of Megalac. Dinius et al. (49) added a rumen protected casein-safflower oil complex to finishing cattle diets and observed increased linoleic acid percentage of marbling fat after 56 days on feed. Hill and West (50) fed 4.5% Megalac to a corn based finishing diet and observed increases in plasma palmitic, palmitoleic, oleic, and linolenic acids after 41 days on feed. The fatty acid composition of Megalac is about 87% palmitic and oleic acids, which suggests these fatty acids escaped biohydrogenation.

Oilseeds. While calcium and protein protected fat complexes are chemically unavailable for rumen biohydrogenation, others have proposed that oilseeds are physically protected from biohydrogenation by their seed coat (51) . The extent of this protection should be dependent upon rate of ruminal digestion, rate of passage and the degree of physical or chemical processing prior to feeding and following mastication. Adding whole cottonseed to finishing rations decreased carcass weight and ribeye area (52), but did not alter other carcass traits including marbling scores or external fat composition (52,53). Ekeren et al. (15) fed high-oleic sunflower seeds to duodenally cannulated steers and reported increased levels of oleic acid in duodenal digesta and feces. This suggests that some of the unsaturated fat escaped hydrogenation, but was also relatively indigestible in the small intestine. Chang et al. (54) observed increased oleic, myristic and stearic acids in tailhead fat of sunflower seed fed steers.

Addition of ground or extruded canola seeds to finishing rations increased stearic and linolenic acids of subcutaneous fat (55) and brisket fat (56). Unsaturated fatty acids present in whole (unprocessed) canola escapes ruminal biohydrogenation but has low intestinal availability; however, grinding, crushing or extruding the canola seed exposes the lipid to greater biohydrogenation and intestinal absorption. Chemical processing of whole canola with sodium hydroxide and hydrogen peroxide decreased ruminal biohydrogenation and allowed for adequate small intestinal digestion of unsaturated fat compared to crushed canola seed (57,58). This chemical treatment greatly increased the flow of oleic, linoleic and linolenic acids to the duodenum and may offer an improved method for altering ruminant fatty acid composition.

Inclusion of graded levels of whole soybeans (0-24% of ration DM) did not change performance or carcass characteristics; however, a numerical trend for increasing quality grade with increased soybean inclusion was noted (59). In contrast, Rumsey et al. (60) fed whole roasted soybeans and did not observe any changes in carcass characteristics. Rule et al. (61) reported numerical increases in quality grade and marbling score for steers fed 14% extruded soybeans without altering marbling fatty acid composition. Feeding extruded soybeans also had minimal effects on subcutaneous, kidney, liver or brisket lipid composition of finishing steers (56) although a previous study indicated increased duodenal, plasma and subcutaneous linoleic and linolenic acid levels with dietary extruded soybeans (62).

Specialty Grains. Recently, corn has been developed that contains twice the oil content of normal corn. Very few studies have been reported which evaluate performance and carcass responses to feeding high oil corn in finishing rations. Andrae et al. (63) found that feeding dry rolled high oil corn increased marbling score and the percentage of cattle grading Choice from 42 to 72%. The percentage of carcasses that qualified for Certified Angus Beef (CAB) was higher for high oil corn than regular corn (Figure 8). Similarly, Trenkle and Belknap (64) reported increased percentages of carcasses grading Choice when whole shelled high oil corn was fed (43% vs. 57%). Feeding high oil corn at similar levels (82% of ration) or isocaloric levels (equal energy content basis) to diets containing control corn increased the percentage of linoleic acid, arachidonic acid, and total PUFA content of marbling fat (Figure 9). Because linoleate and arachidonate are essential fatty acids, their increased presence in tissue suggests that more linoleic acid reached the small intestine and was available for absorption and deposition. In agreement with our results, others have increased the unsaturated fat content in milk by feeding high oil corn (65,66). Increased intestinal supply of linoleic acid could be the result of either decreased ruminal biohydrogenation of fatty acids, an increased dietary supply of unsaturated fat, or a combination of these two factors.

Oil and Forage Level. In beef cattle, limited research is available on increasing muscle CLA levels by altering finishing cattle diets. Research has shown that increasing forage level (67) or feeding high oil corn (68) individually in finishing diets had no effect on CLA content of marbling fat; however if forage level was elevated and high oil corn fed (68), CLA content was increased by 24%. Enser et al. (69) added linseed oil to the diet (60 g fat/kg diet dry matter) of finishing steers and increased total CLA content in longissimus two-fold (35.6 vs. 11.3 mg/100 g muscle) compared to a Megalac supplement. Research is currently underway to examine increasing CLA levels in marbling fat by altering dietary forage and unsaturated oil levels.

Management Effects

Backgrounding systems. Duckett et al. (70) evaluated the effect of backgrounding system on marbling content and composition. The backgrounding systems evaluated were: early weaned (EW; direct entry into feedlot after weaning at 3.5 mo of age); normal weaned (NW: direct entry into feedlot after weaning at 7.9 mo of age); wheat pasture (WP; grazed on wheat pasture for 112 d after weaning at 7.9 mo of age and then entered feedlot at 11.6 mo of age); short grazed (SG; wintered on dry native range after weaning at 7.9 mo of age, grazed on early intensive managed native range for 68d, and then entered feedlot at 15.4 mo of age); and long grazed (LG; wintered on dry native range after weaning at 7.9 mo of age, grazed native range for 122 d, and then entered the feedlot at 17.4 mo of age). Marbling score and the percentage of carcasses grading Choice or Certified Angus Beef were similar for the various backgrounding schemes indicating that animal age plays a minor role in control of marbling deposition. Backgrounding scheme utilized prior to feedlot entry had a minor effect on marbling fatty acid composition. Myristic acid and PUFA content were higher in marbling fat from EW steers. Pentadecylic acid and odd-chain fatty acid contents were higher in marbling fat from WP steers. Stearic acid content was higher in marbling fat from LG.

Ionophores. Ionophores do not appear to influence marbling deposition and have minimal effects on fatty acid composition (71,72). Marmer et al. (71) reported increased odd-chain and branched-chain fatty acids in marbling fat from steers supplemented with Rumensin on a sorghum-sudan diet. The higher levels of these odd- and branched-chain fatty acids may arise from greater quantities of propionate available for *de novo* fatty acid synthesis. Duckett and Wagner (72) reported increased oleic acid concentration and reduced saturated fatty acid amounts in marbling fat from steers fed Cattlyst in the finishing diet (11 mg/kg). These changes suggest that ionophores appear to limit ruminal biohydrogenation possibly through reductions in available hydrogen and/or altered bacteria species.

Implants. On average, anabolic implants reduce marbling score and percent grading Choice by 24% of a degree and 14.5%, respectively (73,74). The percent reduction in marbling score (MS) versus the percent increase in ribeye area (REA) observed with implanting is shown in Figure 11 (75). Overall, there was a negative relationship (% reduction in MS = - 0.796 x percent increase in REA – 1.99; $r^2 = .68$) between reductions in MS and increases in REA observed with various implant types. Single estrogenic (E) or combination (EA) implants reduced MS by about 4% and increased REA by 3% or 4%. Reimplanting (E/E, EA/EA, or E/EA) increased REA by 4 to 8% and reduced MS by 6 to 11%. In a recent study (76), implanting reduced marbling score by about one-half a marbling degree compared to non-implanted controls. The percentage of carcasses grading Certified Angus Beef (CAB) decreased from 20% for non-implanted controls to 7% for EA, 2% for EA/EA, and 13% for E/EA (Figure 12). Implanting increased ribeye area by 7% compared to non-implanted controls. Reimplanting (EA/EA) further increased ribeye area by 8% compared to a single implant of EA. Total fatty acid percentage was lower for implanted than non-implanted controls. On a gravimetric basis (g/2.54 cm thick steak) where the changes in ribeye size with implanting were accounted for, implanting or reimplanting did not alter the total fatty acid amount or amounts of any individual fatty acids. Thus, implanting appears to alter marbling amount and composition through a dilution effect with the increase in ribeye size.

Kennet and Siebert (77) reported differences in fatty acid composition of marbling fat between implanted and nonimplanted steers finished on pasture in southern Australia. Duckett et al. (75) reported increased the percentages of stearic and linolenic acids, and reduced oleic acid percentage with implanting. These changes translated into an increased SFA percentage, and a reduced MUFA percentage. Reimplanting (EA/EA) versus a single implant (EA) did not alter fatty acid composition of the marbling fat. However, implanting with an estrogenic rather than a combination implant first (S/EA vs EA/EA) increased the percentage of palmitic acid, and reduced linoleic acid and PUFA percentages.

Conclusion

Nutrition and management systems can alter marbling deposition and composition. Marbling deposition appears to proceed in a non-linear manner across time-on-feed with a plateau after about 112 d on a finishing diet. Increased marbling scores have been observed in cattle fed increased levels of dietary unsaturated fatty acids in the form of oilseeds, protected oil supplements, or added vegetable oil. These increases in marbling score are typically accompanied by increased unsaturated fatty acid composition of marbling fat. Increasing the dietary supply of unsaturated fatty acids results in higher levels of unsaturated fatty acids escaping ruminal biohydrogenation for increased absorption in marbling fat. In contrast, management practices that stimulate muscle growth such as utilization of anabolic implants appear to reduce marbling deposition through dilution effects. Based on these research findings, it appears that certain events must occur in order to alter marbling fat deposition and composition. These events include: increased marbling deposition in the time period when diet is altered, increased flow of unsaturated fatty acids to small intestine as a result of reduced ruminal biohydrogenation, higher dietary intake or both, and increased absorption of the unsaturated fatty acids in the intestine for deposition. Additional research is needed to explore regulation and potential nutritional manipulation of marbling deposition and composition.

Table 1. Common names, carbon length, degree of unsaturation and percentage of the major fatty acids found in marbling fat.

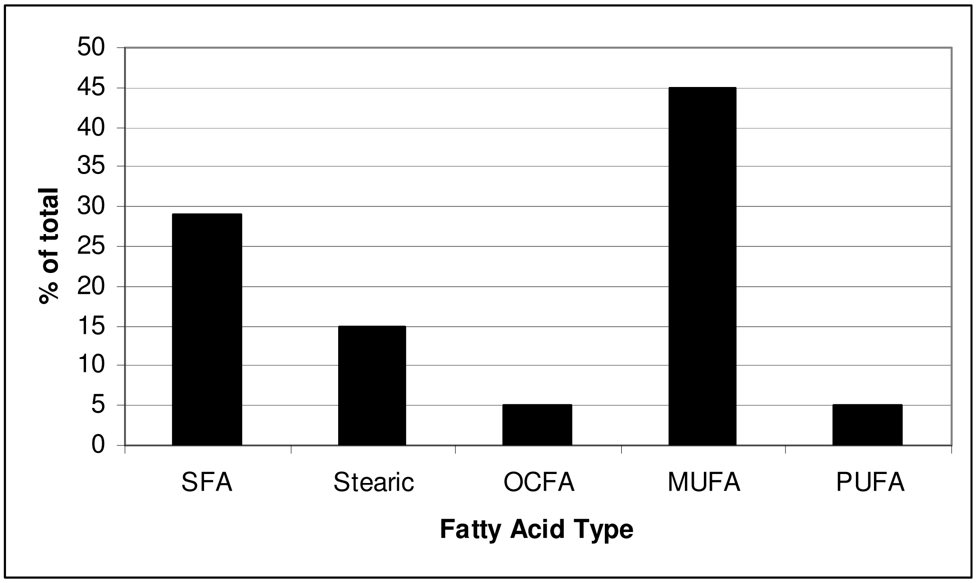
Common Name	Carbon Length	Number of Double Bonds	Fatty Acid Type	%
Myristic acid	14	0	Saturated fatty acid[a]	4
Palmitic acid	16	0	Saturated fatty acid[a]	27
Palmitoleic acid	16	1	Monounsaturated fatty acid	4
Stearic acid	18	0	Saturated fatty acid[b]	15
Oleic acid	18	1	Monounsaturated fatty acid	41
Linoleic acid	18	2	Polyunsaturated fatty acid[c]	4

[a] Hypercholesterolemic (cholesterol-elevating) saturated fatty acid.

[b] Neutral saturated fatty acid.

[c] Essential fatty acids.

Figure 1. Fatty acid types in beef marbling (1)[a].



[a] SFA = saturated fatty acids, hypercholesterolemic; Stearic = saturated fatty acid, neutral; OCFA = odd-chain fatty acid, MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid.

Table 2. Fatty acid composition of a typical feedlot diet, digesta from the small intestine (duodenum), and marbling deposits (16,63).

Fatty acid, %	**Feedlot Diet**	**Digesta**	**Marbling**
Myristic acid	0.18	1.65	2.94
Palmitic acid	14.30	14.06	27.44
Stearic acid	2.21	**51.14**	17.46
Oleic acid	20.46	6.19	**41.30**
Linoleic acid	**52.31**	10.25	3.90
Linolenic acid	6.73	.64	.70
Arachidonic acid			.86
Unsaturated fatty acids	**79.50**	**19.87**	**49.08**

Figure 2. Percentage of carcasses from cattle finished on forage or grain that graded Standard, Select, or Choice (17).

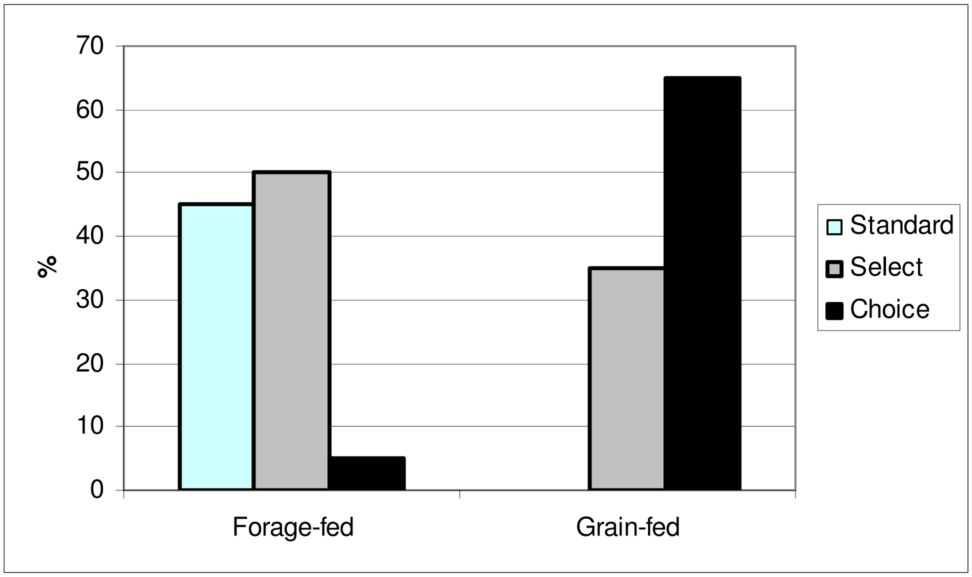


Figure 3. Fatty acid composition of marbling from cattle finished on forage or grain (17).

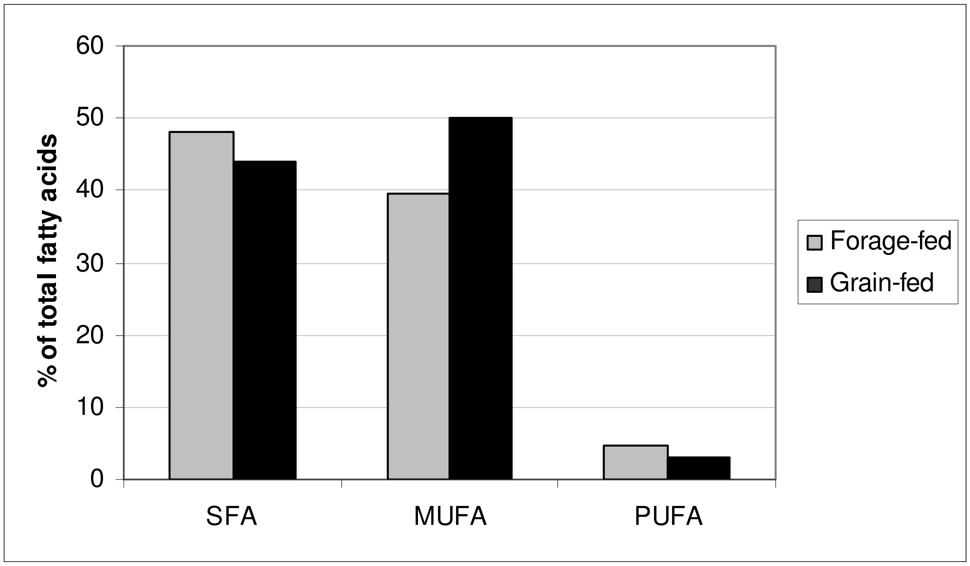


Figure 4. Effect of feeding a high concentrate diet (time-on-feed) on marbling score (24, 25, 26, 29).

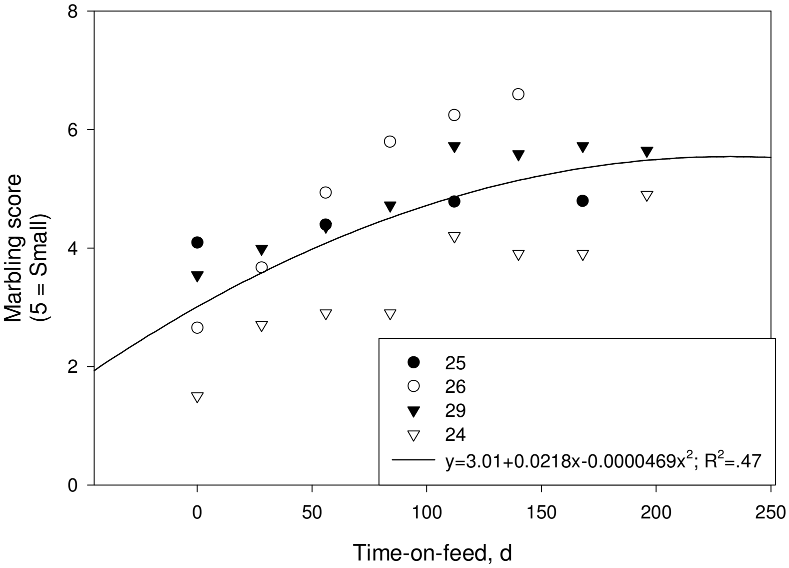


Figure 5. Change in the percent total lipid (marbling) within the longissimus muscle as triglyceride (storage component) or phospholipid (structural component) across time-on-feed (1).

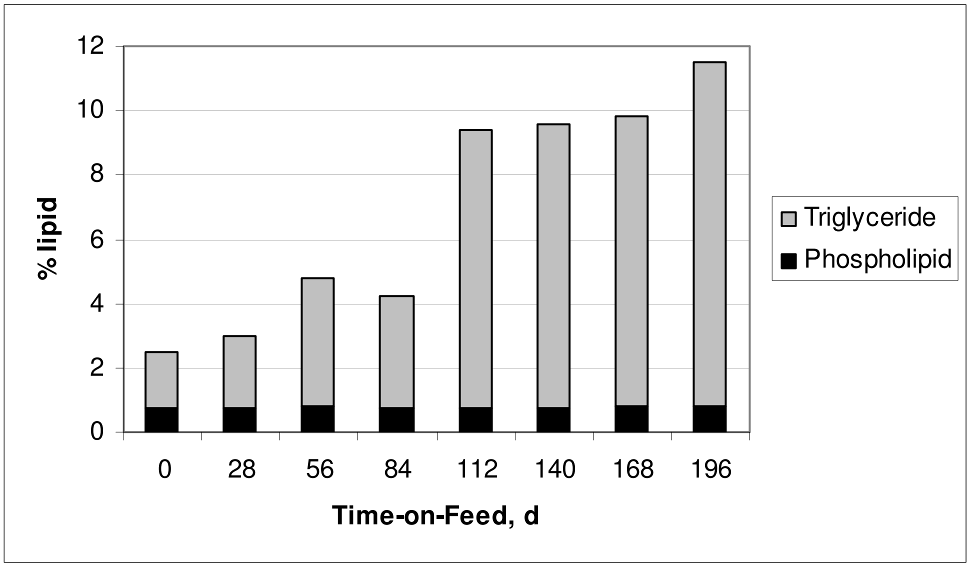
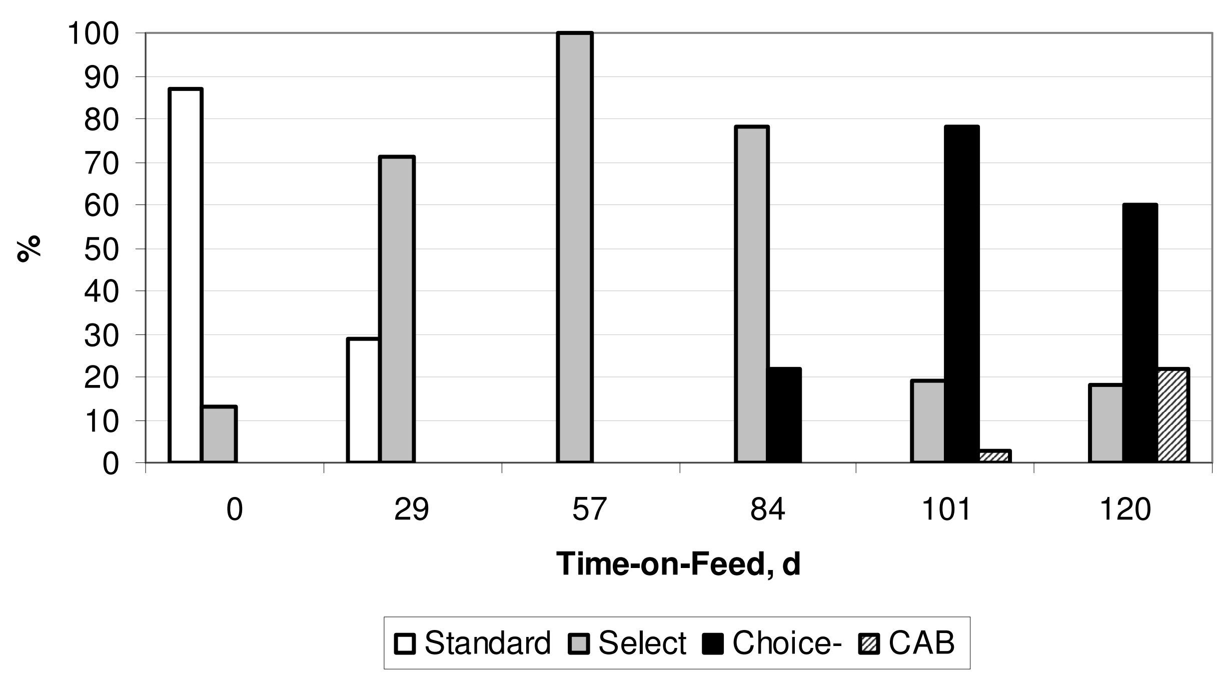


Figure 6. Changes in the percent of carcasses grading Standard, Select, Choice or Certified Angus Beef (CAB) as predicted from real-time ultrasound intramuscular lipid (IML) percentages measured across time-on-feed in Angus-cross heifers (30)[a].



[a] Quality grade: **Standard** = < 3.4% IML; **Select** = 3.4 to 4.99% IML; **Choice**$^-$ = 5.0% to 6.49% IML; **CAB** = > 6.5% IML.

Figure 7. Change in percent of monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids in marbling across time-on-feed.

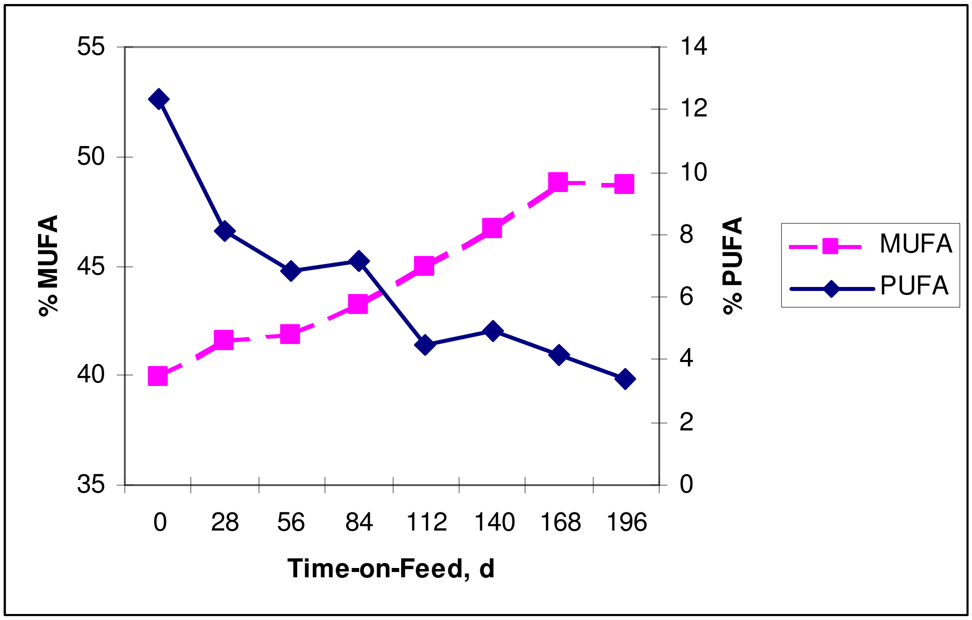


Figure 8. Effect of feeding high oil corn at a similar ration percentage (HOC) or at a similar caloric level (HOC-ISO) to normal corn for 83 d on percentage of carcasses from Angus-cross steers grading Select, Choice, or Certified Angus Beef (CAB; 63).

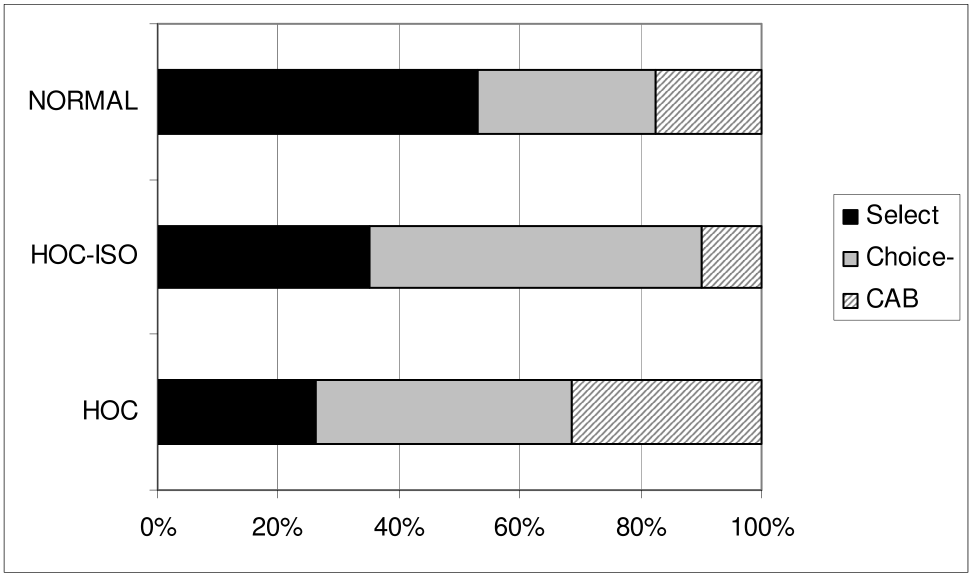


Figure 9. Effect of feeding high oil corn at a similar ration percentage (HOC) or at a similar caloric level (HOC-ISO) to normal corn for 83 d on percentage of essential fatty acids (linoleic (C18:2) and arachidonic (C20:4) acids in marbling fat (63).

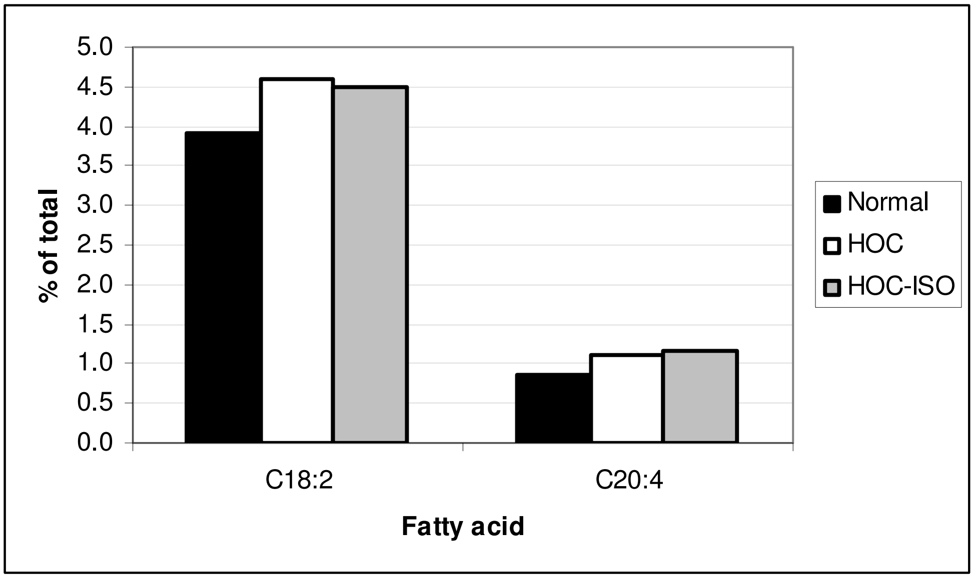
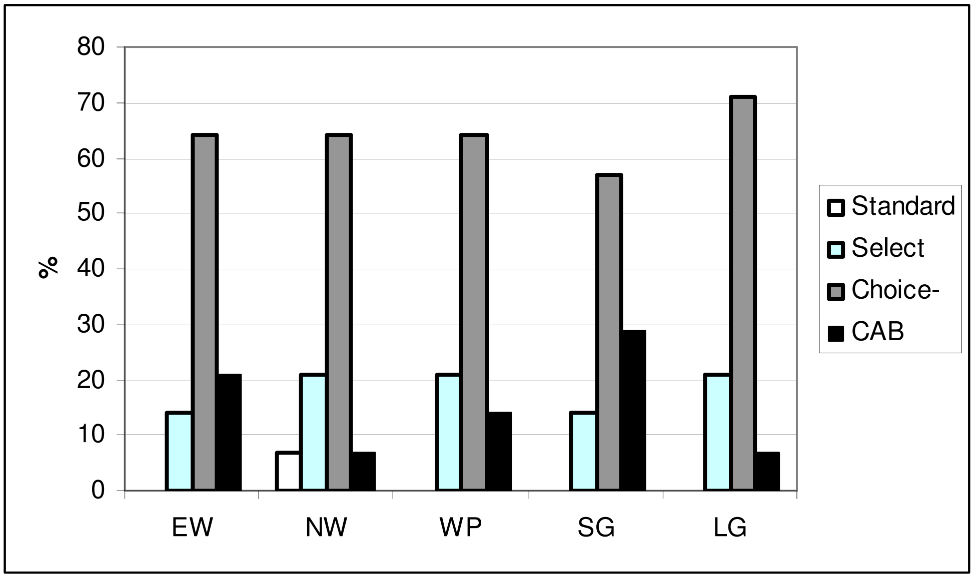
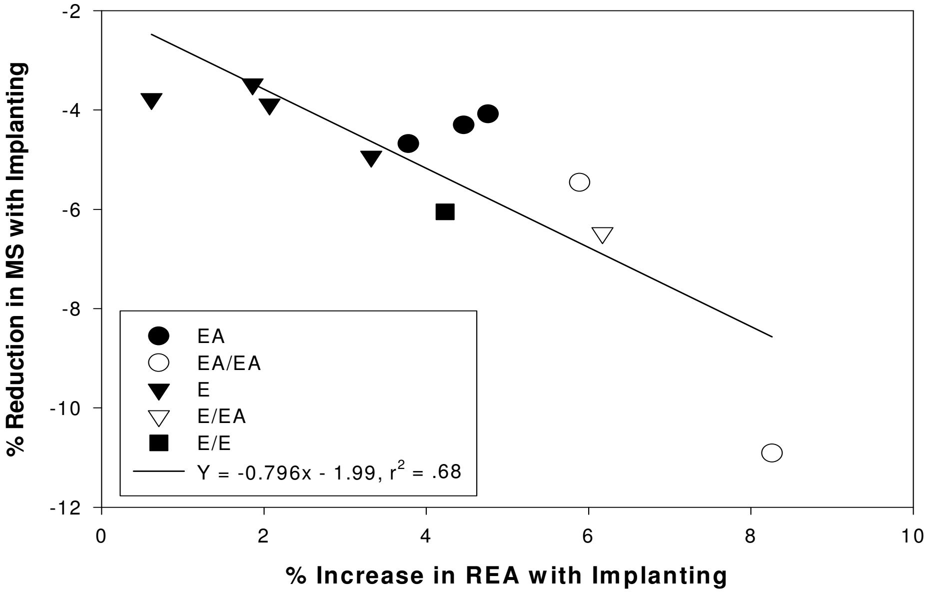


Figure 10. Percentage of carcasses from different backgrounding systems grading Standard, Select, Choice-, or Certified Angus Beef (CAB; 70)[a].



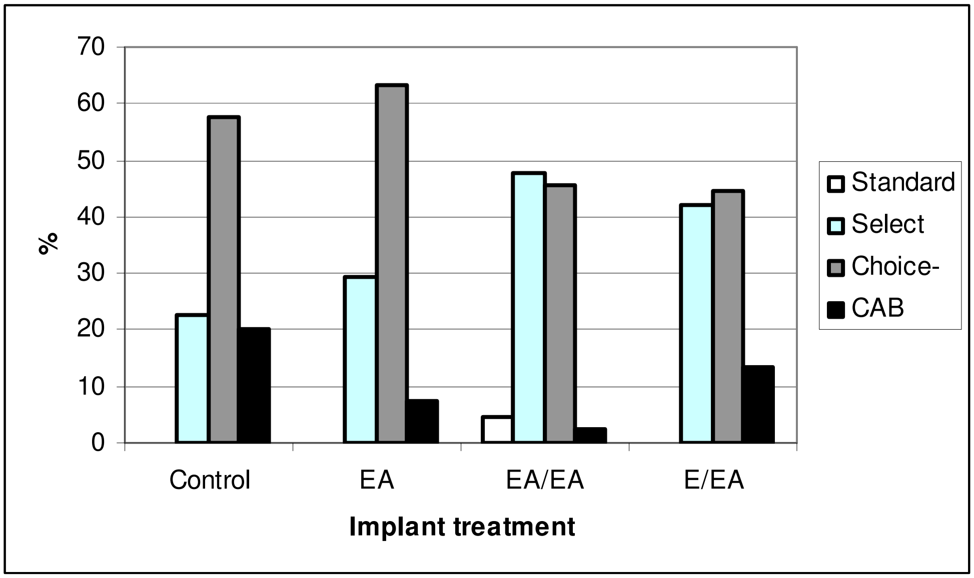
[a]Early weaned (**EW**) = direct entry into feedlot after weaning at 3.5 mo of age; normal weaned (**NW**) = direct entry into feedlot after weaning at 7.9 mo of age; wheat pasture (**WP**) = grazed on wheat pasture for 112 d after weaning at 7.9 mo of age and then entered feedlot at 11.6 mo of age; short grazed (**SG**) = wintered on dry native range after weaning at 7.9 mo of age, grazed on early intensive managed native range for 68d, and then entered feedlot at 15.4 mo of age; and long grazed (**LG**) = wintered on dry native range after weaning at 7.9 mo of age, grazed native range for 122 d, and then entered the feedlot at 17.4 mo of age.

Figure 11. Percent change in ribeye area (REA) and marbling score (MS) with implanting compared to non-implanted controls by implant type (75)[a].



[a]Implant type: **E** = estrogenic activity, implants containing zeranol or estradiol compounds and progesterone; **EA** = both estrogenic and androgenic activity, implants containing both estradiol compounds and trenbolone acetate; "/" denotes reimplant.

Figure 12. Effect of implanting on the percentage of carcasses grading Standard, Select, Choice-, or Certified Angus Beef (CAB; 76)[a].



[a]Implant treatment: **Control** = non-implanted; **EA** = 28 mg of estradiol benzoate plus 200 mg of trenbolone acetate on d 0; **EA/EA** = 28 mg of estradiol benzoate plus 200 mg of trenbolone acetate on d 0 and d 61; **E/EA** = 20 mg of estradiol benzoate plus 200 mg progesterone on d 0 and 28 mg of estradiol benzoate plus 200 mg of trenbolone acetate on d 61; time-on-feed = 127 d.

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