THESIS

THE EFFECT OF DAM NUTRIENT RESTRICTION ON LAMB CARCASS CHARACTERISTICS, RETAIL YIELDS, AND NUTRIENT COMPOSITION

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Kristina Anne Brenman

Department of Animal Sciences

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Master's Committee:

Advisor: Keith Belk

Dale Woerner
Terry Engle
Donald Mykles

ABSTRACT

THE EFFECT OF DAM NUTRIENT DEPRIVATION ON LAMB CARCASS YIELDS, RETAIL CUTS, AND NUTRIENT COMPOSITION

The objective of this study was to determine the effect of dam nutrient restriction on offspring carcass characteristics, retail cut yields, and nutrient composition. Forty one western white rams and ewes were obtained from a previous Colorado State University study of dam nutrient restriction. Prior to gestation, dams were fed 100% of their nutrient requirements. The diet of dams was a vitamin-mineral rich pelleted beet-pulp (77.8% total digestible nutrients [TDN], 90.0% dry matter [DM], and 9.4% crude protein [CP]). At 28 days gestational age, dams were randomly assigned to individual pens and separated into three different treatments: control (100% nutrient requirements), half ration (fed 50% of their nutrient requirements from day 28 until term), and realimented (fed 50% of their nutrient requirements from day 28 until day 78, and then slowly realimented back to 100% for the remainder of gestation). All twin lambs were slaughtered, and hot carcass weight, 12^{th} rib fat, body wall thickness, adjusted fat, ribeye area, ribeye marbling, leg score, leg circumference, conformation, flank streaking, flank firmness, flank color, kidney fat weight, L*, a*, and b* were obtained. After all lambs were slaughtered, one half of each lamb carcass was fabricated in the following subprimals: rack, roast ready, frenched PSO 3x1" (IMPS 204C); shoulder, square-cut, boneless (IMPS 208); Denver ribs, skirt-off (IMPS 209A); Foreshank (IMPS 210); loin, short-cut, trimmed PSO 0x0" (IMPS 232A); flank untrimmed (IMPS 232E); leg, hindshank (IMPS 233F); and leg, shank-off, boneless (IMPS 234A). Lastly, all lambs were utilized to determine dry matter, moisture, crude protein, crude fat, ash, vitamins A and E, trace minerals, and fatty acids. No interactions were found between

treatment and gender for any characteristic, so treatment and gender were analyzed separately. Lambs of ewes that were nutritionally restricted were smaller in size with less fat. Lambs of the realimented group had more fat than either the control or the half ration groups. Rams had more percent lean content than ewes, which was to be expected. Results of this study provide insight on the effect of nutrient restriction on lamb growth and development, as well as nutrient content of American lamb.

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CHAPTER I

LITERATURE REVIEW

THE EFFECTS OF FEED RESTRICTION AND FINISHING TYPES

Investigation of restricted feeding on animals has become increasingly more popular in recent years. Drought and severe weather are times when restriction occurs that impacts the ewe and the offspring. Along with feed restriction has come the question of different finishing regimens and its subsequent impacts on carcass yield and nutritional quality. This literature review examines previous studies pertaining to lamb feed restriction, feeding types, carcass yields, and nutritional composition.

Feed Restriction

Dietary restriction of ewes on offspring has been shown to have negative effects on growth and development of their offspring. Daniel et al. (2007) found an effect on both final slaughter weight and growth rate of lambs when dams were undernourished. In addition, these offspring had a lower ($P < 0.05$) liver, heart, and lung weights compared to control lambs. Muscles in offspring of undernourished ewes were lighter weight, and the fiber diameter size of the *vastus lateralis* was smaller. In both the *longissimus* and the *vastus lateralis,* fiber composition was altered; the numbers of fast twitch fibers being smaller in size than those in control lambs. Finally, maternal dietary restriction had an effect on fat content of the *longissimus* muscle. Fat content of muscle from carcasses of rams was greater than that of ewes (Daniel et al., 2007).

Restrictions on individual lambs have shown to have a negative effect on body and visceral organ masses. Visceral organ masses are smaller for feed restricted lambs compared to control lambs (Warriss et al., 1987; Burrin et al., 1990; Drouillard et al., 1991). Fasting was found to reduce the weights of all body components with the exception of both the fleece and the feet (Warriss et al., 1987). Burrin et al. (1990) numerically put this into perspective by showing that the absolute weights of the liver, stomach, small intestine, and large intestine were 52, 72, 63, and 63% of the absolute weight of control lambs. The liver was found to take the largest toll when lambs were restricted on feed (Warriss et al., 1987; Burrin et al., 1990; Drouillard et al., 1991). Warriss et al. (1987) found a 24% loss of liver weight after the first 48 hours of dietary restriction; whereas Burrin et al. (1990) found an 18% loss over a 21 day nutrient restriction period, and Drouillard et al. (1991) found a 30% loss of liver weight after a 42 day nutrient restriction period. Also, the intestine was found to decrease in relative proportion to empty body weight (Burrin et al., 1990; Drouillard et al., 1991).

Protein or energy feed restrictions have different effects on the body. Lambs fed a protein restricted diet lost protein at a rate of 16 g/day, fat at 15 g/day, and water at 78 g/ day. Wethers and ewes on the energy restricted diet maintained protein mass, but lost fat at 20 g/day and water at 42 g/day. Once returned to a complete diet, the protein restricted lambs gained both protein and fat at a much faster rate than the energy restricted lambs (Drouillard et al., 1991). This indicated that temporary restriction can be reversed by feeding with a complete diet; however, those that did not get a proper diet suffered both carcass wise and organ wise.

A study completed in 2008 showed that lambs born from ewes that were fed 50% of their nutritional needs had smaller birth weights, and these lambs never caught up in weight to the control lambs. Later in development, these lambs deposited more fat compared to lean when in

their “compensatory growth” period, but after 146 days of normal feeding, these lambs had a similar cross sectional measurement for the *longissimus dorsi* muscle and less fat compared to the control lambs. It was hypothesized that nutrient deprived lambs altered their growth pattern to increase the muscle content. These deprived lambs needed less nutrition to gain weight, and also had altered metabolic processes (Tygesen et al., 2008).

Lambs fasted 24 to 72 hours have been found to have differences in carcass characteristics. Lambs fasted for longer periods of time had smaller body walls, less kidney fat weight, lower marbling scores, and darker colored lean (Riley et al., 1981). George et al. (1966) also found that heavier carcasses lost a smaller percent of their weight during a 72 hour fast period compared to lighter lambs. This study indicated that even short periods of fasting can affect carcass quality.

Finishing Type

Several studies have reported differences in carcass and meat quality from lambs fed forage versus concentrate diets. Animals fed concentrate diets had higher average daily gains and had more fat at the same age than those fed forage diets (Summers et al., 1978; McClure et al., 1994; Fluharty et al., 1999; Priolo et al., 2001). Priolo et al. (2001) noted that animals slaughtered at a constant age have different weights, and those slaughtered at a constant weight have different ages when comparing concentrate versus forage fed lambs.

Muscle also was affected by the different diet regimens. Animals fed a concentrate diet had a higher hot carcass weight, larger loin eye, greater dressing percentage, and loin eye area ratio (cm^2 LEA/ kg HCW) (Fluharty et al., 1999). Priolo et al. (2001) found that forage based lambs had lower muscle conformation scores, while concentrate fed lambs had more lean ($P <$

0.05), less fat ($P < 0.01$), and similar bone content to the forage fed lambs. However, lambs fed an alfalfa diet had similar muscle mass but less fat than concentrate lambs. Carcass weights of for the alfalfa fed versus the drylot fed lambs were not statistically different, but were different from the lambs that were fed orchard or rye grasses (McClure et al., 1994).

Lambs fed a concentrate diet had an increased rate of fat accretion in comparison to lambs fed a forage based diet (Summers et al., 1978; McClure et al., 1994; Fluharty et al., 1999; Priolo et al., 2001). Summers et al. (1978) showed that animal fatness was greatest for drylot fed lambs, intermediate for lambs fed both pasture and concentrate, and lowest for lambs solely fed forages. Priolo et al. (2001) found that concentrate fed lambs had an average carcass weight of 15.8 kg, while grass-fed carcasses only averaged 14.7 kg. Differences were found in intramuscular fat ($P < 0.05$) content between the two feeding types (Priolo et al., 2001). This corresponded with the finding that drylot fed lambs were fatter, but lower in moisture, ash, and protein content when compared to grass-based systems (Summer et al., 1978).

Along with differences in fat thickness was the difference in internal organ sizes. Fluharty et al. (1999) found that lambs fed alfalfa had greater liver, omasum, abomasum, small intestine, cecum, and large intestine weights in comparison to lambs fed a concentrate diet. However, lambs fed the concentrate diet had a greater ($P < 0.01$) accretion of visceral fat (Fluharty et al., 1999). Priolo et al. (2001) concluded that concentrate lambs had a heavier carcass and smaller digestive tract, while forage raised animals had a higher dry matter intake and thus a more developed digestive tract. Fluharty et al. (1999) suggested that the larger organ size resulted in a greater energy requirement, so this could have played a role in the smaller hot carcass weight, loin eye area, and dressing percentages in the forage fed lambs.

CARCASS YIELDS

Lamb carcass composition is a moderate to highly heritable trait with estimates ranging from h=0.40 for lean and h=0.45 for fat (Stanford et al., 1998). This means that carcasses are reasonably consistent, especially when looking within the same breed. Carpenter et al. (1964) found that total fat trim was a more reliable measure of carcass value than the percentage of leg, loin, rack, or shoulder. In addition, they found that loineye area was an accurate measure of muscling within a narrow range of carcasses (Carpenter et al., 1964). Most carcasses are assessed based on hot carcass weight, but it was never the best predictor of saleable meat yields (Stanford et al., 1998). Carpenter et al. (1964) was the first to show that as carcass weight increased, fatness increased, and yield of retail cuts declined. In a study by Kemp et al. (1970), average carcass fats ranged from 25.67% in light rams to 34.58% in heavy wethers. They also found that as weight increased, the percent edible portion significantly ($P < 0.01$) decreased for the major cuts and overall carcass. In addition, as weight increased, yields of breast, flank, kidney, and pelvic fat increased, while leg, shank, kidney, and bone waste decreased (Kemp et al., 1970). Snowder et al. (1994) positively correlated hot carcass weight with percentage of kidney and pelvic fat ($r = 0.57$), body wall thickness ($r = 0.82$), and extracted fat ($r = 0.63$), but negatively correlated with leanness (chemical protein) and moisture ($r = -0.55$ and -0.63) respectively. Jones et al. (1995) reiterated this finding by stating that fatness was the most important variable influencing saleable meat yield and, on average, saleable meat yield decreased by 40 g/kg from the leanest to the fattest groups of carcasses.

With a larger carcass comes a larger ribeye area and greater back-fat and rib-fat thickness when considered on a per unit weight basis. Heavier lambs had a higher dressing percentage and less cooler shrink. Heavier lambs produced heavier cuts and a heavier product. However, this

also required a larger fat trim component which can be costly in both yield and economic categories (George et al., 1966).

Sex can also influence carcass yields. Ewe carcasses were found to have lower yields of meat than wether carcasses and rams had a higher yield than wethers when slaughtered at 36, 45, or 54 kilograms respectively (Kemp et al., 1970; Jones et al., 1995). Rams produced more ($P < 0.01$) retail leg, loin, rack, breast, and flank and more ($P < 0.05$) retail shoulder than wethers. In addition wethers were fatter than rams and had higher dressing percents (50% versus 48.4% respectively). However, in the Kemp et al. (1970) study, carcass grade was not affected by sex but more by weight with the heavier wether carcasses grading higher than the ram carcasses. Carcass leans, calculated as a percent of the whole carcass, ranged from 52.42% in heavy wethers to 57.43% in light rams (Kemp et al., 1970). Ewe carcasses had lower yields of saleable meat than wether carcasses, but the difference was smaller when kidney fat was excluded (Jones et al., 1995). Sex class does play a role in determining saleable meat yield, but differences in yield are influenced more by carcass size and fat than from gender effects.

NUTRITIONAL CONTENT

Fat

The amount of fat remaining on meat products has declined in recent years. According to Williams (2007), Australian lamb is lower in fat compared to beef and veal. A trend was set in the marketplace to increase the lean-to-fat ratio by breeding and modern meat cutting techniques. Since this trend began, trimmed lean meats have become relatively low in fat content (<7%) (Williams, 2007). In the United States, the lean-to-fat ratio is approximately 74:26 compared to 89:11 in Australia (Hoke et al., 1999). Enser et al. (1995) compared beef, pork, and lamb for fat

content. They found that lamb had the highest proportion of adipose tissue, averaging 30.2% compared to the 15.6% in beef and 21.1% in pork (Enser et al., 1995). In a more recent study, Badiani et al. (2004), as well as Maranesi et al. (2005), examined Italian heavy lamb carcasses. Once cooked, lamb fat values ranged from 2.70 to 16.5% with an energy value (protein and fat) of 106 to 209 kcal (Badiani et al., 2004; Maranesi et al., 2005).

Mir et al. (2000) completed a study in Canada testing three different dietary treatments: pellets, safflower oil and pellets, or conjugated linoleic acid and pellets. No significant differences were found in total lipid content from samples collected from the diaphragm, leg, rib, and liver. However, the amount of lipid in the liver and subcutaneously in lambs supplemented with conjugated linoleic acid was smaller ($P < 0.05$) compared to the control diet, and the safflower oil lambs had a much higher subcutaneous fat content compared to the control lambs (Mir et al., 2000).

Location in the body can affect the amount of fat extracted. Badiani et al. (1997) examined the nutrient content of both leg and rib-loin roasts after cooking. In the analysis, they found that the leg had more fat retention compared to the rib-loin (Badiani et al., 1997). Hoke et al. (1999) found the opposite; the leg had less grams of fat when compared to the rib and blade cuts. Van Heerden et al. (2007) confirmed the findings of Hoke et al. (1999) that the fat content in grams of the leg was less than that of the shoulder and loin cuts.

Moisture

According to the Dietary Reference for Intakes recommended daily intake guide (RDI), the average male over the age of 19 should consume 3.7 L of water per day, while a woman over the age of 19 should consume 2.7 L of water per day (2005). By definition, total water is

considered to be all water contained in food, beverages, and drinking water (DRI, 2005). Meat products contain water that helps to reach this average daily requirement.

Moisture is said to have an inverse relationship with fat (Fleming., 1969; Hoke et al., 1999; van Heerden et al., 2007). In general, lean meat contains approximately 3.5 g of water per gram of protein, which equates to about ten times as much as the water hydration of other commonly known proteins. Thirty to fifty percent of the total moisture of a meat product is free water (Wierbicki and Deatherage, 1958). Maranesi et al. (2005) found that moisture content of raw lamb legs to be much higher than that reported by Weirbicki and Deatherage (1958); ranging from 67.5 to 76.5%, while Hoke et al. (1999) found the average moisture content of rib-roasts and legs to be 73%.

An average lamb carcass will lose approximately 5.7% of its weight in water losses (i.e., evaporation and sublimination). In the carcasses studied, a correlation coefficient between fat and water of 0.941 ($P < 0.01$) was found when looking at the moisture content of the leg, loin, rack, forequarter, and flap (Fleming 1969). Badiani et al. (1997) and Hoffman et al. (2003) found moisture content of raw lamb legs to range from 66 to 74 g per 100 g of lean.

Protein

Lamb is an excellent source of protein. Raw red meat is said to have around 20 to 25 g of protein per 100 g of raw meat with approximately 94% of the protein being digestible compared to 78% in beans and 86% in whole wheat (Williams, 2007). Badiani et al. (1997) found roasted lamb leg had 57 to 62% of the daily protein needed for an adult of either gender on a mixed diet. In addition, the leg provided 5.5% of the daily energy for men and 7.2% of the daily energy for women (Badiani et al., 1997).

In general, raw lamb meat has a percent of total cut protein value ranging from 15 to 24% (Lubbadeh et al., 1999; Badiani et al., 2004; Maranesi et al., 2005; van Heerden et al., 2007). Once cooked, lamb percent protein levels increase. Badiani et al. (2004) found protein levels to increase from 15.0 to 22.6% in raw meat to 24.4 to 34.4% in cooked lamb leg. Van Heerden et al. (2007) compared multiple cuts from various lambs. In the raw form, the leg had the highest grams of protein per 100 grams of sample, but once cooked the loin and shoulder surpassed it in grams of protein per 100 grams of edible portion. The loin contained the highest average grams of protein when cooked with a value of 27.79 g per 100 g edible portion (Van Heerden et al., 2007).

Ash

Ash values indicate the amount of inorganic material in a product. Raw lamb ash content was found to be very low, ranging from 0.90 to 1.20% (Badiani et al., 2004; Maranesi et al., 2005). Per 100g of lean lamb meat, van Heerden et al. (2007) found mean ash value of 2.88 g for raw meat and 1.07 g for cooked, with the loin having the highest ash value and the shoulder having the lowest. Other studies found ash values of raw lamb to be 1.11 to 1.13g (Badiani et al., 1997) to 0.93 g (Hoke et al., 1999). Once cooked, ash values varied from 1.08-1.09g in the Badiani et al. (1997) study, to 0.83g in the Hoke et al. (1999) study.

Fatty Acids

Fatty acids are one of the most controversial topics when it comes to the diet. Saturated and trans fatty acids are said to be “bad” fatty acids, with dieticians recommending intake to be

as low as possible. Other fatty acids are essential, and many of the essential fatty acids (C18:2, C18:3α, C18:3ɣ, C20:3, C20:4, C20:5, C22:6) are present in meat sources.

Ruminants are said to have a low polyunsaturated fatty acid (PUFA) to saturated fatty acid (SFA) ratio due to rumination (Enser et al., 1997; Wood and Enser 1997; Sañudo et al., 1999). Microorganisms hydrogenate fatty acids in the rumen, which helps to make the n-6: n-3 ratio low as recommended by dieticians (Sañudo et al., 1999). Enser et al. (1997) found the PUFA: SFA ratio to be approximately 0:15 for lamb and the n-6: n-3 ratio to be 1:3, both of which are below the British Department of Health recommended values of 0:45 and 4:0, respectively. SFA values for lean were found to be approximately 40%, while PUFA's range from 11% to 29% of the total fatty acids (Williams 2007). Mean values for SFA, MUFA, and PUFA's were 10.6, 9.28, and 2.10% (Badiani et al., 2004).

In raw lamb meat, the most prevalent fatty acids in descending order were oleic, palmitic, and stearic acids (Enser et al., 1997; Rowe et al., 1999; Badiani et al., 2004; Maranesi et al., 2005). Linoleic and myristic acids followed, but there was a significant distance between the oleic, palmitic, and stearic and linoleic and myristic acids (Badiani et al., 2004; Maranesi et al., 2005). When compared to beef and pork, lamb muscle had the highest percentage by weight of total fatty acids of stearic acid, as well as having the highest percentage by weight of total fatty acids at 18.1%. Myristic acid also was highest in lamb muscle, which contained around 155 mg per 100g of raw lean. Lamb also topped beef in presence of C18:1 trans (Enser et al., 1997).

In general, SFA's comprise 48% of the fat component of red meat (Williams, 2007). In the study by Enser et al. (1995), lamb samples had the highest percent of adipose tissue and intramuscular fatty acids (4.9%). Lamb fat contained twice as much stearic acid on a mg per 100 g basis when compared to beef or pork. In addition myristic acid concentration was highest in

beef and lamb adipose compared to pork. C18:1 trans was highest in lamb adipose tissue. However, pork adipose tissue contained ten times more linoleic acid compared to lamb fat (Enser et al., 1995).

Conjugated linoleic acids (CLA) may contain anti-carcinogenic and weight loss properties that are good for human health. Due to the obesity epidemic, CLA's have been popular to study. Total CLA content for raw lean was found to be approximately 12.78 mg per 100 g of edible portion, while total CLA for cooked lamb was 19.62 mg per 100 g of edible portion (Badiani et al., 2004). The Badiani et al. (2004) mean composition values were similar to the CLA content found by Maranesi et al. (2005), which were 14.8 mg per 100 g of edible portion for raw meat and 23.2 mg per 100 g for cooked. When solely examining lipid content, CLA values were 4.27 mg per g for raw fat and 4.40 mg per g for cooked fat (Maranesi et al., 2005). When considered from a dietary standpoint, lamb rib-loin provided between 4.7 to 9.5% of the adequate daily intake for linoleic acid and the leg provided 5.9 to 11.9% (Badiani et al., 1997).

Fatty acid distribution and retention differed depending on the muscle being discussed. Badiani et al. (1997) found that mg per 100 g concentrations of C18:3, C18:2 conjugated, C20:2, and C20:4 were different when comparing the leg to the rib-loin with the leg having the lower retention values. When comparing the *semimembranosus* to the *longissimus dorsi*, the lamb *semimembranosus* muscle was higher in C16:1, C18:1, C18:2, and C18:3 content, and lower in C18:0 than the *longissimus dorsi* muscle. In addition, the leg had a higher concentration of C18:1 than the back muscles (Bas et al., 2000). Van Heerden et al. (2007) also found the raw leg to have the lowest g per 100 grams of lean fatty acid content compared to the raw shoulder and loin. Also, the leg contained the lowest g per 100 grams of lean fatty acid content of C16:0 (1.50

g/100 g), C18:0 (0.88 g/ 100 g), C18:1n9c (2.14 g/100 g), and C18:2n6c (0.17 g/ 100 g) (Van Heerden et al., 2007).

Breed can also play a role in the fatty acid content of lamb meat. Differences have frequently been found among lamb of different breeds in palmitic, stearic, and oleic acids (Boylan, Berger, and Allen 1976; Sañudo et al., 2000; Hoffman et al., 2003; Díaz et al.,2005). Boylan, Berger, and Allen (1976) compared the fat of F_1 progeny of Finnsheep, Suffolk, and Targhee mixes. They found that the F_1 crossbreds had a greater percentage of myristic, pentadecanoic, and heptadecanoic acids and a lower percentage of stearic and oleic acids compared to the purebreds. In addition, there was a smaller ($P < 0.01$) ratio of palmitic: palmitoleic and a larger ($P < 0.01$) ratio for oleic: stearic in the fat from the crossbred F_1 lambs compared to the purebred lambs. These ratios affected the melting point of lamb fat (Boylan, et al., 1976). In the *semimembranosus* muscle, Hoffman et al. (2003) found MUFA's and SFA's to differ ($P < 0.05$) by breed. They found oleic acid to be the most abundant MUFA, while linoleic acid was the most abundant PUFA. The most abundant SFA was palmitic acid followed by stearic acid. Differences also were found between breeds for palmitic, behenic, and lignoceric acids (Hoffman et al., 2003).

Fatty acid content of British breeds of sheep has commonly been compared to other breeds. Sañudo et al. (2000) found British breeds to have higher mg per 100 g of intramuscular fat of the major fatty acids (palmitic, stearic, and oleic) when compared to German and Spanish sheep breeds. However, Spanish lambs had the highest PUFA: SFA ratio (0.33 versus 0.14-0.15). Within the different breeds, stearic acid had the largest percent difference between the Spanish and British groups ranging from 12.9 to 13.7% in British breeds and 21.1 to 22.2% in Spanish breeds (Sañudo et al., 2000). In a similar study by Díaz et al. (2005), British lambs had

the highest proportion of stearic acid, while Uruguayan lambs had the highest proportion of palmitic acid. Also in this study, Spanish lambs had the lowest proportion of palmitic and stearic acids compared to the other lambs (Uruguayan and British). However, the Spanish lambs did have the highest proportion of arachidonic acid as well as the lowest abundance of intramuscular fat. Similar to the Sañudo et al. (2000) study, the Spanish had the highest PUFA: SFA ratio while the German and British breeds had the lowest (Díaz et al., 2005).

Corn-based diets fed to lambs results in a different fatty acid profile compared to the pasture-based diets. L'Estrange and Mulvihill (1975) examined fatty acid content in the fat of lambs fed a concentrate diet. They found that there were very high levels of odd-numbered and branched-chain fatty acids in subcutaneous fat (L'Estrange and Mulvihill, 1975). In addition, lambs fed whole barley resulted in firmer fat and lower concentrations of C7-C18 branched-chain fatty acids (Wood and Enser 1997). Similarly, Kromann and Cosma (1975) found higher levels of myristoleic, palmitoleic, oleic, and linoleic acids when corn was the main food source for lambs. All C7 to C18 acids are derived from propionic acid, and the levels of this acid are increased when there is an increase of soluble carbohydrate in the diet (Wood and Enser, 1997).

More recent studies showed that feeding corn increased unsaturated fatty acid content of lamb meat. Concentrate diets increased the amount of oleic acid (C18:1) and decreased the amount of saturated fatty acids (Bas et al., 2000; Duckett and Kuber, 2001). As the level of corn increased, the percentage of myristic (C14:0), palmitic (C16:0), and linoleic (C18:2 n-6) increased, while stearic (C18:0) decreased. Also, concentrations of oleic (C18:1) increased and α-linolenic acid decreased (Duckett and Kuber, 2001).

Supplementation with different oils can increase the levels of certain fatty acids in the diet. Lambs supplemented with sunflower seed oil (58 g/ kg concentrate diet) had higher

concentrations of linoleic acid; increasing from 2 g to 7 g/ 100 g in perirenal fat (Wood and Enser, 1997). Lambs fed a protected lipid supplement developed much higher concentrations of C18:3 n-3 and C18:2 n-6 compared to meat from lambs fed grass or linseed supplementation. Linseed-fed sheep produced lamb meat with higher concentrations of C18:3 n-3, C18:2 n-6, and C18:1 n-9 compared to lamb from sheep solely fed grass (Elmore et al., 2005). However, feeding linseed oil did not have an effect on docosahexaenoic acid (DHA) levels in muscle (Raes et al., 2004). Feeding fish oil increased the n-3 content in lamb meat (Demirel er al., 2004; Raes et al., 2004). Meat from lambs fed linfish supplement had the highest amount of neutral CLA's (mg/100g) when compared to Megalac and linseed supplements (Demirel et al., 2004). Raes et al. (2004) found a marked increase in the total n-3 content, especially noted by the increased DHA and eicosapentaenoic acid (EPA) concentrations in the muscle when lambs were supplemented with fish oil.

Unlike beef, lamb has more short chain fatty acids that contribute to mutton flavor and odor (Hornstein and Crowe, 1963; Wong et al., 1975; Elmore et al., 2005). Fatty acids containing 8 to 10 carbons are said to be the primary contributors of the undesirable flavor of cooked mutton (Wong et al., 1975). Subsequent research indicates that there are fourteen compounds that contribute to overall flavor (Crouse et al., 1982). Of these volatile compounds, most notably, are 4-methyloctanoic, 4-methylnonanoic, and 4-ethyloctanoic. All three of these compounds have been found to attribute to muttony or goaty flavor characteristics. The presence of these compounds in parts per million was much higher than the threshold values of acceptability of flavor for detection (Brennand and Lindsay, 1991).

Cholesterol

With increased interest in health, consumer's frequently question the amount of cholesterol in the food they eat. The American Food and Nutrition Board recommended that dietary cholesterol intake be as low as possible while still maintaining a nutritionally adequate diet (2005). Red meat is known for being low fat, moderate in cholesterol, and rich in proteins, vitamins, and minerals (Williams, 2007). Badiani et al. (1997) found that a 100 g serving provides 36% of the safe daily intake of cholesterol, which in 1997 was set to approximately 300 mg per day. Another study reported cholesterol values of control lambs to be between 67.1 and 68.3 mg/ 100g of meat (Lubbadeh et al., 1999).

Animal diet can play a role in the cholesterol content of the animal. Williams (2007) stated that animals fed on pasture have lower cholesterol contents than those fed a grain diet. Arsenos et al. (2000) found that there was a general trend for cholesterol content to be lower in fat samples excised from carcasses that had a higher target end weight. Also, they found that diet restrictions resulted in significant changes in cholesterol content of carcass fat (Arsenos et al., 2000). As the proportion of concentrate allowances decreased and Lucerne hay increased, the cholesterol content in carcass fat increased ($P < 0.001$); however, lambs finished on pasture had lower cholesterol content compared to those fed indoors on concentrate and Lucerne hay (Arsenos et al., 2000; Rowe et al., 1999). In addition, lambs fed low levels of concentrate deposited more cholesterol in carcass fat compared to those fed on high levels (Arseonos et al., 2000). Swize et al. (1991) also found that *semimembranosus* steaks with 0.6 cm of fat had higher ($P < 0.05$) cholesterol content than denuded steaks. However, in this same study, raw *longissimus* steaks did not differ in cholesterol content from the denuded steaks (Swize et al., 1991).

Breed can also play a role in cholesterol content. Arsenos et al. (2000) found that breed, degree of maturity, and the interaction between breed and target slaughter live weight were statistically significant ($P < 0.001$). It was found that high levels of cholesterol content in carcasses were deposited before lambs reached the first half of their mature live weight. However, breed was found to have the largest influence on cholesterol content. Greek lambs were used in this study, and their range of cholesterol values was between 135 and 184 mg/ 100 g adipose; indicating that Greek sheep breeds produced carcasses with lower cholesterol content (Arsenos et al., 2000).

Vitamins

Lamb is an excellent source of vitamin B_{12}. A 100 g serving provides up to two-thirds of the RDI of B_{12} and up to 25% of the daily intake of riboflavin, niacin, B_6, and pantothenic acid. However, lamb is a poor source of thiamin, vitamin A, folate, and vitamin D (Williams, 2007).

Few studies have examined the amount of vitamin retention in lamb after cooking. McIntire et al. (1943) considered different cooking methods and their subsequent effects on vitamin retention. Roasting and broiling were found to result in the highest vitamin retention values compared to braising and stewing. Average retention for thiamin after roasting was 57%, after broiling was 70%, after stewing was 26%, and after braising was 40%. Riboflavin was retained in much higher amounts after cooking; averaging between 87 to 101% in all cooking methods, while nicotinic acid levels were lower than riboflavin ranging from 92 to 100% (McIntire et al., 1943).

Different muscle types yield different vitamin concentrations. Badiani et al. (1997) found that the rib-loin had higher vitamin concentrations compared to the leg. However, in both cuts, vitamin B_{12} far exceeded the recommended daily intake (Badiani et al., 1997). The rib-loin,

when roasted, contained 28.8% and 16.1% of the RDI of niacin and riboflavin, respectively, while the leg only provided 23.8% and 17.5%, respectively. The rib-loin provided 12.9% of the RDI of vitamin B_6 and the leg provided 9.1% of the RDI for vitamin B_6. Similarly, thiamin concentrations ranged from 9.6% in the rib-lion to 6.9% in the leg (Badiani et al., 1997). Similarly, Hoke et al. (1999) found the highest thiamin content to be in the rib, loin, and leg cuts, while lowest was in the foreshank. Riboflavin content was highest in the loin and leg, while vitamin B_{12} content was highest in the shoulder and leg cuts (Hoke et al., 1999). Cooked shoulder, loin, and leg cuts on average provided 11% of the daily B_3, 6% of the B_6, 4% of the B_2, and 3% of the B_1 RDI's (Van Heerden et al., 2007).

Minerals

Lamb is one of the richest sources of the minerals iron and zinc. 100 g of lamb provides approximately one-quarter of the daily adult requirements (Williams, 2007). Badiani et al. (1997) found that a cooked lamb rib-loin roast provided 27.9, 23.9, and 15.7% of the required daily intake of phosphorous, zinc, and iron, while a roasted lamb leg provided 28.8, 32.4, and 21.4% of these minerals, respectively. When comparing cuts on a wet weight basis, the rib-loin was richer in calcium and potassium than the leg (Badiani et al., 1997). Van Heerden et al. (2007) found raw lamb loin contained 0.99 mg iron / 100 g of raw meat, while the raw shoulder had 0.75 mg/ 100 g and the raw leg had 1.14 mg/ 100 g. Cooking of lamb increased iron content, but concentration of iron in lamb meat is lower than beef loin (Van Heerden et al., 2007).

Red meat is a good source of selenium (20% RDI), is low in sodium, and has small amounts of copper (Williams, 2007). When examining the Australian breeds of sheep, Hoke et al. (1999) found that location of the cut affected the concentration of minerals. Thiamin content was highest in the rib, loin, and leg cuts, and was lowest in the foreshank. Riboflavin content

was highest in the loin and leg, while zinc concentrations were lowest in the loin and highest in the foreshank and shoulder cuts. Finally, iron content was lowest in the shoulder and highest in the loin (Lin et al., 1988; Hoke et al., 1999). Muscles primarily comprised of red fibers had higher levels of iron, copper, sodium, zinc, and lower levels of potassium than white fibers (Lin et al., 1988).

CHAPTER II

THE EFFECT OF DAM NUTRIENT DEPRIVATION ON LAMB CARCASS YIELDS, RETAIL CUTS, AND NUTRIENT COMPOSITION

SUMMARY

The objective of this study was to determine the effect of dam nutrient restriction on offspring carcass characteristics, retail cut yields, and nutrient composition. Forty one western white rams and ewes were obtained from a previous Colorado State University study of dam nutrient restriction. Prior to gestation, dams were fed 100% of their nutrient requirements. The diet of dams was a vitamin-mineral rich pelleted beet-pulp (77.8% total digestible nutrients [TDN], 90.0% dry matter [DM], and 9.4% crude protein [CP]). At 28 days gestational age, dams were randomly assigned to individual pens and separated into three different treatments: control (100% nutrient requirements), half ration (fed 50% of their nutrient requirements from day 28 until term), and realimented (fed 50% of their nutrient requirements from day 28 until day 78, and then slowly realimented back to 100% for the remainder of gestation). All twin lambs were slaughtered, and hot carcass weight, 12^{th} rib fat, body wall thickness, adjusted fat, ribeye area, ribeye marbling, leg score, leg circumference, conformation, flank streaking, flank firmness, flank color, kidney fat weight, L*, a*, and b* were obtained. After all lambs were slaughtered, one half of each lamb carcass was fabricated in the following subprimals: rack, roast ready, frenched PSO 3x1" (IMPS 204C); shoulder, square-cut, boneless (IMPS 208); Denver ribs, skirt-off (IMPS 209A); Foreshank (IMPS 210); loin, short-cut, trimmed PSO 0x0" (IMPS 232A); flank untrimmed (IMPS 232E); leg, hindshank (IMPS 233F); and leg, shank-off, boneless (IMPS

234A). Lastly, all lambs were utilized to determine dry matter, moisture, crude protein, crude fat, ash, vitamins A and E, trace minerals, and fatty acids. No interactions were found between treatment and gender for any characteristic, so treatment and gender were analyzed separately. Lambs of ewes that were nutritionally restricted were smaller in size with less fat. Lambs of the realimented group had more fat than either the control or the half ration groups. Rams had more percent lean content than ewes, which was to be expected. Results of this study provide insight on the effect of nutrient restriction on lamb growth and development, as well as nutrient content of American lamb.

INTRODUCTION

Throughout the world, sheep are raised in climates where there is the potential for extreme variation in forages. Many of these places have huge fluctuations in quantity and quality of forages available. Often, less than 50% of the requirements for gestation are not met, and even after supplementation is available later in gestation, lamb growth and development is compromised (Vonnahme et al., 2003).

Studies have shown that maternal nutrient intake will influence the development of offspring (Daniel et al., 2007); regardless of the type of deprivation (protein, calories, or both), maternal dietary restriction can negatively impact the growth and development. During deprivation, a fetus may adapt to the lack of nutrition being provided in order to survive (Harding and Johnston, 1995). Notably, offspring have decreased birth and growth rates, less lean muscle, and increased adiposity (Hegarty and Allen, 1978). In addition, lambs of nutrient restricted ewes have reduced visceral organ sizes (Burrin et al., 1990).

Animals will adapt to nutrient restriction by changing the rates of bone, muscle, and fat deposition (House, 2011). If a ewe is consistently fed half of a normal diet early in gestation through the rest of term, it is very likely that the offspring will suffer in all aspects of growth. Even if the lamb is fed a normal ration, its development will be retarded. The rate of deposition of bone, muscle, and fat have been altered, so when fed a healthy diet, it will take a long time for it to compensate for the stunted development that occurred in utero (House, 2011).

Ewes that were restricted nutritionally and realimented back to a healthy ration will still produce lambs of reduced size at first, but such lambs can compensate for the nutrient deprivation better than those offspring of ewes consistently restricted of nutrients. These lambs will exhibit a type of "compensatory growth" and offspring will gain more mass later (Greenwood et al., 1998).

Lack of nutrition affects carcass characteristics of lambs. Daniel et al. (2007) found that nutrient deprived ram lambs of nutrient deprived ewes will increase fat content and ewe lambs will have a decreased fat content at slaughter. This increase in adiposity is an undesirable characteristic since consumers want leaner products with less fat (Stanford., 1998). Lack of nutrition of ewes will decrease lean yields of the offspring which in turn will impact the size of retail cuts. This is of particular concern for vendors since meat is sold on a per pound basis. The lower yield product will in turn yield less money in the long run for the seller.

Due in part to an increased concern with obesity, consumers more often assess fat content of products they are purchasing. Red meat is said to be a good source of protein, many essential vitamins and minerals, a moderate source of cholesterol, and a low fat content (Williams 2007). However, it is hypothesized that nutrient restriction will have an impact of the nutrient composition of lamb. Potentially, there could be varying levels of nutrients depending on how

long the animal was deprived and if the restriction caused the body to become more sensitive to certain molecules (i.e., certain vitamin or mineral concentrations). Studies have shown that low birth weight lambs require additional time to adapt to a diet outside of the fetus. This slower growth led to higher amounts of protein, ash, and less fat compared to control lambs (Greenwood et al., 1998). These findings indicate that maternal nutrition is an important aspect to consider when considering the nutrient composition lambs and the long run impact on the industry.

Thus, the objectives of this study were to determine the effect of maternal diet restriction at varying levels on carcass characteristics, retail weights, and nutritional values on lambs.

MATERIALS AND METHODS

Selection:

Forty-one multiparous, western white faced rams and ewes were obtained from a previous Colorado State University study of dam nutrient restriction. Procedures for this study complied with the requirements of the United States Department of Agriculture. Protocols for care and use were approved by the Colorado State University Institutional Care and Use Committee. Prior to gestation, dams were fed 100% of their nutrient requirements. The diet of dams was a vitamin-mineral rich pelleted beet-pulp (77.8% total digestible nutrients [TDN], 90.0% dry matter [DM], and 9.4% crude protein [CP]). At 28 days gestational age, dams were randomly assigned to individual pens and separated into three different treatments: control (100% nutrient requirements), half ration (fed 50% of their nutrient requirements from day 28 until term), and realimented (fed 50% of their nutrient requirements from day 28 until day 78, and then slowly realimented back to 100% for the remainder of gestation). On day 78, realimentation consisted of increasing the feed ration back to 100% over a one week period.

Only twin lamb offspring were used in data collection because fewer studies have examined twin nutrient restriction compared to singleton lambs. In addition, twins are more prevalent in the western United States than singletons and triplets. Once born, lambs were allowed to suckle freely or provided with milk replacer when ewes were not able to produce enough milk. At 10 weeks of age, offspring were weaned and provided with 150% of their recommended feeding rate. Offspring were fed a pelleted feed consisting of 90.5% dry matter (on a dry matter basis the diet contained NEm, Mcal/kg=1.67; NEg, Mcal/kg=1.03; TDN, %=73.3; crude protein, %=9.4; crude fat, %= 0.63).

All offspring were humanely slaughtered at 18 weeks of age in a facility located in Evans, Colorado. Carcasses were chilled at the slaughter facility (2°C) for 24 hours. At 24 hours post mortem, carcasses were evaluated and hot carcass weight, 12^{th} rib fat, adjusted rib fat, body wall thickness, ribeye area, marbling score, leg score, leg circumference, conformation, kidney fat weight (g), flank streaking, flank firmness (soft, firm, extra firm), and flank lean maturity and color were determined. In addition, ribeye L*, a*, and b* were measured using a Hunter Lab Miniscan^{TM} (Hunter Lab Associates, Inc., Reston, VA). Kidney fat was removed from both sides of the carcasses and weighed after chilling. One half of each lamb was quartered at the facility in Evans, Colorado and frozen (-20°C) until fabrication at the Colorado State University Meat Laboratory.

Fabrication:

Once defrosted for 24 to 48 hours, lamb foresaddle and hindsaddle weights were recorded separately. Carcasses were fabricated into the following subprimals: rack, roast ready, frenched PSO 3x1" (IMPS 204C); shoulder, square-cut, boneless (IMPS 208); Denver ribs, skirt-

off (IMPS 209A); Foreshank (IMPS 210); loin, short-cut, trimmed PSO 0x0" (IMPS 232A); flank untrimmed (IMPS 232E); leg, hindshank (IMPS 233F); and leg, shank-off, boneless (IMPS 234A). All subprimals were trimmed of fat to an approximate 0.3 cm level and weighed. Once subprimals were weighed, bone and connective tissue were separated from lean and fat, each constituent was individually weighed, and vacuum packaged. The weight of the lean/fat and bone/connective tissue was summed and divided by the hindsaddle + foresaddle weight; 98 to 102% of the carcass weight was required to be accounted for. Lean and fat were ground using a table top grinder. After an initial coarse grind (Hobart Model 84186, Troy, OH), the lamb was mixed for approximately one minute in a standing mixer (Keebler Engineering Co., Chicago, IL). This product was then fine ground, using the table top grinder, and evenly distributed throughout a 1.89 L Sterilite tub (Sterilite Corporation, Townsend, MA). Three sample areas were selected using a 5.1 cm diameter PVC pipe. Approximately three 100 g samples from the PVC pipe were placed into a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), labeled, and stored at -20°C until further analysis.

CHEMICAL ANALYSIS

Homogenization:

Ground lamb samples were sorted by identification number and two of the 100 g Whirl-Pak bag samples from the same lamb were combined for homogenization. The product was submersed in liquid nitrogen and homogenized using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS) until the contents became a fine powder. Homogenized samples were placed into a new Whirl-Pak bag (Nasco, Ft. Atkinson, WI), labeled, and stored at -80°C until further analysis.

Dry Matter and Moisture Analysis

Dry matter and moisture were determined by following the AOAC moisture removal process (AOAC, 1995). A 2 g sample from each lamb was placed into an aluminum tin (low form, aluminum, fluted; Fisher Scientific, Pittsburgh, PA). Samples were placed into a forced air drying oven (Thelco Lab Oven, Mandel Inc., Guelph, Ontario, Canada) at 100°C for at least 16 hours and then placed into a desiccator to cool. Tins were removed from the desiccator and total weight (dry sample + pan) was recorded. The loss of weight after drying was considered the percent moisture. Remainder weight was considered dry matter. Both weights were multiplied by 100 to obtain the percent moisture values.

Ash Analysis

Ash was determined based on the oven method described in AOAC (1995). Approximately 1 g of sample was placed into a dry, pre-weighted crucible. Crucibles were placed into a Thermolyne box furnace at 600°C and burned for 12 h (Thermo Fisher Scientific, Pittsburgh, PA). The crucibles were allowed to cool in a desiccator before being weighed. Ash was calculated as the remainder by weight.

Lipid Analysis

Total lipid was extracted from a 1 g sample as stated by Folch et al. (1957) and modified by Bligh and Dyer (1959). Saponification and methylation was accomplished by adding a 2:1 chloroform methanol solution to the sample. These samples were placed on an orbital shaker and then filtered through ashless filter paper (Grade 41, Whatman Inc. Piscataway, NJ). Salt (0.9% concentration) was added, and samples were placed in a refrigerator for 24 h. Once removed, the solution was separated and the lower portion was placed into a scintillation

vial and dried under nitrogen gas, allowed to dry for approximately 30 min, and then placed in a forced air drying oven for 24 h. Samples were then weighed to determine percent fat.

Fatty Acid Determination

Fatty acids were determined using gas chromatography on a Hewlett Packard (Avondale, PA) Model 6890 series II gas chromatograph fixed with a series 7683 injector as well as a flame ionization detector and a 100-m x 0.25-mm (id) fused silica capillary column (SP-2560 Supelco Inc. Bellefonte, PA). At a flow rate of 1.0 ml/min, helium was used as the carrier gas. The column temperature was steadily increased to reach a peak temperature of 225°C. Each sample ran for approximately 100 min, and individual fatty acids were determined based on frequency of appearance which was based on a HP internal standard (Nu-Chek Inc., Elysian, MN). Upon determination, fatty acids retention times were determined and had to fall within ±0.2 range to be considered to be the specific fatty acid that was denoted by the internal standard.

Protein Analysis

Crude protein was determined using the AOAC (1996) standard method. Once initialized by 10 blank standards, three more blanks of EDTA (9.75% nitrogen) were used for calibration. Approximately 0.1 g of sample was placed into aluminum combustion tins and the weight was recorded. Once optimized based on the standard, each sample was multiplied by a factor of 6.25 to determine the percent crude protein (Merrill and Watt, 1973).

Cholesterol Analysis

Determination of cholesterol content was as described by Sale et al. (1984). Tris Hydrochloride, Triton X-100, sodium cholate, horseradish peroxidase, cholesterol oxidase, cholesterol esterase, and o-dianisidine were obtained from Sigma- Aldrich Company. Ethanol

(1.5 ml) was added to folch samples, vortexed, and allowed to sit over night. 0.26 g of sodium cholate, 1 ml of triton 100-X, 0.02 g of horseradish peroxidase, 3.56 g of tris hydromethyl animomethane hydrochloride, 0.02 g of O- dianisidine, 0.50 g of cholesterol oxidase, and 0.26 g of cholesterol esterase were combined to make a solution (reagent A). Of Reagent A, 0.80 ml was added to a folch (see lipid analysis) + ethanol solution and allowed to sit in a hot water bath at 37°C for 30 min. Once removed, solutions were compared to standards that were a combination of 0.8 ml of reagent A, 0.95 g of 99% pure Sigma grade cholesterol, and 50 ml of isopropyl alcohol. Samples were read using a Spectronic GENESYS 5 (Thermo Electron Corp., Madison, WI). Absorbance was recorded and converted to give a cholesterol value in mg/ 100 g.

Vitamin Analysis

Vitamin extraction is based off of the Nutritional Biochemistry Laboratory procedures. Briefly, 0.1 g of sample was added to 1.0 ml of antioxidant. Tubes were placed in a drying oven for approximately 2 min (85°C), saturated with KOH, and then placed back in the oven for another 14 min. An additional 6.0 ml of hexane was added, and tubes were vortexed for 10 min. One half (3.0 ml) of hexanes were separated out and placed into separate tubes, and additional 1.5 ml of standard hexanes were added to each sample. Samples and standards were evaporated, and 0.70 ml of methanol was added to each tube and vortexed. Samples were then placed in an HPLC (Waters 717 Plus Autosampler, Waters Corp., Milford, MA) for analysis.

Mineral Analysis

Tissue samples were analyzed via inductively coupled plasma-atomic emission spectroscopy (ICP-AES) methods (Braselton et al., 1997 as described by Ahola et al., 2004). Approximately 2 g of homogenate sample from each lamb were extracted; however, only 1 g of sample was used for analysis. Samples were dried in Teflon containers for 4 h at 95°C then

weighed. Nitric acid was added to the Teflon container, capped, and allowed to digest over night in an oven. Digest was transferred with water to a flask and brought to volume so that the acid concentration was 5%. Samples were completed by simultaneous/ sequential ICP-AES with fixed cross-flow nebulization.

Statistical Analysis:

Data were analyzed using PROC MIXED in SAS (SAS Institute, Cary, NC). Orthogonal contrasts (Control vs. 50-100 & 50-50 and 50-100 vs. 50-50) were used with a nested repeated measurement of ewe within treatment. Means were determined for each treatment using LSMEANS, and separated using the PDIFF function. Contrasts were used to compare the control group to the two restricted groups, as well as restricted groups to each other. The class statement contained treatment, gender, and ewe. Denominator degrees of freedom were adjusted using a Kenward Roger adjustment. Type I error was set at $\alpha=0.05$, so differences were only considered if the alpha was below this level. Since no interactions between treatment and gender were found, data were analyzed looking at treatment and gender effects separately.

RESULTS AND DISCUSSION

Carcass Characteristics

Carcass data separated by treatment are presented in Table 2.1 and by gender in table 2.2. Gender had a significantly larger impact on yields than treatment. Kemp et al. (1970), as well as Jones et al. (1995), found that ewe carcasses had lower carcass muscle yields than rams. In addition ram carcasses were leaner (Kemp et al., 1970). Consistently in this study, ewe carcasses were fatter and lower yielding than ram carcasses (P=0.0061 for HCW; P=0.0326 for

REA). Hot carcass weight, ribeye area, and leg score and circumference were all lower in ewes compared to rams, but ewes had higher fat measurements (body wall and fat thicknesses) and quality grades (ribeye marbling: 312.3 for rams versus 329.7 for ewes). Statistically significant differences between rams and ewes were found for hot carcass weight (P=0.0061), ribeye area (P=0.0326), flank streaking (P=0.0115), kidney fat (P=0.0194), and a* values (P=0.0283).

When separated by treatment, differences were found between all treatments, as well as between realimented and the half ration groups for kidney fat (Table 2.1). Control lambs were largest for hot carcass weight (21.17 kg), ribeye area (13.74 cm^2), ribeye marbling (332.22), leg score (10.98), leg circumference (37.37 cm), conformation (239.79), flank streaking (390.0), and flank firmness (1.76). Lambs whose dams received half of the set ration were consistently lowest for hot carcass weight, 12^{th} rib fat, body wall, adjusted fat, ribeye area, and kidney fat. These current findings are similar to the findings of Droulliard et al. (1991). In the Droulliard et al. (1991) study, lambs that were protein restricted lost protein, fat, and water at a high rate for each day that they were restricted. Once returned to a complete diet, lambs gained protein and fat at a much faster rate than control lambs, which agreed with the results of Tygesen et al. (2008). We hypothesized that there may be some altered metabolic processes, similar to compensatory gain, that occurred due to nutrient restriction. Both treatment groups had smaller ribeyes than controls (P<0.05), indicating that nutrient restriction in dams affects muscularity of offspring. Realimented and the half ration lambs differed in kidney fat (P=0.0086), with kidney fat weight being greater in the realimented lambs. This overcompensation for gain of muscle and fat had an impact on the quality of these lambs. The quality grades for ribeye marbling scores and flank streaking scores were lower compared to control lambs, while also having darker red,

more blue ribeyes based on Hunter Miniscan values. Riley et al. (1981) also found that fasted lambs had darker colored meat with lower marbling scores.

Compared to industry studies, these lambs were far lower in carcass composition than both conventionally and naturally- raised animals. However, this was expected since these lambs were not as far along on the growth curve as conventional lambs are when they are slaughtered. According to Eckerman et al. (2011), the average hot carcass weight for a conventionally- raised lamb was 37.0 kg while naturally- raised was 36.5 kg. In the present study, mean hot carcass weight, even for the control, was much less at 21.17 kg, followed by the realimented at 20.93 kg, and lastly by the half ration treatment group at 18.73 kg. In addition, lambs in this study were lower in ribeye area; with ribeyes ranging from 11.94 to 13.74 cm^2 compared to the Eckerman et al. (2011) study where ribeyes ranged from 16.58 to 17.16 cm^2. Even when separated by gender, males still did not come close to the carcass characteristics described by Eckerman et al. (2011). Since lambs were slaughtered in this study at such a young age, they did not have the time to gain muscle and fat compared to the lambs described by Eckerman et al. (2011). Regardless, the data do indicate that the nutrient restriction of the ewe influenced the development of lambs.

Even when compared to a forage fed group of lambs, lambs in the current study did not reach the average hot carcass weight of 31.4 kg for those slaughtered at 67.5% of their mature weight (Borton et al., 2005). However, lambs in our study were much younger than those in the Borton et al. (2005) study, which would have had an impact on the hot carcass weight. The lambs in this study were slaughtered at 18 weeks of age, so they did not have enough time before slaughter to reach their optimum slaughter potential weights.

When analyzed by gender rams consistently were heavier muscled and lower in fat. This finding was not consistent with the results of Daniel et al. (2007) in which rams of dams that were nutritionally deprived had an increase in the fat content of the muscle when compared to the female lambs in the study. However, this may not be a fair study to compare to since in this current study all rams and all ewes were averaged together ignoring treatment (Table 2.2). This could have been different if all animals were separated both by treatment and by gender.

Ram carcasses were heavier (P=0.0061) than ewe carcasses in this study. Similar to the Jones et al. (1995) study, ewe carcasses were smaller muscled than ram carcasses with lower saleable meat yields. Kidney fat weight was greater (P=0.0194) for ewes, so with this fat removed, there was an ever greater discrepancy in hot carcass weights between rams and ewes in this study. This also was an indicator that ewes generated carcasses with much lower saleable meat yields.

When examining the Hunter Miniscan values, rams had higher L* values, meaning that they had a brighter white color than ewes. The a* and b* values were higher for ewe carcasses. Higher a* and b* values indicated more of a red and yellow tint rather than a greener and bluer tinge that is indicated by lower a* and b* values. This makes sense since ewe carcasses had more ribeye marbling. The intramuscular fat would help to brighten the lean and give higher yellow values with a more red hue.

Daniel et al. (2007) found that feed restriction decreased fiber diameter and the amount of fast twitch fibers in both the *longissimus dorsi* and the *vastus lateralis*. The reasonably high L* values and high a* values could imply that in utero muscle differentiation was shifted more towards making white muscle fibers rather than red. With fewer red muscle fibers, there would be higher a* values (Tables 2.1 and 2.2).

Retail Yields

Information about retail cut weights compared by treatment is found in Table 2.3; retail cut weights presented by gender are shown in Table 2.4. When comparing across treatment means, the Denver rib and frenched rack were statistically different. The frenched rack was also the only significant cut when comparing the control to the two restricted groups, as well as the restricted to the half ration treatment. No other contrasts were significant. The control had the most percent lean tissue as well as a many of the boneless subprimals. Offspring of ewes that were fed half of a healthy ration had the most percent bone.

Control lambs had the highest percent of lean tissue, which indicates that nourishment was being shunted to other bodily functions in nutritionally deprived lambs while in utero. Since these lambs were deprived in utero, all nutrients were being used for survival of both the lamb and ewe. Once born, restricted lambs utilized all consumed nutrients to maintain homeostasis, and focused less on muscle growth. Interestingly, lambs of ewes that were realimented had the least amount of connective tissue and larger bone mass than control lambs. These lambs shunted most of their nutrients to facilitate bone growth rather than lean mass or connective tissue. However, realimented lambs also had a high fat content based on carcass characteristics (Table 2.1) and proximate analysis (Table 2.5). This high fat content added to the overall lean tissue mass, helping this treatment group to have the highest bone mass and second highest lean tissue mass (see Table 2.3).

Studies in cattle have indicated that in times of nutrient restriction the growth pattern and rate of deposition of bone, muscle, and fat is modified. When normal feeding resumes, nutrient restricted cattle were smaller than cattle of the same age that were not deprived. Cattle

that are severely restricted will have very little compensatory growth. If recovered too quickly, protein mass will not catch up and the animal will lay down fat faster than normally fed cattle (House, 2011). This can be extrapolated to this lamb study as well. Those that were part of the half ration treatment group were slowest at gaining lean or fat and had a much lower percent lean tissue. Those in the realimented group experienced rapid fat distribution. When examining the retail cuts from carcasses of the realimented group, the realimented lambs had the most percent fat (Table 2.5) and had a total lean tissue percentage that was close to the control groups. This indicated that the lambs in this group laid down fat as opposed to lean.

When compared by gender, no differences were found. Ewes had the highest percent of total carcass for the following subprimals: foresaddle, Denver rib, shoulder, flank, connective tissue, and total lean tissue. Since all cuts were fabricated down to a consistent 0.3 cm level, little can be attributed to fat adding weight. Kemp et al. (1970) found that ewe carcasses had lower yields than ram carcasses. This was partially due to the fact that the female carcasses had more fat than the male carcasses. This study did not find ewe carcasses to be lower in percent yield than rams, but rams did have higher percent bone which added weight (and subsequently elevated the percent of the total carcass yield) to subprimals with bone left in.

NUTRIENT COMPOSITION

Moisture and Dry Matter

All percent moisture and dry matter values can be found in Tables 2.5 and 2.6. Dry matter and moisture did not differ by treatment, but did differ by gender (P=0.0459) with rams having lower percent dry matter and higher percent moisture compared to ewes. When comparing within treatment groups, those that were the offspring of ewes fed a half ration

numerically had the highest percent of moisture at 61.47%. This percent moisture value was still lower than what both Maranesi (2005) and Hoke et al. (1999) found. Both studies found the average moisture content to be above 67.5% which in turn made percent dry matter values lower than found in this current study. Regardless of comparing by treatment or by gender in this study, none of the groups reached above 61.47% moisture. Dry matter values were high since moisture values were low.

Carcasses will lose approximately 5.7% of weight in water loss (Fleming, 1969). Since lambs in the current study lacked what is considered to be an average amount of fat, carcasses were more prone to evaporative losses. A greater amount of fat would have helped to prevent cooler shrink which could have affected the percent moisture values found in the current study.

Rams had higher percent moisture and lower percent dry matter content than ewes. Many studies have stated that moisture is inversely related to fat (Fleming 1969; Hoke et al., 1999; van Heerden et al., 2007). In this study moisture was also found to be inversely related to fat. Rams did have lower percent fat contents when compared to ewes, so rams had the higher moisture content. Rams had more lean tissue, and size of the carcasses could have helped to play a role in the amount of moisture in the product. More lean and less shrink would lead to a higher water content in the product. However, the moisture values are still lower than what previous studies have found.

Ash

Ash values did not differ by treatment or by gender (Tables 2.4 and 2.5). Biadiani et al. (2004) and Maranesi et al. (2005) found average ash values to range from 0.90 to 1.20%, while in this study; values were slightly lower, ranging from 0.78 to 0.82%.

Crude Fat

Percent crude fat values are located in Table 2.5 by treatment and 2.6 by gender. Since these lambs were poorly marbled and lacked subcutaneous fat, all lambs were lower in percent fat (18.70 to 21.61%) compared to the 30.2% found in the Enser et al. (1995) study. Lambs had the equivalent percent of fat as pork (21.1%), but this should not have been the case. Lamb is said to be the fattest when compared to beef and pork (Enser et al., 1995). As would be expected, the half ration lambs had the lowest percent fat content, and the realimented group had the highest percent fat. This was consistent with the Lin et al. (1988) study that found that there was an inverse relationship between moisture and lipid content. Lambs that were part of the half ration treatment had the highest moisture content, but the lowest fat content.

It was speculated that the half ration lambs were using all dietary intake for compensatory growth since while in utero they lacked a lot of essential nutrients in the diet to help with growth. While in utero, fibroblasts were differentiated to grow into muscle or bone rather than fat. Mir et al. (2000) hypothesized that, with certain feeds, the system that recruits fibroblasts for adipocytes can become deactivated. This could have been the case here if this fibroblast system is initiated by a certain nutrient or reaction that could have not occurred in these nutritionally deprived lambs. Conversely, those that were part of the realimented group differentiated fibroblasts into fat.

Ewes are expected to have a higher fat content when compared to rams; this is the case in this study as well. This higher fat content comes from ewes having higher body wall and 12^{th} rib fat measurements, as well as higher ribeye marbling and flank streaking scores. In other words, ewes had more intramuscular and intermuscular fat. Even though all lambs were cut to have a 0.3 cm of fat maximum, many of the rams did not even have that much external fat to

trim, so less fat was added to the ground product that was used for analysis. In addition, the intramuscular fat would have an impact on the amount of crude fat and since ewes scored higher on average in marbling and flank streaking, this would mean that more intramuscular fat was added to the ground product.

Fatty Acids

No differences were detected between treatment groups in the fatty acid profile. Similar to the Badiani et al. (2004) study, the most prevalent fatty acids in their study were: oleic (C18:1), palmitic (C16:0), stearic (C18:0), linoleic (C18:2), and myristic (C14:0) acids. In this current study, these same fatty acids were consistently the most prevalent. For the carcasses of the control lambs palmitic (C16:0) was by far the most prevalent at 32.44%, followed by myristic (C14:0) at 24.24%, and stearic (C18:0) at 17.34%. Carcasses of the realimented group were highest in palmitic (C18:0) (30.22%), followed by myristic (C14:0) (18.87%), and palmitic (C16:0) (12.74%). The half ration lambs were highest in palmitic (C16:0) at 31.81%, followed by stearic (C18:0) at 14.23%, and myristic (C14:0) at 12.39%.

Compared to the Sañudo (2000) and Días (2005) studies, the percent of fatty acids varied. Both studies found levels of palmitic (C16:0) to be lower than was found in the current study (22-23% versus 32-33%). Levels of myristic (C14:0), linoleic (C18:2) and linolenic (C18:3ɣ) acids were also higher in the current study, but levels of stearic were lower. The reason for the discrepancies in fatty acid composition between previously published studies and the current experiment are unknown. However, the two previous experiments examined fatty acid composition in intramuscular fat of ram lamb carcasses of Spanish and British breeds that were 4-5 months of age before slaughter (Sañudo et al.,2000), and in the Días (2005) study, 20 lambs from different countries were utilized and fatty acid composition was derived from the

longissimus dorsi muscle. Furthermore, both of these studies used the GLM procedure in SAS; however, the Sañudo (2000) study tested main effects using the Bonferroni t-test, while Días (2005) used Student Newman-Keuls test. This current study analyzed the whole carcass for analysis and utilized Kenward- Roger approximation with the MIXED procedure. It is also possible that the feed was easier to break down and the microbes were able to break down the feed into smaller fatty acid chains more efficiently. However, more research is necessary to examine effect of the nutrient deprivation on fatty acid breakdown.

Since ruminants contain microbes to hydrogenate fatty acids, there should be a higher percent of saturated fatty acids compared to fatty acids. Enser et al. (1997) claimed that there was a high mg per 100 g of C18:0 and C18:1 in the muscle compare to other fatty acids. However, in this current study, C16:0 was higher in prevalence. Numerically, half ration lambs had the lowest amount of saturated fatty acids and the highest amount of polyunsaturated fatty acids. It was speculated that the nutrient deprivation could have affected the mechanisms and organisms that hydrogenate fatty acids. Fatty acids were not hydrogenated as efficiently in these lambs. Conversely, realimented lambs had the highest amount of saturated fatty acids with very few polyunsaturated fatty acids. This realimentation could have increased the rate of fatty acid breakdown into saturated fatty acids.

According to the Dietary Reference Intakes (2005) linoleic acid is required for human males at 14-17 g/ day and for females at 10-12 g/ day. α- linolenic (C18:3α) acids is required at 1.6 g/ day for males and 1.1 g/ day for females. Lambs in this study would provide very little in terms of either fatty acid, but they do provide some of each. With a well rounded diet, lamb would be a reasonable way to obtain some α- linolenic (C18:3α) and linoleic (C18:2) acids in the diet.

Lamb contains low levels of all of the essential fatty acids (C12:0, C16:1, C18:2, C18:3α, and C18:3ɣ). These are necessary for human health that must be obtained from external sources. Lamb will provide low to moderate levels of all of these fatty acids, which is rare since most food sources do not contain all of these fatty acids. Of these, C16:1 and C18:3ɣ were present in a reasonably large amount relative to the whole carcass.

Gender had no impact on fatty acid composition of the whole carcass. However, percent values of some of the main saturated fatty acids (C12:0, C14:0, and C16:0) were still higher than reported in other experiments (Días et al., 2005; Sañudo et al., 2000). However, both the Sañudo (2000 and the Días (2005) studies only looked at male carcasses. In addition, lambs in this study could have been more efficient in hydrogenating fatty acids; however, there is no significant evidence to prove this.

This study did show that lamb contains volatile fatty acids, which are suspected of providing the muttony flavor (Wong et al., 1975). Values of these volatile fatty acids in the parts per million range have been found to affect the flavor profile (Brennand and Lindsay, 1991). In the current study, all of these volatile fatty acids were found to be a very small percentile of the total carcass, but still high enough to be detected. Unlike beef, lamb does contain these short chain fatty acids. Lambs in the current study were small compared to industry average, so industry lambs with more carcass lean and fat may have a higher percent presence of these volatiles. One could argue that industry lambs would have higher percentages of these fatty acids relative to the whole carcass which would increase the presence of muttony flavor.

Crude Protein

Percent crude protein values can be found in Table 2.5 and by gender in Table 2.6. Crude protein values did not differ by either gender or treatment. However, when comparing the

two restricted groups to each other, statistical differences were found (P=0.0044). Percent crude protein in this current study were similar to the findings of Bianiani et al. (2004), but percent values are still at the low end of what Badiani et al. (2004) found. Carcasses of the half ration lambs had higher percent protein compared to the realimented group. Overall, lambs that were part of the half ration group numerically had the highest percent protein content, followed by the control and finally by the realimented groups. Rams also had higher crude protein values than ewes. The half ration lambs having the highest protein levels corresponds with the findings of Hoffman et al. (2003) where lamb muscles with the highest percent of protein had the lowest percent fat.

As is consistent with most species, ram lambs had a higher percent crude protein compared to ewe lambs. However, the percent values were close between the two genders. Even with the difference, both genders had similar percent crude protein value as stated by Badiani et al. (2004).

Cholesterol

Mean values for cholesterol can be found in Tables 2.5 and 2.6. When examining both by gender and by treatment, there were no statistical differences. As found by Badiani et al. (1997), these lambs would provide a safe daily intake of cholesterol based on the 1997 maximum recommended values for cholesterol intake of 300 mg. In 2011, this recommended value was the same, and realimented lambs had the highest amount of cholesterol at 58.92 mg/ 100 g of cholesterol; still lower than the recommended maximum intake. Control lambs were even lower at 55.24 mg/ 100 g. Values in the current study were lower than values found by Lubbadeh et al. (1999) of 67.1 to 68.3 mg/ 100 g. According to the Dietary Reference Intakes Guide (2005), it is recommended that intakes of cholesterol be as low as possible while still consuming a

nutritionally adequate diet. Although lamb may be higher than other foods in cholesterol, it still provides many necessary nutrients for a healthy diet which should be considered as well when examining these moderate cholesterol values.

Swize et al. (1991) found beef steaks that had 0.6 cm of fat had similar levels of cholesterol compared to denuded steaks. Cholesterol is primarily synthesized endogenously and stored in membranes. It has been said that fat has less cholesterol than lean (Reiser, 1975). The half ration lambs had the lowest mg per 100 g of cholesterol which corresponds with the smallest amount of lean tissue (Table 2.3). The realimented group had the highest mg per 100 g of cholesterol. Although the realimented lambs did not have the most muscle, we hypothesize that since they were temporarily deprived, the liver and the rest of the body was more sensitive and was stimulated to make more cholesterol at a more rapid rate than those in both the half ration and control groups. The control lambs did and were expected to have a high value of cholesterol when comparing the groups since they were leanest and had a small amount of fat relative to the amount of lean. When comparing the groups, control lambs had higher levels of protein and lower levels of fat compared to the realimented group. Thus, they had the second highest amount of cholesterol.

Vitamins

No differences were detected between treatments for either vitamin E or vitamin A content (Table 2.5). There were no significant differences between vitamins when compared by gender (Table 2.6). The mg per 100 g of vitamin A was higher in rams than ewes. Vitamin E values were close with rams having a higher mg per 100 g of vitamin E compared to ewes. Although ewes have more fat to store both vitamins A and E, both were not stored in very high concentrations.

Control lambs numerically had the highest levels of vitamin E while realimented lambs had the lowest. When adjusted for both crude protein or for crude fat, no differences were found between groups. Vitamin E is said to be essential for reproduction, so those lambs that were nutritionally restricted may not have received enough vitamin E in utero. Since realimented lambs had low percent crude protein and fat values, they had less places to store vitamin E and most likely were not able to utilize it as well as control lambs. Half ration lambs were in the middle of the two since they did have some fat and did obtain some vitamin E while in utero. Also, these lambs may have been more sensitive to lower levels of vitamin E, so they were able to maintain higher levels.

The amount (mg per 100 g) of these vitamins was different when compared to Australian lambs. According to the Williams (2007) review paper, Australian lambs had higher levels of vitamin A (8.6 μg/ 100 g) and lower levels of vitamin E (0.44 mg/ 100 g). This is in part due to Australian lambs having a higher emphasis on forage based feeds. In addition, it could be due to breed, season, and age as well, which was found in the Lin et al. (1988) study.

Levels of vitamin A in lamb are very low and do not come close to reaching the recommended daily intake for humans. The average male requires approximately 600 μg per day of vitamin A, and an 8 g serving of a lamb that was in the control group would only provide 1.44 μg of vitamin A. This would be an extremely small contribution to the recommended dietary allowance. Vitamin E also is low, but a better contributor to reaching the recommended daily intake. Both males and females require 15 mg per day. An 8 g serving of lamb from the control group would provide 1.18 mg of vitamin E, which is approximately 1/15 of the dietary allowance.

Minerals

Six minerals were found in lamb meat (Tables 2.7 and 2.8). None were found to differ when comparing by treatment. When comparing the two restricted groups to each other, selenium was found to be significant (P=0.0362). Surprisingly, of those found, the half ration group had the highest mg per 100 g levels of iron, selenium, and zinc. When compared to the Hoffman et al. (2003) study, lambs in the current study were higher in copper, iron, and zinc. However, when compared to the Hoffman et al. (2003) study, lambs in this current study were lower in manganese and selenium. Differences between the two studies could have been due to age of slaughter of the lambs.

When compared to Australian lambs, the lambs in the current study had higher levels of copper, iron, and zinc. Other minerals that were measured in the current study were not extracted from the Williams (2007) study. Again, differences could have been due to age, breed, feeding regimen, location, and season. Colorado could have higher levels of copper, iron, and zinc in the water and feed compared to Australia which would increase the levels of minerals in this study. This would be the same rationale that Lin et al. (1988) used in their study when they compared mineral content of New Zealand and Australian lambs.

Many minerals are stored in different parts of the body which could explain why mineral contents numerically were close but still differed by treatment and by gender. For example, many minerals are required for bone growth and are stored in bone. Since the ewes on the half ration and the realimented ration lacked those minerals, the lambs would have problems with bone development and most likely would have very little mineral stored. Lambs of ewes that were realimented were able to compensate once they received a healthy ration. These lambs were oversensitive to the mineral content and had more bone than either of the other treatments.

They increased the absorbance of minerals during digestion to compensate for the deficiency. Lambs that were part of the half ration treatment could have been unable to obtain enough mineral and remained in a deficient state.

When comparing by gender rams had higher mg per 100 g of iron, manganese, selenium, and zinc content. Ewes had higher mg per 100 g of copper, and both had the same amount of cobalt. Of these minerals no differences were found. Humans store most of their zinc in bone and muscle (Walravens,1979). If lambs metabolize zinc the same, then on average, ram lambs with the larger muscle and bone mass could store more zinc than ewes. Manganese is stored in bone as well, so again the larger muscles and bone masses of males could help to store a larger amount of manganese. In addition, manganese is stored in reasonably large amounts in the liver, pancreas, and kidney, which one would assume that with the larger body size of the ram lambs would have larger internal organs (Keen et al., 2000).

According to the dietary reference intakes, the amount of copper that both male and females should consume per day is 700 μg/ day. Regardless of treatment, lamb will provide a reasonable amount of that if someone consumes an 8 g serving of meat. For this 8 g serving, a person would receive approximately 18.4 μg of copper. Based on the control treatment, an 8 g serving of lamb would provide a reasonable amount of iron (approximately 0.22 mg). With an average requirement of 5-6 mg/d, this is a reasonably large amount of iron to be provided by one source in the diet. Finally, this would also provide a reasonably large amount of zinc that is necessary in the diet. However, lamb would be a poor source for selenium. Lamb provides a relatively large amount of many of the essential nutrients that the body needs in order to stay healthy.

IMPLICATIONS

Maternal restriction has long term effects on body and nutrient composition. Lambs whose dams were nutritionally deprived are consistently smaller with increased fatness relative to lean. These animals are low in hot carcass weight. Restriction had a negative effect on quality grade as well. Percent of each retail cut was lower than previous studies. However, it is important to note that these lambs were all slaughtered very young and were not very far along on their growth curve.

Nutritionally, this is one of the first studies to examine the nutritional content of American lamb. Although these are outliers to normal lamb, they still gave a general idea of the nutritional profile of American lamb, as well as help to prove what the nutritional consequences are of nutrient deprivation in utero. American lamb is nutritious and should be considered part of a healthy diet. It has sufficient levels of vitamins A and E, iron, manganese, zinc, and low levels of the essential fatty acids. In addition, it has high protein, low fat, and low to moderate cholesterol. These are all constituents of a healthy diet based on dietary reference intakes published by the National Academies Press.

Nutrient restriction had an impact on nutrient composition. All proximate analysis were lower than what was considered industry average for other countries, event those that keep lambs on a primarily forage based diet. This is an issue since health conscious people would consider consuming lamb for its high levels of vitamins, minerals, and protein.

Lamb contains more short chain fatty acids than other species. This contributes to muttony off flavors that many consumers do not like. Although it would be impossible to eliminate all short chain fatty acids, it is possible to explore if certain breeds contain lower levels

of these fatty acids. In addition, research should be conducted to examine if there are ways to mitigate the flavor that these short chain fatty acids provide.

As is the case with most species, females in this study were smaller than males and had a slightly different composition. Females had less lean and more fat. In reality, all differences were so minute that treatment would be a much bigger factor than gender.

Care should be taken to ensure that ewes are not nutritionally restricted and more studies should be conducted to investigate when during gestation nutrient restriction has the most effect on carcass characteristics and nutrient composition. Finally, more should be investigated on compensatory growth for in times of drought when ewes will be nutritionally deprived and lambs will need more attention to reach a final slaughter weight.

Table 2.1 Least square means ±SEM and P-values for lamb carcass traits separated by treatment

	Treatment[a]			P-value		
Trait	H±SE	R±SE	C±SE	C vs R&H	RvsH	P-Value[f]
Number of Animals	13	12	16			
HCW, kg	18.73±0.9	20.93±0.9	21.17±0.8	0.2146	0.1017	0.1179
12th Rib Fat, cm	0.3±0.01	0.4±0.01	0.4±0.01	0.7987	0.1763	0.3745
Body Wall, cm	1.30±0.01	1.60±0.01	1.50±0.01	0.3871	0.0510	0.0969
Adjusted Fat, cm	0.12±0.01	0.16±0.01	0.16±0.01	0.4193	0.1557	0.2512
Ribeye Area, cm^2	11.94±0.65	12.19±0.65	13.74±0.58	0.0328	0.7659	0.0905
Ribeye Marbling[b]	316.9 ±22.2	313.9±23.6	332.22±20.7	0.5301	0.9264	0.8154
Leg Score	10.37±0.35	10.30±0.37	10.98±0.33	0.1377	0.8858	0.3218
Leg Circumference[c],cm	36.31±1.13	36.14±1.20	37.37±1.05	0.4048	0.9195	0.6992
Conformation[d]	219.67±7.80	234.69±8.30	239.79±7.26	0.1886	0.2018	0.1792
Flank Streaking[b]	368.8±27.7	337.7±29.6	390.0±26.1	0.2803	0.4525	0.4321
Flank Firmness[e]	1.63±0.15	1.74±0.16	1.76±0.14	0.6718	0.6099	0.7916
Flank Color	A^{30} ±3.71	A^{30}±3.95	A^{30}±3.46	0.6182	0.4802	0.6941
Kidney Fat, g	304.21±40.5	477.45±42.8	339.24±37.4	0.2953	0.0086	0.0212
L*	41.10±0.75	40.11±0.78	40.70±0.68	0.9166	0.3751	0.6642
a*	7.30±0.42	8.03±0.44	8.14±0.38	0.3418	0.2420	0.3106
b*	9.50±0.43	9.43±0.45	9.48±0.39	0.9782	0.9188	0.9944

a- H= Fed 50% from d 28-term, R= Fed 50% from d28-78 and then slowly realimented to 100% for the remainder of gestation, C= Control

b- 100-199= Practically Devoid, 200-299= Traces, 300-399= Slight, 400-499=Small, 500-599= Modest, 600-699= Moderate, 700-799= Slightly Abundant, 800-899= Moderately Abundant

c- Circumference measure around largest part of leg with tape measure

d- 130-Good-; 160=Good; 190=Good+; 230=Choice-; 260=Choice; 290=Choice+; 330=Prime-; 360=Prime; 390=Prime+

e- 1=Soft; 2=Firm; 3=Extra Firm

f- P-Value considered significant if P≤0.05

Table 2. 2 Least square means ± SEM and P-value for carcass traits separated by gender

	Gender[a]		
Trait	M±SE	F±SE	P-Value[f]
Number of Animals	20	21	
HCW, kg	21.45±0.64	19.11±0.64	0.0061
12th Rib Fat, cm	0.03±0.01	0.04±0.01	0.1110
Body Wall, cm	1.40±0.01	1.50±0.01	0.0659
Adjusted Fat, cm	0.03±0.01	0.04±0.01	0.0733
Ribeye Area, cm^2	13.29±0.45	11.94±0.45	0.0326
Ribeye Marbling[b]	312.3±14.7	329.7±14.87	0.2579
Leg Score	10.49±0.25	10.61±0.25	0.6607
Leg Circumference[c], cm	36.85±0.82	36.36±0.82	0.6337
Conformation[d]	229.14±5.5	233.62±5.5	0.4823
Flank Streaking[b]	354.7±17.2	376.3±17.3	0.1021
Flank Firmness[e]	1.58±0.10	1.84±0.10	0.0115
Flank Color	A^{30}±2.53	A^{40}±2.56	0.0970
Kidney Fat, g	324.5±30.4	422.8±30.7	0.0194
L*	41.10±0.65	40.17±0.65	0.3548
a*	7.27±0.34	8.38±0.34	0.0283
b*	9.09±0.36	9.85±0.36	0.1620

a- M=Male F=Female

b- 100-199= Practically Devoid, 200-299= Traces, 300-399= Slight, 400-499=Small, 500-599= Modest, 600-699= Moderate, 700-799= Slightly Abundant, 800-899= Moderately Abundant

c- Circumference measure around largest part of leg with tape measure

d- 130-Good-; 160=Good; 190=Good+; 230=Choice-; 260=Choice; 290=Choice+; 330=Prime-; 360=Prime; 390=Prime+

e- 1=Soft; 2=Firm; 3=Extra Firm

f- P-Value considered significant if P≤0.05

Table 2.3 Retail cut as a percent of the whole lamb carcass ± SEM and P-values separated by treatment

	Treatment[a]			P-Value		
Cut[b]	H±SE	R±SE	C±SE	Cvs R&H	R vs H	P-Value[f]
Number of Animals	13	12	16			
Foresaddle	53.18±0.47	52.55±0.48	53.06±0.42	0.7195	0.3652	0.6203
Hindsaddle	46.82±0.47	47.45±0.48	46.94±0.42	0.7195	0.3652	0.6203
Denver Rib	2.59±0.13	2.22±0.13	2.69±0.11	0.0711	0.0497	0.0373
Shoulder	15.41±0.36	14.90±0.38	15.05±0.33	0.7954	0.3405	0.3198
Foreshank	6.68±0.24	6.28±0.25	6.31±0.22	0.5467	0.2730	0.4434
Frenched Rack	5.20±0.13	5.11±0.13	5.60±0.12	0.0126	0.6409	0.0358
Flank	4.78±0.35	5.02±0.37	4.81±0.32	0.8276	0.6497	0.8810
Loin	7.44±0.27	7.50±0.28	7.50±0.25	0.9314	0.8757	0.9833
Hindshank	4.35±0.18	4.48±0.19	4.45±0.17	0.8853	0.6126	0.8651
Boneless Leg	19.63±0.49	20.39±0.52	20.53±0.45	0.3800	0.3003	0.6156
Bone[c]	22.58±0.60	22.17±0.63	21.36±0.55	0.1656	0.6412	0.3303
Connective Tissue[d]	0.44±0.08	0.24±0.08	0.37±0.07	0.7394	0.1024	0.2330
Lean Tissue[e]	75.60±0.65	76.89±0.68	77.11±0.59	0.2764	0.1900	0.2294

a- H= Fed 50% from d 28-term, R= Fed 50% from d28-78 and then slowly realimented to 100% for the remainder of gestation, C= Control

b - All muscles were fabricated to have a fat thickness of 0.3cm or less

c- Bone weight after bones were scraped of all lean, fat, and connective tissue

d- Connective tissue separated from lean, fat, and bone

e- Lean Tissue= lean and fat summed after separation from bone and connective tissue

f- P-Value considered significant if $P \leq 0.05$

Table 2.4 Retail cut as a percent of the whole lamb carcass ± SEM and P-values separated by treatment

	Gender[a]		
Cut	M±SE	F±SE	P-Value[f]
Number of Animals	20	21	
Foresaddle	52.69±0.41	53.17±0.41	0.4469
Hindsaddle	47.31±0.41	46.83±0.41	0.4469
Denver Rib	2.47±0.10	2.53±0.10	0.6881
Shoulder	14.89±0.31	15.36±0.31	0.3198
Foreshank	6.58±0.20	6.27±0.20	0.3038
Frenched Rack	5.41±0.13	5.21±0.13	0.3661
Flank	4.61±0.28	5.13±0.28	0.1969
Loin	7.52±0.23	7.44±0.23	0.8205
Hindshank	4.48±0.13	4.37±0.13	0.5202
Boneless Leg	20.31±0.37	20.06±0.38	0.6156
Bone[c]	22.67±0.49	21.41±0.49	0.6412
Connective Tissue[d]	0.33±0.08	0.37±0.08	0.7827
Lean Tissue[e]	76.00±0.55	77.06±0.55	0.1947

a- M=Male, F=Female
b- All muscles were fabricated to have a fat thickness of 0.3cm or less
c- Bone weight after bones were scraped of all lean, fat, and connective tissue
d- Connective tissue separated from lean, fat, and bone
e- Lean Tissue= lean and fat summed after separation from bone and connective tissue
f- P-Value considered significant if $P \leq 0.05$

Table 2.5 Least square means ± SEM and P-value for raw whole lamb proximate analysis separated by treatment

	Treatment[a]			P-Value		
Analysis	H±SE	R±SE	C±SE	C vs R&H	RvsH	P-Value[b]
Number of Animals	13	12	16			
Dry Matter, %	38.53±0.93	40.53±1.02	39.11±0.85	0.7109	0.1597	0.3498
Moisture, %	61.47±0.93	59.47±1.02	60.89±0.85	0.7109	0.1597	0.3498
Ash, %	0.78±0.03	0.81±0.03	0.82±0.3	0.4718	0.4869	0.5880
Crude Fat, %	18.70±1.05	21.61±1.15	19.63±0.96	0.6797	0.0762	0.1922
Crude Protein, %	16.87±0.18	16.17±0.12	16.84±0.17	0.3199	0.0044	0.2665
Vitamin E, µg/100g	122.42±20.9	77.38±20.3	146.90±18.6	0.0618	0.1366	0.0611
Vitamin A, µg/g	0.22±0.02	0.23±0.02	0.19±0.02	0.2816	0.5995	0.4728
Cholesterol,mg/100g	58.48±4.74	58.92±5.19	55.24±4.29	0.5454	0.9511	0.8290

a- H= Fed 50% from d 28-term, R= Fed 50% from d28-78 and then slowly realimented to 100% for the remainder of gestation, C= Control

b- P-Value considered significant if $P \leq 0.05$

Table 2. 6 Least square means ± SEM and P-value for proximate analysis of raw whole lamb separated by gender

	Gender[a]		
Analysis	M±SE	F±SE	P-Value[b]
Number of Animals	20	21	
Dry Matter, %	38.27±0.76	40.51±0.76	0.0459
Moisture, %	61.73±0.76	59.49±0.76	0.0459
Ash, %	0.81±0.02	0.80±0.02	0.9183
Crude Fat, %	18.47±0.86	21.49±0.86	0.0175
Crude Protein, %	16.92±0.27	16.34±0.23	0.4315
Vitamin E, µg/100g	118.88±15.7	112.26±15.5	0.7557
Vitamin A, µg/g	0.23±0.02	0.20±0.02	0.3541
Cholesterol, mg/100g	56.71±3.95	58.39±3.93	0.7688

a- M=Male, F=Female

b- P-Value considered significant if $P \leq 0.05$

Table 2.7 Least square means ± SEM and P-value for raw whole lamb trace mineral analysis separated by treatment

	Treatment[a]			P-Value		
Mineral	H±SE	R±SE	C±SE	C vs R&H	R vs H	P-Value[b]
Number of Animals	13	12	16			
Cobalt, µg/g	0.01±0	0.01±0	0.01±0	0.1688	0.5378	0.3242
Copper, µg/g	2.29±0.26	2.75±0.28	2.33±0.24	0.5480	0.2461	0.4333
Iron, µg/g	30.60±1.43	27.37±1.51	28.48±1.33	0.7672	0.1362	0.3022
Manganese, µg,g	0.27±0.02	0.30±0.02	0.31±0.02	0.3425	0.3110	0.3740
Selenium, µg/g	0.61±0.03	0.52±0.03	0.54±0.02	0.5288	0.0362	0.0864
Zinc, µg/g	79.80±3.38	70.02±3.57	71.84±3.12	0.4508	0.0602	0.1215

a- H= Fed 50% from d 28-term, R= Fed 50% from d28-78 and then slowly realimented to 100% for the remainder of gestation, C= Control

b- P-Value considered significant if $P \leq 0.05$

Table 2. 8 Least square means ± SEM and P-value for lamb raw whole carcass trace minerals separated by gender

	Gender[a]		
Mineral	M±SE	F±SE	P-Value[b]
Number of Animals	20	21	
Cobalt, µg/g	0.01±0	0.01±0	0.4053
Copper, µg/g	2.26±0.20	2.66±0.20	0.1236
Iron, µg/g	29.34±1.02	28.29±1.03	0.4000
Manganese, µg,g	0.33±0.02	0.27±0.02	0.0670
Selenium, µg/g	0.58±0.02	0.53±0.02	0.1499
Zinc, µg/g	76.31±2.49	71.46±2.51	0.1609

a- M=Male, F=Female

b- P-Value considered significant if $P \leq 0.05$

Table 2.9 Least square means ± SEM and P-value for % fatty acids of raw whole lamb separated by treatment and gender

Fatty Acid	Treatment[a]			Gender[b]						
	H	R	C	M	F	SEM	C vs R&H	R vs H	P-Value[c]	P-Value[d]
Number of Animals	13	12	16	20	21					
6:0	0.06	-	-	-	0.05	0.02	-	-	-	-
8:0	0.13	0.09	0.08	0.10	0.08	0.05	0.68	0.41	0.34	0.42
9:0	0.19	0.19	0.13	0.10	0.22	0.07	0.84	0.61	0.70	0.54
10:0	0.37	0.52	0.42	0.40	0.48	0.09	0.14	0.24	0.32	0.12
11:0	0.05	0.09	-	0.08	-	0.01	0.24	-	0.81	-
12:0	1.73	1.73	1.38	1.37	1.93	0.14	0.92	0.67	0.37	0.72
12:1	0.13	0.05	0.10	-	0.18	0.02	0.45	0.39	0.27	-
13:0	0.10	0.16	0.13	0.14	0.09	0.04	0.68	0.54	0.38	0.23
14:0	14.25	11.47	12.65	13.07	12.58	0.24	0.20	0.72	0.41	0.47
14:1	0.31	0.38	0.35	0.32	0.37	0.08	0.81	0.86	0.80	0.74
15:0	1.72	1.34	1.49	1.44	1.54	0.21	0.24	0.41	0.31	0.39
15:1	0.45	0.19	0.20	0.15	0.36	0.19	0.08	0.71	0.28	0.21
16:0	33.90	32.75	33.55	33.60	33.19	0.62	0.61	0.71	0.62	0.84
16:1T	0.01	0.09	0.05	0.06	0.01	0.01	0.31	0.12	0.41	0.68
16:1	3.18	4.84	2.62	3.21	3.88	0.22	0.24	0.18	0.14	0.46
17:0	4.42	5.42	3.84	4.15	4.87	0.32	0.58	0.21	0.41	0.36
17:1	1.48	0.38	2.14	1.51	1.13	0.24	0.09	0.06	0.08	0.61
18:0	9.16	9.38	10.55	9.64	9.91	0.21	0.81	0.62	0.73	0.67
Σ 18:1[e]	9.40	8.47	11.19	9.20	9.98	0.14	0.37	0.15	0.31	0.31
18:1T Δ9	4.27	3.94	3.04	4.08	3.47	0.18	0.51	0.41	0.71	0.43
18:2TT	7.40	3.82	6.33	6.21	5.71	0.23	0.07	0.09	0.12	0.91
18:2	0.32	0.37	0.29	0.28	0.38	0.02	0.71	0.62	0.81	0.58
18:3γ	5.34	12.32	7.39	8.70	7.95	0.21	0.09	0.08	0.12	0.81
18:3α	-	0.22	0.29	0.15	0.18	0.10	-	0.71	0.92	0.59
20:0	0.32	0.37	0.38	0.45	0.23	0.08	0.84	0.92	0.97	0.29
20:1Δ8	0.41	-	-	0.18	0.12	0.05	-	-	-	0.33
20:1Δ11	0.37	0.51	-	0.31	0.23	0.11	-	-	0.38	0.18
20:2	-	0.61	0.95	0.61	0.43	0.19	-	0.62	0.79	0.31
20:5	0.17	0.09	0.10	0.10	0.14	0.01	0.67	0.79	0.81	0.84
20:3Δ11Δ14Δ17	0.37	0.21	0.38	0.36	0.30	0.05	0.76	0.72	0.83	0.93

a- H= Fed 50% from d 28-term, R= Fed 50% from d28-78 and then slowly realimented to 100% for the remainder of gestation, C= Control

b- M= male, F= female

c- P-value comparing all three treatment groups

d- P-value comparing genders

e- Σ18:1= Σ18:1Δ6+ 18:1Δ9/TΔ11+18:1Δ11

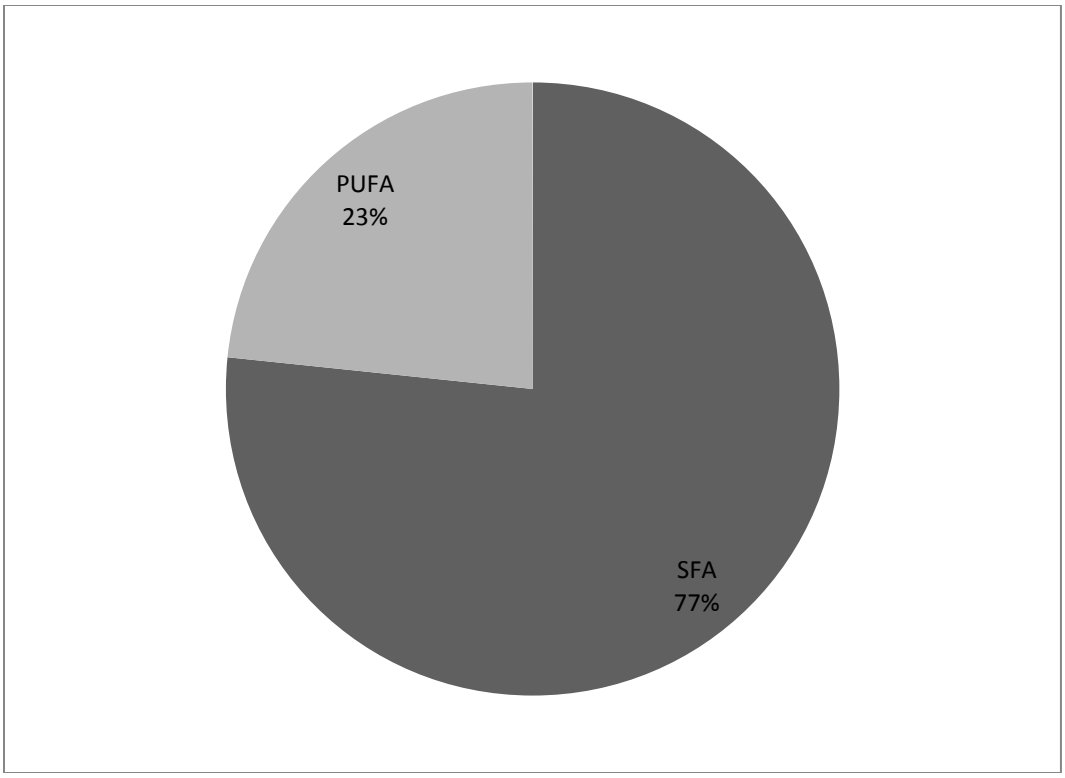

Figure 2.1 Percent of whole carcass of SFA and PUFA of control lambs

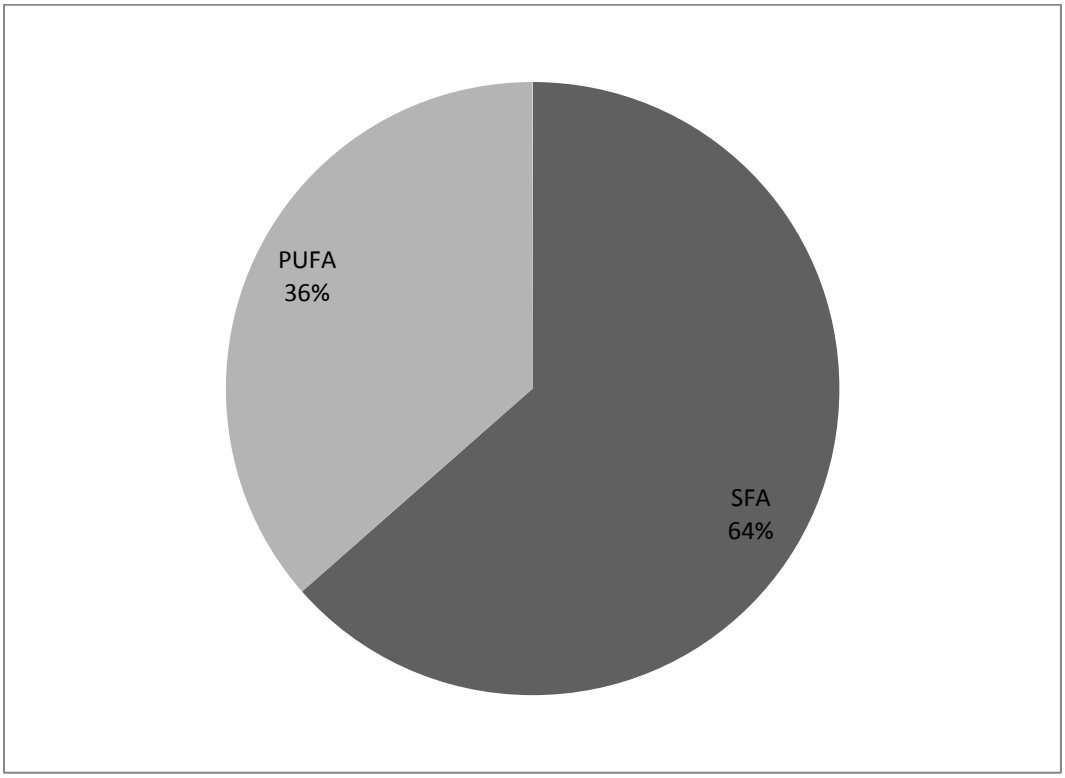

Figure 2.2 Percent of whole carcass of SFA and PUFA of realimented lambs

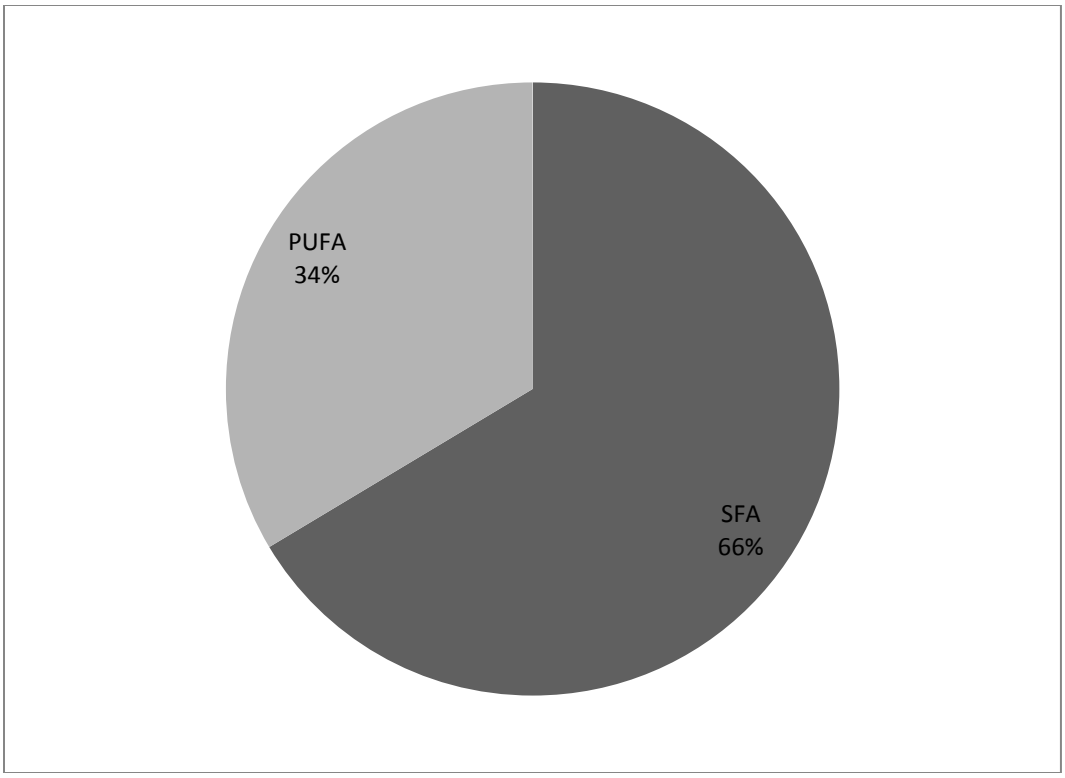

Figure 2.3 Percent of whole carcass of SFA and PUFA of half ration lambs

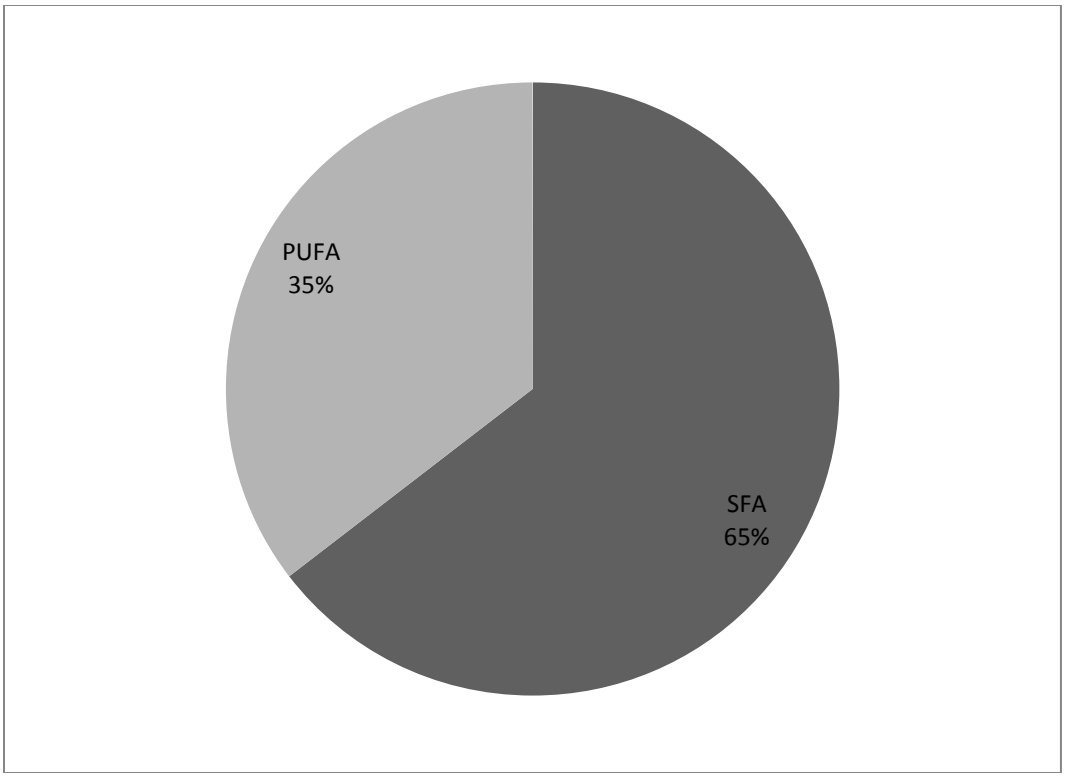

Figure 2.4 Percent of whole carcass of SFA and PUFA of ram lambs

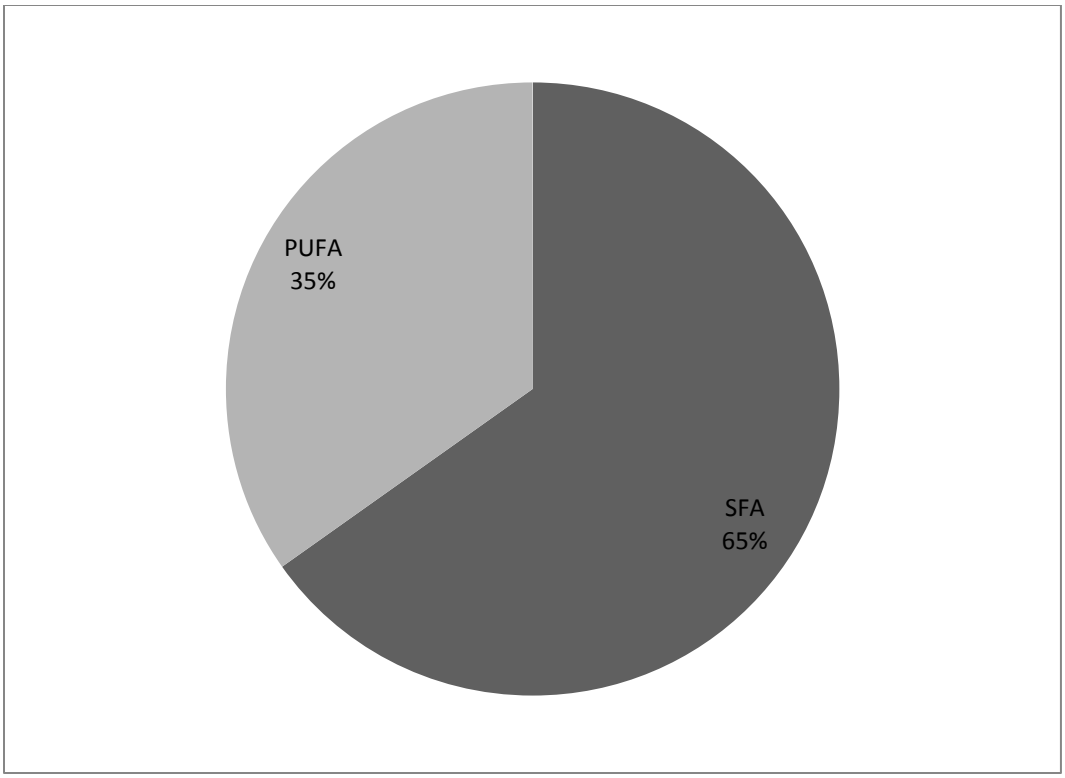

Figure 2.5 Percent of whole carcass of SFA and PUFA of ewe lambs

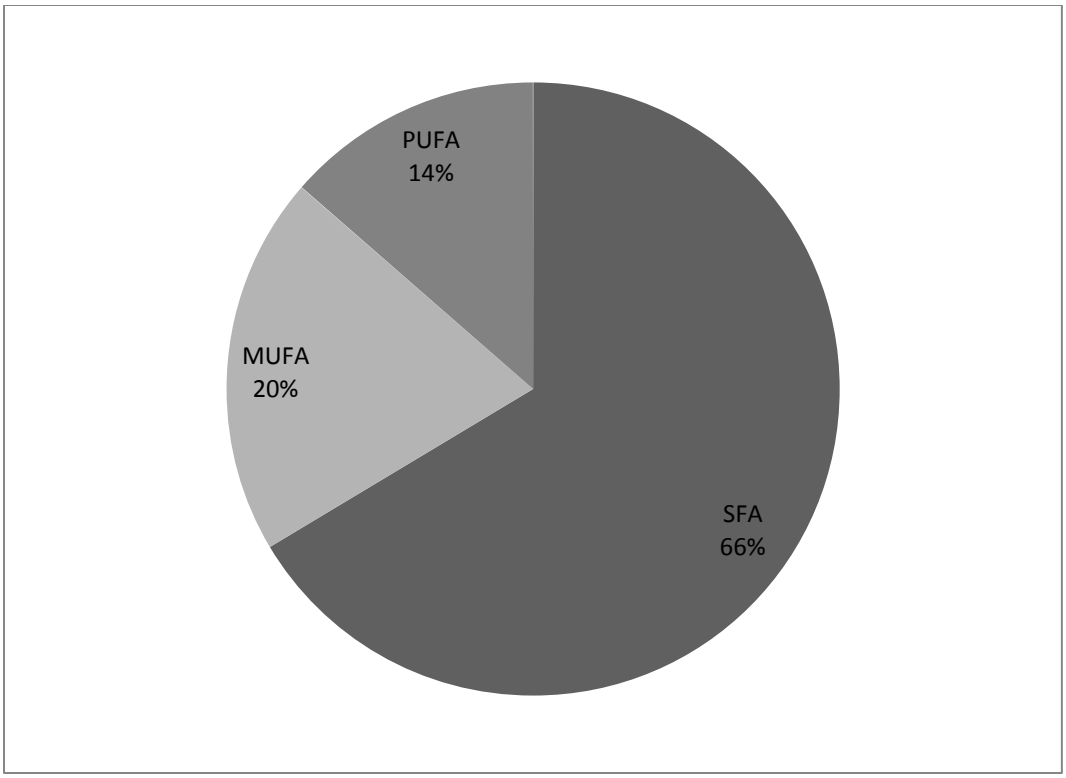

Figure 2.6 Percent of whole carcass of SFA, MUFA, and PUFA of control lambs

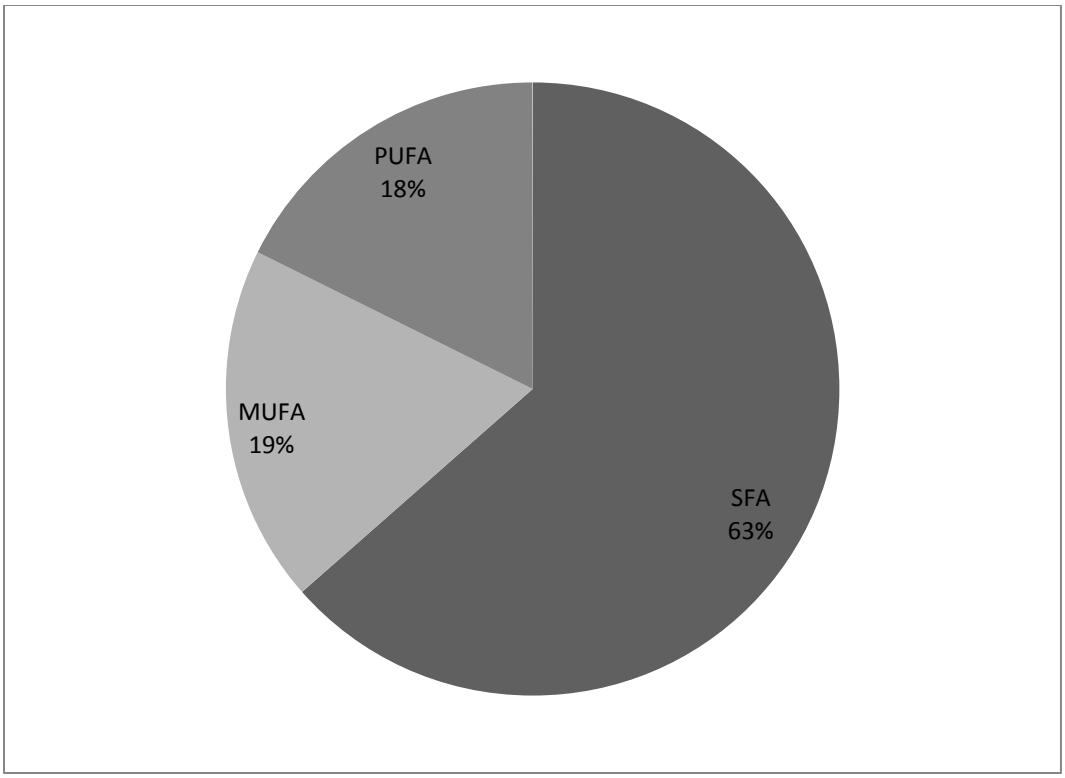

Figure 2.7 Percent of whole carcass of SFA, MUFA, and PUFA of realimented lambs

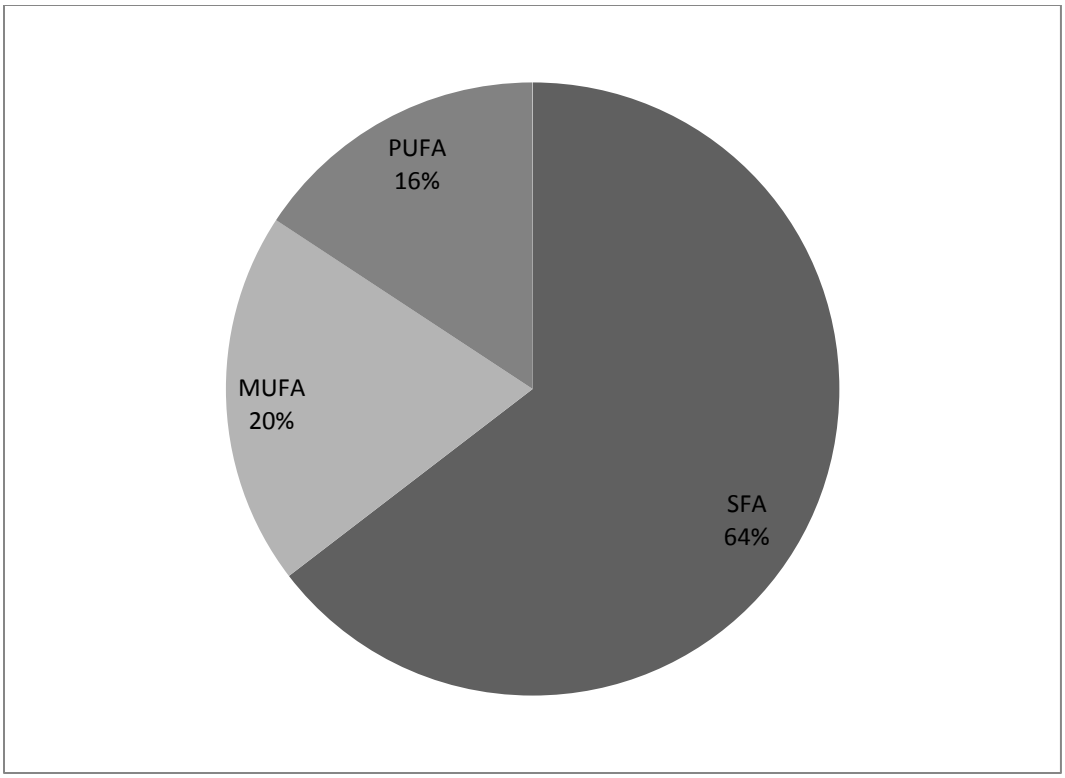

Figure 2.8 Percent of whole carcass of SFA, MUFA, and PUFA of half ration lambs

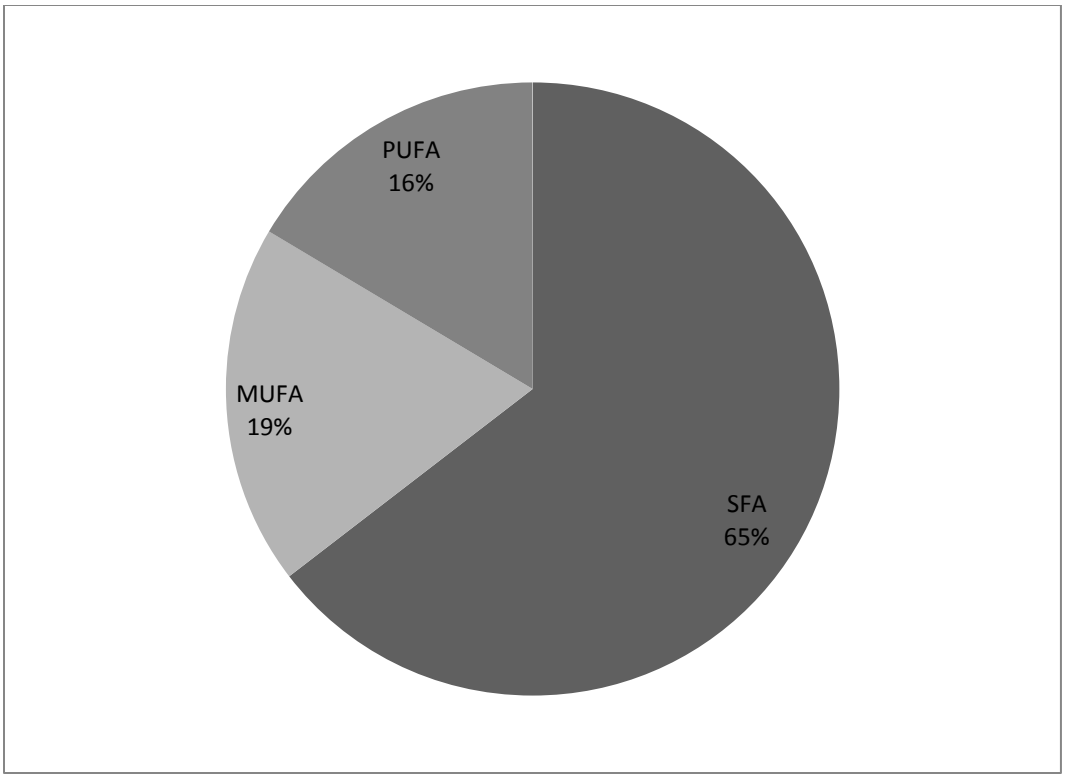

Figure 2.9 Percent of whole carcass of SFA, MUFA, and PUFA of ram lambs

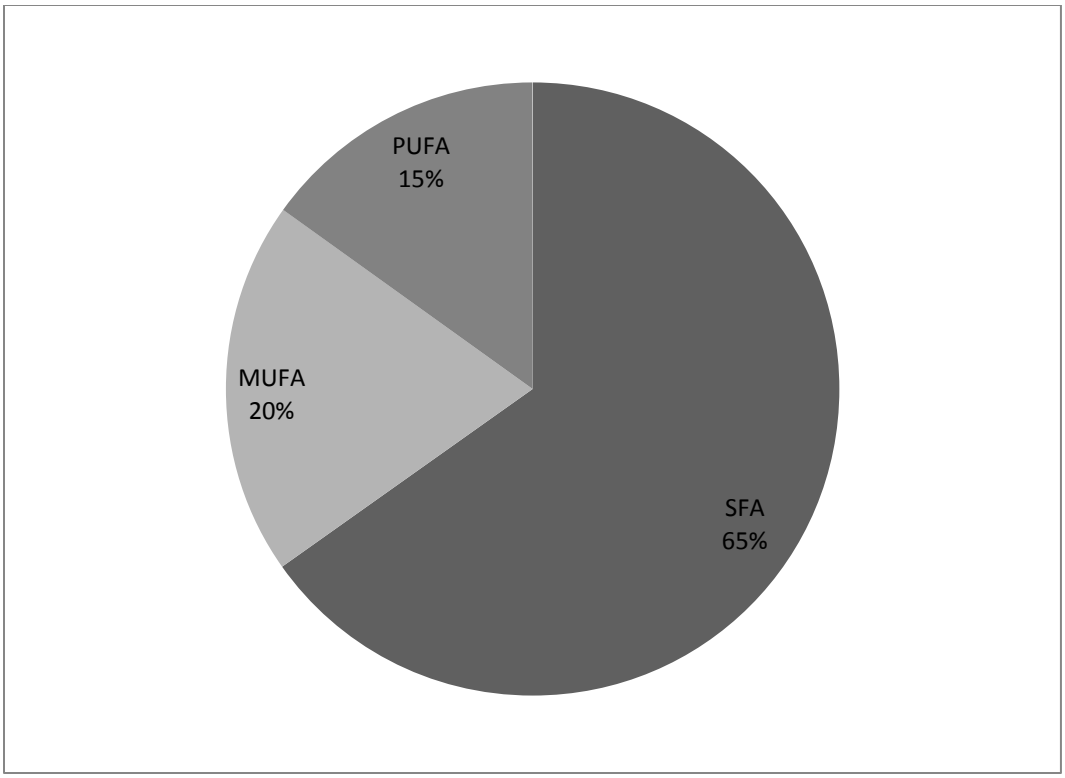

Figure 2.10 Percent of whole carcass of SFA, MUFA, and PUFA of ewe lambs

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APPENDIX I

Treatments

Treatment	CSU ID	EWE	Gender
Control			
	3	58	M
	5	58	F
	13	88	F
	21	94	F
	22	70	F
	24	97	M
	25	88	F
	27	94	M
	30	70	F
	31	85	M
	33	97	F
	36	10	F
	37	76	M
	40	18	F
	42	76	F
	48	18	M
Realimented			
	9	13	F
	12	106	F
	14	13	F
	15	50	M
	23	108	F
	26	98	M
	28	106	M
	32	108	M
	39	102	M
	43	102	F
	44	40	M
	46	40	M
Fed 50%			
	1	69	F
	2	69	F
	4	54	F
	6	60	M
	7	71	F
	10	62	M
	11	22	F
	16	22	M

17	60	F
29	62	M
38	47	M
45	35	M
47	47	M

APPENDIX II

Minerals

CSU ID	Gender	Cobalt (ug/g)	Copper (ug/g)	Iron (ug/g)	Manganese (ug/g)	Molybdenum (ug/g)	Selenium (ug/g	Zinc (ug/g)
1	1	0.01	2	27	0.2	0	0.6	71
2	1	0.02	2	32	0.2	0	0.6	80
3	0	0.01	2	29	0.2	0	0.6	83
4	1	0.01	2	34	0.2	0	0.6	71
5	1	0.01	2	26	0.2	0	0.5	66
6	0	0.01	2	24	0.2	0	0.5	68
7	1	0.01	2	27	0.2	0	0.5	62
9	1	0.01	2	27	0.2	0	0.5	70
10	0	0.01	2	28	0.3	0	0.6	75
11	1	0.01	3	27	0.2	0	0.7	83
12	1	0.01	6	31	0.2	0	0.5	76
13	1	0.01	2	29	0.3	0	0.5	71
14	1	0.01	4	26	0.4	0	0.5	66
15	0	0.01	2	21	0.2	0	0.4	58
16	0	0.01	3	35	0.3	0	0.8	103
17	1	0.01	2	29	0.3	0	0.5	77
21	1	0.01	4	26	0.2	0	0.5	70
22	1	0.01	2	28	0.2	0	0.8	71
23	1	0.01	3	29	0.3	0	0.5	78
24	0	0.01	3	34	0.3	0	0.5	77
25	1	0.01	2	24	0.3	0	0.4	61
26	0	0.01	2	28	0.4	0	0.5	70
27	0	0.01	2	27	0.4	0	0.6	72
28	0	0.03	3	36	0.5	0	0.7	96
29	0	0.01	2	37	0.5	0	0.7	95
30	1	0.01	2	25	0.4	0	0.4	65

31	0	0.01	3	30	0.3	0	0.7	72
32	0	0.01	2	24	0.4	0	0.5	65
33	1	0.01	4	34	0.5	0	0.5	77
36	1	0.01	2	28	0.3	0	0.5	66
37	0	0.01	2	30	0.3	0	0.5	68
38	0	0.01	3	39	0.3	0	0.6	94
39	0	0.01	2	20	0.3	0	0.5	53
40	1	0.01	2	27	0.4	0	0.6	80
42	1	0.01	2	29	0.3	0	0.5	70
43	1	0.01	2	23	0.2	0	0.5	58
44	0	0.01	2	33	0.4	0	0.6	82
45	0	0.02	2	25	0.2	0	0.5	69
46	0	0.02	3	35	0.2	0	0.6	80
47	0	0.01	3	37	0.4	0	0.7	106
48	0	0.01	2	27	0.3	0	0.5	73

APPENDIX III

SAS Code

```
proc mixed scoring=2 covtest;
class trt ewe gender;
model HCW  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model RibFat  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model adjusted  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model BW  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model REA  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
```

```
model Legscore  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model LegCirc  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model KidneyFat  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model L  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model a  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model b  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;
```

```
proc mixed scoring=2;
class trt ewe gender;
model conformation  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model firmness  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

proc mixed scoring=2;
class trt ewe gender;
model marbling  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model flstreaking  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model flcolor  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

proc mixed scoring=2;
class trt ewe gender;
model Cobalt  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;
```

```
  proc mixed scoring=2;
class trt ewe gender;
model Copper  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model iron  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model manganese  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model molybdenum  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model selenium  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model zinc  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
```

```
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

class trt ewe gender;
model vite  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model vita  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

proc mixed scoring=2;
class trt ewe gender;
model DM  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model moisture  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model ash  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model CF  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
```

```
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model CP  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

proc mixed scoring=2;
class trt ewe gender;
model Denver  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model shoulder  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model foreshank  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model frenched  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
```

```
model flank  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model loin  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model hindshank  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model bnlsleg  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model bone  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model CT  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;
```

```
   proc mixed scoring=2;
class trt ewe gender;
model soft  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model foresaddle  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;

  proc mixed scoring=2;
class trt ewe gender;
model hindsaddle  = trt gender /ddfm=kenwardroger;
repeated / subject = ewe(trt) type=cs;
lsmeans trt gender/ pdiff;
contrast '1 vs 2&3' trt -2 1 1;
  contrast '2 vs 3' trt 0 1 -1;
```

APPENDIX IV

Adjusted LS Means for proximate analysis by treatment with CF as a Covariate

	Treatment[a]					
Analysis	H	R	C	C vs R&H	R vs H	P-Value[b]
Number of Animals	13	12	16			
Dry Matter, %	39.54	39.01	39.39	0.7598	0.2811	0.5371
Moisture, %	60.46	60.98	60.61	0.7598	0.2811	0.5371
Ash, %	0.77	0.83	0.82	0.4990	0.1574	0.2764
Crude Protein, %	16.65	16.59	16.75	0.5556	0.8272	0.8202

a- H= Fed 50% from d 28-term, R= Fed 50% from d28-78 and then slowly realimented to 100% for the remainder of gestation, C= Control

b- P-Value considered significant if $P \leq 0.05$