Effects of Energy Source, Energy Level, Sex, and Age on Growth, Performance, Carcass Characteristics, Meat Characteristics, and Flavor Intensity of Lambs, Yearling Ewe Lambs, and Mature Ewes

Thesis

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Abstract

Sheep were fed to determine the effects of energy source, energy level, lamb sex, and sheep age on growth, performance, carcass and meat characteristics and the flavor profile of sheep. Ninety six lambs (n=48 ewes and n=48 wethers) were offered ad libitum access to whole shelled corn (WSC), ad libitum access to alfalfa pellets, or access to a WSC offered at 85% of the ad libitum diet. Lambs were raised to 59.0 and 63.5 kg for ewe and wether lambs, respectively, before being removed from the feeding trial, with 48 lambs (n=24 ewes and n= 24 wethers) being sent for slaughter and the other 48 lambs remaining on feed until a year of age. Lambs offered ad libitum access to WSC had the greatest average daily gain (ADG), efficiency of gain (G:F), and cheapest feed cost per unit of gain (COG) when compared to lambs offered alfalfa pellets and limit-fed WSC. Lambs offered WSC produced heavier and fatter carcasses due to greater dressing percentages and lower visceral organ weights compared to lambs offered alfalfa pellets. Differences due to sex were minimal because the experiment was designed to harvest lambs at similar points of maturity. Lambs (long-feds) that remained on feed were fed for an additional 118 days before deciding to remove lambs early (294 days of age instead of 365+ days of age) because they became too fat and heavy to structurally support themselves in the feedlot. Long-fed lambs offered ad libitum access to WSC still had the greatest ADG and G:F when compared to long-fed lambs offered alfalfa pellets and limit-fed WSC. Long-fed lambs offered ad libitum access to WSC also produced the

fattest carcasses, while limit-fed lambs produced carcasses with similar amounts of fat to alfalfa fed lambs. Sixteen yearling ewe lambs and 16 mature ewes were also fed ad libitum WSC and ad libitum alfalfa pellet diets to compare meat characteristics with the 16 ewe lambs fed the same two diets. Numerical differences were observed for greater G:F, lower dry matter intake, and lower COG when yearling ewe lambs and mature ewes were offered WSC compared to alfalfa pellets. Offering WSC also decreased the total tract weight and increased the amount of fat deposited on carcasses from yearling ewe lambs and mature compared to offering alfalfa pellets. Meat characteristics were analyzed in two trials. Trial 1 was a completely randomized design with a 3 × 2 factorial arrangement of treatments to identify differences due to sheep age and diet. Trial 2 was a completely randomized design with a 3 × 2 × 2 factorial arrangement of treatments to identify differences due to diet, lamb sex, and lamb age. Samples from the loins and ground shoulder were saved to determine the percent extractable lipid and ultimate pH. Loins and ground shoulder patties were cooked used in an untrained taste panel to rate lamb flavor intensity, off-flavor intensity and off-flavors. Loins were also used to conduct slice shear force as an objective measurement of tenderness. The ultimate pH decreased with increasing sheep age, with ewe lambs tended to have greater pH measurements compared to yearling and mature ewes and shorter-fed lambs having greater pH compared to long-fed lambs. Slice shear force measurements were lower for loins aged for 14 day compared to loins froze on day 1. A taste panel representative of typical lamb consumers in the Midwest typically reported greater lamb flavor and off-flavor intensity scores due to increasing sheep age and feeding alfalfa pellets compared to feeding a WSC diet. Correlations between lamb flavor and off-flavor intensity mean scores with other carcass and meat characteristics demonstrated no significant linear relationship with carcass fat measurements. Other variables with significant linear correlations only displayed weak correlations with lamb flavor and off-flavor intensity. Overall, these variables that demonstrate a lack of correlation exhibits the difficulty the American sheep industry has with classifying quality lamb on a consistent basis. The use of feeding a WSC diet at greater levels of restriction can offer producers cheap, efficient performance, with reductions in energy expended towards maintaining visceral organs, and reduce carcass fatness at heavy slaughter weights.

Dedication

To my parents:

Mark A. Jaborek and Pamela J. Jaborek

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Chapter 1.

Literature Review

Introduction

The American Lamb Industry Road Map Project (2013) has made a detailed outline, along with an established timeline, to accomplish their goals for industry improvements in a timely manner. Product characteristics, demand creation, productivity improvement, and industry collaboration, have been recognized as the major areas in the American lamb industry that need improvement. Information is needed regarding the effects of energy source, energy level, sex, and maturity on growth, carcass and meat characteristics of sheep. In order to address the goals of the American Lamb Industry Roadmap Project, it will be necessary to identify higher quality lamb products so the American Lamb Industry will be able to consistently produce high quality products on a regular basis. Nutritional programs and diets can vary drastically within the lamb industry depending on location. In the Midwestern part of the United States, grain is more readily available to livestock producers, making it easy for producers to finish their animals on high- energy grain diets in the feedlot. However, in the Western part of the United States, finishing sheep on large acreages of pasture is more available and convenient. The use of ad libitum whole shelled corn (WSC) and alfalfa pellet diets represents these high and low energy diet types, respectively. While, the alfalfa pellets may not accurately reflect the Western style diet due to nutritional differences between pelleted forage and grazed forage. The use of restricted intake of an ad libitum WSC based diet was investigated to potentially improve feed efficiency and reduce the amount of carcass fat on lambs being fed high concentrate diets. Studying these different diet types also allowed us to focus on the effect diet has on the flavor of sheep meat. Others have already recognized volatile organic compounds such as branched chain fatty acids to be the cause of mutton flavor, (Watkins et al., 2011, Watkins et al., 2013, Watkins et al., 2014; Wong et al., 1975b; and Young et al., 2003) while pastoral flavor is caused by the accumulation of skatole (Young et al., 2003; Schreurs et al., 2007; Watkins et al., 2013). Sex of the sheep also plays a major role in the classification of sheep carcass maturity (Ho et al., 1989; and Field et al., 1990) as well as carcass conformation (Jeremiah et al., 1997a) and other meat characteristics, such as flavor (Sutherland and Ames, 1996; and Young et al., 2006). Even though diet and sex effects still pose questions for meat quality concerns, age/maturity also has a major influence on the lamb industry's ability to produce a consistent product for consumers. There have been questions for concern about whether the USDA quality grading system can accurately classify sheep carcasses on a consistent basis for meat quality (Ho et al., 1989 and Field et al., 1990).

Effects of diet on lamb growth and performance

Over the past 60 years, the effects diet type has on lamb growth and performance have been studied extensively. Crouse et al. (1981) studied the effects of feeding lambs a high-energy corn based diet, or a low-energy alfalfa hay based diet. Crouse et al. (1981) found that lambs fed the high energy diet finished with greater slaughter weights as a result of greater average daily gain (ADG). More recent studies followed and began to investigate the effects of pasture based diets in comparison to concentrate diets. McClure et al. (1994) studied the effects of grazing either orchardgrass, ryegrass, or alfalfa pasture, versus a 100 percent concentrate diet. Final weight and ADG were greater for lambs fed the concentrate diet, followed by lambs grazing alfalfa, and lastly lambs grazing orchard or ryegrass (McClure et al., 1994). Another study compared grazing lambs on alfalfa, a concentrate diet fed in the feedlot, and a diet that consisted of lambs grazing ryegrass then being transferred to the feedlot to be fed a concentrate diet for the remaining 42 days on feed (DOF; Murphy et al., 1994c). Lambs fed concentrate the entire time resulted in greater ADG than lambs transferred to a concentrate diet after grazing ryegrass. Although, not significantly different, lambs fed the concentrate diet were on feed for 63, whereas lambs grazing alfalfa and lambs fed ryegrass/concentrate remained on feed for an additional 33 and 50 days respectively, to reach the same final body weight as concentrate-fed lambs. In a similar study, that considered a mixed diet of forage and concentrate, Murphy et al. (2003) fed lambs one of three diets: high concentrate (whole shelled corn), high forage (alfalfa silage), or a 50:50 mixture of corn and alfalfa silage. The lambs fed the high concentrate and mixed diet resulted in greater ADG with fewer DOF than the lambs fed the high forage diet. Lambs consuming the high concentrate diet consumed less feed than lambs fed the other diets, which resulted in a superior feed efficiency. Lambs fed the mixed diet were also more feed efficient than lambs fed the high forage diet (Murphy et al., 2003). Finally, Borton et al. (2005a) compared lambs fed a concentrate diet to lambs grazing ryegrass and found that lambs fed the concentrate diet had an ADG 2 times greater than lambs grazing ryegrass. A lower ADG resulted in lambs grazing ryegrass to remain on trial for an average of 194 extra days to reach a similar final body weight of the concentrate fed lambs. Clearly, substantial evidence has been provided from previous research that proves lambs fed high concentrate diets will outperform lambs being fed high forage or pasture diets.

Effects of diet on lamb carcass characteristics

Similar to lamb performance, carcass characteristics can also vary by diet type. Lambs fed the high energy diet by Crouse et al. (1981) resulted in greater hot carcass weight (HCW), fat thickness (FT), body wall thickness (BWT), loin muscle area (LMA), percent kidney and pelvic fat, leg conformation score, yield grade (YG), fat color (more yellow), and quality grade (QG), but flavor score was lower (less intense) and there was no difference in maturity score when compared to lambs fed a low energy diet. When Crouse et al. (1983) fed lambs iso-nitrogenous and iso-caloric diets of alfalfa and soybean meal (SBM) base, carcasses from lambs fed alfalfa based diets resulted in greater live weights, FT, BWT, kidney fat, YG, and QG, with no differences for maturity or fat color. Similar to the results of Crouse et al. (1981), Field et al. (1990) also experienced greater chilled carcass weight, ribeye area (REA), fat depth (FD), BWT, kidney fat, leg conformation score, YG, and QG, in addition to greater body conformation scores and flank streaking from lamb carcasses produced on a high energy diet (corn) instead of a lower energy diet (corn silage). Lambs fed a high concentrate diet or mixed diet by Murphy et al. (2003) produced greater REA, BWT, and percent kidney, pelvic, and heart fat (%KPH), with no differences in HCW, FD, conformation scores, marbling, or QG.

Borton et al. (2005a) also reported carcasses with no difference in conformation scores between concentrate and forage-fed (grazed ryegrass) lambs, but lambs fed the concentrate did produce carcasses with greater HCW, FT, BWT, LMA, lean quality scores, YG, and QG. With the exception of the carcass results from Crouse et al. (1983), high energy concentrate diets produced carcasses with greater weights, LMA, and measurements of fat. A possible reason for the poorer carcass characteristics from lambs fed SBM as a protein source compared to alfalfa could have been due to the large proportion (33%) of corn cobs in the SBM based diet.

Reported physical carcass composition in the literature of lambs fed different diets seems to vary. McClure et al. (1994) reported lambs grazing orchardgrass and ryegrass pasture to have the least amount of lean muscle, fat, and bone with the lightest carcass weights when compared to lambs grazing alfalfa or being fed a concentrate diet in the drylot. Concentrate fed lambs also produced greater carcass weights and amounts of fat compared to lambs grazing alfalfa. In contrast, Murphy et al. 1994c reported similar amounts of lean and bone, and lower carcass weights from carcasses grown on an alfalfa diet, which resulted from reduced fattiness when compared to carcasses from lambs fed concentrate. Chemical composition of alfalfa raised lambs also had greater amounts of water and protein, with less fat when compared to lambs fed concentrate (Murphy et al., 1994c). Results from Borton et al. (2005b) also contradict those previously mentioned, by reporting carcasses from concentrate fed lambs to have less bone, total lean, and more fat compared to pasture raised lamb carcasses. To conclude, when lamb carcasses are at similar weights, alfalfa or pasture based diets reduce the amount of fat on lamb carcasses as compared to concentrate diets, thus resulting in greater percentages of lean and bone.

Effects of diet on meat characteristics from lamb carcasses

Diet can also significantly affect various meat characteristics or palatability attributes of the lamb carcass. Many have studied the flavor profile of lamb raised on white clover pastures (Cramer et al., 1967; Shorland et al., 1970; Schreurs et al., 2007). Early on, Cramer et al. (1967) reported lambs that had grazed white clover had a more intense flavor in the lean and fat, as well as an intense chop odor when compared to lambs grazing perennial ryegrass. Shorland et al. (1970) agreed, and also found lambs raised on white clover pastures produced lean and fat that had greater flavor intensities during various weeks of grazing. Shorland et al. (1970) also found the flavor intensities were greater in the shoulder and loin lean than lean from the leg of 10 week hogget (yearling) carcasses. Years later, Young et al. (2003) and Schreurs et al. (2007) attributed the high ratio of protein to readily fermentable carbohydrates in legumes as the cause for the production of pastoral flavors. Since white clover contains a higher ratio of protein to readily fermentable carbohydrates than grasses, greater flavor intensities were observed from lambs that consumed white clover pastures. Flavor intensities have been shown to be greater from lambs raised on low energy diets when compared to high energy diets (Crouse et al., 1981). Borton et al. (2005) also reported more off flavors and off odors from lamb produced on a forage diet, while lamb produced on a concentrate diet resulted in better flavor, greater juiciness, and greater overall acceptability ratings, while having similar tenderness scores. Crouse et al. (1983) reported their SBM based diet produced lamb with a mustier flavor, and with a less desirable aftertaste and fat aroma compared to the alfalfa diet. As previously mentioned, these off odors and flavors could have been produced by the relatively large quantities of corn cobs present in the SBM diet.

Rousset-Akrim et al. (1997) reported four significant flavors identified by a trained sensory panel when consuming lamb and mutton: sheepmeat, animal, liver, and poultry. Sheepmeat flavor was the most intense flavor across all dietary treatments, but was significantly greater in ram lambs that were grown slowly on pasture. Liver flavor was the most distinguishable flavor in meat from mature ewes grazing on pasture. Poultry and animal flavors scores were numerically higher for light weight grain fed lambs and heavy weight slow grown pasture lambs, respectively. Sheepmeat, cabbage, roast, animal, and rancid odors were the cooked fat odors most often associated with meat from ram lambs grown slowly on pasture at both light and heavy body weights. Rousset-Akrim et al. (1997) believe these findings verify that fat is the main source of the distinct sheepmeat odor and flavor detected in the meat from sheep.

Murphy et al. (2003) studied the effect diet had on lamb tenderness. Lambs fed the high concentrate diet produced chops with greater Warner-Bratzler shear force (WBSF) measurements (4.87 kg) compared to lambs fed the mixed or high forage diet (3.39 kg and 3.70 kg, respectively). A trained sensory panel also recognized that chops from lambs fed the high concentrate diet were less tender than the mixed diet, with chops from lambs fed the high forage diet being intermediate.

From the literature we can conclude that pasture diets produce lamb with more off flavors and off odors compared to high concentrate diets. However, lamb produced by consuming a high concentrate diet may have reduced tenderness compared to lamb produced by diets that are forage based or contain lower levels of concentrate. Most importantly, the fat from sheep carcasses is most likely the cause of sheepmeat flavor and odor recognized in the meat from sheep.

Effects of diet on fatty acid composition and skatole concentrations in sheep

Differences in fatty acid (FA) composition of lamb can be caused by dietary differences. Busboom et al. (1981) reported the FA composition from lambs fed a high concentrate diet resulted in greater levels of 10-17 carbon long branched-chain fatty acids (BCFA) compared to lambs fed a low energy diet (62.20 mg/g fat and 36.73 mg/g fat, respectively). Lamb fed the high energy diet also contained greater levels of odd numbered chain FAs, which also contribute to the production of softer and oilier fat. Busboom et al. (1981) also reported lamb carcasses produced by consuming the high energy diet to have yellower fat compared to lamb carcasses produced by consuming the low energy diet. Miller et al. (1986) studied the effects of fatty acid composition when cull ewes were switched from grazing pasture to the feedlot for 40 days before slaughter. Similarly to Busboom et al. (1981), Miller et al. (1986) found that cull ewes supplemented with corn in the feedlot produced carcasses with more BCFA, particularly 4-methylated BCFA (10, 12, and 14 carbon long chains). Ewes finished in the feedlot also produced carcasses with a greater percent total lipid in the subcutaneous fat and *Longissimus* muscle. Young et al. (2003) also support the findings of elevated levels of BCFA in the fat from lambs fed concentrate diets. Levels of 4-methyloctanoic acid (MOA) and 4-methylnonanoic acid (MNA) were significantly greater in the fat from lambs fed corn or an alfalfa concentrate diet compared to the fat from lambs grazing pasture. Lambs fed the two concentrate diets (alfalfa pellets and corn) also had a higher ratio of unsaturated FA to saturated FA, which resulted in oilier, more translucent fat on lamb carcasses. However, pasture diets typically produced lambs with fat that contained greater levels of skatole and indole compared to lambs fed corn or alfalfa concentrate (Young et al., 2003). Overall, high energy concentrate diets can lead to the increased rate of deposition of BCFA in the subcutaneous fat of sheep and produce yellow, soft, oily fat.

Production of branched-chain fatty acids and skatole in sheep

A selection of branched chain fatty acids, MOA, MNA, and 4-ethyloctanoic acid (EOA), have been recognized as the causative agents of mutton flavor in sheep meat (Wong et al., 1975b; Young et al., 2003; Watkins et al., 2010, 2014), whereas skatole has been recognized as the cause for pastoral flavors (Young et al., 1997, 2003; Schreurs et al., 2007, 2008; Watkins et al., 2014). High levels of branched chain fatty acids can be found in the fat depots of sheep consuming high concentrate diets (Duncan et al., 1974; Duncan and Garton, 1978; Miller et al., 1986; Brennand and Lindsay, 1992). The production of volatile fatty acids such as acetate, propionate, and butyrate, are made by microbial fermentation of the dietary starch and sugars in the rumen. With the consumption of a high grain diet greater amounts of propionate are produced. Propionate is then adsorbed through the rumen epithelium and transported by the portal vein to the liver where propionate will be metabolized for gluconeogenesis. However, when there is an over-abundance of propionate produced, it becomes incorporated in de novo FA synthesis. The carboxylation of propionate forms methylmalonyl-CoA which can be used as one of the precursors in FA synthesis (Scaife and Garton, 1975). Methylmalonyl-CoA becomes substituted for malonyl-CoA, a precursor in FA synthesis. Due to the incomplete metabolism of excess propionate and the incorporation of methylmalonyl-CoA into FA synthesis, BCFA are formed and deposited in the adipose tissue of sheep. Deposition of these BCFA in the adipose tissue can vary in location (Brennand and Lindsay, 1992). Brennand and Lindsay (1992) found that more MOA was deposited in the rump and more EOA was deposited in the shoulder, both at levels above their detectable threshold. Incorporation of BCFA from bacterial deamination of branched-chain amino acids (valine, leucine, and isoleucine) can be absorbed in the small intestine and deposited in the adipose tissue and contribute to the overall concentration of BCFA in the adipose tissue in sheep as well (Allison et al., 1978). Variations of BCFA concentrations in sheep adipose tissue and propionate production may also be caused by the diversity of the micro flora in the rumen.

Pastoral flavor of sheep meat has been attributed to the compound 3-methylindole, more commonly known as skatole (Young et al., 2003; Schreurs et al., 2007, Schreurs et al., 2008). Accumulation of skatole in the adipose tissue of sheep is caused by the enhanced degradation of tryptophan in the rumen (Deslandes et al., 2001; Young et al., 2003; Schreurs et al., 2008). Pasture diets typically contain high levels of protein to the level of readily digestible carbohydrate which provides tryptophan at higher levels in the rumen (Young et al., 2003). When the ratio of protein to readily digestible carbohydrate is high, the rumen bacteria degrade excess tryptophan due to the low levels of energy supplied by readily digestible carbohydrate to incorporate amino acids into microbial protein (Schreurs et al., 2008). Therefore, tryptophan becomes degraded by the rumen bacteria into indolepyruvate, which can be further degraded into indole or indoleacetate, and indoleacetate can be further degraded into 3-methylindole (Deslandes et al., 2001). The majority of indole and skatole is absorbed through the rumen epithelium (Roy et al., 2004), with smaller amounts being adsorbed in the duodenum. Once skatole is absorbed into the blood stream it is taken to the liver to be metabolized, but some skatole will escape and be deposited in the adipose tissue (Schreurs et al., 2008).

Effects of restricted feed intake in lambs

Murphy et al. (1994a) conducted an experiment to study the effects of restricting the feed intake of lambs fed various levels of concentrate. Dietary treatments consisting of greater levels of concentrate and restricting feed intake the greatest resulted in greater dry matter (DM), organic matter (OM), acid detergent fiber (ADF), and neutral detergent fiber (NDF) digestibility. Starch digestion was not affected, but apparent nitrogen digestion was improved on the treatment with the greatest feed restriction and greatest amount of concentrate. In their second trial, Murphy et al. (1994a) fed a 92 percent concentrate diet at feed restrictions of 90, 80, and 70 percent of ad libitum intake. Greater feed restriction resulted in improved digestibility of DM, OM, ADF, starch, and crude protein. Calculated maximal nitrogen retention was at 89 percent of ad libitum intake. In another study, Murphy et al. (1994b) reported ADG, dry matter intake (DMI), DOF, and final weight to have significant linear effects. Final weight, ADG, and DMI decreased with increased feed restriction, while DOF increased with increased feed restriction. There was no significant difference in gain to feed ratio (G:F) due to the level of feed restriction. Increased feed restriction also affected the carcass composition by increasing the amount of lean, while decreasing the amount of fat, with no difference in the amount of bone. The chemical composition expressed increases in moisture content, while showing no difference in the percent protein, and a decrease in the percent fat with increased feed restriction. Fluharty and McClure (1997) also fed a high concentrate diet at 85 percent of ad libitum intake. No differences were found for final body weight, DOF, and G:F, but lambs offered ad libitum intake did result in the greater ADG. In effort to compare iso-caloric and iso-protein alfalfa and high concentrate diets, Fluharty et al. (1999) restricted feed intake to 85 percent of the ad libitum intake of lambs grazing alfalfa by the use of NRC equations. The results showed no differences in performance, but improved DM, OM, and NDF digestibility in lambs limit-fed concentrate when compared to lambs grazing alfalfa. Nitrogen retention, apparent nitrogen digestion, and true nitrogen digestion were greater for the limit-fed lambs. Carcass data reported shows that HCW and dressing percentage were greater in the lambs fed a restricted high concentrate diet, with no other carcass trait differences for LMA, FD, BWT, %KPH, leg conformation score, QG, YG, and lean or fat color score. Greater feed restrictions while feeding a high concentrate diet can improve the digestibility of the diet, as well as improve the ability of the lambs to retain dietary nitrogen.

Effects of restricted feed intake on lamb visceral organ weight

When comparing restricted feed intake of a high concentrate diet to ad libitum intake, ad libitum intake resulted in a greater weight of the rumen/reticulum and large intestine (Fluharty and McClure, 1997). With increases in visceral organ weight, additional energy is needed to maintain these heavier organs. Since G:F was not significantly different, this use of energy is not being used to produce lean tissue weight and can therefore be considered an inefficient use of available energy. Fluharty et al. (1999) also reported increased visceral organ weights in lambs due to the consumption of bulky forage diets when compared to a restricted feeding of a high concentrate diet. While HCW and visceral fat weight were greater in high concentrate limit-fed lambs, lambs grazing alfalfa had greater liver, omasum, abomasum, small intestine, cecum, and large intestine weights. Lighter HCW and lower dressing percentages of the lambs consuming alfalfa is likely due to the increased energy required for maintenance of those larger visceral organs.

Effects of sex on lamb growth and performance

The sex of the lambs on feed can significantly affect the resulting growth and performance observed by some sheep producers and lamb feeders. Crouse et al. (1981) fed ram and wether lambs and found that ram lambs had significantly greater slaughter weights and ADG. McClure et al. (1994) found that over a three year span, male lambs (rams and wethers) had greater ADG, final body weights, and chilled carcass weights than female lambs. A study done by Okeudo et al. (2008) compared the growth of fours sexes of lambs and found that intact rams and vasectomized ram lambs had greater ADG than ewe lambs, with wether lambs being intermediate. The general conclusion is that rams grow the fastest, followed by wethers and finally ewes.

Effects of sex on lamb carcass characteristics

Crouse et al. (1981) reported greater HCW, LMA, fat color score (more yellow), and maturity for ram carcasses than wethers. Whereas, wethers produced carcasses with greater FD, BWT, kidney fat, YG and QG scores, with no difference in leg conformation scores. Crouse et al. (1983) reported differences between carcasses from ram and ewe lambs, with ram lambs having greater live weights, and fat color scores (more yellow). Although there was no difference in maturity scores or QG, ewe carcasses had greater FD, BWT, kidney fat, leg conformation scores, and YG than ram carcasses. Ho et al. (1989) studied the effects of sex, using ewe, wether, and ram lambs, on carcass characteristics at five different ages. Wethers produced the heaviest carcass weights between the three different sexes. Ewe carcasses had greater FD, BWT, percent kidney fat, and YG, followed by wether carcasses, and lastly ram carcasses. However, ewe carcasses had the smallest LMA of the three sexes. Rams had the lowest leg conformation score, as well as the lowest overall carcass conformation score. Ho et al. (1989) also noticed that ram carcasses contained fat that was softer and more yellow compared to carcasses from ewe and wether lambs. Ewe and wether carcasses resulted in more desirable flank streaking scores and QG scores compared to ram carcasses. Field et al., (1990) reported the effect of sex, between wether and ewe carcasses on carcass characteristics. No differences were found for LMA, FD, BWT, leg conformation score, body conformation score, kidney fat weight, flank streaking score, YG and QG between wether and ewe carcasses. The only difference was that wethers produced heavier cold carcass weights than ewes. Jeremiah et al. (1997a) conducted a comprehensive study that compared the effects of sex (ram, wether, and ewe) on carcass composition from 1660 lambs sent to market. Ram carcasses were the leanest, had the most bone, and most moisture followed by wethers and finally ewes. The opposite pattern was reported for the amount of fat and intramuscular fat (IMF) present on carcasses. Carcass characteristics reported by Jeremiah et al. (1997c) show there were no differences for LMA, but ewe carcasses had the greatest FD, BWT, and conformation scores followed by carcasses from wethers and finally rams. Fat from ram carcasses was more yellow than fat from the other two sexes. Ram carcasses also produced the lightest (L*) and yellowest (b*) colored lean, with no difference in the redness (a*) of lean color (Jeremiah, 1997e). Ewe carcasses had the best water binding capacity, followed by wether carcasses and finally ram carcasses. These results provide clear evidence that shows carcasses from ram lambs are leaner than wether or ewe carcasses.

Effects of sex on meat characteristics from lambs

There does not seem to be conclusive evidence to distinguish the effects sex may have on meat characteristics of lamb. Mendenhall et al. (1979) reported no differences between carcasses from all three sexes (ram, wether, and ewe) for consumer evaluated tenderness, juiciness, flavor, and overall acceptability. However, ram carcasses did have greater WBSF measurements (2.2 kg) compared to wether and ewe carcasses (1.8 and 1.7 kg respectively). Ho et al. (1989) also reported greater WBSF for chops from ram carcasses (3.63 kg) compared to wether and ewe carcasses (2.77 and 2.45 kg respectively). This is in agreement with Okeudo et al. (2008), who found that lamb chops from vasectomized rams and intact rams had greater shear force measurements than chops from ewe carcasses, with chops from wether carcasses being intermediate. Similarly, Young et al. (2006) reported greater shear force measurements from the *Semimembranosus* muscle from ram carcasses when compared to wether carcasses and shear force values also increased with increasing animal age. Crouse et al. (1981) reported greater flavor intensities in chops from ram carcasses compared to wether carcasses. Crouse et al. (1983) found that lamb chops from rams had more mutton flavor and that the intensity of the mutton flavor increased with additional (DOF) when compared to chops from ewes. Chops from ewe carcasses were more reminiscent of a browned flavor and had a better aftertaste and fat aroma. Jeremiah et al. (1997b) reported that loin roasts from ewes were the most tender, with roasts from wether carcasses being intermediate, and finally roasts from ram carcasses being the least tender. This was also the trend for the amount of perceivable connective tissue in lamb roasts. No clear differences were detected for the flavor or juiciness of loin roasts sampled by the experienced trained taste panel. To conclude, sex of the lamb may have some effect on meat characteristics, with increased tenderness from ewe carcasses followed by wether carcasses and finally ram carcasses. Flavor scores caused by the sex of the lamb appear to follow the same trend as tenderness, but other factors may have a more significant impact on flavor than sex.

Effects of sex on branched-chain fatty acid and skatole concentrations in ovine adipose tissue

Busboom et al. (1981) reported greater concentrations of BCFA in ram lambs compared to wether lambs (62.20 mg/g and 36.73 mg/g fat, respectively). Branched-chain fatty acid concentration also increased in ram lambs over the 63 day period before the second slaughter group was harvested. Ram carcasses also had noticeably yellower fat with a softer, oilier texture than the fat from wether carcasses. Sutherland and Ames (1996) measured the sex × time interaction of ram and wether lambs at 12 and 30 weeks of age and its effects on BCFA concentrations. Thirty week old ram lambs produced greater concentrations of MOA acid and MNA than wethers at 30 weeks and rams at 12 weeks of age. Sutherland and Ames also reported that concentration of MOA (2.85 mg/kg) was at or above its odor threshold for each of the four treatment groups, but not for MNA (92.7 mg/kg). Likewise, Young et al. (2003) noticed numerically greater MOA and MNA concentrations in ram fat compared to wether fat, however it was not significant. Again, Young et al. (2006) studied the effects sex had on BCFA concentrations, but this time over the course of 122 to 668 days of age (DOA). Once again, rams had greater concentrations of both MOA and MNA compared to wethers. There were significant sex × time interactions or trends for both MOA and MNA to increase with increasing age. Young et al. (2006) noted that MNA concentrations lagged behind MOA concentrations and were often not detected in younger animals. Skatole and indole concentrations were also greater in ram fat and they increased with advancing age. Young et al. (2003) reported no difference in skatole concentrations between rams and wethers on pasture, but indole concentrations were greater in the fat from rams grazing pasture than wethers grazing pasture at 132 DOA, but not 232 DOA.

Effects of animal age on meat characteristics and branched-chain fatty acid concentrations

Animal age can significantly affect the sensory properties of sheep meat. Weller et al. (1962) studied the effect of lamb age and weight and found that the semi-trained taste panel preferred older lambs (200 to 245 DOA) when compared to younger lambs. Older lamb was found to be milder in flavor intensity and to have a more natural lamb flavor. No differences were found for shear force measurements between age and weight of lamb carcasses (Weller et al., 1962). Batcher et al. (1969) studied the flavor differences between lamb (7 to 8 months of age) and yearling mutton (15 to 16 months of age). They found no differences between the two classes of sheep meat for sliced meat (roasted leg, broiled loin chops, or braised shoulder) flavor. However, broth created from 7 to 8 month old lamb had a more intense flavor when compared to 15 to 16 month old yearling mutton (Batcher et al., 1969). Batcher et al. (1969) also reported that when 20 percent fat was added to lamb patties, meat from rams had a more intense flavor than the meat from wethers. But, when no fat was added there was no difference, thus supporting the comment mentioned earlier by Rousset-Akrim et al. (1997), that fat may be the reason for flavor differences. Consumer acceptance of shank roast flavor was greater for lambs 6-12 months of age, while butt roast flavor acceptability was greater for lambs 6-15 months of age (Jeremiah et al., 1998c). Jeremiah et al. (1998c) reported roast flavor was less acceptable to consumers when roasts were from lambs 3-6 months of age. Surprisingly, both Jeremiah et al. (1998c) and Batcher et al. (1969) report that there may be a lack of consumer acceptability of lamb flavor from younger lambs. Ho et al. (1989)

reported WBSF measurements from rib chops to be lower from lambs 459 and 652 DOA compared to 271, 361, and 557 DOA. This is an interesting finding that is difficult to explain, because WBSF is known to typically increase with age. Both Wiese et al. (2005) and Pethick et al. (2005) investigated whether or not there were any differences in sheep meat quality between sheep of different ages. Wiese et al. (2005) grouped sheep by dentition; group 1 had to have all their temporary milk teeth, group 2 could have up to one missing milk tooth as long as the emerging permanent tooth was below the height of the remaining milk teeth, while group 3 had fully grown permanent teeth. No differences were found for pH or shear force measurements of the sheep meat (Wiese et al., 2005). A trained taste panel conducted by Wiese et al. (2005) also found no differences for tenderness, juiciness, or flavor, but consumers rated juiciness and overall liking greater for groups 2 and 3 compared to group 1, with tenderness being greater for group 3 compared to group 1. Group 3 had the darkest lean (L*), possibly due to increased myoglobin concentrations, while group 2 had lean that was more red (a*) and yellow (b*). Pethick et al. (2005) made comparisons of sheep meat quality by months of age: 8.5, 20, 32.5, 44.5, 56.5, and 68.5. Shear force measurements of the *Semimembranosus* were not significantly different, but the shear force measurements of the *Longissimus* were significantly different, with linear, quadratic, and cubic relationships. Lean color became darker (L*) and the myoglobin concentration increased with age. Consumer sensory reported by Pethick et al. (2005) decreased tenderness and juiciness with age, with sheep meat from 44.5 month old sheep being the least liked and having the least liked flavor. Both Weise et al. (2005) and Pethick et al. (2005) concluded that meat quality differences between age groups are much smaller than suggested and sheep meat classifications should be reconstructed.

USDA Grading ---Maturity, Yield and Quality Grading

In the U.S. sheep carcasses can be classified into one of four categories: young lamb, older lamb, yearling mutton, and mutton (USDA, 1992). Lamb carcasses generally have slightly wide, moderately flat rib bones, and a light red lean color with a firm texture. Yearling carcasses tend to have more moderately wide, flat rib bones along with a lean that is slightly dark red in appearance and a coarser texture of lean than lamb carcasses. Mutton carcasses have wide, flat rib bones with lean that is dark red in color and has a coarse texture. The U. S. grading system assesses break/spool joint status of the carcass to classify it as lamb, yearling, or mutton. A carcass with two perfect break joints can be classified as a lamb or yearling mutton depending on other maturity indicators on the carcass. A carcass with only one perfect break joint can still be classified as lamb as long as its other maturity indicators classify the carcass as lamb as well. A carcass with two spool joints can be classified as yearling mutton or mutton depending on the other carcass maturity indicators. Other maturity indicators on the carcass that are assessed are lean and skeletal maturity indicators, such as: lean color, lean texture, rib bone color and shape. Lean maturity indicators are given greater precedence compared to skeletal indicators. Carcasses can be given two grades, one for an indication of quality and the other for carcass yield. The QG reflects the palatability characteristics as well as the conformation of the carcass. While YG represents the percent boneless closely trimmed retail cuts (BCTRC) (cuts trimmed to at least 0.10

inches of fat) available to the consumer. Prime, Choice, Good, and Utility grades can be given to lamb or yearling mutton carcasses. While only Choice, Good, Utility, and Cull grades can be given to mutton carcasses. Quality grade is comprised of the fat flank streaking inside the carcass to consider the lean color, lean texture, and marbling. Quality grade also includes the carcass conformation score, which reflects the portion of edible lean to the portion of inedible lean. Carcasses that receive higher conformation scores are heavily muscled, appear to have thick, plump, and well-rounded hind legs. These carcasses are also thick across their backs and shoulders and have a thin, even layer of fat distributed across the carcass. When combining palatability and conformation scores to create a QG the palatability score has greater precedence over the conformation score. For example, a QG Prime cannot be given to the carcass if the palatability score is not of a Prime grade itself, no matter how high the conformation score. However, when the opposite is true and the palatability score is of a Prime grade, for example, then the conformation score must be above average choice at least for the carcass to receive a Prime Quality grade. Yield grades are assigned by using an equation that uses FT ($YG = 0.4 + (10 \times \text{fat thickness (inches)})$). Carcasses with backfat measurements between 0.00-0.15 inches, 0.16-0.25 inches, 0.26-0.35 inches, 0.36-0.45 inches, and greater than 0.46 inches are assigned YG 1 , 2 , 3, 4, and 5 respectively. Carcasses weighing either 55 or 85 pounds should have body wall thicknesses of 0.75 or 0.85 inches, 0.90 or 1.00 inches, 1.05 or 1.10 inches, 1.20 or 1.30 inches, or greater than 1.30 inches for Yield grades 1, 2, 3, 4, and 5 respectively (USDA,1992).

Consideration for a detention based maturity classification system for sheep

Lawrence et al. (2001) conducted a study to investigate the relationship between using a dentition based system or the United States Department of Agriculture (USDA) skeletal ossification system to grade the maturity of beef carcasses. The USDA targets cattle at or under 30 months of age for the A maturity classification, while cattle 30-42 months of age are targeted to receive B maturity recognition. Carcass maturity grades C, D, and E are typically thought to be cattle approximately 42-72 months, 72-96 months, and greater than 96 months of age, respectively. Lawrence et al. (2001) recorded dentition of cattle having 0, 2, 4, 6, or 8 permanent incisors. Based on the literature, Lawrence et al.(2001) found permanent tooth eruption of 2, 4, 6, and 8 teeth would correspond to mean ages of 24, 30, 38, and 45 months of age, respectively. Data collected showed no relationship between the two maturity grading systems. In their first experiment there were only 162/1264 carcasses that agreed on maturity when using dentition and skeletal ossification and only 54/200 agreed in the second experiment. Lack of agreement was due to the consistent categorization of older cattle into younger maturity classifications. Results from the first experiment showed that 91.5, 89.1, 82.2, and 64 percent of the cattle with 0, 2, 4, or 6 permanent incisors, respectively, were rewarded A maturity. Results from the second experiment showed that 100, 97.5, 75, 72.5, and 40 percent of the cattle with 0, 2, 4, 6, or 8 permanent incisors, respectively, were rewarded A maturity. The use of a skeletal ossification based maturity system appears to be less accurate at classifying carcasses based on chronological age. However, the real concern is how the two systems relate to the palatability/meat characteristics of the carcass.

This idea relates directly back to the classification system the USDA uses to classify sheep carcasses. There is concern that there are not any significant palatability differences, indicative of meat quality, between lamb and yearling mutton. Studies have been conducted in the past to examine the effects of chronological age on the carcass maturity of sheep (Ho et al., 1989; Field et al., 1990). It is commonly known that sex hormones, such as estrogen and testosterone, participate in bone development. When sexual maturity is reached these sex hormones remain present for extended periods of time at elevated levels. This reduces the proliferation of the new chondrocytes responsible for increasing bone length. Instead, the chondrocytes already present, mature and ossify the epiphyseal growth plate. The USDA classification system for sheep carcasses that is based on break joint status is clearly biased in favor of wethers, the castrated sex. Ho et al. (1989) reported break joints were more mature on ram carcasses, followed by ewe carcasses, and lastly wether carcasses. Epiphyseal growth plate thickness was greatest for wether carcasses, followed by ram carcasses, then ewe carcasses. Field et al. (1990) also reported greater growth plate widths for wether carcasses compared to ewe carcasses. Surprisingly, the force required to break the growth plate was not significantly different between wether and ewe carcasses (145 vs. 113 kg, respectively) (Field et al., 1990). When Ho et al. (1989) studied the effects of carcass maturity on sheep carcasses at different ages (271, 361, 459, 557, and 652 DOA), they found differences due to chronological age and sex. The authors reported ewes at

459 DOA produced carcasses that had 3/10 ossified growth plates, 4/10 had spool joints and 4/10 had their yearling teeth. Wethers of the same age produced carcasses without any fused growth plates or spool joints, while 6/10 had their yearling teeth. Rams of the same age produced carcasses that had 1/10 ossified growth plates, 2/10 had spool joints, and 5/10 had their yearling teeth. However, at 557 DOA, all ewe and ram lambs had ossified epiphyseal growth plates, spool joints, and yearling teeth, but only 2/10 wethers had fused growth plates, 2/10 had spool joints, and all 10 had their yearling teeth. Field et al. (1990) also reported that at 469 DOA ewe lambs produced carcasses with 14/20 fused growth plates, 11/20 spool joints (3 with uneven break joints), while 14/20 had their yearling teeth. Wethers the same age didn't produce carcasses with any fused growth plates or spool joints and 17/21 had their yearling teeth. All wethers at 578 DOA were classified as yearlings according to their dentition, but epiphyseal cartilage was still present and all wether lambs had break joints. At 662 DOA, 6/10 wethers still had break joints. This data clearly exhibits a sex effect on break joint status of lambs and should provide enough reason to consider the use of a dentition based maturity classification system. Though, a dentition based maturity classification system may have biases also.

Permanent tooth eruption has been known to vary by sex (Ho et al., 1989), breed (Arrowsmith et al., 1974; Aitken and Meyer, 1982; Cocquyt et al., 2005), and diet (Arrowsmith et al., 1974). In the study conducted by Ho et al. (1989), they report permanent tooth eruption occurred at least 30 days earlier in rams compared to ewes. Cocquyt et al. (2005) reported ranges for permanent tooth eruption of 2, 4, 6, 8 permanent teeth for six sheep breeds at the respective ages: 12-18, 15-26, 24-42, 32-48 months of age. Cocquyt et al. (2005) reported the eruption of the first pair of permanent teeth is the most accurate indicator or permanent tooth eruption for chronological age indication, because the eruption of other permanent teeth may be affected by other factors such as improper tooth eruption. Aitken and Meyer (1982) estimated mean ages for the first permanent tooth to erupt in Romneys, Perendales, Suffolks, and Southdowns at 475, 465, 460, and 530 DOA respectively, based on the ranges gathered for tooth eruption. Average permanent tooth eruption for 2, 4, 6, and 8 teeth were 427, 633, 813, and 983 DOA for Blackhead Persians and 453, 738, 932, and 1166 DOA for Dorpers respectively (Arrowsmith et al., 1974). Arrowsmith et al. (1974) also noted that by feeding a supplement (cottonseed meal) to dams during the later stage of gestation, during lactation, and to lambs after weaning, the age at which the first pair of permanent teeth erupts in lambs occurs 33 days earlier. Feeding supplement also reduced the days for the eruption of 4, 6, and 8 permanent teeth by 73, 70, and 104 days. However, the findings of Field et al. (1990) reported no difference in permanent tooth eruption due to diet. In order to replace the skeletal ossification/break joint status based maturity system now in use by the USDA, with a dentition based maturity system, more research will most likely be needed to force a change.

Using Selected Ion Flow Tube – Mass Spectrometry (SIFT-MS) to detect volatile compounds

Selected Ion Flow Tube – Mass Spectrometry is a form of mass spectrometry which can analyze volatile organic compounds (VOCs) at parts-per-trillion by volume (ppt/v). The use of SIFT-MS also allows for real-time quantitative analysis of VOCs, which eliminates extensive sample preparation work needed by other detection methods, thus reducing experimental error. Other analytical techniques, such as gas chromatography- mass spectrometry (GC-MS), require traps to collect VOCs. Traps allow VOCs time to escape or degrade due to the extensive sample preparation and collection times needed (Spanel and Smith, 1999). Elimination of this sample preparation also reduces the increased chance for human error. Using SIFT-MS allows the user to analyze a wide variety of VOCs with the use of three reagent ions (H_3O^+, NO^+, and O_2^+). The SIFT-MS technique passes air and water vapor through a microwave discharge to produce the three reagent ions. These positively charged reagent ions then travel through a quadrupole mass filter where the reagent ions are sorted by their mass to charge ratio. The quadrupole mass filter selects one reagent ion at a time to enter the flow tube and can switch to another reagent ion in milliseconds. Next, the selected reagent ions pass into the flow tube where they interact by soft chemical ionization reactions with the sample gas in the presence of a carrier gas (Nitrogen or Helium). The use of soft chemical ionization transfers less energy to the VOC entering the flow tube, resulting in reduced product fragmentation. The product ions are passed through a second quadrupole mass filter before being presented to a mass spectrometer detection system that records the counts of each. By combining the experimental counts with known rate coefficients (k) for the reaction between the VOC and reagent ion and the known dilution of the sample gas into the carrier gas, the absolute concentration of the VOCs can be calculated. The SIFT-MS technique is also discussed in peer reviewed papers done by other researchers (Spanel and Smith, 2002; Smith and Spanel, 2005).

Selected Ion Flow Tube – Mass Spectrometry has various modes for detecting and reporting VOC concentrations. In the full scan mode, SIFT-MS does a full mass scan for product ion masses in a selected range using the three reagent ions. While a single ion mode (SIM) method focuses on only the selected product ion masses for the VOC of interest.

Sampling the VOCs in the developed headspace with SIFT-MS can be done by inserting a passivated needle into the septum of a sealed jar containing the solid or liquid sample. Snow and Bullock (2010) have reviewed the factors which influence the development of the headspace above a given sample. These factors are based on Dalton's law, Raoult's law, and Henry's law. Dalton's law of partial pressures states that the total pressure of a mixture of gases is the sum of all the partial pressures of each component within the gas mixture. This is described by the equation: $P_{total} = p_i + \ldots\ldots + p_n$, where P_{total} is the total pressure and p_i is the partial pressure. Raoult's law states that the partial vapor pressure of each dissolved component in the gas mixture is proportional to the mole fraction of the component in the solid or liquid sample. This is described by the equation: $p_i = kx_i$, where p_i is the dissolved solute, k is the proportionality constant of the vapor pressure at a given temperature, and x_i is the solute in the solid or liquid sample. Lastly, Henry's gas law states that at a constant temperature, the amount of solute dissolved from the solid or liquid sample is proportional to the partial pressure of the solute to the sample at equilibrium. Henry's law can be compared to Raoult's law, because it relates the partial vapor pressure of the solute in the gas mixture to its mole fraction within the solid or liquid sample. This is illustrated by the equation: $p_i = Hx_i$, where p_i is the dissolved solute, H is Henry's constant, and x_i is the solute in the solid or liquid sample. Henry's constant can be found by using the inverse slope of the measured headspace versus the concentration of the compound within the solid or liquid sample (Spanel and Smith, 2002). It is also important to consider both the partition coefficient and the phase ratio of the sample. The partition coefficient considers the concentration of analyte in the solid or liquid sample to the concentration of the analyte in the headspace. The phase ratio is the ratio of the volume of sample to the volume of the headspace. For both, the partition coefficient and phase ratio, the lower the value, the more available analyte there is in the developed headspace.

Other factors can affect VOC concentrations, such as the polarity of the various compounds within the sample (Castada et al., 2015). Castada et al. (2015) reported different concentrations of VOCs in the developed headspace from known concentrations of sample mixtures. With the addition of a more polar compound into the sample mixture, the concentration of the less polar compound in the headspace decreases. Similarly, with the addition of a less polar compound into the sample mixture, the concentration of the more polar compound increases in the headspace. This information could have potential insight for managing the release of the volatile compounds responsible for mutton flavor experienced while eating sheep meat.

The use of SIFT-MS technology has been applicable to the environmental sciences, medical sciences, cell biology, food sciences, agricultural sciences, and industrial manufacturing fields. Selected ion flow tube – mass spectrometry has been used to conduct air quality analysis, breath and urine analysis for disease detection, monitor cell and bacterial cultures, flavor detection of food products, VOC thresholds for motor vehicle quality, and the detection of fossil fuels. Though flavor detection has been studied extensively, flavor detection of raw meat products using SIFT-MS is limited. One exception was reported by Olivares et al. (2012) who used SIFT-MS to detect VOCs involved with the oxidation of beef steaks in modified atmosphere packaging. With little information published in regards to flavor/VOC detection of meat products with SIFT-MS, there is a need for more research to be done studying meat products using SIFT-MS. It is possible SIFT-MS could be used in an industrial setting to classify carcasses by measuring VOCs responsible for lamb flavor and off-flavor intensities.

Conclusion

There has been a vast amount of research done over the past 60 years pertaining to the effects of diet, sex, and age/maturity on the growth, carcass, and meat characteristics of sheep. However, there have been many different results reported for each of these variables, thus making it difficult to distinguish which report is an accurate depiction of sheep and sheep meat. It has been commonly recognized that high energy or high concentrate diets will produce greater weight gains and higher quantities of carcass fat compared to low energy diets, higher in forage concentration. Animals consuming high energy diets have been reportedly known to possess yellower carcass fat than contemporaries consuming low energy diets, which is the opposite of beef carcasses. In regards to sex, rams have been recognized as having yellower, softer fat compared to ewes or wethers. Rams are typically leaner than ewes and wethers. Therefore, ewes and have greater amount of total carcass fat, IMF, and greater Yield and Quality grades. An important concern is the ability of the American lamb industry to produce high quality lamb on a consistent basis for its consumers. Tenderness isn't the greatest concern of the lamb industry, since shear force values are typically under the tenderness thresholds (about 4.6 kg using Warner-Bratzler shear force) established by Shackelford et al. (1991), Miller et al. (2001), and Hopkins et al. (2006). The larger concern involves sheep meat flavor, even though it is understood consumer preference for sheep meat flavor can vary with geological location (Prescott et al., 2001). Being able to identify the causes of off odors, off flavors, mutton flavor and/or lamb flavor intensity will help the American sheep industry and USDA classify sheep more correctly for Quality grade based on the palatability attribute of concern, flavor. Many have researched the cause of these muttony compounds and the general consensus revolves around the BCFA (MOA, MNA, and EOA) (Wong et al., 1975b; Young et al., 2003; Watkins et al., 2010, Watkins et al., 2014). Other off flavors, such as pastoral flavor, can be of concern for sheep raised or finished on high forage or pasture diets, particularly comprised of legumes. Indoles, such as skatole, and phenolic compounds seem to contribute to these pastoral flavors and odors (Young et al., 2003 and Schreurs et al., 2007). Identifying a physiological maturity indicator on the carcass would help classify these carcasses by quality, which would be greatly beneficial in a slaughter plant setting and to the American lamb industry.

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Chapter 2.

Effect of energy source and level, and sex on growth, performance, and carcass characteristics of lambs

ABSTRACT

The objective of the study was to compare ad libitum or restricted intake of whole shelled corn (WSC) versus ad libitum alfalfa pellets, and sex of the lamb, on lamb growth and performance. Ewe (n=48) and wether (n=48) lambs were blocked by sex and stratified by initial weight to pen. The three diets fed were ad libitum WSC, 85% intake of ad libitum intake WSC diet, or an ad libitum alfalfa pellet diet. There were four lambs per pen, and eight replicate pens per dietary treatment. Ewe and wether lambs were removed from the study when pens reached an average weight of 59.0 and 63.5 kg, respectively. Statistical analysis was conducted using the PROC MIXED statement in SAS with diet and sex as fixed effects, diet and sex nested within pen as the random effect, and initial weight, final weight and initial × final weight interaction were used as covariates if $P < 0.20$. For daily DMI, gain to feed ratio, and feed cost of gain data, pen averages were used for the analysis and the random statement was removed. The LSMEANS and DIFF statements were used to distinguish significant ($P < 0.05$) differences between treatments and record the standard error. Average daily gain (ADG)

of lambs fed the ad libitum WSC diet was greater ($P < 0.05$) than lambs fed the restricted WSC and alfalfa pellet diets, which resulted in fewer ($P < 0.01$) days on feed for lambs fed ad libitum WSC. Lambs fed alfalfa pellets had a greater ($P < 0.01$) daily dry matter intake (DMI) than lambs fed the WSC diets. Wether lambs had greater ($P < 0.01$) daily DMI compared to ewe lambs. Gain to feed ratio was greatest ($P < 0.05$) for lambs fed ad libitum WSC, followed by lambs restricted WSC ($P < 0.01$), and finally lambs fed the alfalfa pellet diet. Whole shelled corn cost \$0.15/kg, alfalfa pellets cost \$0.60/kg, and supplements cost \$0.51/kg on an as-fed basis. The resulting feed cost of gain was greatest ($P < 0.01$) for alfalfa pellet fed lambs, followed by lambs restricted WSC, and lastly lambs fed ad libitum WSC. Lambs fed the WSC diets produced greater hot carcass weight (HCW) ($P < 0.01$) and greater ($P < 0.01$) dressing percent compared to lambs fed alfalfa pellets. Lambs consuming ad libitum WSC had greater amounts ($P < 0.05$) of kidney fat compared to lambs consuming a restricted diet of WSC or ad libitum alfalfa pellets. Lambs consuming either of the WSC diets produced greater ($P < 0.05$) amounts of visceral fat. Alfalfa fed lambs had greater tissue weight of the reticulum ($P < 0.05$), omasum ($P < 0.01$), and total digestive tract ($P < 0.05$). Lambs fed WSC had greater ($P < 0.05$) backfat and body wall thicknesses, marbling scores, and yield grades ($P < 0.01$) compared to lambs fed alfalfa pellets. Wether lambs had greater ($P < 0.05$) final BW and HCW compared to ewe lambs. Overall, lambs fed ad libitum WSC grew more efficiently at a lower cost of gain while producing carcasses with greater amounts of fat, whereas lambs fed alfalfa pellets had a lower dressing percentage and greater total digestive tract weight.

Key words: lambs, feedlot, corn, alfalfa, growth, carcass

Introduction

The purpose of the American Lamb Industry Roadmap project (2014) was to analyze the challenges of the American lamb industry and propose solutions to these challenges so the American lamb industry could become a larger competitor in the meat industry. The current per capita consumption of lamb is low, below 0.5 kg, which is well below other sources of meat (American Lamb Industry Roadmap, 2014). Some of the major goals outlined in the American Lamb Industry Roadmap project were to improve the productivity of American lamb and make it a premier product consumers would choose to purchase on a regular basis. With a considerable amount of the previous sheep research becoming outdated, it is an objective of the American lamb industry to reevaluate American lamb productivity and American lamb product characteristics.

In the past, increasing the slaughter weights of lambs was a goal of the American Sheep Industry (Harrison and Crouse, 1978). However, more recently the American Sheep Industry has had the difficulty of balancing the heavy slaughter weights of lambs with a desirable amount of fat thickness (American Lamb Industry Roadmap, 2014). The Roadmap project proposes to implement a value-based pricing system that would award producers for high quality lamb and discount producers for marketing lower quality lamb or lambs with excessive fat cover. Consumers have expressed aversion or unwillingness to select retail cuts with greater levels of fat (Jeremiah et al., 1993). Our research investigated the use of feeding different energy sources at differing levels to manage the production of fat in feedlot lambs.

The American lamb industry would also like to improve the productivity of American lamb by reducing the seasonality of lamb in the United States and improving the efficiency of gain compared to the cost of production. In the United States, lamb is most commonly consumed during the Easter, Thanksgiving, and Christmas holidays (American Lamb Industry Roadmap, 2014). Research implementing restricted feed intakes of high concentrate diets has shown that a greater feed restriction will result in more days on feed (DOF) to finish lambs (Murphy et al., 1994a). Implementing a restricted feed intake of a high concentrate diet or feeding lambs forage may be options for slowing the growth of lambs, thus reducing the seasonal production of lamb. By reducing the seasonality of lamb consumption in the United States, the industry will be able to better supply American lamb to meet the demand, thus causing less price fluctuation within the industry. This would help prevent producers from retaining finished lambs for more days on feed and increasing the amount of fat deposited in these lambs. In addition to reducing seasonality, improving the efficiency of the cost required to produce lean gain needs to be improved. In order for American lamb to compete with lamb imported from New Zealand and Australia, the cost of production must decrease and become more competitive. Therefore, the diet fed needs to increase lean tissue growth and intramuscular fat deposition while limiting unnecessary or excessive amounts fat deposition in subcutaneous, seam, and visceral fat depots. Previous research has shown energy source (Fluharty et al., 1999) and energy intake level (Fluharty and McClure, 1997) can impact the efficiency of the lamb’s visceral organs of nutrient utilization for lean tissue growth and carcass composition (Murphy et al, 1994a; Murphy et al., 1994b). This research also aimed to investigate how energy source and level could affect the feed cost of gain of lambs.

Therefore, the objectives of this study were to investigate the effects of energy source and level, and sex on growth, performance, and carcass characteristics of lambs. We hypothesized that feeding a whole shelled corn (WSC) diet at a 15% restriction from ad libitum intake, would reduce the amount of fat deposited on lamb carcasses compared to lambs consuming ad libitum WSC due to reduced energy intake. Additionally, we hypothesized that lambs offered ad libitum alfalfa pellets would have the least efficient gain due to greater dry matter intake (DMI) of a low energy dense feed and a greater visceral organ weight, but produce leaner carcasses compared to lambs consuming ad libitum WSC.

Materials and Methods

Animal procedures were approved by the Institutional Animal Care and Use Committee (IACUC protocol number 2015A00000023) of The Ohio State University and animal care followed guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Experimental design and treatments

Ninety-six Dorset × Hampshire lambs (initial body weight (BW) = 30.1 ± 1.7 kg) were used in a randomized complete block design experiment to determine the effects of energy source (alfalfa pellets versus corn fed ad libitum or corn fed at 85% ad libitum) on growth and carcass characteristics. Experimental diets fed to lambs during the study are shown in Table 2.1. Dietary ingredient costs on an as-fed basis for WSC, alfalfa pellets and supplement were \$0.15/kg, \$0.60/kg, and \$0.51/kg, respectively. Lambs were housed at the Ohio Agriculture Research and Development Center's sheep research feedlot inside a covered barn in Wooster, OH throughout the duration of this experiment, from April, 2015 through August, 2015. Lambs were individually weighed, ear tagged, and vaccinated with Covexin8 (Schering-Plough Animal Health Limited, Upper Hutt, New Zealand) at approximately 28 days of age and re-vaccinated with a booster shot seven days before weaning. Lambs were allotted to 24 pens, four lambs per pen, blocked by sex, stratified by initial BW and randomly assigned a dietary treatment, with two replicate pens. All pens were constructed on either expanded metal or hard plastic flooring with three metal gates and a wooden fence line feed bunk on the fourth side. Pen dimensions were 1.49 × 4.88 m with 1.49 m of bunk space. Each pen was equipped with an automatic watering cup, so water was available to lambs at all times.

Feeding and performance data collection

Diets fed to lambs were formulated to meet the dietary nutrient requirements of lambs (NRC, 2007). Feed samples of 100 g were collected every 14 days throughout the experiment. Fifty grams was used to determine weekly DMI by drying the sample at 100ºC (AOAC, 1984). The remaining 50 grams was dried in a forced air oven at 55ºC, ground to pass through a 2-mm screen, and analyzed for dry matter (DM) (AOAC, 1984) and neutral detergent fiber (NDF) (Van Soest et al., 1991).

Sheep were fed on a pen basis. Feed offered and feed refused was weighed daily for each pen prior to re-feeding at 0830 to record feed intake. Since sorting was expected, feed was not allowed to remain in the feed bunk for more than one day before being discarded. Preceding the experimental trial, lambs were fed a completely pelleted transition diet consisting of 48% corn and 22% distillers grain. At the start of the trial, 10% of the transition diet was exchanged for an equivalent amount of the experimental diet every day. Therefore, a 10 day transition period took place before lambs received their experimental diet. Each change in diet occurred on a daily basis. Initially, all lambs were offered feed at the rate of 2.5% of their live body weight, on a dry matter basis, using the average pen weight within the weight block. At each diet change, lambs had their feed intake reduced by 0.002 kg DM per animal per day. Pens of lambs never had their intake increased or decreased by more than 0.227 kg of feed DM per pen per day.

Initial BW was determined by using the average BW taken on two consecutive days before feeding occurred at 0830 at the start of the trial, with interim BW measurements taken every 14 days and a final BW taken before removal from the feedlot for slaughter. Average daily gain, DMI, gain to feed ratio (G:F) (kg of BW gain / kg of feed consumed), and days required to reach harvest weight were determined for all lambs. Sheep were removed from the trial for slaughter at the Ohio State University abattoir, on a pen basis, as each pen reached the predetermined BW. Predetermined BW for removal of ewe and wether lambs from the study were 59.0 and 63.5 kg, respectively. This was done to remove lambs at similar levels of fatness and maturity. Since, Wylie et al. (1997) reported ewe lambs began to deposit fat sooner than wether and ram lambs, allowing male lambs to be taken to heavier weights.

Visceral organ and carcass data collection

All sheep were weighed prior to stunning, and stunning was conducted by the use of a captive bolt gun. Live weight and sheep identification (ear tag number) was recorded. Dentition (eruption of permanent teeth through the gums) was evaluated and recorded, as well as the number of break or spool joints on each carcass, which was used for carcass classification. Kidney fat was removed from the carcasses, weighed and recorded and added back to the HCW. Two lambs per pen were randomly selected for data collection of visceral organ weight. Visceral organs (rumen, reticulum, omasum, abomasum, spleen, small intestine, large intestine, cecum, heart, liver, and visceral fat) were removed and any adhering adipose tissue was stripped from these organs. Visceral organs were flushed with water, squeezed, and allowed to drip dry before being weighed. Before chilling, hot carcass weights were recorded to determine dressing percentage. After chilling for 24 hours at 0 – 4°C, carcasses were ribbed between the 12^{th} and 13^{th} ribs to record longissimus muscle area (LMA), backfat thickness (BF), body wall thickness (BWT), marbling score, conformation score, and leg score to calculate USDA Quality and Yield grades, as well as percent boneless closely trimmed retail cuts (%BCTRC).

Statistical analysis

The experimental design was a randomized complete block design with a 3 × 2 factorial arrangement of treatments to distinguish differences between diet (ad libitum alfalfa pellets, ad libitum WSC, or restricted-fed WSC) and sex (ewes and wethers). Statistical analysis was performed using the MIXED procedure in SAS (SAS Inst. Inc., Cary, NC). The statistical model used was: $Y_{ijkl} = \mu + D_i + S_j + DS_{ij} + p_k + e_{ijkl}$, where D_i

= diets fed, S_j = sex and DS_{ij} = the interaction between the diet and sex, all were fixed effects and p_k = pen (nested with diet by sex), was the random effect and e_{ijkl} = the error. Pen averages were used for the analysis of daily DMI, gain to feed ratio, and feed cost of gain data, and the random effect was removed from the model. Initial BW, initial BW × diet interaction and Final BW were used as covariates within the analysis when $P < 0.20$. Initial BW and Final BW covariates minimized the deviation of BW within each of the two sexes, as there were differences at the beginning and end of the trial. The LSMEANS and DIFF statements were used to record treatment means, standard errors and distinguish differences between treatment levels. A significant p-value was considered at ($P < 0.05$).

Results and Discussion

Growth and performance

There were no significant interactions ($P > 0.05$) between diet and sex for the performance characteristics of lambs. Ewe and wether lambs had an average age of 176 and 178 days, and lambs consuming ad libitum WSC, ad libitum alfalfa pellets, and limit-fed corn had an average age of 163, 186, and 182 days, respectively. Final BW of wether lambs was greater ($P < 0.05$) than the final BW of ewe lambs as planned by the experimental design (Table 2.2.). Lambs fed the ad libitum WSC diet had a greater ($P < 0.05$) ADG than lambs limit-fed WSC or fed alfalfa pellets, which also resulted in the fewest ($P < 0.01$) DOF for lambs fed ad libitum WSC. Increasing the level of concentrate in the diet is known to increase the rate of gain of lambs (Ferrell et al., 1979). Similarly, Fluharty and McClure (1997) reported lambs fed ad libitum intake of a 100% concentrate diet had a greater ADG compared to lambs with a restricted intake of 85% compared to the ad libitum intake lambs. McLeod and Baldwin (2000) also reported greater ADG and efficiency of gain by lambs consuming pelleted diets of 75% concentrate versus 75% forage. Diets with increasing levels of concentrates decrease the acetate:propionate ratio in the rumen when fed to lambs (Hart et al., 1991; Fimbres et al., 2002). Armstrong and Blaxter (1957) and Armstrong et al. (1958) determined the heat increments of the individual volatile fatty acids (VFA) and mixtures of VFA produced in the rumen and reported acetic acid, propionic acid, and butyric acid to have a heat increment of 67.1, 43.7, and 38.1 Cal/ 100 Cal. acid given, respectively in fattening sheep. Therefore, the net energy content of the longer carbon chain VFA is greater and the mixture with the least amount of acetic acid was more energetically efficient and allowed for more energy to be retained by the sheep for fat growth. Daily DMI was greater ($P < 0.01$) for lambs fed alfalfa pellets compared lambs fed either of the WSC diets to increase energy intake needed for maintenance and growth. This is consistent with previous literature that reports lambs fed forage based diets have a greater DMI compared to lambs fed high-concentrate diets (Murphy et al., 2003). The reduced energy density of forage based diets compared to concentrate diets requires animals to have a greater DMI to meet energy needs. Bulky forages, such as long stemmed hay and haylages, can limit gut fill and energy intake of the animal compared to pelleted forages (Meyer et al., 1959). The use of alfalfa pellets in a forage based diet allows for greater DMI (Palandines et al., 1964; Wright et al., 1963) and the production of more volatile fatty acids compared to bulky forages (Wright et al., 1963). Ad libitum WSC fed lambs had greater ($P < 0.01$) daily DMI compared to lambs limit-fed WSC as planned in the experimental methods. Wether lambs had a greater ($P < 0.01$) daily DMI than ewe lambs. Greater daily DMI by wether lambs compared to ewe lambs may be due to allowing wether lambs to grow an additional 4.5 kg before being removed from the feedlot, since Ferrell et al. (1979) reported ram lambs to have a greater DMI compared to ewe lambs and suggested this was due to ram lambs having a greater metabolic BW. Efficiency of gain was greatest ($P < 0.01$) for lambs fed the ad libitum WSC diet, followed by the lambs limit-fed WSC, and finally lambs fed alfalfa pellets. In contrast, Fluharty and McClure (1997) observed no differences in efficiency of gain when comparing ad libitum intake and limited intake of a high concentrate diet fed to lambs. Results from Murphy et al. (2003) are in agreement with our results showing that lambs fed high concentrate diets have greater efficiency of gain compared to lambs fed high forage diets. The greater expense of feeding alfalfa pellets resulted in the greatest ($P < 0.01$) feed cost of gain for lambs fed alfalfa pellets, followed by lambs limit-fed WSC, and lastly lambs fed ad libitum WSC over the feeding trial ($4.62/kg, $1.08/kg, and $0.94/kg, respectively). Ewe lambs tended ($P = 0.06$) to have a lower feed cost of gain compared to wether lambs.

Visceral organ weight

There were no significant interactions ($P > 0.05$) between diet and sex for the weight of visceral organs. Lambs fed either of the WSC diets resulted in greater HCW ($P < 0.01$) and dressing percentage ($P < 0.01$) compared to lambs fed the alfalfa pellets (Table 2.3.). These results are primarily due to greater amounts of carcass fat and reduced visceral organ weights from the lambs fed either of the WSC diets. Lambs fed the ad libitum WSC diet had greater ($P < 0.05$) amounts of kidney fat compared to lambs fed alfalfa pellets, and lambs limit-fed WSC tended ($P = 0.09$) to have greater amounts of kidney fat compared to lambs fed alfalfa pellets. The weights of the reticulum ($P < 0.05$) and omasum ($P < 0.01$) were greater for alfalfa fed lambs compared to the lambs fed the WSC diets. Lambs fed ad libitum WSC tended ($P =0.06$) to produce greater omasum weights compared to lambs limit-fed WSC. Wether lambs had greater ($P < 0.05$) spleen weights compared to ewe lambs. Small and large intestine weights tended ($P = 0.13$ and $P = 0.09$, respectively) to be affected by diet, with numerically larger intestine weights from lambs fed the alfalfa pellets. Cecum weights tended ($P = 0.06$) to be affected by diet, with lambs fed ad libitum WSC having numerically greater cecum weights compared to lambs fed alfalfa pellets. The liver weights tended ($P = 0.09$) to be affected by diet, with numerically larger liver weights from lambs fed alfalfa pellets. In contrast, McLeod and Baldwin (2000) reported greater liver weights from lambs consuming a 75% pelleted concentrate diet compared to a 75% forage pelleted diet when fed similar energy intakes. The results of Fluharty et al. (1999) are in agreement with our current results, reporting greater liver weights from lambs grazing alfalfa pasture compared to a limited intake of a concentrate diet at similar calculated energy intakes (973 g vs. 908 g, respectively). Visceral fat weight was lower ($P < 0.05$) for lambs fed alfalfa pellets compared to lambs fed either of the WSC diets. Greater visceral fat weights from concentrate-fed lambs compared to lambs grazing alfalfa have also been reported by others investigating the effects of energy source on visceral organ weight (Fluharty et al., 1999). McLeod et al. (2007) reported greater amounts of alimentary fat from steers supplied with abomasal glucose infusions compared to steers with abomasal starch hydrolysate. Lambs consuming WSC in this study are likely suppling larger quantities of starch and glucose to the small intestine compared to lambs consuming alfalfa pellets, making the energy substrate readily available for use and storage. Wether lambs tended ($P = 0.06$) to produce greater visceral fat compared to ewe lambs. This may be the result of greater DMI and the use of extra energy substrate from an increased DMI for increased visceral fat production. A total tract weight consisting of the rumen, reticulum, omasum, abomasum, small and large intestine, and cecum weights was significantly greater ($P < 0.05$) for lambs fed alfalfa pellets compared to lambs fed either of the WSC diets. Similarly, lambs consuming alfalfa pasture compared to a limit-fed diet of WSC produced 29% greater total tract weights (3166g vs. 2454g, respectively) when fed to 48 kg (Fluharty et al., 1999). McLeod and Baldwin (2000) also reported greater total tract weight from lambs consuming a 75% forage pelleted diet compared to a 75% concentrate pelleted diet. No significant differences were found between the weight of the rumen, abomasum, or heart of lambs from different energy sources. McLeod et al. (2007) reported their increase in total digestive tract weight was partially due to a disproportionate increase in specific visceral organ weights, such as the rumen because of the site which starch was supplied. No significant differences were observed from the visceral organ weight between ad libitum WSC fed lambs and limit-fed WSC lambs in this study, unlike those reported by Fluharty and Murphy (1997). Fluharty et al. (1999) reported similar findings, that lambs fed alfalfa produced greater liver, omasum, and small and large intestinal weights than lambs limit-fed a concentrate diet. However, they also reported lambs fed alfalfa to have greater abomasum and cecum weights, which we did not observe.

McBride and Kelly (1990) reviewed the energy cost of adsorption and metabolism of the gastrointestinal tract (GIT) and liver in ruminants. As a percentage of whole body oxygen consumption, the GIT and liver are responsible for about 40%. This is in large part due to the energy used to control the ion gradient and rapid protein turnover (synthesis and degradation) of the GIT. Burrin et al. (1989) reported the level of feed intake can affect the oxygen consumption of these organs. They showed the oxygen consumption of the portal drained viscera and liver of lambs fed at maintenance were 37 and 63% lower than that of lambs fed ad libitum intake on a high concentrate diet. Burrin et al. (1990) also showed increased weights from the liver, stomach and small intestines as a result of increasing the metabolizable energy intake (MEI) of lambs. There is a common understanding that MEI has a positive relationship with increasing visceral organ weights, Oxygen use by the portal drained viscera, dietary energy source and DMI (McBride and Kelly, 1990; McLeod and Baldwin, 2000; McLeod et al., 2007; Reynolds et al., 1991). The effects of energy source and DMI have a compounding effect on this relationship which makes it difficult to determine the true cause and effect. McLeod et al. (2000) fed pelleted alfalfa and concentrate at a low and high energy intake level and reported MEI was significant for all increases of visceral organ weight, but diet only caused the increase in weight in the reticulum, omasum, small intestine, and liver. In order to obtain similar MEI between diets consisting either forage or concentrate, DMI of the forage treatment will have to be greater to match the MEI of the animals consuming the concentrate diet. The level of dry matter intake or inert bulk of the ingesta as it moves through the digestive tract appears to be the cause for increased visceral organ weights, rather than MEI alone. Therefore, the metabolic use and efficiency of energy for maintenance and growth can be greatly influenced by nutrition when the GIT and its metabolic processes are affected. With greater visceral organ weights from lambs fed alfalfa pellets, more energy had to be used for greater maintenance requirements before energy could be used for lean tissue growth.

Carcass characteristics

At harvest, all lambs had their temporary incisors and all lamb carcasses produced break joints at the time of slaughter, clearly indicating “lamb maturity”. Lambs had a mean age of 178 days at the time of slaughter. Field et al. (1990) reported carcasses from lambs 261 and 356 days of age (DOA) to possess break joints. Lambs fed the ad libitum WSC diet were removed from the study at a younger age ($P < 0.01$), 163 DOA compared to 185 and 181 DOA for lambs fed alfalfa pellets and limit-fed WSC, respectively (Table 2.1.).

Final BW off test ($P < 0.05$) and final BW at the abattoir ($P < 0.01$) were greater for wether lambs compared to ewe lambs (65.2 vs. 61.1kg, respectively) by design as mentioned in the experimental methods (Table 2.4.). However, final BW of lambs at the abattoir tended ($P = 0.08$) to be affected by diet, with lambs fed ad libitum WSC having numerically greater final BW at the abattoir compared to lambs fed alfalfa pellets. This may have developed due to the significant impact diet had on the percent of BW shrinkage from the time spent traveling from the feedlot to the time of slaughter, with lambs fed alfalfa pellets having the greatest ($P < 0.01$) percent BW shrink compared to lambs fed WSC. The passage rate of the diet likely influenced the percent BW shrink of lambs, because forage based diets have a greater passage rate compared to concentrate diets through the digestive tract (Poore et al., 1990). Thompson et al. (1987) reported fatter lambs lose less weight during transportation and the time spent fasting before slaughter. The rate of passage and level of lamb fatness could help explain the differences in BW shrink between lambs fed WSC and alfalfa pellets. Lambs fed WSC had greater ($P < 0.01$) HCW and dressing percentages compared to lambs fed alfalfa pellets. Although, lambs fed ad libitum WSC tended to have greater HCW and dressing percentages compared to lambs limit-fed WSC ($P = 0.08$ and $P = 0.09$, respectively). These results are consistent with Crouse et al. (1981), who reported that lambs fed a high-concentrate diet will produce greater HCW compared to lambs fed a low energy diet consisting of primarily alfalfa pellets. Wether lambs also produced greater ($P < 0.01$) HCW and tended ($P = 0.07$) to have less BW shrink compared to ewe lambs. Heavier wether carcasses were expected because of heavier final BW compared to ewe lambs. Backfat thickness, BWT, kidney fat weight and YG were greater ($P < 0.01$) for lamb carcasses from lambs fed either of the WSC diets. Lamb carcasses from lambs fed ad libitum WSC tended ($P = 0.06$) to have more kidney fat compared to carcasses from lambs limit-fed WSC. Greater measurements of carcass fat and decreased visceral organ weight are likely the reason for greater HCW and dressing percent for WSC fed lambs compared to lambs fed alfalfa pellets. Greater measurements of lamb carcass fatness from lambs fed high-energy, high concentrate diets support the results of Crouse et al. (1981) and Field et al. (1990). Fluharty et al. (1999) reported no difference between lambs grazing alfalfa pasture compared to lambs limit-fed WSC for carcass fat measurements, however lambs were slaughtered at a lighter weight (50 kg) compared to lambs in this study and fed to meet similar energy intakes. It has been reported that with additional time on feed to reach greater slaughter weights (54 kg to 64 kg) the level of carcass fatness in lambs will also increase (Lloyd et al., 1981). From the research previously cited, one can deduce that lambs fed high concentrate diets begin to deposit carcass fat sooner than lambs fed low concentrate diets, resulting in more fat at a live BW between 50-65 kg. Diet tended ($P = 0.10$) to affect LMA, with carcasses from limit-fed WSC lambs having the numerically largest LMA (18.54cm^2) and carcasses from alfalfa fed lambs having the smallest LMA (16.04cm^2). These LMA measurements fall below the average LMA of 19.55cm^2 from retail lamb chops sampled from the U. S. during the 2015 National Lamb Quality Audit (Hoffman et al., 2016). Larger LMA measurements collected during the 2015 National Lamb Quality Audit may be an indication of a larger sized lamb being marketed in the U.S. compared to the lambs in this study. Leg conformation scores tended ($P = 0.09$) to be greater for wether lamb carcasses compared to carcasses from ewe lambs. Marbling scores were greater ($P < 0.05$) from carcasses from WSC fed lambs. In contrast, Murphy et al. (2003) reported no significant difference for marbling scores or total lipid percent in the longissimus muscle between lambs fed a high-concentrate diet compared to lambs fed haylage. However, other investigators report greater percentage of total lipids in the longissimus muscle from lambs fed concentrate diets compared to lambs grazing pasture (Aurousseau et al., 2004; Nuernburg et al., 2005). Diet tended (P = 0.07) to affect %BCTRC from lamb carcasses, with alfalfa fed lambs producing carcasses with the greatest %BCTRC, followed by the carcasses from lambs limit-fed WSC, and lastly carcasses from lambs fed ad libitum WSC. While lamb carcasses from lambs fed alfalfa pellets had the greatest %BCTRC, lamb carcasses from lambs fed WSC would still produce numerically more BCTRC on a weight basis in this study. Murphy et al. (1994a) reported similar lean tissue gain per day from lambs with different restricted intake levels (100, 85, and 70%) of a concentrate-based diet, but decreased fat gain per day as feed restriction increased. This agrees with the trend for greater LMA and numerically less carcass fat from lambs limit-fed WSC compared to lambs fed ad libitum WSC. Further research using restricted intake of WSC may be necessary to determine the appropriate feed restriction in relation to greater final BW or level of carcass fatness to optimize the cost inputs for lean tissue gain, because our hypothesis of restricting feed intake of a WSC diet to 85% did not significantly reduce carcass fatness at our selected harvest BW for lambs. Murphy et al. (1994b) reported numerically greater lean gain per day and significantly greater fat gain per day from lambs fed ad libitum concentrate when compared to lambs that grazed alfalfa. These results also supports our findings that lambs fed concentrate grew with a faster rate of gain with a numerically larger LMA and greater carcass fatness. No significant differences were detected for carcass conformation scores, lean color and quality scores, and QG. Previous research has reported greater HCW, BF, BWT, kidney fat, LMA, leg conformation score, YG, and QG when lambs were fed high-concentrate, high-energy diets compared to low energy diets with greater levels of forage (Crouse et al., 1981; Field et al., 1990). In the current study we did not observe different leg conformation scores and QG, possibly due to the subjectivity of these measurements. Similar results by Field et al. (1990) reported no difference between wether and ewe lamb carcasses for BF, BWT, LMA, leg and body conformation scores, YG, and QG, only HCW. Also in agreement with our results, Murphy et al. (2003) reported no differences between lambs fed a high-concentrate diet compared to lambs fed haylage for lean color and QG.

As shown in the visceral organ section, energy utilization can vary depending on the energy source and site of digestion. Ferrell et al. (1979) studied the growth and energy utilization of growing lambs (32, 42, 54, and 66 kg) fed three diets with increasing amounts of concentrate (10, 50, and 85%). Lambs had greater amounts of water, fat, and retained energy with increasing level of concentrate in the diet, but the amount of protein was similar between diets with varying levels of concentrate. However, at a constant empty BW, the amount of carcass protein decreased with increasing levels of concentrate in the diet. Lambs fed increasing levels of concentrate had greater feed efficiency, metabolizable energy available for gain, daily energy retained, and a lower heat production at maintenance. As lambs increased BW, feed efficiency and metabolizable energy available for gain decreased. Heat production at maintenance and retained carcass energy also decreased for the low (10%) and medium (50%) level concentrate diets, but were similar between increasing BW of lambs fed the high (85%) level of concentrate. The efficiency of metabolizable energy used for gain improved with increasing level of concentrate in the diet. The energy cost of gain for protein deposition was 45 kcal/g, while fat gain was only 14 Kcal/g. The efficiency of metabolizable energy used for gain was 13 and 67% for protein and fat gain, respectively. McLeod et al. (2007) reported greater retained energy by the animal when supplying the small intestine with more starch due to greater adipose deposition. These results help explain why lambs fed WSC in this study became fatter compared to lambs fed alfalfa pellets.

Conclusion

Lambs fed ad libitum WSC had the greatest ADG and gain to feed ratio resulting in fewer days on feed required to reach the predetermined final BW. The ad libitum WSC diet also resulted in a lower feed cost of gain compared to limit-fed WSC or ad libitum intake of alfalfa pellets. Feeding WSC decreased the total digestive tract weight, allowing energy to be used for lean tissue and fat production rather than increased maintenance requirements from visceral organs. Lambs fed WSC diets produced greater HCW, measurements of BF and BWT, marbling scores and YG. Lambs fed WSC also produced numerically larger LMA and similar amounts of boneless closely trimmed retail cuts. Feeding WSC can improve the rate and efficiency of growth and performance of lambs at a significantly reduced feed cost (4× cheaper), but also increase total carcass fatness compared to feeding lambs alfalfa pellets.

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Table 2.1. Nutrient composition of lamb diets.

	Dietary Treatments		
	Alfalfa Pellets	Ad Lib. WSC	Limit-fed WSC
<u>Ingredient</u>	-------------- % Dry matter basis --------------		
Pelleted alfalfa	90.00	---	---
Whole shelled corn	---	85.00	80.00
<u>Supplement</u>			
Ground Corn	6.32	---	2.35
Soybean meal	1.00	11.02	12.96
Urea	0.20	1.00	1.18
Limestone	---	1.00	1.18
Monosodium phosphate	0.50	---	---
Sheep salt [a]	0.50	0.50	0.59
Vitamin A, 30,000 IU/g	0.01	0.01	0.01
Vitamin D, 3,000 IU/g	0.01	0.01	0.01
Vitamin E, 44 IU/g	0.05	0.05	0.05
Selenium, 201 ppm	0.13	0.13	0.15
Amaferm, 141 g/kg	0.39	0.39	0.46
Ammonium chloride	0.40	0.40	0.47
A-V blend	0.50	0.50	0.59
<u>Analyzed Composition</u>			
Crude protein, %	16.53	15.93	17.33
NDF, %	43.27	8.07	7.92
ADF, %	34.47	2.39	2.42
Calcium, %	1.20	0.42	0.52
Phosphorus, %	0.40	0.34	0.35
NE_m, Mcal/kg	0.97	2.38	2.36
NE_g, Mcal/kg	0.41	1.66	1.65

[a] Contained > 90.2% NaCl, 0.1% Zn, 0.8% Mn, 0.125% Fe, 0.01% I, and 0.002% Co, and 0.009% Se.

Table 2.2. Least squares means of growth and performance of lambs.

	Diet [1]				Sex		
Item	Ad lib. WSC	Ad lib. Alfalfa	Limit-fed WSC	SEM [2]	Ewe	Wether	SEM [2]
Days on feed, d	87.5 [c]	110.2 [d]	104.8 [d]	3.77	99.8	101.9	3.08
Initial BW, kg	30.10	30.14	30.22	0.983	29.31	31.00	0.802
Off test BW, kg	62.2	62.4	62.1	1.10	60.66 [g]	63.86 [f]	0.895
ADG, kg/d	0.372 [a]	0.291 [b]	0.310 [b]	0.0191	0.323	0.326	0.0156
DMI, kg/d	1.440 [d]	2.008 [c]	1.274 [e]	0.0197	1.538 [j]	1.610 [i]	0.0155
NE_m intake, Mcal/d	3.426 [c]	1.949 [e]	3.003 [d]	0.0413	2.720 [j]	2.865 [i]	0.0337
NE_g intake, Mcal/d	2.390 [c]	0.824 [e]	2.099 [d]	0.0282	1.723 [j]	1.819 [i]	0.0230
G:F, kg/kg	0.2583 [c]	0.1456 [e]	0.2416 [d]	0.00509	0.2193	0.2111	0.00415
Feed cost of gain, $/kg	0.935 [e]	4.624 [c]	1.079 [d]	0.0293	2.178	2.248	0.0239

[a, b] Diet means within a row without a common superscript letter differ ($P < 0.05$).

[c, d, e] Diet means within a row without a common superscript letter differ ($P < 0.01$).

[f, g] Sex means within a row without a common superscript letter differ ($P < 0.05$).

[h,i] Sex means within a row without a common superscript letter differ ($P < 0.01$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of ad libitum whole shelled corn diet

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

Table 2.3. Least square means of visceral organ weights of lambs.

	Diet[1]				Sex		
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**SEM[2]**	**Ewe**	**Wether**	**SEM[2]**
Final BW, kg[3]	60.2	57.5	58.6	1.49	57.2	60.4	1.19
HCW, kg	35.58 ^{c}	31.50 ^{d}	34.18 ^{c}	0.479	33.37	34.13	0.383
Dressing percent, %	60.34 ^{c}	53.09 ^{d}	57.99 ^{c}	0.805	57.36	56.92	0.65
Kidney fat, g	951 ^{a}	521 ^{b}	796 ^{a}	95.0	750	762	77.6
Rumen, g	937	992	933	58.6	918	990	47.7
Reticulum, g	133 ^{b}	191 ^{a}	140 ^{b}	11.9	153.8	157.8	9.66
Omasum, g	125.3 ^{d}	192.2 ^{c}	94.1 ^{d}	9.29	140.2	134.2	7.59
Abomasum, g	225	240	216	16.0	226	228	13.1
Spleen, g	102.8	99.2	115.4	7.36	94.9 ^{f}	116.8 ^{e}	5.93
Small intestine, g	1032	1279	1034	82.4	1076	1154	67.3
Large intestine, g	509	731	466	72.6	553	584	59.3
Cecum, g	143	84	119	13.2	114	117	10.6
Liver, g	1085	1206	1056	41.1	1120	1111	32.3
Heart, g	262.1	247.5	252.0	7.42	259.9	247.7	5.95
Visceral fat, g	2230 ^{a}	1690 ^{b}	2130 ^{a}	117	1857	2180	93.8
Total tract, g[4]	3120 ^{b}	3700 ^{a}	2990 ^{b}	132	3170	3370	107

$^{a, b}$ Diet means within a row without a common superscript letter differ ($P < 0.05$).

$^{c, d}$ Diet means within a row without a common superscript letter differ ($P < 0.01$).

$^{e, f}$ Sex means within a row without a common superscript letter differ ($P < 0.05$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of Ad libitum whole shelled corn diet

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] Final BW is the weight collected at the abattoir just before harvest.

[4] Total tract weight is the sum of the Rumen, Reticulum, Omasum, Abomasum, Small and Large intestine, and Cecum weights.

Table 2.4. Least squares means of carcass characteristics of lambs.

	Diet [1]				Sex		
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**SEM [2]**	**Ewe**	**Wether**	**SEM [2]**
Off test BW, kg	64.6	63.8	61.0	1.17	61.09 [f]	65.18 [e]	0.947
Final BW, kg [3]	61.1	57.0	58.2	1.07	56.25 [h]	61.30 [g]	0.862
Shrink, % [4]	5.29 [d]	10.63 [c]	4.87 [d]	0.672	7.79	6.07	0.541
HCW, kg	35.87 [c]	32.04 [d]	34.32 [c]	0.519	32.71 [h]	35.45 [g]	0.418
Dressing percent, %	60.75 [c]	53.84 [d]	58.38 [c]	0.795	57.86	57.45	0.638
Kidney fat, g	1110 [c]	501 [d]	832 [c]	83.1	810	818	66.4
Backfat thickness, cm	0.96 [c]	0.52 [d]	0.89 [c]	0.548	0.84	0.74	0.442
Body wall thickness, cm	2.70 [c]	1.93 [d]	2.62 [c]	0.113	2.445	2.385	0.0909
LM area, cm^2	17.56	16.04	18.54	0.669	16.88	17.88	0.54
Leg Conformation [5]	11.41	11.67	11.76	0.281	11.29	11.93	0.226
Carcass Conformation [5]	11.51	11.88	11.53	0.398	11.38	11.90	0.323
Marbling score [6]	448 [a]	353 [b]	461 [a]	23.0	422	420	18.6
Lean Color/Quality [5]	12.81	12.38	12.48	0.272	12.42	12.69	0.221
Quality Grade [5]	12.01	11.65	12.08	0.327	11.63	12.21	0.265
Yield Grade [7]	4.18 [c]	2.45 [d]	3.88 [c]	0.216	3.70	3.30	0.174
BCTRC, % [8]	44.52	46.49	45.42	0.460	45.41	45.54	0.371

[a, b] Diet means within a row without a common superscript letter differ ($P < 0.05$).

[c, d] Diet means within a row without a common superscript letter differ ($P < 0.01$).

[e, f] Sex means within a row without a common superscript letter differ ($P < 0.05$).

[g, h] Sex means within a row without a common superscript letter differ ($P < 0.01$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of Ad libitum whole shelled corn diet

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] Final BW is the weight collected at the abattoir just before harvest.

[4] Shrink refers to the weight lost from travel and lairage.

[5] Leg conformation, Carcass conformation, Lean color/quality, and Quality grade are based on a numeric scale: 11 = avg. choice, 12 = high choice, and 13 = low prime.

[6] Marbling score is subjective and based on a numeric scale: 300-399 = slight, 400-499 = small.

[7] Yield grade = $(((BF/2.54) \times 10) + 0.4)$

[8] Percent boneless closely trimmed retail cuts = $49.94 - (0.085 \times HCW) + (2.46 \times LMA) - (4.38 \times BF) - (3.53 \times BWT)$

Chapter 3.

Effect of energy source and level, and sex on growth, performance, and carcass characteristics of long-fed lambs

ABSTRACT

The objective of the present study was to assess energy source, level, and sex of the lamb, on the growth, performance, and carcass characteristics of long-fed lambs (218 days on feed; DOF and 294 days of age; DOA). Ewe (n=24) and wether (n=24) lambs were blocked by sex and stratified by initial weight to pens containing four lambs within a pen, with two pens of each sex assigned to each of the three dietary treatments. The three diets offered were ad libitum access (WSC100) to whole shelled corn (WSC), 85% intake of the ad libitum WSC diet (WSC85), and ad libitum access to alfalfa pellets (AP). Statistical analysis was conducted using the PROC MIXED procedure in SAS with diet and sex as the fixed effects, diet and sex nested within pen as the random effect, and initial weight was used as a linear covariate if $P < 0.20$. Daily dry matter intake (DMI), gain to feed ratio (G:F), and feed cost per unit of gain data were analyzed on a pen average basis, with no random effect in the model. Average daily gain (ADG) was assessed using a repeated measures approach from weights collected at three time points (when lambs were 219, 247, and 294 DOA on average). Lambs offered WSC100 had

greater ($P < 0.05$) ADG than lambs offered WSC85 or AP (0.29, 0.24, 0.25 kg/day, respectively), which resulted in a greater ($P < 0.05$) final body weight (93.6, 83.4, 86.0 kg, respectively). Lambs offered AP had greater ($P < 0.01$) DMI than lambs offered WSC100 or WSC85. Wether lambs had a greater final body weight (90.6 vs. 87.5 kg; $P < 0.05$), ADG (0.27 vs. 0.25 kg/day; $P < 0.05$), and DMI (1.93 vs. 1.80 kg/day; $P < 0.01$) when compared to ewe lambs. Lambs fed WSC had a greater ($P < 0.01$) G:F and a lower ($P < 0.01$) feed cost per unit of gain when compared to lambs fed AP. Lambs offeredWSC100 had greater final body weight ($P < 0.05$), hot carcass weight (HCW) ($P < 0.05$) and visceral fat ($P < 0.01$) compared to lambs fed AP or WSC85. Lambs consuming WSC had lighter reticulum ($P < 0.01$), omasum ($P < 0.01$), small ($P < 0.01$) and large intestine ($P < 0.05$), cecum ($P < 0.05$), and total tract weights ($P < 0.01$), but a greater ($P < 0.05$) amount of kidney fat compared to lambs fed AP. Wether lambs had a greater ($P < 0.05$) HCW, but lighter ($P < 0.05$) small intestine weight compared to ewe lambs. Carcasses from lambs offered WSC100 had greater final body weight ($P < 0.01$), HCW ($P < 0.01$), backfat (BF) ($P < 0.05$), body wall thickness (BWT) ($P < 0.01$), yield grade (YG) ($P < 0.05$), and marbling score ($P < 0.05$) compared to carcasses from lambs fed AP or WSC85, resulting in a lower percentage of boneless closely trimmed retail cuts ($P < 0.05$) from lambs fed WSC100. Both WSC diets produced carcasses with greater ($P < 0.01$) dressing percentages and kidney fat weights when compared to carcasses from lambs fed AP. Wether lamb carcasses had a greater final body weight, HCW, dressing percentage, and BWT when compared to ewe lamb carcasses. Overall, lambs offered WSC grew faster and more efficiently with a lower feed cost of gain. Lambs offered

WSC100 also had a lower total digestive tract weight compared to lambs fed AP; however, feeding WSC100 produced carcasses with greater amounts of fat in multiple carcass depots when compared to lambs fed AP or WSC85.

Key words: long-fed lambs, feedlot, corn, alfalfa, growth, carcass, heavy weight

Introduction

The trend for increasing slaughter weight of lambs in the U.S. is a problem for the American lamb industry as it usually results in excessively fat lamb carcasses. The average live weight of marketed sheep has increased about 0.4 kg per year since 1958 (Figure 3.1.). Greater lamb slaughter weights are occurring in the U.S. because lambs marketed through the traditional market channel are sold on a live weight basis that does not consider carcass composition and quality. Lamb producers and feeders are able to maximize their profit by continuing to feed their lambs until the total cost per unit of gain equals the market price of lamb. Seasonal supply and demand market fluctuations can force lamb producers and feeders to wait to market their lambs until the demand increases, resulting in extra time on feed for market ready lambs. Continuing to feed finished lambs past their ideal endpoint while waiting for the demand of lamb to increase creates long-fed lambs with heavier weights and excessive carcass fat. Excessively fat lambs contribute to the inconsistent eating quality of lamb supplied to the market chain and pose a threat to the American lamb industry (American Lamb Industry Roadmap, 2013). Consumers have a negative perception of fat and as a result use it as a selection criterion when purchasing meat. Mendenhall and Ercanbrack (1979) reported consumers selected their lamb products based on the leanness (the size and amount of lean) and the amount of fat (subcutaneous and intermuscular) observed on the retail cut. Southam and Field (1969) reported consumers preferred loin and rib lamb chops from heavier lambs because of a greater amount of lean. Jeremiah et al. (1993) reported over 92 percent of consumer participants rejected untrimmed loin chops due to the appearance of excessive amounts of fat when comparing loin chops from ram, wether, and ewe lambs harvested within 5 slaughter weight ranges (40.5-49.5, 50-58.6, 58.9-67.7, and 68.2-76.8 kg). While the problem of excess subcutaneous fat can be resolved by trimming, other cuts that contain more intermuscular fat are unable to be trimmed without destroying the retail cut. Consequently, lambs that are overly fat require extra fabrication time and money for the removal of excess fat. The use of excess trim fat from these lambs also presents another problem. Species specific flavors associated with sheep are deposited in the adipose tissue of these animals resulting in "muttony" or other undesirable flavors (Brennand and Lindsay, 1992). Therefore, excessive lamb trim fat is not typically utilized for meat processing and discarded as waste or possibly rendered.

Previous research has reported that grazing lambs on alfalfa pasture when compared to feeding a high concentrate diet with ad libitum access resulted in reduced carcass fat, slower rate of gain, and more days on feed to reach the same body weight (Murphy et al., 1994b). Similarly, restricting feed intake of a high concentrate diet can produce carcasses with reduced fat, but lambs have a lower rate of gain and require more days on feed (Murphy et al., 1994a). The use of forages and/or restricted feed intake when feeding high concentrate diets also has an impact on the nutrient utilization by the visceral organs of lambs when compared to feeding a high concentrate diet to lambs with ad libitum access (Fluharty and McClure, 1997; Fluharty et al., 1999).

The present study aimed to investigate the effects of energy source, energy level, and sex of the lamb on the growth, performance, and carcass characteristics of long-fed lambs (218 days on feed; DOF and 294 days of age; DOA). We hypothesized that feeding lambs for an extended period of time past the typical market weight would create excessively fat lambs on all diets fed. Lambs fed high concentrate diets would grow at a greater rate and convert feed into live weight gain more efficiently than lambs fed alfalfa pellets. We expected lambs offered ad libitum access to alfalfa pellets to have the least efficient gain due to greater DMI and a greater visceral organ weight, but produce slightly leaner carcasses compared to lambs offered ad libitum access to WSC.

Materials and Methods

Animal procedures were approved by the Institutional Animal Care and Use Committee (IACUC protocol number 2015A00000023) of The Ohio State University and animal care followed guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Experimental design and treatments

Forty-eight Dorset × Hampshire lambs (initial body weight (BW) = 30.1 ± 1.7 kg) were used in a randomized complete block design experiment to determine the effects of energy source (ad libitum access to alfalfa pellets versus WSC offered ad libitum or WSC offered at 85% ad libitum) on their growth, performance, and carcass characteristics. Experimental diets fed to lambs during the study are shown in Table 3.1. Lambs were continued on feed from the study conducted in Chapter 2 that assessed the growth of typical weight market lambs in the Eastern United States. Dietary ingredient costs on an as-fed basis for WSC, alfalfa pellets and supplement were \$0.15/kg, \$0.60/kg, and \$0.51/kg, respectively at the time of the study. Lambs were housed at the Ohio

Agriculture Research and Development Center's sheep research feedlot inside a covered barn in Wooster, OH throughout the duration (April, 2015 through December, 2015) of the experiment. Lambs were individually weighed, ear tagged, and vaccinated with Covexin8 (Schering-Plough Animal Health Limited, Upper Hutt, New Zealand) at approximately 28 days of age and re-vaccinated with a booster shot seven days before weaning. Ewe (n=24) and wether (n=24) lambs were blocked by sex and stratified by initial weight to pens containing four lambs within a pen, with two pens of each sex assigned to each of the three dietary treatments. Pens were constructed on either expanded metal or slotted plastic flooring with three metal gates and a wooden fence line feed bunk on the fourth side. Pen dimensions were 1.49 × 4.88 m with 1.49 m of linear bunk space. Each pen was equipped with an automatic watering cup providing lambs ad libitum access to water.

Feeding and performance data collection

Diets (Table 3.1.) fed to lambs were formulated to meet the dietary nutrient requirements of lambs (NRC, 2007). A 100 gram feed sample from each diet was collected every 14 days throughout the experiment. Fifty grams was used to determine weekly dry matter (DM) content by drying the sample at 100ºC (AOAC, 1984) to make adjustments and calculations for dry matter intake (DMI) and the remaining 50 grams was dried in a forced air oven at 55ºC, ground to pass through a 2-mm screen, and analyzed for DM content (AOAC, 1984) and neutral detergent fiber (NDF) (Van Soest et al., 1991).

Sheep were fed on a pen basis. Feed offered and feed refused was weighed daily for each pen prior to re-feeding at 0830 to record feed intake. Since sorting was expected, feed was not allowed to remain in the feed bunk for more than one day before being discarded. Preceding the experimental trial, lambs were fed a completely pelleted transition diet consisting of 48% corn and 22% distillers grain. At the start of the trial, 10% of the transition diet was exchanged for an equivalent amount of the experimental diet every day. Therefore, a 10 day transition period took place before lambs were receiving their experimental diet. Initially, all lambs were offered feed at the rate of 2.5% of their live BW, on a DM basis, using the average pen weight within the weight block. At each diet change, lambs had their feed intake reduced by 0.002 kg DM per animal per day. Pens of lambs never had their intake increased or decreased by more than 0.227 kg of feed DM per pen per day throughout the duration of the trial.

Initial BW was determined by using the average BW taken on two consecutive days at 0830 before feeding occurred, with interim BW measurements taken every 14 days until the completion of the study of in Chapter 2 and switching interim BW measurements to every 28 days, with an off-test BW taken before removal from the feedlot for slaughter. Average daily gain, DMI, gain to feed ratio (G:F) (kg of BW gain / kg of feed consumed), and days required to reach harvest weight were determined for all lambs. Lambs were proposed to be fed to at least a year of age and be removed on a pen basis. However, the weights attained by the lambs on trial began to compromise the structural integrity of the lambs. A decision was made to remove the lambs from the trial earlier than planned for slaughter at the Ohio State University abattoir on a pen basis to obtain similar DOF for lambs across the three dietary treatments.

Visceral organ and carcass data collection

Final live BW was measured just prior to stunning, and stunning was conducted by the use of a captive bolt gun. Dentition (eruption of permanent teeth through the gums) and the number of break or spool joints on each carcass were assessed for carcass maturity classification. Kidney fat was removed from the carcasses, weighed and recorded and added back to the HCW. Two lambs per pen were randomly selected for data collection of visceral organ weight. Visceral organs (rumen, reticulum, omasum, abomasum, spleen, small intestine, large intestine, cecum, heart, liver, and visceral fat) were removed and any adhering adipose tissue was stripped from these organs. Visceral organs were flushed with water, squeezed, and allowed to drip dry before being weighed. Before chilling, hot carcass weights were recorded to determine dressing percentage. After chilling for 24 hours at 0 – 4°C, carcasses were ribbed between the 12th and 13th ribs to record longissimus muscle area (LMA), backfat thickness (BF), body wall thickness (BWT), marbling score, body conformation score, and leg score to calculate USDA Quality and Yield grades, as well as percent boneless closely trimmed retail cuts (%BCTRC).

Statistical analysis

The experimental design was a randomized complete block design with a 3 × 2 factorial arrangement of treatments to distinguish differences between diet (ad libitum alfalfa pellets, ad libitum WSC, or restricted-fed WSC) and sex (ewes and wethers).

Statistical analysis was performed using the MIXED procedure in SAS (SAS Inst. Inc., Cary, NC). The statistical model used was: $Y_{ijkl} = \mu + D_i + S_j + DS_{ij} + p_k + e_{ijkl}$, where D_i = diets fed, S_j = sex and DS_{ij} = the interaction between the diet and sex, all as fixed effects, and p_k = pen (nested with diet by sex) as the random effect, and e_{ijkl} = the error. Pen averages were used for the analysis of daily DMI, G:F, and feed cost per unit of gain data and the random effect was removed from the model. Initial BW and initial BW × diet interaction were used as covariates within the analysis when $P < 0.20$. The initial BW covariate minimized the deviation of BW within each of the two sexes, as there were slight differences at the beginning of the trial. Repeated measures were used to analyze the ADG of lambs at three different ages during the long-fed stage (219, 247, 294 DOA). The Huynh-Feldt covariance structure was found to best fit the data and was therefore used. The LSMEANS and DIFF statements were used to record treatment means, standard errors and distinguish differences between treatment levels. At $P < 0.05$, differences amongst treatments were considered significant.

Results and Discussion

Growth and performance

Lambs in this study will be referred to as long-fed lambs due to the amount of time spent on feed. Long-fed lambs were on trial for a similar ($P > 0.05$) number of days (218 days) between dietary treatments; however, ewe lambs were on trial for 2 more days compared to wether lambs ($P < 0.05$) due to pens being removed from trial for slaughter on different days (Table 3.2.). Lambs were 278-305 DOA when removed from the feeding trial. Ewe and wether lambs had an average age of 295 and 293 days, and lambs consuming ad libitum WSC, ad libitum alfalfa pellets, and limit-fed corn had an average age of 294, 292, and 295 days, respectively. Final BW was greater ($P < 0.05$) for lambs offered ad libitum access to WSC compared to lambs limit-fed WSC and lambs offered ad libitum access to alfalfa pellets (93.6, 83.4, 86.0 kg, respectively). There was a trend ($P = 0.08$) for a diet × sex interaction for the off-test BW of lambs. The off-test BW of lambs in this trial are the largest in published literature searched by the authors, thus making direct comparisons to the literature somewhat difficult. Crouse et al. (1981) and Borton et al. (2005a) have reported live weights of lambs achieving 76 and 77 kg, respectively, and represent the best opportunity for comparisons. Off-test BW was also greater ($P < 0.05$) for wether lambs when compared to ewe lambs because of their greater ($P < 0.05$) ADG. Okeundo and Moss (2008) reported the rate of gain by male lambs (intact, vasectomized, or castrated) is greater than the rate of gain by female (ewe) lambs. Lambs offered ad libitum access to WSC had a greater ($P < 0.05$) ADG compared to lambs limit-fed WSC or lambs offered ad libitum access to alfalfa pellets. This is in agreement with other investigators that reported ad libitum access of a WSC diet resulted in a greater ADG compared to limit-feeding WSC (Fluharty and McClure, 1997), and forage based diets can have similar ADG performance when compared to lambs limit-fed WSC (Fluharty et al., 1999). There was a significant ($P < 0.05$) diet × sex interaction for the DMI of long-fed lambs (Figure 3.2.). Ewe and wether lambs fed alfalfa pellets had the greatest DMI followed by wether lambs with ad libitum access to WSC, then ewes with ad libitum access to WSC and limit-fed wether lambs, and lastly ewe lambs limit-fed WSC. This interaction demonstrates that wether lambs consumed more WSC when offered ad libitum access compared to ewes, but not when offered alfalfa pellets ad libitum. As a result of greater DMI of WSC by wether lambs, the limit-fed group was also offered more to eat compared to limit-fed ewes, because feed restriction was based on the intake of lambs with ad libitum access to WSC within each sex. Overall, wether lambs had a greater ($P < 0.05$) DMI compared to ewe lambs. Greater DMI of alfalfa pellets by long-fed lambs is in agreement with previous literature that forage-fed lambs have a greater DMI compared to lambs fed high-concentrate diets in order to meet energy requirements (Ferrell et al., 1979; Murphy et al., 2003). This may represent the difference in the efficiency of energy utilization towards BW gain in lambs fed alfalfa pellets or WSC. This additional intake of energy corresponds to the increased ADG of wether lambs compared to ewe lambs. Feed cost per unit of gain was greater ($P <0.05$) for long-fed lambs offered ad libitum access to alfalfa pellets ($6.82/kg BW gained) due to the greater expense of alfalfa pellets and the decreased G:F compared to lambs offered WSC. While feed cost per unit of gain was similar ($P > 0.05$) among long-fed lambs offered feed ad libitum or limit-fed WSC ($1.35/kg vs. $1.48/kg BW gained).

The repeated ADG measurement of long-fed lambs during the long-fed stage had a significant ($P < 0.01$) sex × time interaction (Figure 3.3.), and there was a trend ($P = 0.10$) for a diet × sex × time interaction (Figure 3.4). The ADG of long-fed ewe lambs increased from 247 to 294 DOA, and the ADG of long-fed wether lambs decreased from 219 to 294 DOA (Figure 3.3.). Figure 3.3 displays a stable, if not increasing ADG for long-fed ewes, whereas the ADG of long-fed wether lambs was beginning to decline when reaching approximately 200 DOF and 300 DOA. The ADG of ewe lambs continued to increase throughout the long-fed phase until harvest while the ADG of wether lambs with ad libitum access to WSC and alfalfa pellets decreased during the long-fed phase. This may demonstrate that the growth of wether lambs had begun to plateau and were further along their growth curve compared to ewe lambs.

With additional days on feed (214-223 vs. 67-116 days), long-fed lambs reached heavier live weights compared to the younger, typical market weight lambs that were taken to an endpoint based on live BW as reported in Chapter 2, but at a reduced rate of weight gain per day (0.33 vs. 0.26 kg/day). Borton et al. (2005a) reported a reduction in the ADG of lambs when they were taken from 52 to 77 kg BW. Ferrell et al. (1979) also reported decreases in ADG and feed efficiency with increasing body weight. However, Crouse et al. (1981) did not report a difference for the ADG of lambs when taken to heavier slaughter BW from 62 to 76 kg BW. Long-fed lambs also consumed more feed (1.86 vs. 1.57 kg/day) compared to younger, typical market weight lambs from the study conducted in Chapter 2 at a reduced gain to feed ratio (0.15 vs. 0.22 kg/kg). The increase for feed intake is not surprising with additional BW since Ferrell et al. (1979) reported greater DMI along with greater maintenance requirements for heavier lambs. This resulted in a greater feed cost per unit of gain (3.2 vs 2.2 $/kg) for long-fed lambs compared to market ready lambs reported in Chapter 2. Overall, long-fed lambs begin to have reduced performance and efficiency resulting in additional input costs for BW gain. The majority of this retained dietary energy (about 90%) has been reported to be put towards BW gain in the form of undesirable fat tissue gain (Armstrong and Blaxter, 1957; Ferrell et al., 1979).

Visceral organ weight

Lambs offered ad libitum access to WSC had greater ($P < 0.05$) final BW and greater ($P < 0.01$) HCW compared to lambs limit-fed WSC or lambs offered ad libitum access to alfalfa pellets (Table 3.3.). Final BW was not significantly different ($P > 0.05$) between ewe and wether lambs; however, wether lambs had greater ($P < 0.05$) HCW compared to ewe lambs. This was because wether lambs had greater ($P < 0.01$) dressing percentages compared to ewe lambs (64.4 vs. 60.9%, respectively), likely due to more carcass fat. Greater ($P < 0.01$) dressing percentages from lambs fed WSC compared to lambs fed alfalfa pellets was due to greater measurements of carcass fat and lower visceral organ weights. Lambs fed WSC had greater ($P < 0.01$) amounts of kidney fat compared to lambs fed alfalfa pellets. This is in agreement with Crouse et al. (1981) when they compared the percentage of kidney and pelvic fat from lambs fed a high concentrate diet and fed an alfalfa pellet diet. Lambs fed alfalfa pellets had greater ($P < 0.01$) reticulum and omasum weights compared to lambs fed WSC. Lambs fed alfalfa pellets also had greater small ($P < 0.01$) and large ($P < 0.05$) intestine, and cecum ($P < 0.05$) weights compared to lambs fed WSC. Interestingly, wether lambs had lower ($P < 0.05$) small intestine weights (700 vs 846 g, respectively) and tended ($P = 0.11$) to have greater large intestine weights (730 vs. 623 g, respectively) compared to ewe lambs. Liver weights from lambs fed alfalfa pellets were greater ($P < 0.05$) than liver weights from lambs limit-fed WSC (1415 vs. 955 g), with lambs offered ad libitum WSC being intermediate (1182 g). Greater liver weights from lambs consuming alfalfa pellets compared to lambs consuming WSC agree with the results reported in Chapter 2. However, these results contrast with other previous literature and are difficult to explain. McLeod and Baldwin (2000) reported that liver weights were greater from lambs fed a 75% concentrate diet compared to a 75% forage diet. Other research supports the results of McLeod and Baldwin (2000), by reporting greater metabolizable energy intake by lambs, results in greater liver weight (Johnson et al, 1990). No significant differences for liver weights were observed between lambs limit-fed WSC or offered ad libitum access to WSC. In contrast, Fluharty and McClure (1997) reported lambs offered ad libitum access to WSC to have greater liver weights compared to the liver from lambs limit-fed WSC. Rompala and Hoagland (1987) also reported that ad libitum access to alfalfa pellets compared to an access of 85% ad libitum resulted in greater lamb liver weights. Lambs offered ad libitum access to WSC had greater ($P < 0.01$) amounts of visceral fat compared to lambs fed alfalfa pellets or limit-fed WSC. Although not significantly different, the weight of the rumen and abomasum were numerically greater from lambs offered ad libitum access to alfalfa pellets compared to lambs offered WSC. Overall, lambs consuming alfalfa pellets had greater ($P < 0.01$) total tract weights compared to lambs consuming WSC. This is in agreement with reports from McLeod and Baldwin (2000) when they fed a 75% forage based diet compared to a 75% concentrate diet and observed increases in the total tract weight from lambs.

Allowing lambs to remain on feed for a longer period of time resulted in many similarities of visceral organ weights between typical market weight lambs in the Eastern

U.S. reported in Chapter 2 and long-fed lambs in this study. Both typical market lambs from the study done in Chapter 2 and long-fed lambs from this study expressed similarities due to diet for the rumen, reticulum, omasum, abomasum, small and large intestine, heart, and total tract weights. Differences were also noticed with the other organs between these lambs due to the effects of diet. The amount of kidney fat long-fed lambs consuming limited WSC possessed became similar to that of long-fed lambs offered ad libitum access to WSC. Small intestine weights from WSC fed lambs decreased drastically (about 420 g) as typical market weight lambs became long-fed lambs. Interestingly, long-fed wether lambs offered ad libitum access to WSC and limited amounts of WSC experienced extreme small intestine weight loss of 569 and 496 g, respectively. The cecum weight of typical market weight lambs from Chapter 2 was smallest when lambs were offered alfalfa, but as long-fed lambs, became significantly heavier when compared to long-fed lambs offered WSC. Across the three diets, the liver weight of long-fed lambs showed significant differences with additional DOF, whereas typical market weight lambs from the study in Chapter 2 did not. Finally, the amount of visceral fat deposited by long-fed lambs that were limit-fed WSC became less than long-fed lambs given ad libitum access to WSC, but still more than lambs offered ad libitum access to alfalfa pellets. Overall, visceral organ weight trends by diet and lamb sex remained similar between young lambs from Chapter 2 and the long-fed lambs in this study.

Carcass characteristics

At harvest, all lambs had their temporary incisors and all long-fed lamb carcasses produced break joints at the time of slaughter, clearly indicating "lamb maturity". Off-test BW (93.1, 83.4, and 85.2 kg, respectively; $P < 0.05$) and final BW (88.7, 79.8, 78.3 kg, respectively; $P < 0.01$) were greater for lambs offered ad libitum access to WSC compared to lambs limit-fed WSC or lambs offered ad libitum access to alfalfa pellets (Table 3.4.). Off-test BW (90.7 vs. 83.9 kg) and final BW (85.3 vs. 79.2 kg) were greater ($P < 0.05$) for wether lambs compared to ewe lambs. The percentage of BW shrink, acquired during travel from the feedlot to the abattoir and lairage time, was greater ($P < 0.01$) for lambs consuming alfalfa pellets compared to lambs consuming WSC. Lambs offered ad libitum access to WSC had the greatest ($P < 0.01$) HCW compared to lambs limit-fed WSC or lambs offered ad libitum access to alfalfa pellets (58.2, 51.0, and 46.9 kg, respectively). While lambs limit-fed WSC had greater ($P < 0.01$) HCW compared to lambs offered alfalfa pellets. Dressing percentage (DP) was greater ($P < 0.01$) for lambs offered WSC compared to lambs offered alfalfa pellets (64% vs. 60%, respectively). The dressing percentages observed in this study are greater than those reported by Borton et al. (2005a) when they fed lambs to 77kg. This is of no surprise because dressing percentages tend to increase with increasing slaughter weights (Field and Whipple, 1998). Wether lambs had greater ($P < 0.01$) HCW (55.7 vs. 48.3 kg) and dressing percentage (65.0 vs. 60.9%) compared to ewe lambs. Carcasses from lambs consuming WSC had greater ($P < 0.01$) amounts of kidney fat compared to carcasses from lambs consuming alfalfa pellets. There was a significant ($P < 0.05$) diet × sex interaction for carcass kidney fat in long-fed lambs (Figure 3.5.). Wether lambs limit-fed WSC had greater amounts of kidney fat compared to ewe and wether lambs offered alfalfa pellets, while wether lambs offered alfalfa pellets had the least amount of carcass kidney fat compared to all other lambs. Carcasses from lambs offered ad libitum access to WSC had greater ($P < 0.05$) BF, YG, marbling score, and greater ($P < 0.01$) BWT compared to carcasses from lambs limit-fed WSC or lambs offered ad libitum access to alfalfa pellets. However, carcasses from lambs that were limit-fed WSC tended ($P = 0.06$) to have greater BWT compared to carcasses from lambs offered alfalfa pellets. Wether lamb carcasses had greater ($P < 0.05$) BWT and lower ($P < 0.01$) percent BCTRC compared to ewe lamb carcasses. Carcasses from lambs limit-fed WSC and lambs offered alfalfa pellets had greater ($P < 0.01$) percent BCTRC compared to lambs offered ad libitum access to WSC (41.0 and 42.0, respectively, vs. 38.2%). Even though long-fed lamb carcasses from lambs offered ad libitum access to WSC had a lower %BCTRC, they still produce a greater total weight of BCTRC. The extra weight from these heavy lamb carcasses allows the packer to make more money from this added weight due to greater HCW potentially (Field and Whipple, 1998). However, from a consumer standpoint, the added fat from these long-fed lambs is a negative consequence. Jeremiah et al. (1993) reported that over 92% of their consumers would reject untrimmed lamb chops because of the excess fat. Diet tended ($P = 0.08$) to affect LMA, with carcasses from lambs offered WSC having numerically greater LMA compared to carcasses from lambs offered alfalfa pellets. The LMA measurements from these long-fed lambs is greater than the industry average ($19.55 cm^2$), as reported by Hoffman et al. (2016). Leg conformation scores from lamb carcasses tended (P = 0.08) to have a diet × sex interaction. No significant differences (P > 0.05) were observed for carcass conformation score, lean color/quality, and QG.

Allowing market weight ready lambs from the study conducted in Chapter 2 to remain on feed for extended time (+119 days) resulted in greater carcass measurements for long-fed lambs in this study. Long-fed lambs had greater final BW, HCW, DP, kidney fat, BF, BWT, LMA, marbling score, and YG compared to shorter-fed, market ready lambs from Chapter 2. Results from Borton et al. (2005a) and Crouse et al. (1981) support these findings of greater carcass measurements from heavy weight lambs compared to lighter weight lambs. Misock et al. (1976) also reported increases in kidney fat, BF, and marbling score with increasing HCW and DOA for lambs. Ferrell et al. (1979) reported the chemical composition of gain for lambs which showed a pattern for decreased protein:fat gain with increasing BW on a high and medium level concentrate diet, while the protein:fat gain on the low level concentrate diet remained similar with increasing BW. The change in %BCTRC by diet from typical weight market lambs to long-fed lambs was greater for lambs offered ad libitum access to WSC (-6.29%) compared to lambs offered ad libitum access to alfalfa pellets (-4.50%), while lambs limit-fed WSC (-3.43%) had the least amount of change. Long-fed lambs with ad libitum access to a high concentrate diet begin to deposit a greater amount of fat compared to long-fed lambs with ad libitum access to a high forage diet. Interestingly, long-fed lambs that were limit-fed WSC had the least amount of change for %BCTRC. Therefore, limit-feeding lambs WSC may be a viable option to control energy utilization for lean tissue growth instead of fat growth in long-fed lambs.

Conclusion

Long-fed lambs offered ad libitum access to WSC had the greatest ADG, resulting in a greater off-test weight, and the lowest feed cost per unit of gain compared to long-fed lambs offered alfalfa pellets with ad libitum access, or lambs limit-fed WSC. Wether lambs also gained faster and produced heavier carcasses compared to ewe lambs. Feeding WSC decreased the total digestive tract weight of long-fed lambs allowing more energy to be used for lean tissue growth instead of increased maintenance requirements from visceral organs. Long-fed lambs offered WSC had greater HCW, dressing percentages, and tended to have greater LMA measurements. Long-fed lambs offered WSC at 85% of ad libitum intake produced carcasses that had less BF, BWT, and a lower YG and marbling score compared with carcasses from long-fed lambs offered ad libitum access to WSC. Long-fed lambs offered WSC ad libitum produced carcasses with greater amounts of fat and a lower %BCTRC compared with long-fed lambs offered alfalfa pellets or long-fed lambs limit-fed WSC. Continuing to feed lambs to slaughter weights in this study can result in an excessive amount of waste fat and may compromise the structural integrity of the lamb’s feet and legs.

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Table 3.1. Nutrient composition of long-fed lamb diets.

	Dietary Treatments		
	Alfalfa Pellets	Ad Lib. Corn	Limit-fed Corn
Ingredient	------------- % Dry matter basis --------------		
Pelleted alfalfa	90.00	---	---
Whole shelled corn	---	85.00	80.00
Supplement			
Ground Corn	6.32	---	2.35
Soybean meal	1.00	11.02	12.96
Urea	0.20	1.00	1.18
Limestone	---	1.00	1.18
Monosodium phosphate	0.50	---	---
Sheep salt [a]	0.50	0.50	0.59
Vitamin A, 30,000 IU/g	0.01	0.01	0.01
Vitamin D, 3,000 IU/g	0.01	0.01	0.01
Vitamin E, 44 IU/g	0.05	0.05	0.05
Selenium, 201 ppm	0.13	0.13	0.15
Amaferm, 141 g/kg	0.39	0.39	0.46
Ammonium chloride	0.40	0.40	0.47
A-V blend	0.50	0.50	0.59
Analyzed Composition			
Crude protein, %	16.53	15.93	17.33
NDF, %	43.27	8.07	7.92
ADF, %	34.47	2.39	2.42
Calcium, %	1.20	0.42	0.52
Phosphorus, %	0.40	0.34	0.35
NE_m, Mcal/kg	0.97	2.38	2.36
NE_g, Mcal/kg	0.41	1.66	1.65

[a] Contained > 90.2% NaCl, 0.1% Zn, 0.8% Mn, 0.125% Fe, 0.01% I, and 0.002% Co, and 0.009% Se.

Table 3.2. Least squares means of growth and performance of long-fed lambs**.**

	Diet [1]				**Sex**		
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**SEM** [2]	**Ewe**	**Wether**	**SEM** [2]
Days on feed, d	218.40	218.45	218.65	0.496	219.50 [f]	217.50 [g]	0.405
Initial BW, kg	30.1	30.1	30.2	1.69	29.3	31.0	1.38
Off test BW, kg	93.6 [a]	86.0 [b]	83.4 [b]	1.64	84.7 [g]	90.6 [f]	1.34
ADG, kg/d	0.2888 [a]	0.2523 [b]	0.2434 [b]	0.00777	0.2503 [g]	0.2727 [f]	0.00633
DMI, kg/d	1.631 [d]	2.578 [c]	1.385 [e]	0.0140	1.795 [i]	1.934 [h]	0.0114
NE_m intake, Mcal/d	3.882 [c]	2.499 [e]	3.269 [d]	0.0232	3.050 [i]	3.383 [h]	0.0190
NE_g intake, Mcal/d	2.707 [c]	1.057 [e]	2.285 [d]	0.0153	1.900 [i]	2.133 [h]	0.125
G:F, kg/kg	0.1788 [c]	0.0995 [d]	0.1760 [c]	0.00298	0.152	0.151	0.00243
Feed cost per gain, $/kg	1.35 [d]	6.82 [c]	1.48 [d]	0.159	3.16	3.27	0.130

[a, b] Diet means within a row without a common superscript letter differ ($P < 0.05$).

[c, d, e] Diet means within a row without a common superscript letter differ ($P < 0.01$).

[f, g] Sex means within a row without a common superscript letter differ ($P < 0.05$).

[h, i] Sex means within a row without a common superscript letter differ ($P < 0.01$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of Ad libitum whole shelled corn diet

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

Table 3.3. Least squares means of visceral organ weights of long-fed lambs

	Diet [1]				Sex		
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**SEM [2]**	**Ewe**	**Wether**	**SEM [2]**
Final BW, kg [3]	90.3 [a]	79.9 [b]	77.5 [b]	2.28	80.5	84.7	1.83
HCW, kg	58.8 [c]	47.5 [d]	49.3 [d]	1.48	49.0 [f]	54.7 [e]	1.19
Dressing percent, %	65.07 [c]	59.35 [d]	63.57 [c]	0.608	60.92 [h]	64.42 [g]	0.489
Kidney fat, g	2800 [a]	1810 [b]	2510 [a]	162	2440	2310	129
Rumen, g	966	1039	883	62.2	964	962	49.9
Reticulum, g	154.0 [d]	203.6 [c]	136.9 [d]	9.26	167.1	162.5	7.41
Omasum, g	99 [d]	205 [c]	93 [d]	13.6	141	124	11.1
Abomasum, g	246	305	220	26.4	270	244	21.5
Spleen, g	133	111	119	10.4	124.3	116.8	8.52
Small intestine, g	610 [d]	1094 [c]	614 [d]	42.9	846 [e]	700 [f]	34.4
Large intestine, g	595 [b]	845 [a]	589 [b]	49.3	623	730	39.5
Cecum, g	66.9 [b]	95.2 [a]	64.1 [b]	6.85	78.6	72.2	5.49
Liver, g	1182 [ab]	1415 [a]	955 [b]	74.7	1173	1195	57.7
Heart, g	309	284	281	13.5	283	299	10.4
Visceral fat, g	7140 [c]	4310 [d]	4870 [d]	457	5260	5620	353
Total tract, g [4]	2740 [d]	3790 [c]	2600 [d]	132	3090	2990	106

[a, b] Diet means within a row without a common superscript letter differ (P < 0.05).

[c, d] Diet means within a row without a common superscript letter differ (P < 0.01).

[e, f] Sex means within a row without a common superscript letter differ (P < 0.05).

[g, h] Sex means within a row without a common superscript letter differ (P < 0.01).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of Ad libitum whole shelled corn diet

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] Final BW is the weight collected at the abattoir just before harvest.

[4] Total tract weight is the sum of the Rumen, Reticulum, Omasum, Abomasum, Small and Large intestine, and Cecum weight.

Table 3.4. Least squares means of carcass characteristics of long-fed lambs

	Diet [1]				Sex		
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**SEM [2]**	**Ewe**	**Wether**	**SEM [2]**
Off test BW, kg	93.1 [a]	85.2 [b]	83.4 [b]	1.68	83.9 [g]	90.7 [f]	1.36
Final BW, kg [3]	88.7 [c]	78.3 [d]	79.8 [d]	1.63	79.2 [g]	85.3 [f]	1.33
Shrink, %	4.73 [d]	8.10 [c]	4.25 [d]	0.317	5.54	5.98	0.258
HCW, kg	58.2 [c]	46.9 [e]	51.0 [d]	1.12	48.31 [i]	55.72 [h]	0.911
Dressing percent, %	65.32 [c]	59.72 [d]	63.82 [c]	0.799	60.94 [i]	64.97 [h]	0.652
Kidney fat, g	2780 [c]	1840 [d]	2720 [c]	123	2503	2393	99.7
Back fat thickness, cm	1.742 [a]	1.217 [b]	1.424 [b]	0.0901	1.389	1.533	0.0733
Body wall thickness, cm	4.78 [c]	3.48 [d]	3.94 [d]	0.141	3.83 [g]	4.30 [f]	0.115
LM area, cm^2	23.18	20.46	22.47	0.714	21.85	22.21	0.580
Leg Conformation [4]	12.28	12.15	12.42	0.207	12.21	12.36	0.168
Carcass Conformation [4]	12.57	12.63	12.98	0.191	12.64	12.81	0.155
Marbling score [5]	609 [a]	446 [b]	492 [b]	24.1	498	533	19.6
Lean Color/Quality [4]	13.41	12.75	12.69	0.300	12.79	13.12	0.244
Quality Grade [4]	13.39	12.88	13.31	0.189	13.04	13.34	0.153
Yield Grade [6]	7.26 [a]	5.19 [b]	6.01 [b]	0.355	5.87	6.44	0.289
BCTRC, % [7]	38.23 [d]	41.99 [c]	41.04 [c]	0.475	41.50 [h]	39.35 [i]	0.386

[a, b] Diet means within a row without a common superscript letter differ ($P < 0.05$).

[c, d, e] Diet means within a row without a common superscript letter differ ($P < 0.01$).

[f, g] Sex means within a row without a common superscript letter differ ($P < 0.05$).

[h, i] Sex means within a row without a common superscript letter differ ($P < 0.01$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of Ad libitum whole shelled corn diet

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] Final BW is the weight collected at the abattoir just before harvest.

[4] Leg conformation, Carcass conformation, Lean color/quality, and Quality grade are based on a numeric scale: 11 = avg. choice, 12 = high choice, and 13 = low prime.

[5] Marbling score is subjective and based on a numeric scale: 400-499 = small, 500-599 = modest, 600-699 = moderate.

[6] Yield grade = $(((BF/2.54) \times 10) + 0.4)$

[7] Percent boneless closely trimmed retail cuts = $49.94 - (0.085 \times HCW) + (2.46 \times LMA) - (4.38 \times BF) - (3.53 \times BWT)$

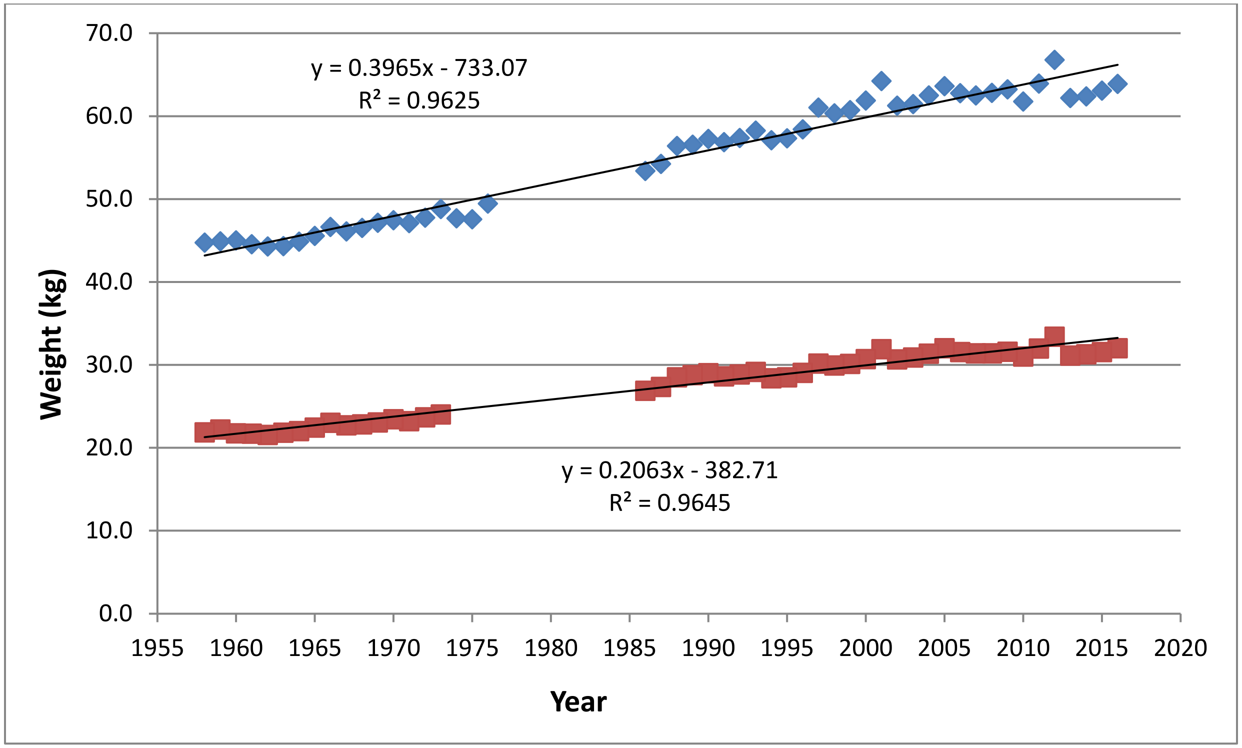

Figure 3.1. Historical weights of sheep marketed for slaughter from 1958-2016 (USDA, 2016). Linear regressions for live weight (♦) and dressed weight (■) are shown.

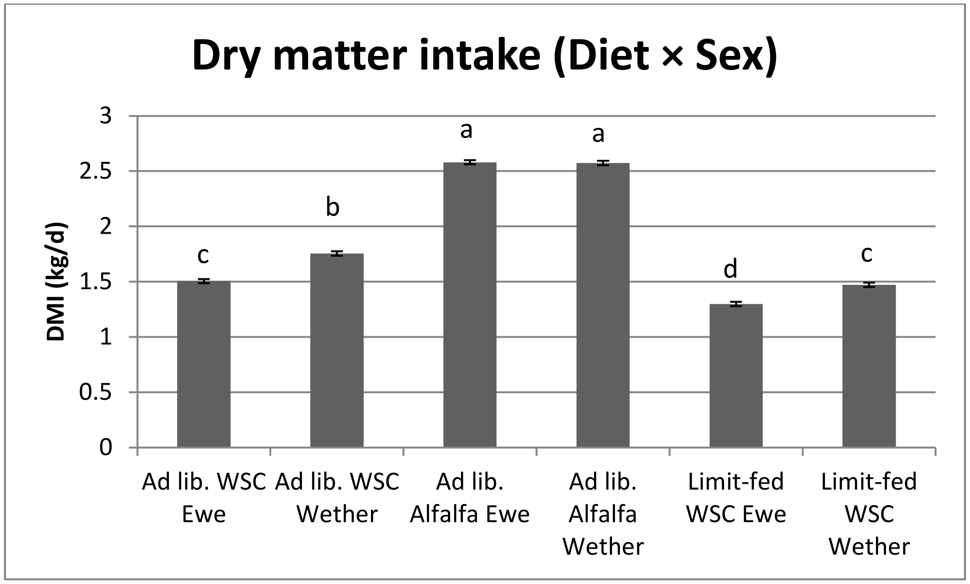

Figure 3.2. Diet × sex interaction for dry matter intake of long-fed lambs. Treatment least squares means without a common letter (a, b, c, d) are significantly different ($P < 0.05$).

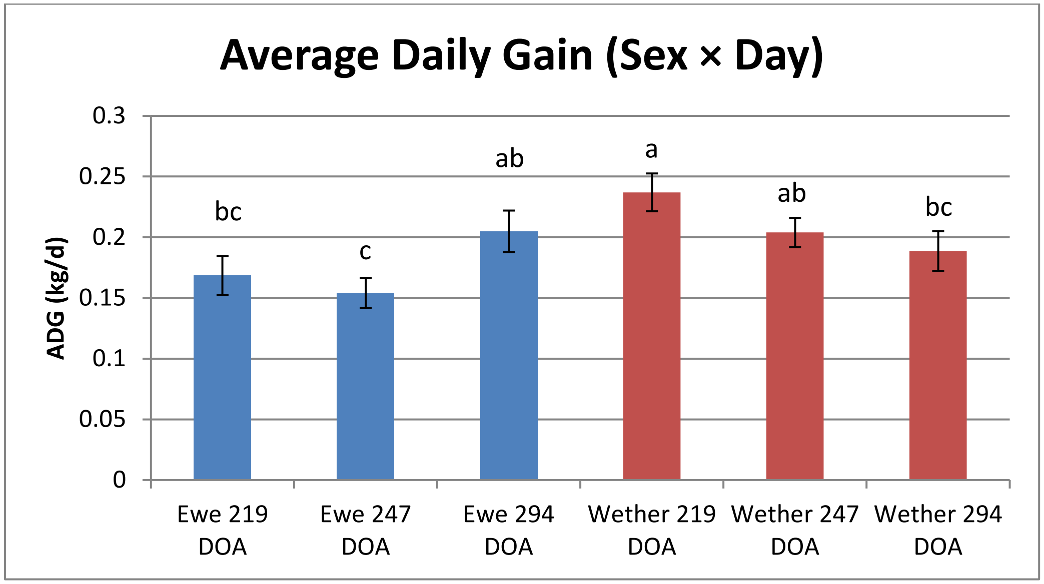

Figure 3.3. Sex × weigh day (expressed as days of age; DOA) interaction for average daily gain of long-fed lambs. Ewe 219 DOA was the ADG of ewes with an average age of 219 days, Ewe 247 DOA was the ADG of ewes with an average age of 247 days, and Ewe 294 DOA was the ADG of ewes with an average age of 294 days. Wether 219 DOA was the ADG of wethers with an average age of 219 days, Wether 247 DOA was the ADG of wethers with an average age of 247 days, and Wether 294 DOA was the ADG of wethers with an average age of 294 days. Treatment means without a common letter (a, b, c) are significantly different ($P < 0.05$).

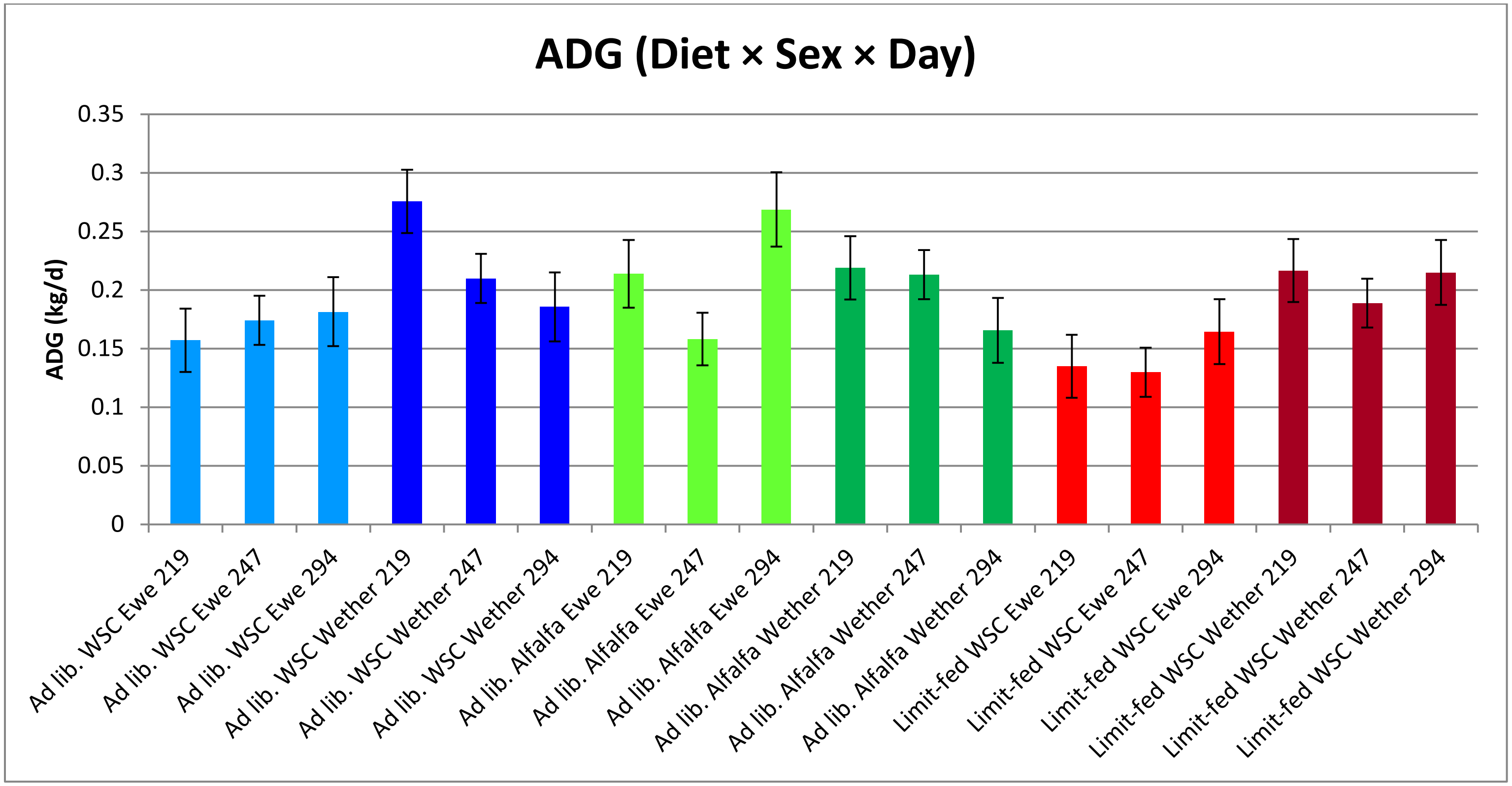

Figure 3.4. Diet × sex × weigh day (expressed as days of age; DOA) interaction for average daily gain of long-fed lambs. Ad lib. WSC is ad libitum access to a WSC diet, Limit-fed WSC is 85% access to the WSC diet, and Ad lib. Alfalfa is the ad libitum access of alfalfa pellets. Ewe 219 was the ADG of ewes with an average age of 219 days, Ewe 247 was the ADG of ewes with an average age of 247 days, and Ewe 294 was the ADG of ewes with an average age of 294 days. Wether 219 was the ADG of wethers with an average age of 219 days, Wether 247 was the ADG of wethers with an average age of 247 days, and Wether 294 was the ADG of wethers with an average age of 294 days.

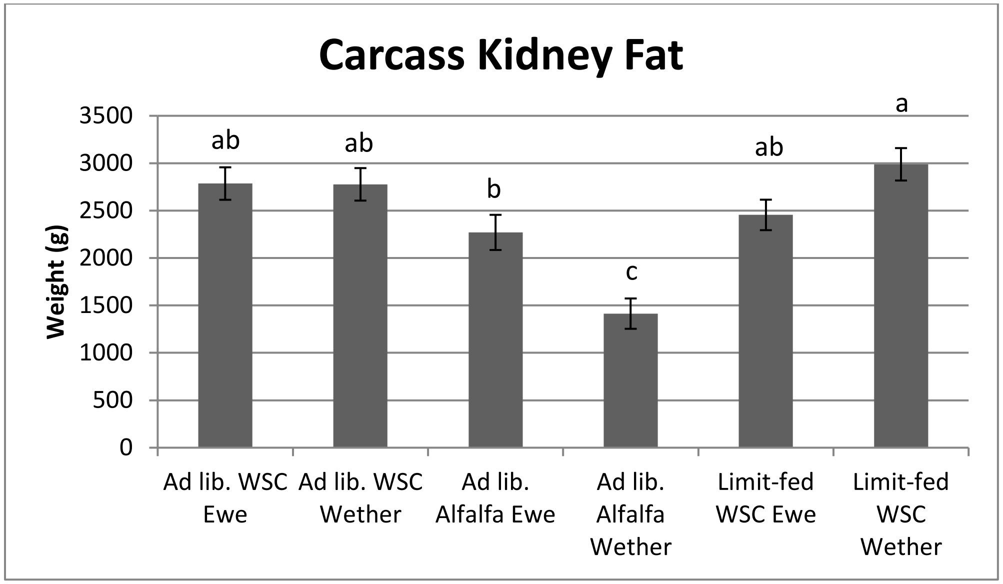

Figure 3.5. Diet × sex interaction for carcass kidney fat from long-fed lambs. Treatment least squares means without a common letter (a, b, c) are significantly different ($P < 0.05$).

Chapter 4.

Effect of energy source on the growth, performance, and carcass characteristics of yearling and mature ewes

ABSTRACT

The objective of the present study was to determine the effects of energy source on the growth, performance, and carcass characteristics of yearling ewe lambs and mature ewes. Yearling ewe lambs (n=16) and mature ewes (n=16) were each used in their own randomized complete block design experiment and randomly assigned a diet consisting primarily of whole shelled corn (WSC) or alfalfa pellets. Pen was used as the experimental unit since sheep were randomly assigned to a pen with four sheep per pen. Statistical analysis was conducted using the PROC MIXED procedure in SAS with diet as the fixed effect and diet nested within pen as the random effect. Daily dry matter intake (DMI), gain to feed ratio (G:F), and feed cost per unit of gain data were analyzed on a pen average basis, with no random effect in the model. Significant differences were achieved when $P < 0.20$. Yearling ewe lambs offered ad libitum access to WSC had a lower ($P < 0.01$) feed cost per unit of gain because of greater ($P < 0.10$) G:F and lower ($P < 0.01$) DMI when compared to yearling ewe lambs offered ad libitum access to alfalfa pellets. Yearling ewe lambs fed WSC had lower reticulum ($P < 0.15$), omasum ($P <$

0.15), and small intestine ($P < 0.10$) weights, which contributed to an overall lower ($P < 0.15$) total tract weight when compared to yearling ewe lambs fed alfalfa pellets. Yearling ewe lambs fed WSC produced carcasses with greater amounts of kidney fat ($P < 0.15$), backfat ($P < 0.10$), and body wall thickness ($P < 0.05$)) and a lower ($P < 0.10$) percent boneless closely trimmed retail cuts (%BCTRC) compared to carcasses from yearling ewe lambs fed alfalfa pellets. Mature ewes offered ad libitum access to WSC had a greater ($P < 0.15$) average daily gain and lower ($P < 0.05$) DMI, which resulted in a greater ($P < 0.15$) G:F and lower ($P < 0.10$) feed cost per unit of gain when compared to mature ewes offered ad libitum access to alfalfa pellets. Mature ewes fed WSC had lower omasum ($P < 0.10$), small intestine ($P < 0.20$), and total tract weights ($P < 0.20$) and greater ($P < 0.20$) spleen weight when compared to mature ewes fed alfalfa pellets. Mature ewes fed WSC produced carcasses with greater amounts of kidney fat ($P < 0.10$), backfat ($P < 0.15$), body wall thickness ($P < 0.20$) and lower %BCTRC ($P < 0.05$) when compared to carcasses from mature ewes fed alfalfa pellets. Overall, feeding WSC to yearling ewe lambs and mature ewes will have a greater, more efficient, and cheaper BW gain with lower total tract weights and greater amounts of carcass fat when compared to feeding alfalfa pellets.

Key words: mature ewe, yearling lambs, corn, alfalfa, carcass, heavy weight

Introduction

Mature ewes can be culled from the breeding flock for various reasons after weaning a lamb. At the time of weaning, mature ewes are typically lacking body condition due to the extreme energy demand drawn from the mother's body to meet the energy requirements during lactation to produce milk for their lambs. In the United States, when sheep are marketed through the traditional marketing channel, they are sold on a live weight basis that does not consider carcass composition or quality. Therefore, sheep producers and feeders can benefit from feeding lean mature ewes for a short period to quickly add body weight (BW) and increase their monetary returns.

Currently in the United States, the sheep and lamb market experiences seasonal fluctuations for the demand of lamb and mutton. As a result of this seasonal decline in the demand for sheep meat, packers refrain from purchasing lambs from producers and lamb feeders. When packers are not interested in buying lambs from producers and lamb feeders, market weight lambs are forced to remain in the feedlot on feed until they can be marketed. As a result, some of these lambs can reach a year of age and deposit fat in excessive amounts.

The objective of this study was to investigate the effects of energy source on the growth, performance, and carcass characteristics of yearling and mature ewes. We hypothesized that feeding mature ewes after weaning lambs for approximately 60+ days could increase live BW and increase the body condition of these ewes. We expected greater and more efficient rates of gain from ewes offered WSC compared to ewes offered alfalfa pellets. While ewes offered alfalfa pellets would have a greater dry matter intake (DMI) and as a result have greater visceral organ weights compared to ewes offered WSC. We also expected carcasses from ewes consuming WSC to have greater amounts of fat deposition and muscling compared to ewes consuming the alfalfa pellet diet.

Materials and Methods

Animal procedures were approved by the Institutional Animal Care and Use Committee (IACUC protocol number 2015A00000023) of The Ohio State University and animal care followed guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Experimental design and treatments

Sixteen Dorset × Hampshire yearling ewe lambs (initial BW = 60.5 ± 7.2 kg) and 16 Dorset × Hampshire mature ewes (initial BW = 71.9 ± 8.6 kg) were each used in their own randomized complete block design experiment to determine the effects of energy source (ad libitum access to an alfalfa pellet diet versus ad libitum access to a WSC diet) on their growth, performance, and carcass characteristics. Experimental diets fed to lambs during the study are shown in Table 4.1. Dietary ingredient costs on an as-fed basis for WSC, alfalfa pellets and supplement were \$0.15/kg, \$0.60/kg, and \$0.51/kg, respectively at the time of the study. Sheep were housed at the Ohio Agriculture Research and Development Center's sheep research feedlot inside a covered barn in Wooster, OH throughout the duration of the experiment. Yearling and mature ewes were blocked by age (yearling and mature) and stratified by initial weight to pens containing four sheep within a pen, with two pens receiving each dietary treatment. Yearling ewes and two pens (1 offered alfalfa pellets and 1 offered WSC) of mature ewes were in the feedlot from April, 2015 through July, 2015. The remaining two pens of mature ewes (1 offered alfalfa pellets and 1 offered WSC) were in the feedlot from September, 2015 through December, 2015 due to the availability of animals at one time. Pens were constructed on either expanded metal or slotted plastic flooring with three metal gates and a wooden fence line feed bunk on the fourth side. Pen dimensions were 1.49 × 4.88 m with 1.49 m of linear bunk space. Each pen was equipped with an automatic watering cup providing lambs ad libitum access to water.

Feeding and performance data collection

Diets (Table 4.1.) fed to lambs were formulated to meet the dietary nutrient requirements of lambs (NRC, 2007). A 100 gram feed sample from each diet was collected every 14 days throughout the experiment. Fifty grams was used to determine weekly dry matter (DM) content by drying the sample at 100ºC (AOAC, 1984) to make adjustments and calculations for dry matter intake (DMI) and the remaining 50 grams was dried in a forced air oven at 55ºC, ground to pass through a 2-mm screen, and analyzed for DM content (AOAC, 1984) and neutral detergent fiber (NDF) (Van Soest et al., 1991).

Sheep were fed on a pen basis. Feed offered and feed refused was weighed daily for each pen prior to re-feeding at 0830 to record feed intake. Since sorting was expected, feed was not allowed to remain in the feed bunk for more than one day before being discarded. At the start of the trial, 10% of the transition diet was exchanged for an equivalent amount of the experimental diet every day. Therefore, a 10 day transition period took place before sheep were receiving their experimental diet. Initially, all sheep were offered feed at the rate of 2.5% of their live BW, on a DM basis, using the average pen weight within the weight block. At each diet change, sheep had their feed intake reduced by 0.002 kg DM per animal per day. Pens of sheep never had their intake increased or decreased by more than 0.227 kg of feed DM per pen per day throughout the duration of the trial. Preceding the experimental trial, yearling lambs were raised on pasture, much the like yearling lambs raised in the Western United States, to represent the lambs that become excessive fat in the feedlot if not marketed at the appropriate market weight.

Initial BW was determined by using the average BW taken on two consecutive days at 0830 before feeding occurred, with interim BW measurements taken every 14 days, and off-test BW taken before removal from the feedlot for slaughter. Average daily gain, DMI, gain to feed ratio (G:F) (kg of BW gain / kg of feed consumed), and days required to reach harvest weight were determined for all lambs. Yearling lambs were fed in the feedlot for a short duration (63.5 days on feed) before they were removed from the feedlot on a pen basis for slaughter at the Ohio State University abattoir. Mature ewes were fed in two groups and ewes within each group were fed for a similar number of days on feed (DOF; 60 or 83 days) before being removed from the feedlot on a pen basis for slaughter at the Ohio State University abattoir.

Visceral organ and carcass data collection

Final live BW was measured just prior to stunning, and stunning was conducted by the use of a captive bolt gun. Dentition (eruption of permanent teeth through the gums) and the number of break or spool joints on each carcass were assessed for carcass maturity classification. Kidney fat (KF) was removed from the carcasses, weighed and recorded and added back to the HCW. Two lambs per pen were randomly selected for data collection of visceral organ weight. Visceral organs (rumen, reticulum, omasum, abomasum, spleen, small intestine, large intestine, cecum, heart, liver, and visceral fat) were removed and any adhering adipose tissue was stripped from these organs. Visceral organs were flushed with water, squeezed, and allowed to drip dry before being weighed. Before chilling, hot carcass weights were recorded to determine dressing percentage. After chilling for 24 hours at 0 – 4°C, carcasses were ribbed between the 12^{th} and 13^{th} ribs to record longissimus muscle area (LMA), backfat thickness (BF), body wall thickness (BWT), marbling score, body conformation score, and leg score to calculate USDA Quality and Yield grades, as well as percent boneless closely trimmed retail cuts (%BCTRC).

Statistical analysis

The experimental design was a randomized complete block design with two diets (ad libitum alfalfa pellets and ad libitum WSC). Statistical analysis was performed using the MIXED procedure in SAS (SAS Inst. Inc., Cary, NC). The statistical model used was: $Y_{ijkl} = \mu + D_i + p_j + e_{ij}$, where D_i = diets fed, as the fixed effect, and p_k = pen (nested with diet) as the random effect, and e_{ij} = the error. Pen averages were used for the analysis of daily DMI, G:F, and feed cost per unit of gain data and the random effect was removed from the model. There was no significant effect due to mature ewes being fed in two different groups; therefore it was not used in the final model. The LSMEANS and DIFF statements were used to record treatment means, standard errors and distinguish differences between treatment levels. Due to limited experimental units, at $P < 0.20$, differences amongst treatments were considered significant.

Results and Discussion

Growth and performance of yearling ewes

Yearling ewe lambs were put on trial at similar initial BW ($P > 0.20$) and were on trial for 63.5 days regardless of dietary treatment. There were no significant differences due to energy source between lambs offered ad libitum access to alfalfa pellets or ad libitum access to WSC for off-test BW or ADG ($P > 0.20$; Table 4.2.). In contrast, increasing the level of concentrate in the diet fed to sheep usually results in a greater ADG (Ferrell et al., 1979). Yearling lambs offered WSC had a lower DMI ($P < 0.01$) and greater net energy intake for maintenance ($P < 0.05$) and gain ($P < 0.01$). Since, feeding forages results in greater acetate:propionate ratio when compared to feeding concentrates to lambs (Hart et al., 1991; Fimbres et al, 2002). Sheep consuming alfalfa pellets are consuming less energy because Armstrong and Blaxter (1957) have shown that volatile fatty acids (VFA) with longer carbon chains are more energy dense. Allen et al. (2008) have also discussed hepatic oxidative theory and the effect propionate may have on regulating feed intake. Therefore, an animal consuming a WSC diet that produces a greater percentage of propionate would reach satiety sooner than an animal consuming an alfalfa pellet diet that produces a lower percentage of propionate. With numerically greater ADG and a lower DMI, yearling lambs consuming WSC had a greater ($P < 0.10$) G:F when compared to yearling lambs consuming alfalfa pellets. Greater G:F for yearling ewe lambs fed WSC when compared to feeding forage is in agreement with the results of Murphy et al. (2003). Greater feed costs and lower G:F resulting from alfalfa pellets resulted in a much greater ($P < 0.01$) feed cost per unit of gain for yearling lambs offered alfalfa pellets compared to yearlings lambs offered WSC (1.29 vs. 6.53 $/kg gained) in the feedlot.

Growth and performance of mature ewes

Mature ewes were on trial for an average of 72 days regardless of dietary treatment. There was not a significant difference ($P > 0.20$) for off-test BW between mature ewes offered alfalfa pellets and mature ewes offered WSC, even though mature ewes were 7.5 kg heavier when they consumed the WSC diet (Table 4.3.). Even though, this is not statistically significant, 7.5 kg has a significant economic impact because sheep are sold on a weight basis. Mature ewes offered ad libitum access to WSC had a greater ($P < 0.15$) ADG when compared to mature ewes offered ad libitum access to alfalfa pellets. The increase in ADG by mature ewes consuming WSC can be explained by a greater net energy intake for maintenance ($P < 0.10$) and gain ($P < 0.05$) when compared to mature ewes consuming alfalfa pellets. As a result of consuming a lower energy diet consisting primarily of alfalfa pellets, mature ewes consuming the alfalfa pellets had a greater ($P < 0.05$) DMI to increase their energy intake when compared to mature ewes consuming WSC. The G:F ($P < 0.15$) and feed cost per unit of gain ($P < 0.10$) was greater for mature ewes offered WSC instead of alfalfa pellets (0.18 vs. 0.09 kg/kg and 1.37 vs. 7.55 $/kg, respectively). The cost of per kg of BW gain was 5.5 times cheaper from the WSC diet when compared to the alfalfa pellet diet fed to mature ewes.

Visceral organ weight of yearling ewe lambs

Yearling lambs offered ad libitum access to WSC had a numerically greater final BW, HCW, and dressing percentage (59.3 vs 56.8 %, respectively) when compared to yearling lambs offered ad libitum access to alfalfa pellets (Table 4.4.). These numerical increases for final BW and HCW of yearling lambs that consumed WSC may be the reason for numerical differences for greater kidney (1920 vs 1380 g) and visceral (3900 vs 3210 g) fat compared to yearling lambs consuming alfalfa pellets. Yearling lambs that consumed the alfalfa pellet diet had greater reticulum ($P < 0.15$), omasum ($P < 0.15$), and small intestine ($P < 0.10$) weights compared to yearling lambs that consumed WSC. No other significant differences were observed for the rumen, abomasum, spleen, large intestine, cecum, liver, and heart. However, the total tract weight from yearling lambs offered alfalfa pellets was 21.6% greater ($P < 0.15$) when compared to the total tract weight from yearling lambs offered WSC. Greater total tract weights for yearling ewe lambs offered ad libitum access to alfalfa pellets increase the maintenance requirements of these organs and utilize energy that could otherwise be used for lean tissue growth when compared to yearling ewe lambs offered ad libitum access to WSC (Fluharty et al., 1999).

Visceral organ weight of mature ewes

Mature ewes offered ad libitum access to WSC had a numerically greater final BW (92.1 vs. 80.6 kg) and dressing percentage (55.3 vs 51.0 %, respectively) and significantly greater ($P < 015$) HCW when compared to mature ewes offered ad libitum access to alfalfa pellets (Table 4.5.). The mature ewes that consumed WSC had 114% more kidney fat ($P < 0.20$) and 68% more visceral ($P < 0.15$) fat compared to mature ewes consuming alfalfa pellets. McLeod et al. (2007) reported greater amounts of alimentary fat from steers supplied with abomasal glucose infusions compared to steers with abomasal starch hydrolysate. Mature ewes consuming WSC in this study are likely suppling larger quantities of starch and glucose to the small intestine compared to lambs consuming alfalfa pellets, making the energy substrate readily available for use and storage. Mature ewes that consumed the alfalfa pellet diet had greater omasum ($P < 0.10$), spleen ($P < 0.20$), and small intestine ($P < 0.20$) weights compared to mature ewes that consumed WSC. No other significant differences were observed for the rumen, reticulum, abomasum, large intestine, cecum, liver, and heart. However, the total tract weight from mature ewes offered alfalfa pellets was greater ($P < 0.20$) when compared to the total tract weight from mature ewes offered WSC (5660 vs. 5120 g, respectively). Again, feeding alfalfa pellets causes an inefficient use of energy towards the maintenance of visceral organs instead of lean tissue growth when compared to feeding sheep WSC (Fluharty et al., 1999).

Carcass characteristics from yearling ewe lambs

Yearling ewe lambs had an average age of 421 days at the time of harvest. Frequency of break joint and permanent tooth eruption status from yearling ewe lambs fed WSC or alfalfa pellets is shown in Table 4.6. Three out of 15 yearling ewe lambs revealed eruption of their first pair of permanent incisors, all three yearling ewe lambs with erupted permanent incisors had been fed WSC. Our results are in agreement with the results of Arrowsmith et al. (1974) who reported that feeding a high energy diet to lambs would cause the eruption of the first pair of permanent incisors to occur 33 days earlier compared to lambs on a low energy diet. In contrast, Field et al. (1990) found no difference in the first pair of permanent teeth erupted due to diet. Six out of 15 yearling ewe lamb carcasses still produced break joints. Four yearling ewe lamb carcasses with break joints had been fed WSC, while two yearling ewe lamb carcasses with break joints had been fed alfalfa pellets. Interestingly, while all yearling ewe lambs fed alfalfa pellets did not have their first pair of permanent incisors, but 75% percent of their carcasses had spool joints. In the case of yearling ewe lambs fed alfalfa pellets, break/spool joint classification appears to be more accurate at classifying yearling ewe lambs as yearling carcasses.

Off-test BW was not significantly affected ($P > 0.20$) by dietary treatment as shown in Table 4.7. However, the percentage of BW shrink experienced by yearling ewes as they were transported from the feedlot to the abattoir and the lairage time before harvest was greater ($P < 0.15$) for yearling ewe lambs consuming alfalfa pellets when compared to yearling ewe lambs consuming WSC. Yearling ewe lambs that were offered

WSC produced carcasses with greater amounts of KF ($P < 0.15$), BF ($P < 0.10$), greater BWT ($P < 0.05$), and YG ($P < 0.10$) compared to yearling ewe carcasses from lambs offered alfalfa pellets. This resulted in a lower ($P < 0.10$) %BCTRC for yearling ewe carcasses raised with WSC when compared to yearling ewe carcasses raised with alfalfa pellets. However, because yearling ewes fed alfalfa pellets had a significantly greater percentage of BW shrink, they produced carcasses with numerically lower HCW compared to yearling ewes fed WSC. This results in fewer BCTRC on a weight basis for these yearling ewes fed alfalfa pellets when compared to yearling ewes fed WSC (18.2 vs. 19.2 kg, respectively).

Carcass characteristics from mature ewes

Mature ewes expressed the same differences for carcass characteristics due to diet as yearling ewe lambs. Mature ewes offered ad libitum access to alfalfa pellets had a greater ($P < 0.20$) percentage of BW shrink due to transportation and lairage time when compared to the mature ewes offered ad libitum access to WSC (Table 4.8.). The passage rate of the diet likely influenced the percent BW shrink of lambs, because forage based diets have a greater passage rate compared to concentrate diets through the digestive tract (Poore et al., 1990). Thompson et al. (1987) have reported fatter lambs lose less weight during transportation and the time spent fasting before slaughter. The rate of passage and level of lamb fatness could help explain the differences in BW shrink between lambs fed WSC and alfalfa pellets. A 2 % body weight shrink can have a significant economic impact depending on the diet fed, especially when marketing heavy weight sheep. Mature ewes offered WSC produced carcasses with greater amounts of

KF greater ($P < 0.10$), BF greater ($P < 0.15$), greater BWT greater ($P < 0.20$), and YG greater ($P < 0.15$) when compared to carcasses from mature ewes offered alfalfa pellets. These results are in agreement with Crouse et al. (1981) and Field et al. (1990) that sheep fed high-energy diets deposit more fat when compared to sheep fed low-energy diets. Since mature ewes that were fed WSC had numerically greater HCW compared to mature ewes fed alfalfa pellets, carcasses from mature ewes fed WSC will produce greater numerical amounts of BCTRC when compared to carcasses from mature ewes fed alfalfa pellets (21.0 vs. 19.1 kg, respectively) even though mature ewe fed alfalfa pellets produced carcasses with a greater ($P < 0.05$) %BCTRC compared to carcasses from mature ewes fed WSC.

Conclusion

In conclusion, feeding yearling ewe lambs and mature ewes a WSC based diet results in a greater and more efficient rate of gain that results in a lower feed cost per unit gained when compared to feeding an alfalfa pellet diet. Feeding WSC to yearling ewe lambs and mature ewes also reduced the total tract weight of visceral organs compared to feeding alfalfa pellets, which allows more energy to be put towards lean tissue gain. However, feeding WSC to yearling ewe lambs and mature ewes increases the amount of fat deposited on the carcass when compared to feeding alfalfa pellets.

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Table 4.1. Nutrient composition of diets fed to yearling and mature ewes

	Dietary Treatments	
	Alfalfa Pellets	Ad Lib. Corn
Ingredient	--------% Dry matter basis --------	
Pelleted alfalfa	90.00	---
Whole shelled corn	---	85.00
Supplement		
Ground Corn	6.32	---
Soybean meal	1.00	11.02
Urea	0.20	1.00
Limestone	---	1.00
Monosodium phosphate	0.50	---
Sheep salt [a]	0.50	0.50
Vitamin A, 30,000 IU/g	0.01	0.01
Vitamin D, 3,000 IU/g	0.01	0.01
Vitamin E, 44 IU/g	0.05	0.05
Selenium, 201 ppm	0.13	0.13
Amaferm, 141 g/kg	0.39	0.39
Ammonium chloride	0.40	0.40
A-V blend	0.50	0.50
Analyzed Composition		
Crude protein, %	16.53	15.93
NDF, %	43.27	8.07
ADF, %	34.47	2.39
Calcium, %	1.20	0.42
Phosphorus, %	0.40	0.34
NE_m, Mcal/kg	0.97	2.38
NE_g, Mcal/kg	0.41	1.66

[a] Contained > 90.2% NaCl, 0.1% Zn, 0.8% Mn, 0.125% Fe, 0.01% I, and 0.002% Co, and 0.009% Se.

Table 4.2. Least squares means of the growth and performance of yearling ewe lambs.

	Diet [1]			
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**SEM [2]**	**P-value [3]**
Days on feed, d	63.5	63.5	3.50	1.000
Initial BW, kg	60.8	60.4	2.74	0.934
Off test BW, kg	81.3	79.1	4.02	0.734
ADG, kg/d	0.325	0.295	0.0449	0.688
DMI, kg/d	1.703	2.849	0.069	**0.007**
NE_m intake, kcal/d	4.05	2.76	0.164	**0.031**
NE_g intake, kcal/d	2.83	1.17	0.114	**0.009**
G:F, kg/kg	0.190	0.100	0.02120	**0.096**
Feed cost of gain, $/kg	1.29	6.53	0.129	**0.001**

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] A significant p-value is established when $\alpha \leq 0.200$.

Table 4.3. Least squares means of the growth and performance of mature ewes.

	Diet [1]			
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**SEM [2]**	**P-value [3]**
Days on feed, d	72	72	11.5	1.000
Initial BW, kg	71.7	71.9	1.88	0.940
Off test BW, kg	99.7	92.2	3.95	0.312
ADG, kg/d	0.393	0.289	0.0278	**0.125**
DMI, kg/d	2.24	3.17	0.268	**0.013**
NE_m intake, kcal/d	5.32	3.08	0.397	**0.057**
NE_g intake, kcal/d	3.71	1.30	0.248	**0.021**
G:F, kg/kg	0.180	0.093	0.02340	**0.120**
Feed cost of gain, $/kg	1.37	7.55	1.07	**0.056**

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] A significant p-value is established when $\alpha \leq 0.200$.

Table 4.4. Least squares means of the weight of visceral organs from yearling ewe lambs.

	Diet [1]			
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**SEM [2]**	**P-value [3]**
Final BW, kg [4]	76.8	74.6	3.23	0.684
HCW, kg	45.6	42.3	2.98	0.516
Dressing percent, %	59.3	56.8	1.35	0.320
Kidney fat, g	1920	1380	203	0.201
Rumen, g	1221	1234	71.5	0.913
Reticulum, g	159	221	18.3	**0.138**
Omasum, g	139	234	26.2	**0.126**
Abomasum, g	291	356	34.7	0.319
Spleen, g	116.8	114.5	5.52	0.799
Small intestine, g	800	1340	119	**0.084**
Large intestine, g	590	610	182	0.941
Cecum, g	316.4	283.5	71.8	0.777
Liver, g	1320	1350	104	0.881
Heart, g	299	294	17.2	0.838
Visceral fat, g	3900	3210	278	0.224
Total tract, g [5]	3520	4280	233	**0.145**

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] A significant p-value is established when $\alpha \leq 0.200$.

[4] Final BW is the weight collected at the abattoir just before harvest.

[5] Total tract weight is the sum of the Rumen, Reticulum, Omasum, Abomasum, Small and Large intestine, and Cecum weights.

Table 4.5. Least squares means of the weight of visceral organs from mature ewes.

	Diet [1]			
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**SEM [2]**	**P-value [3]**
Final BW, kg [4]	92.1	80.6	4.51	0.214
HCW, kg	50.9	41.1	3.59	**0.124**
Dressing percent, %	55.3	51.0	1.91	0.257
Kidney fat, g	1780	830	345	**0.191**
Rumen, g	1906	1814	75.1	0.478
Reticulum, g	319	321	23.5	0.952
Omasum, g	217	352	30.1	**0.087**
Abomasum, g	462	506	44.7	0.556
Spleen, g	166.7	141.8	7.94	**0.156**
Small intestine, g	1101	1318	69.6	**0.159**
Large intestine, g	910	1110	167	0.478
Cecum, g	210	230	107	0.884
Liver, g	1780	1610	165	0.550
Heart, g	404	380	21.3	0.512
Visceral fat, g	4480	2660	497	**0.122**
Total tract, g [5]	5120	5660	166	**0.151**

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] A significant p-value is established when $\alpha \leq 0.200$.

[4] Final BW is the weight collected at the abattoir just before harvest.

[5] Total tract weight is the sum of the Rumen, Reticulum, Omasum, Abomasum, Small and Large intestine, and Cecum weights.

Table 4.6. Effect of diet on the eruption of permanent incisors and break joint status of yearling ewe lambs.

		Diet	
Item	**#**	**Ad lib. WSC**	**Ad lib. Alfalfa**
Number of yearling ewe lambs	15	7	8
Number of erupted permanent incisors	0	4	8
	1	2	0
	2	1	0
Number of break joints	0	3	6
	1	2	0
	2	2	2

Table 4.7. Least squares means of carcass characteristics of yearling ewe lambs.

	Diet [1]			
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**SEM [2]**	**P-value [3]**
Off test BW, kg	81.1	79.1	4.00	0.756
Shrink, %	5.09	8.38	0.856	**0.110**
Final BW, kg	76.9	72.4	3.13	0.416
HCW, kg	46.2	41.1	3.26	0.380
Dressing percent, %	59.8	56.9	1.79	0.362
Kidney fat, g	2130	1160	269	**0.121**
Backfat thickness, cm	1.027	0.724	0.0694	**0.086**
Body wall thickness, cm	3.27	2.38	0.139	**0.043**
LM area, cm^2	17.4	17.6	1.07	0.939
Leg Conformation [4]	12.06	11.50	0.832	0.676
Carcass Conformation [4]	11.87	11.38	0.635	0.634
Marbling score [5]	617	539	77.9	0.549
Quality Grade [4]	12.20	11.25	0.782	0.478
Yield Grade [6]	4.44	3.25	0.273	**0.086**
BCTRC, % [7]	41.65	44.39	0.603	**0.082**

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] A significant p-value is established when $\alpha \leq 0.200$.

[4] Leg conformation, Carcass conformation, Lean color/quality, and Quality grade are based on a numeric scale: 11 = choice, 12 = high choice, and 13 = prime.

[5] Marbling score is subjective and based on a numeric scale: 500-599 = modest, 600-699 = moderate.

[6] Yield grade = (((BF/2.54) × 10) + 0.4)

[7] Percent boneless closely trimmed retail cuts = 49.94 - (0.085 × HCW) + (2.46 × LMA) - (4.38 × BF) - (3.53 × BWT)

Table 4.8. Least squares means of carcass characteristics of mature ewes.

	Diet [1]			
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**SEM [2]**	**P-value [3]**
Off test BW, kg	100.1	92.2	3.91	0.283
Shrink, %	7.21	9.63	0.830	**0.172**
Final BW, kg	92.9	83.5	4.48	0.269
HCW, kg	51.3	43.0	3.92	0.271
Dressing percent, %	55.4	51.6	1.70	0.255
Kidney fat, g	2080	920	241	**0.072**
Backfat thickness, cm	0.95	0.54	0.117	**0.126**
Body wall thickness, cm	2.80	1.86	0.303	**0.154**
LM area, cm^2	16.3	16.0	2.06	0.908
Leg Conformation [4]	13.42	11.63	0.814	0.257
Carcass Conformation [4]	12.35	11.63	0.937	0.637
Marbling score [5]	484	481	43.0	0.964
Quality Grade [4]	8.14	8.25	0.773	0.929
Yield Grade [6]	4.15	2.53	0.461	**0.126**
BCTRC, % [7]	40.97	44.46	0.592	**0.050**

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] The reported standard error of the mean is the greatest between the levels within the treatment.

[3] A significant p-value is established when $\alpha \leq 0.200$.

[4] Leg conformation, Carcass conformation, Lean color/quality, and Quality grade are based on a numeric scale: 11 = choice, 12 = high choice, and 13 = prime.

[5] Marbling score is subjective and based on a numeric scale: 500-599 = modest, 600-699 = moderate.

[6] Yield grade = $(((BF/2.54) \times 10) + 0.4)$

[7] Percent boneless closely trimmed retail cuts = $49.94 - (0.085 \times HCW) + (2.46 \times LMA) - (4.38 \times BF) - (3.53 \times BWT)$

Chapter 5.

Effect of energy source and level, and sex on meat characteristics and flavor profile of sheep

ABSTRACT

Meat characteristics were analyzed in two trials to determine differences between meat characteristics and the flavor profile from sheep. Trial 1 was a completely randomized design with a 3 × 2 factorial arrangement of treatments to identify differences due to sheep age (n=16 lambs, n=16 yearlings, and n=16 mature) and diet (alfalfa pellets and whole shelled corn; WSC). Mature ewes had greater ($P < 0.05$) Minolta a* values taken from the lean when compared to lean from ewe lambs. Offering WSC resulted in a greater ($P < 0.05$) Minolta a* value from the fat over the rack from sheep carcasses. Cooking loss and slice shear force values were greater for loins aged 1 day versus 14 days. Cooking loss ($P < 0.05$) and slice shear force ($P < 0.01$) also had significant age × diet × postmortem aging interaction. The longissimus muscle from mature ewes had greater ($P < 0.05$) off-flavor intensity scores when compared to ewe lambs and yearling ewe lambs. Lamb flavor intensity was greater ($P < 0.05$) in ground shoulder patties from sheep fed alfalfa pellets compared to WSC and mature ewes compared to ewe lambs. Trial 2 was a completely randomized design with a 3 × 2 × 2

factorial arrangement of treatments to identify differences due to diet (ad libitum alfalfa pellets, ad libitum WSC, and 85% restricted intake of WSC), lamb sex (n=48 ewes and n=48 wethers), and lamb age (short-fed lambs and long-fed lambs). Shorter-fed lambs had a significantly higher ($P < 0.05$) pH when compared to long-fed lambs. There was a diet × sex interaction ($P < 0.05$) for Minolta a* values. Long-fed lambs had greater ($P < 0.05$) Minolta a* values from the fat over the rack of the carcass compared to shorter-fed lambs. Offering WSC to lambs produced carcasses with greater ($P < 0.05$) Minolta a* values when compared to fat on carcasses from lambs offered alfalfa pellets. Long-fed lambs had a greater percent of lipid in the *Longissimus dorsi* ($P < 0.01$) and ground shoulder ($P < 0.01$) when compared to lambs that were fed for a shorter period of time. Lambs offer ad libitum access to WSC had a greater ($P < 0.01$) percentage of lipid in the ground shoulder when compared to lambs offered ad libitum alfalfa pellets and limit-fed WSC. Percent cooking loss and slice shear force values decreased ($P < 0.05$) with aging loins for 14 days versus 1 day. Cooking loss had a significant ($P < 0.01$) diet × lamb age × postmortem aging interaction. While slice shear force had a significant ($P < 0.01$) lamb sex × postmortem aging interaction. Long-fed lambs had greater lamb flavor ($P < 0.01$) and off-flavor ($P < 0.05$) in the *Longissimus* muscle and in the ground shoulder patty ($P < 0.01$) when compared to shorter-fed lambs. Greater lamb flavor intensity scores were given to lambs consuming the alfalfa pellet diet when compared to lambs consuming WSC. Correlations between lamb flavor and off-flavor intensity mean scores with other carcass and meat characteristics demonstrated no significant linear relationship with carcass fat measurements.

Key words: lamb flavor, slice shear force, meat color, meat quality

Introduction

The American Lamb Industry Roadmap Project (2013) states that the focus of the American sheep industry should be directed towards product characteristics in order to improve the consumer's eating experience by providing them with a consistent and premier lamb product every time. The 2015 National Lamb Quality Audit (Hoffman et al., 2016) identified eating satisfaction as the most important quality attribute when deciding to purchase lamb. Eating satisfaction and quality were most commonly described as lamb flavor or taste by respondents. In the United States sheep are marketed on a live body weight basis. Therefore, sheep producers and feeders are able to increase the amount of profit they receive with greater live body weights. However, as body weight increases, the body composition of the lambs begins to change, with a shift towards greater fat deposition instead of lean tissue. The current quality grading system used in the United States is heavily influenced by carcass fatness and utilizes break joint status as an indicator of maturity. Therefore, the American sheep industry has no system that truly measures quality characteristics indicative of eating satisfaction. Implementing a marketing system that can differentiate eating quality and reward or penalize high and low quality lambs, respectively is without doubt needed in this industry.

While lamb tenderness is not a general concern of the American sheep industry, lamb flavor is more variable and can present inconsistent eating experiences for consumers. According to the 2015 National Lamb Quality Audit (Hoffman et al., 2016) lamb flavor is an indication of quality for consumers and has been reported to be inconsistent at times, making it a threat to the industry. Previous research has shown that compounds deposited in the fat of sheep are responsible for species specific flavors of sheep. Branched-chain fatty acids deposited in the fat have been identified as responsible for the 'mutton-like' flavors or increases in lamb flavor intensity in sheep meat (Wong et al., 1975a; Wong et al., 1975b). Garton et al. (1972) reported that feeding barley or diets that produce a higher proportion of propionate during rumen fermentation results in the production and storage of more methyl-branched chain fatty acids in the fat of sheep. Feeding lambs on legume pastures have been reported to increase the lamb flavor and off-flavors experienced when compared to lamb raised on grass pastures (Cramer et al., 1967). Young et al. (2003) have reported skatole as the compound responsible for pastoral flavor that contributes to 'muttony' flavors. Watkins et al. (2014) quantified the three main branched-chain fatty acids and pastoral compounds and observed greater consumer acceptability of grilled sheep meat when the concentrations of these compounds were low.

This research investigates the meat characteristics due to energy source, lamb sex, and the age of the sheep. Therefore, we investigated the eating characteristics, such as lamb flavor and tenderness, which can influence the eating quality of sheep meat. We hypothesized that feeding a forage source (alfalfa pellets), particularly a legume to lambs, would increase the lamb flavor intensity taste panelists experience while eating the meat from these lambs when compared to lambs fed a whole shelled corn diet. We also expected lamb flavor and off-flavor intensities to increase in meat samples from older sheep when compared with meat from younger lambs. Tenderness was expected to decrease as the age of the lamb or sheep increased. No differences due to the sex of the lamb were expected.

Materials and Methods

Forty-eight typical market lambs, 48 long-fed lambs, 16 yearling ewe lambs, and 16 mature ewes of Dorset × Hampshire breed composition were used in two experimental trials. Trial 1 utilized 16 ewe lambs, 16 yearling ewes, and 16 mature ewes offered either ad libitum WSC or ad libitum alfalfa pellets to distinguish the effects of energy source and sheep age on meat and flavor characteristics. Trial 2 utilized 48 shorter-fed ewe and wether lambs and 48 long-fed ewe and wether lambs offered one of three diets (ad libitum WSC, restricted intake to 85% of ad libitum WSC diet, or ad libitum alfalfa pellets) to determine the effects energy source and level, lamb sex, and sheep age on meat and flavor characteristics. All sheep were housed at the Ohio Agriculture Research and Development Center's sheep research feedlot inside a covered barn in Wooster, OH throughout the duration of this experiment, from April, 2015 through December, 2015. Sheep were allotted to 32 pens, four sheep per pen, blocked by sex, and stratified by initial BW and randomly assigned a dietary treatment. All pens were constructed on either expanded metal or hard plastic flooring with three metal gates and a wooden fence line feed bunk on the fourth side. Pen dimensions were 1.49 × 4.88 m with 1.49 m of bunk space. Each pen was equipped with an automatic watering cup to provide sheep with ad libitum access to water at all times.

Feeding and performance data collection

Feeding and performance data information were presented previously for typical market weight lambs (Chapter 2) and long-fed lambs (Chapter 3). Yearling and mature ewes were randomly assigned ad libitum whole shelled corn (WSC) or ad libitum alfalfa pellet diets previously shown in Chapters 2 and 3. Feeding procedures for yearling and mature ewes were the same as for typical market lambs from Chapter 2 and long-fed lambs from Chapter 3.

Typical market lambs from Chapter 2 were removed from the feedlot for slaughter on a pen basis when ewe and wether lambs reached an average BW of 59.0 kg 63.5 kg, respectively. Long-fed lambs from Chapter 3 were removed from the feedlot for slaughter on a pen basis with similar days on feed (DOF) for each of the three diets. Yearling and mature ewes were fed to simulate a 60 day white fat cow finishing strategy. Therefore, yearling and mature ewes were removed from the feedlot for slaughter at the Ohio State University abattoir after being fed for an average of 63.5 and 71.5 days, respectively.

Carcass data collection

All sheep were weighed prior to stunning, and stunning was conducted by the use of a captive bolt gun. Live weight and sheep identification (ear tag number) was recorded. Dentition (eruption of permanent teeth through the gums) was evaluated and recorded, as well as the number of break or spool joints on each carcass, which was used for carcass classification. Kidney fat was removed from the carcasses, weighed and recorded and added back to the HCW. Before chilling, hot carcass weights were recorded to determine dressing percentage. After chilling for 24 hours at 0 – 4˚C, carcasses were ribbed between the 12^{th} and 13^{th} ribs to record longissimus muscle area (LMA), backfat thickness (BF), body wall thickness (BWT), marbling score, conformation score, and leg score to calculate USDA Quality and Yield grades, as well as percent boneless closely trimmed retail cuts (%BCTRC). Minolta L*, a*, and b*; paleness, redness and yellowness, respectively, were measured to determine fat color over the rack and shoulder (free of lean) and lean muscle color on a butterflied loin chop that was allowed to bloom for 20 minutes. After lean muscle color was collected, the butterflied loin chop was packaged and frozen at -25°C to be used to determine ultimate pH at 24 hours postmortem and the total percent lipid. One loin from the rack was cut in half and randomly assigned an aging treatment of 1 or 14 days before freezing at -25°C. The boneless square cut shoulder was aged for 14 days before being ground through a course plate and frozen at -25°C.

Laboratory procedures

Butterflied loin chops were broken down with a mortar and pedestal and ground with the use of liquid nitrogen. Ten micrograms of ground, frozen tissue was weighed into a micro centrifuge tube from each butterflied loin chop to determine pH. Samples were returned to the freezer (-25°C) until pH analysis was conducted. Samples for pH analysis had 800μl of iodoacetic acid added to each sample and then were homogenized. Samples for pH were then, centrifuged for 5 minutes at 10,000 rpm and placed in the heating block at 25°C until pH analysis was conducted with the pH probe.

Total lipid extraction from the butterflied lamb chop followed the methods of Fisher et al. (2013). Two replicates of 2 grams of ground tissue from loin butterfly chops were placed inside 2 sheets of folded filter paper for total lipid analysis. The remainder of ground tissue was saved and kept frozen at -25°C. Upon analysis, sample packets were freeze dried for 22-24 hours to remove the moisture from the ground meat samples. Packets were removed from the freeze dryer and weighed. Next, samples were placed into glass cylinders for lipid extraction by conducting soxhlet extraction. One liter of a 87:13 solution of chloroform:methanol was used per cylinder and allowed to run for 12 hours. In order to confirm samples were free of moisture after lipid extraction was completed, samples were allowed to vent in the film hood before being placed into the oven at 100°C. Samples were weighed again and total lipid percent was determined.

Cooking and Slice shear force procedure

Longissimus dorsi (aged 1 and 14 days) and ground shoulder samples were randomly blocked by treatment to cooking and sampling day and cooked in a random order for their respective meat cut. All samples were thawed overnight in the cooler at 0-4°C. The ground shoulder samples were made into 2.5 cm thick patties for cooking and serving. The raw and cooked weight, temperature of meat when removed from the grill and peak internal temperature was recorded for the entire loin and shoulder patty. Loin and shoulder patty samples were cooked on a clam style George Foreman grill at 190°C. Loins were pulled from the grill once they reached an internal temperature of 65°C, while shoulder patties were pulled at an internal temperature of 71°C. Loins were cooked to 65°C to replicate a temperature that is more commonly used among the general population, whereas the shoulder patties were cooked to 71°C to insure they were safe to eat. We chose to measure slice shear force (SSF) because it has been reported as having a stronger correlation with sensory panel tenderness when compared with Warner-Bratzler shear force (Shackelford et al., 1999a). The protocol used for SSF is from Shackelford et al. (2004), which has been slightly modified from the original protocol (Shackelford et al., 1999a; 1999b), for smaller loins from lambs in relation to beef loins. We modified this procedure by cooking the entire lamb loin, instead of cooking 2.5 cm steaks. Steaks were cut after cooking and 1-cm-thick, 2.5-cm-long slices were removed from each cooked steak parallel to the muscle fibers. These slices were cut in a slice box at a 45 degree angle to obtain the correct parallel orientation of the muscle fibers. The slice length of 2.5 cm was smaller for lambs (Shackelford et al. 2004) than that used for beef (Shackelford et al, 1999a; 1999b) of 5 cm due to size constraints. Therefore, 2 pieces were laid end to end in the shearing apparatus. Each sample was sheared with a flat, blunt-end blade using the electric testing machine (Model TA.XT2^{plus}). The crosshead speed was set at 500mm/min and the peak force required to shear the sample was recorded.

Taste Panel procedure

Samples from the loins aged for 14 days and the ground shoulder patties were used for sensory testing. After cooking samples and acquiring meat samples for SSF, samples were cut into 1.5 cm cubes for sensory analysis. Initially loin sensory samples were placed into 50 ml centrifuge tubes and set into a water bath; however the authors later detected an aroma from the tubes. Therefore, the sensory samples were placed into Ziploc freezer bags and placed in a water bath at 65°C to keep warm.

The taste panel for the loin was conducted for 8 days followed by the shoulder patties for another 8 days. The taste panel consisted of volunteer graduate students and office staff at The Ohio State University. Taste panels were conducted 3 times a day at 9am, 12pm, and 3pm. Panelists were given instructions of how to appropriately participate in the taste panel (not allowed to eat 1 hour before a tasting session) and offered 8 samples at each session. Panelists were provided a record sheet for each sample to record their response. Record sheets asked panelists to rate their response to the intensity of the lamb flavor and off flavors of the sample on a scale from 0 to 100, with 0 being very mild and 100 being very intense. Panelists were also able to record an intensity value for the off flavors provided or record off-flavors not on the list. Off flavors provided on the record sheet were: sweet, sour, salty, bitter, umami/meaty, browned, metallic, livery, bloody, grassy, fecal/barnyard, urinary/ammonia, or others. One sample was randomly selected and presented to the panel at a time, with the instruction to chew the sample for at least 5 to 10 seconds to experience the flavor profile of the meat sample. Panelists were provided with unsalted crackers, apple juice, and distilled water for cleansing their palates when starting and before moving on to the next sample provided.

Statistical analysis

The experimental design for Trial 1 was a randomized complete block design with a 3 × 2 factorial arrangement of treatments to distinguish differences between diet (ad libitum alfalfa pellets and ad libitum WSC) and sheep age (lamb, yearling, mature). Statistical analysis was performed using the MIXED procedure in SAS (SAS Inst. Inc., Cary, NC). The statistical model used was: $Y_{ijkl} = \mu + D_i + A_j + DA_{ij} + p_k + e_{ijkl}$, where D_i = diets fed, A_j = age and DA_{ij} = the interaction between the diet and sheep age, all as fixed effects, and p_k = pen (nested with diet by age) as the random effect, and e_{ijkl} = the error. The experimental design for Trial 2 was a randomized complete block design with a 3 × 2 × 2 factorial arrangement of treatments to distinguish differences between diet (ad libitum alfalfa pellets, ad libitum WSC, and limit-fed WSC) and sheep age (shorter-fed lambs and long-fed lambs). Statistical analysis was performed using the MIXED procedure in SAS (SAS Inst. Inc., Cary, NC). The statistical model used was: $Y_{ijkl} = \mu + D_i + A_j + S_k + DA_{ij} + DS_{ik} + SA_{jk} + DAS_{ijk} + p_l + e_{ijklm}$, where D_i = diets fed, A_j = age, and S_k = the sex of the lamb, DA_{ij} = the interaction between the diet and sheep age, DS_{ik} = the interaction between the diet and sex, SA_{jk} = the interaction between the sheep's age and sex, and DAS_{ijk} = the interaction between the diet, sheep age, and sex, all as fixed effects, and p_k = pen (nested with diet by age) as the random effect, and e_{ijkl} = the error. The statistical model was updated with the addition of the main effects and interactions for the postmortem aging variable for the statistical analysis of slice shear force and cooking loss from loins. The LSMEANS and DIFF statements were used to record treatment means, standard errors and distinguish differences between treatment levels. At $P < 0.05$, differences amongst treatments were considered significant. The CORR procedure in SAS was used to make linear correlations between lamb flavor and off-flavor intensity scores with other carcass and meat characteristic measurements.

Results and Discussion

Trial 1

pH and Color

The ultimate pH of a *Longissimus dorsi* chop sample was not significantly ($P > 0.05$) influenced by the effects of diet or the age of the sheep (Table 5.1.). However, there was a trend ($P = 0.11$) for ewe lambs to have a higher ultimate pH compared to mature ewes. Zhong et al. (2011) reported higher 24 hour ultimate pH from the *Longissimus dorsi* muscle for 6 month old lambs when compared to 24 month old sheep. The greater cause for pH difference may also be due to carcass fatness and HCW, as Smith et al. (1976) reported a greater amount of fat cover allows the carcass to cool slower, maintaining temperatures more suitable for autolytic enzymes to actively degrade the myofibers, and reduce cold shortening of the sarcomere, thus increasing tenderness. Results from Chapter 2 show that ewe lambs had a backfat thickness of 0.84 cm, while results from Chapter 4 reported average backfat thicknesses of 0.87 and 0.73 cm for yearling ewe lambs and mature ewes, respectively. Backfat alone doesn't match the findings by Smith et al. (1976) because ewe lambs had more backfat and a higher ultimate pH compared to mature ewe carcasses. However, when you also consider the size of the sheep carcasses; ewe lambs had an average HCW of 33 kg (Chapter 2) and yearling and mature ewes had HCW of 43 and 47 kg, respectively (Chapter 4). Therefore the overall size of the carcass along with backfat depth explains why ewe lambs tended to have a higher pH compared to mature ewes. It is interesting though, that we didn't observe greater pH differences between sheep fed WSC and sheep fed alfalfa pellets because of the differences in backfat and HCW.

Minolta L* values measuring the *Longissimus dorsi* tended (P = 0.06) to be greater or lighter colored for ewe lambs compared to yearling ewe lambs (Table 5.1). While Minolta a* values from the *Longissimus dorsi* were greater (P < 0.05) or redder for mature ewes compared to ewe lambs and yearling ewe lambs. Minolta b* values from the lean tended (P = 0.06) to be greater or more yellow from mature ewes when compared to ewe lambs. Diet did not significantly affect Minolta values taken from the *Longissimus dorsi* muscle. Minolta measurements taken from the fat over the rack (free of lean) showed no significant response for L* values due to diet or the age of the sheep. Minolta a* measurements from the fat were greater (P < 0.05) or more red for carcasses from sheep fed WSC when compared to carcasses from sheep fed alfalfa pellets. Yellowness or Minolta b* tended (P = 0.09) to be greater for mature ewes when compared to ewe lambs. Crouse et al. (1978) reported subjective lean and fat color scores from light weight ewe lambs that were fed low, medium, and high energy diets. Our results agree with those from Crouse et al. (1978) that show patterns for yellower fat and darker colored lean from lower energy diets and with increasing age. Crouse et al. (1981) also reported yellower fat from heavy weight lambs fed low energy diets when compared to feeding lambs high energy diets. Our results however, did not exhibit higher ultimate pH or lower L* values due to feeding alfalfa pellets as Priolo et al. (2001) discuss when compared to feeding concentrate based diets. This may be due to a lower activity level by lambs in the feedlot, the addition of supplement that contributes to the alfalfa pellet diet, and having sufficient levels of fat cover when compared to typical ruminants grazing pasture. We also didn't see an increase in pH and darkness of the lean with age; actually we were beginning to just see the opposite with higher pH and darker lean from ewe lambs compared to mature ewes.

Percent total lipid in the Longissimus dorsi and ground shoulder patty

The percent total lipid in the *Longissimus dorsi* was not significantly affected by diet or age of the sheep in Trial 1 (Table 5.2.). However, there was a trend (P = 0.07) for yearling ewe lambs to have a greater percent lipid in the *Longissimus dorsi* when compared to ewe lambs. Our results agree with those of Nuernburg et al. (2005) who reported lipid percentages (3.7 vs. 1.2 %, respectively) from the *Longissimus* muscle of lambs fed concentrate and lambs that had grazed pasture. The lower lipid percentages reported by Nuernburg et al. (2005) may be due to having younger lambs, as there lambs were only 115 and 123 days of age for lambs grazing alfalfa or fed concentrate, respectively, when they were harvested at a live weight of 40 kg. No significant (P > 0.05) differences were found for the percent lipid in the ground shoulder patty due to diet or age treatments. Numerical increases of lipid in the shoulder for sheep offered WSC compared to alfalfa pellets is consistent with other measures of fatness from these carcasses. The same is true for the relationship to sheep age, because yearling ewes were fatter than mature ewes and lastly ewe lambs.

Cooking loss and slice shear force

The percentage of loss attained during cooking for ground shoulder patties was not significantly (P > 0.05) affected by sheep age treatments. Cook loss from loins was significantly greater ($P < 0.01$) for loins aged for only 1 day when compared with loins aged for 14 days postmortem. There was a diet trend ($P= 0.07$) for the loins from sheep offered alfalfa pellets to have a greater cooking loss when compared with loins from sheep offered WSC. This is interesting since shoulders from sheep offered WSC had a greater numerical percentage of lipid. The cook loss from loins also had a significant ($P < 0.05$) sheep age × diet × postmortem age interaction (Figure 5.1.). With day 1 loins from ewe lambs offered alfalfa pellets having the greatest cooking loss, day 1 loins from mature ewes offered alfalfa pellets being intermediate, and day 1 loins from lambs offered WSC having the least amount of cooking loss. All other loins were intermediate to day 1 loins from mature ewes offered alfalfa pellets and day 1 loins from ewe lambs offered WSC.

Slice shear force values were greater ($P < 0.01$) for loins aged for 1 day when compared to loins wet aged for 14 days before freezing. There was a significant ($P < 0.01$) interaction between diet, sheep age, and postmortem age (Figure 5.2.) for SSF. The best explanation for these results, especially from yearling ewes fed alfalfa pellets, would be due to the amount of missing data that had to be thrown out because of the challenges experienced (blade bending and hitting the stand) collecting the SSF data on the texture analyzer. No significant ($P > 0.05$) SSF differences were found due to diet or sheep age treatments specifically.

Taste panel

Lamb flavor and off-flavor intensity scores for ewes in Trial 1 are shown in Table 5.3. Lamb flavor intensity scores were not significantly ($P > 0.05$) different between diet and age treatments from *Longissimus dorsi* samples. Off-flavor intensity scores were also not significantly ($P > 0.05$) different between WSC and alfalfa treatments from *Longissimus dorsi* samples. However, off-flavor intensity scores were greater ($P < 0.05$) for mature ewes when compared to ewe lambs and yearling ewe lambs from *Longissimus dorsi* samples. Ground shoulder patty samples from sheep fed alfalfa pellets resulted in a greater ($P < 0.05$) lamb flavor intensity score when compared to samples from sheep fed WSC. Lamb flavor intensity scores increased with increasing sheep age, with mature ewes having significantly ($P < 0.05$) larger lamb flavor intensity scores when compared to ewe lambs, with yearling ewe lambs being intermediate. Although, there was a developing trend ($P = 0.10$) for yearling ewe lambs to have greater lamb flavor intensity scores compared to ewe lambs. No significant ($P > 0.05$) lamb flavor intensity differences were observed between WSC and alfalfa treatments from ground shoulder patty samples. However, there was a developing trend ($P = 0.09$) for ground shoulder samples from mature ewes to have greater off-flavor intensity scores compared to ewe lambs. Results from Trial 1 begin to indicate that lamb flavor intensity and off-flavor intensity increase with the age of the sheep and that feeding sheep alfalfa pellets results in higher lamb flavor and off-flavor intensity scores when compared to feeding sheep WSC.

The most frequently noted off-flavors not indicative of lamb flavor by taste panelists were umami/meaty, browned, and metallic for *Longissimus dorsi* samples (Table 5.4.). Off-flavors of bitter and livery were used more frequently to describe samples from sheep fed alfalfa pellets when compared to samples from sheep fed WSC. Umami/meaty off-flavors were used more frequently for mature ewes, with yearling ewes being intermediate, and umami/meaty being used to describe *Longissimus dorsi* samples from lambs the least. Metallic, fecal/barnyard, and grassy off-flavors were observed more frequently from mature ewes when compared to yearling ewes or ewe lambs. The most frequently noted off-flavors by taste panelists were umami/meaty, browned, metallic, livery, grassy, and fecal/barnyard for ground shoulder patty samples (Table 5.5.). Off-flavors observed more frequently by taste panelists from samples from sheep fed alfalfa pellets when compared to samples from sheep fed WSC were sour, umami/meaty, grassy, and fecal/barnyard. Ground shoulder patty samples from yearling and mature ewes exhibited more sour, salty, bitter, umami/meaty, livery, and fecal/barnyard off-flavors when compared to samples from ewe lambs.

Trial 2

pH and Color

The ultimate pH of the *Longissimus dorsi* chop sample was not significantly affected by diet or sex of the lamb, however there was a trend ($P = 0.11$) for shorter-fed lambs to have a higher pH when compared to long-fed lambs (Table 5.6). This trend can once again be explained by the results from Smith et al. (1976), because long-fed lambs (Chapter 3.) had greater backfat measurements (1.46 vs.0.79 cm) and HCW (52 vs. 34 kg) compared to shorter-fed lambs (Chapter 2.). However, it is again surprising that pH differences were not observed between the three diets fed to lambs because of the differences in backfat and HCW amongst dietary treatments.

Diet and lamb age had no significant effect on the Minolta L*, a*, b* values from the *Longissimus dorsi* (Table 5.6). There was a trend ($P = 0.08$) for greater Minolta b* values from the lean of wether lamb carcasses when compared to ewe lamb carcasses. A diet × sex interaction ($P < 0.05$) was present with carcasses from wether lambs offered ad libitum access to WSC and carcasses from wether lambs with ad libitum access to alfalfa pellets having greater ($P < 0.05$) Minolta a* values for lean when compared to carcasses from ewe lambs with ad libitum access to WSC and carcasses from wether lambs limit-fed WSC (Figure 5.3.). In contrast to our results, Okeudo and Moss (2008) found no significant color differences from the lean between castrated male lambs and ewe lambs. Long-fed lambs produced carcasses that had a greater ($P < 0.05$) Minolta L* value for fat color and carcasses from lambs offered ad libitum access to WSC tended ($P = 0.09$) to have lower Minolta L* values from the fat on the carcass compared to carcasses from lamb offered alfalfa pellets and lambs limit-fed WSC. Carcasses from lambs offered ad libitum access to WSC also had significantly redder or greater ($P < 0.05$) Minolta a* values when compared to carcasses from lambs offered ad libitum access to alfalfa pellets, and tended ($P = 0.11$) to have greater fat a* values compared with carcasses from lambs limit-fed WSC. No significant Minolta b* values for fat were observed due to diet, lamb age, and the sex of the lamb.

Percent total lipid in the Longissimus dorsi and ground shoulder patty

The percent total lipid in the *Longissimus dorsi* was significantly greater ($P < 0.01$) for long-fed lambs when compared to shorter-fed lambs (Table 5.7). It would be interesting to find out if this effect was due to actual age of the lambs or the number of days they spent on feed; however, in this trial these variables are confounded. Trial 1 would suggest that sheep age is more of a factor than days on feed, since yearling and mature ewes were on feed for an average of 63.5 and 71.5 days, respectively, compared to an average of 101.5 days for ewe lambs and had numerically greater percentages of lipid in the *Longissimus dorsi*. Future research is needed to discern whether lamb age or days on feed are the reason for increased percentages of lipid in the *Longissimus dorsi* muscle. There was also a trend ($P = 0.08$) for wether lambs to have a greater percent of lipid in the *Longissimus dorsi* when compared to ewe lambs. This would relate to the greater marbling scores of long-fed wether lamb carcasses compared to long-fed ewe lamb carcasses reported in Chapter 3. There was a trend ($P = 0.09$) for diet to affect the percent of total lipid in the *Longissimus dorsi* of lambs. Lambs offered ad libitum access to WSC tended to produce carcasses with a greater percentage of lipid in the *Longissimus dorsi* when compared to carcasses from lambs offered ad libitum access to alfalfa pellets. Murphy et al. (1994b) reported that feeding lambs concentrate diets increased the amount of fat in the loin when compared to lambs grazing alfalfa. Murphy et al. (1994a) reported linear effects for decreased percentages of fat in the loin when greater feed restriction occurred on a high concentrate diet. Our results appear to be in agreement with those of Murphy et al. (1994a) and Murphy et al. (1994b). A significantly greater ($P < 0.01$) percentage of lipid in the ground shoulder patty from long-fed lambs when compared to shorter-fed lambs is explained by the extreme increase in carcass fatness of long-fed lambs compared to shorter-fed lambs as reported in Chapter 3. Lamb carcasses from lambs offered ad libitum access to WSC deposited a greater ($P < 0.01$) amount of fat in the shoulder when compared to lamb carcasses from lambs offered alfalfa pellets or limit-fed WSC as evidence by a greater ($P < 0.01$) percentage of lipid. Again, this pattern relates to the greater amounts of carcass fat from long-fed lambs offered ad libitum WSC in comparison to lamb carcasses from long-fed lambs offered ad libitum alfalfa pellets or long-fed lambs limit-fed WSC. Interestingly, Murphy et al. (1994a) and Murphy et al. (1994a) did not find these same differences from the chemical composition analysis conducted on the shoulder from lamb carcasses. Since our lambs were heavier (Chapter 2 and Chapter 3) compared to the lambs from Murphy et al. (1994a) and Murphy et al. (1994b) this could be a function of greater amounts of fat being deposited as intermuscular fat in the shoulder when lambs begin to reach heavier weights. However, Borton et al. (2005) reported the greatest percentage of total fat in the shoulder from heavy weight lambs offered corn, followed by normal weight lambs offered corn, then normal weight lambs grazing pasture, and lastly heavy weight lambs grazing pasture. The results from Borton et al. (2005) were influenced by significant differences in the percent of subcutaneous fat, with only numerical increases in the percent intermuscular fat from shoulders from lambs.

Cooking loss and Slice shear force

Cooking loss from loins from lambs in Trial 2 was significantly greater ($P < 0.05$) from loins aged for 1 day when compared to loins aged for 14 days postmortem (Table 5.7). Cooking loss from loins also had significant interactions between diet and postmortem aging ($P < 0.05$), diet, postmortem aging, and sheep age ($P < 0.05$; Figure 5.4.), as well as sex, postmortem age and sheep age ($P < 0.05$; Figure 5.5.). While there were significant interactions for the cook loss from loins, the actual application seems irrelevant.

Slice shear force values were greater ($P < 0.01$) for loins aged for 1 day when compared to loins aged 14 days postmortem. There was a significant ($P < 0.01$) interaction between sex of the lamb and postmortem aging treatment for the SSF of loins in Trial 2. Slice shear force values of loins from ewe lambs had a greater increase in tenderness between day 1 and day 14 aging treatments when compared to loins from wether lambs. Day 1 loins from ewe and wether lambs had greater SSF values compared to day 14 loins from both ewe and wether lambs. Shackelford et al. (2012) reports mean SSF values for loin chops aged for 7 days postmortem from lambs of various sire breed, with an average age of 7 months to be in the range of 19.8 to 26.3 kg. The shorter-fed lambs in this trial may be slightly more tender with day 1 and day 14 loin SSF values of 23.5 and 16.2 kg, respectively, when compared to lambs from Shackelford et al. (2012).

Taste panel

Table 5.8 reports the lamb flavor and off-flavor intensity scores due to the diet fed, the sheep's age, and the sex of the sheep. No significant ($P > 0.05$) differences for lamb flavor and off-flavor intensity scores from the *Longissimus dorsi* were observed between the three diets fed and ewe and wether lambs. Long-fed lambs had greater lamb flavor ($P < 0.01$) and off-flavor ($P < 0.05$) intensity scores when compared to typical market weight lambs. Lamb flavor intensity scores from ground shoulder patty samples were greater ($P < 0.01$) from lambs fed alfalfa pellets when compared to samples from lambs fed WSC. This result is in agreement with results reported by Crouse et al. (1981) that heavy weight lambs fed a low energy dense diet comprised of alfalfa pellets had a greater flavor intensity when compared to lambs fed a high energy diet. Off-flavor intensity scores from ground should loins were not significantly different due to diet. Long-fed lambs had greater (P < 0.01) lamb flavor and off-flavor intensity scores from ground shoulder loins when compared to typical market weight lambs. Lamb flavor intensity (P = 0.13) and off-flavor intensity (P = 0.06) scores from ground shoulder loins tended to be greater from ewe lambs when compared to wether lambs. Results from Trial 2 indicate that increasing the sheep's age increases the lamb flavor and off-flavor intensity of sheep meat, while differences due to diet and lamb sex are less obvious.

Umami/meaty and browned were the two most frequently identified off-flavors from *Longissimus dorsi* samples in Trial 2 (Table 5.9.). *Longissimus dorsi* samples from sheep fed WSC were more frequently described as having umami/meaty off-flavors and less frequently having fecal/barnyard off-flavors when compared with samples from sheep fed alfalfa pellets. No differences in the frequency of off-flavors identified between samples from sheep of differing sex. However, long-fed lamb *Longissimus dorsi* samples were reported as having fecal/barnyard off-flavors more frequently than longissimus samples from typical market weight lambs. The most commonly identified off-flavors from ground shoulder patty samples were umami/meaty, browned, metallic, and grassy (Table 5.10.). Ground shoulder patty samples from sheep limit-fed WSC were more frequently reported as having umami/meaty off-flavors. Livery off-flavors were most frequently used to describe ground shoulder patty samples from ewe lambs when compared to wether lambs. Ground shoulder patty samples from long-fed lambs were reported as having more livery, fecal/barnyard, and other off-flavors. Other off-flavors were most commonly reported to be greasy/fatty off-flavors experienced while chewing the ground shoulder patty sample.

Correlations with lamb flavor and off-flavor intensities

Correlations between mean lamb flavor and off-flavor taste panel scores with other numerical carcass and meat characteristic data show that lamb flavor and off-flavor intensity is not linearly correlated. Measurements of backfat, body wall thickness, and percent lipid in the *Longissimus dorsi* were not significant ($P > 0.05$) for correlations with loin lamb flavor and off-flavor intensity scores and shoulder lamb flavor and off-flavor intensity scores. Therefore, we cannot assume that the amount of fat deposited on the carcass determines lamb flavor and off-flavor intensity. Days of age, live weight, and the number of permanent teeth erupted had significant ($P < 0.05$) positive linear correlations with loin lamb flavor and off-flavor intensity scores and shoulder lamb flavor and off-flavor intensity scores. The number of break joints expressed significant ($P < 0.01$) negative linear correlations with loin and shoulder lamb flavor intensity. Even though days of age, live weight, the number of permanent teeth erupted, and the number of break joints from the carcass expressed correlations, the correlations were quite weak ($r < 0.35$). These weak correlations with lamb flavor and off-flavor intensities demonstrate why the American sheep industry has had difficulty distinguishing quality lamb on a consistent basis.

Conclusion

In conclusion, measurements of tenderness appear to be adequate for all the sheep in this study, however, allowing 14 days for postmortem aging can significantly improve tenderness. Taste panel scores expressed patterns for greater lamb flavor and off-flavor intensity from sheep fed alfalfa pellets and older sheep. No differences in flavor intensity were observed due to lamb sex. Correlations with mean taste panel scores for loin and shoulder lamb flavor and off-flavor intensity show that carcass fatness is not linearly correlated. While other variables such as days of age, live weight, permanent tooth eruption and break joint status have significant linear correlations with lamb flavor and off-flavor intensity, however, the linear correlations are quite weak.

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Table 5.1. Least squares means of color characteristics of the lean (*Longissimus dorsi*) and fat (over the rack) and ultimate pH from ewe carcasses in Trial 1

	Diet [1]			Age [2]			
Item	**WSC**	**Alfalfa**	**SEM [3]**	**Lamb**	**Yearling**	**Mature**	**SEM [3]**
pH	5.692	5.713	0.0246	5.763	5.696	5.649	0.0323
Lean color [4]							
L*	39.45	39.24	0.592	40.91	37.72	39.41	0.72
a*	24.35	24.38	0.200	23.75 [d]	24.13 [d]	25.21 [c]	0.243
b*	6.93	6.66	0.202	6.30	6.70	7.38	0.246
Fat color [4]							
L*	71.6	73.26	0.765	73.83	71.47	72.00	0.931
a*	11.32 [a]	8.91 [b]	0.683	8.63	10.51	11.21	0.832
b*	9.59	10.1	0.556	8.93	9.27	11.35	0.679

[a, b] Diet means within a row without a common superscript letter differ ($P < 0.05$).

[c, d] Age means within a row without a common superscript letter differ ($P < 0.05$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] Age treatments: Refers to the maturity of the sheep.

[3] The reported standard error of the mean is the greatest between the levels within the treatment.

[4] Minolta L* is the lightness, a* is the redness, and b* is the yellowness of the lean and fat.

Table 5.2. Least squares means of meat characteristics of ewes in Trial 1

	Diet [1]			Age [2]			
Item	**WSC**	**Alfalfa**	**SEM [3]**	**Lamb**	**Yearling**	**Mature**	**SEM [3]**
Total lipid, %							
Longissimus dorsi	4.31	3.93	0.286	3.42	4.84	4.09	0.346
Ground shoulder patty	26.3	20.2	3.10	18.7	29.6	21.5	3.82
Cook loss, % [4]							
Longissimus dorsi aged 1 day	14.83	17.23	0.691	16.47	15.44	16.19	0.895
Longissimus dorsi aged 14 days	13.94	14.52	0.632	14.26	13.50	14.93	0.822
Ground shoulder patty	40.0	36.2	1.97	35.4	40.9	38.0	2.42
Slice shear force, kg [4]							
Longissimus dorsi aged 1 day	22.9	24.3	1.71	22.4	23.8	24.5	2.14
Longissimus dorsi aged 14 days	15.8	16.6	1.73	16.7	13.1	18.7	2.13

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] Age treatments: Refers to the maturity of the sheep.

[3] The reported standard error of the mean is the greatest between the levels within the treatment.

[4] Cook loss and Slice shear force had significant ($P < 0.01$) day effects between day 1 and day 14.

Table 5.3. Least squares means of flavor intensity of the loin and ground shoulder from ewes in Trial 1.

	Diet [1]			Age [2]			
Item	**WSC**	**Alfalfa**	**SEM [3]**	**Lamb**	**Yearling**	**Mature**	**SEM [3]**
Longissimus dorsi							
Lamb flavor intensity	41.4	42.1	3.50	39.9	40.9	44.5	3.66
Off-flavor intensity	12.3	14.0	3.38	11.2^{d}	10.6^{d}	17.7^{c}	3.47
Ground shoulder patty							
Lamb flavor intensity	38.1^{b}	44.6^{a}	2.82	37.8^{d}	41.8^{cd}	44.4^{c}	2.95
Off-flavor intensity	11.3	12.7	2.98	9.7	12.2	14.1	3.07

^{a,b} Diet means within a row without a common superscript letter differ ($P < 0.01$).

^{c,d} Age means within a row without a common superscript letter differ ($P < 0.05$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet.

[2] Age treatments: Refers to the maturity of the sheep.

[3] The reported standard error of the mean is the greatest between the levels within the treatment.

Table 5.4. Frequency of off-flavors identified by panelists in loin samples from ewes in Trial 1.

	Total	**Diet**		**Age**		
Item		**WSC**	**Alfalfa**	**Lamb**	**Yearling**	**Mature**
Sweet	2.78	1.75	3.94	2.98	3.70	1.55
Sour	4.40	4.80	3.94	3.57	0.78	8.89
Salty	0.69	1.31	0.00	0.00	1.55	0.74
Bitter	7.87	4.42	8.37	8.93	7.75	6.67
Umami/meaty	17.36	19.21	15.27	12.50	17.05	23.70
Browned	10.65	10.92	10.34	10.71	11.63	9.63
Metallic	10.19	11.35	8.87	8.33	9.30	13.33
Livery	8.10	5.68	10.84	7.14	6.98	10.37
Bloody	5.39	5.68	4.43	4.17	6.20	5.19
Grassy	5.56	5.68	5.42	1.79	0.78	14.81
Fecal/Barnyard	4.40	3.06	5.91	2.98	1.55	8.89
Urinary/Ammonia	4.63	5.24	3.94	4.76	5.43	3.70
Others	2.31	1.31	3.45	2.38	1.55	2.96

Table 5.5. Frequency of off-flavors identified by panelists in ground shoulder samples from ewes in Trial 1.

	Total	Diet		Age		
Item		**WSC**	**Alfalfa**	**Lamb**	**Yearling**	**Mature**
Sweet	8.41	6.47	10.29	5.74	11.93	7.89
Sour	4.35	1.18	7.43	1.64	5.50	6.14
Salty	8.41	7.06	9.71	5.74	9.17	10.53
Bitter	3.48	4.00	2.94	0.82	4.59	5.26
Umami/meaty	17.70	14.12	21.14	14.75	17.43	21.05
Browned	13.91	11.76	16.00	12.30	15.60	15.04
Metallic	11.01	12.35	9.71	9.84	11.01	12.28
Livery	10.14	8.24	12.00	6.56	11.01	13.16
Bloody	1.45	1.76	1.14	2.46	0.92	0.88
Grassy	12.46	10.59	14.29	13.93	10.09	13.36
Fecal/Barnyard	11.30	9.41	13.14	5.74	11.93	16.67
Urinary/Ammonia	5.51	7.06	4.00	5.74	4.59	6.14
Others	2.61	3.53	1.71	0.82	3.67	3.51

Table 5.6. Least squares means of color characteristics of the lean (*Longissimus dorsi*) and fat (over the rack) and pH from lamb carcasses in Trial 2

	Diet [1]				Age [2]			Sex		
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**SEM [3]**	**Lamb**	**Long-fed**	**SEM [3]**	**Ewe**	**Wether**	**SEM [3]**
pH	5.693	5.647	5.660	0.0216	5.694 [c]	5.640 [d]	0.0174	5.676	5.659	0.0178
Lean color [4]										
L*	40.13	40.38	39.30	0.388	41.19	38.68	0.326	39.73	40.14	0.320
a*	24.41	24.61	24.14	0.242	24.32	24.45	0.200	24.17	24.60	0.196
b*	7.04	7.03	6.64	0.178	6.80	7.00	0.147	6.70	7.10	0.145
Fat color [4]										
L*	72.88	74.97	74.09	0.602	73.14 [d]	74.83 [c]	0.499	74.25	73.72	0.489
a*	10.19 [a]	7.44 [b]	8.63 [ab]	0.637	9.11	8.40	0.523	8.27	9.24	0.518
b*	9.49	9.55	8.74	0.490	8.93	9.60	0.405	8.93	9.60	0.398

[a, b] Diet means within a row without a common superscript letter differ ($P < 0.05$).

[c, d] Age means within a row without a common superscript letter differ ($P < 0.05$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of Ad libitum whole shelled corn diet.

[2] Age treatments: Refers to the maturity of the sheep.

[3] The reported standard error of the mean is the greatest between the levels within the treatment.

[4] Minolta L* is the lightness, a* is the redness, and b* is the yellowness of the lean and fat.

Table 5.7. Least squares means of meat characteristics of lambs in Trial 2

	Diet [1]				Age [2]			Sex		
Item	Ad lib. WSC	Ad lib. Alfalfa	Limit-fed WSC	SEM [3]	Lamb	Long-fed	SEM [3]	Ewe	Wether	SEM [3]
Total lipid, %										
Longissimus dorsi	5.03	3.90	4.32	0.333	3.72^{d}	5.12^{c}	0.274	4.05	4.79	0.271
Ground shoulder patty	34.0^{a}	23.2^{b}	25.4^{b}	1.95	16.0^{d}	39.1^{c}	1.54	26.9	28.2	1.550
Cook loss, % [4]										
Longissimus dorsi aged 1 day	14.65	16.37	16.01	0.575	15.97	15.56	0.451	15.40	16.13	0.462
Longissimus dorsi aged 14 days	14.86	14.50	13.93	0.550	14.23	14.61	0.452	14.80	14.04	0.448
Ground shoulder patty	40.1	36.2	37.3	1.30	35.3	40.4	1.04	37.0	38.6	1.05
Slice shear force, kg [4]										
Longissimus dorsi aged 1 day	22.9	22.9	23.8	1.91	23.5	22.9	1.47	24.5	21.9	1.49
Longissimus dorsi aged 14 days	15.1	16.1	15.6	1.56	16.2	15.0	1.26	13.8	17.5	1.29

$^{a, b}$ Diet means within a row without a common superscript letter differ ($P < 0.01$).

$^{c, d}$ Age means within a row without a common superscript letter differ ($P < 0.01$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of Ad libitum whole shelled corn diet.

[2] Age treatments: Refers to the maturity of the sheep.

[3] The reported standard error of the mean is the greatest between the levels within the treatment.

[4] Cook loss and Slice shear force had significant ($P< 0.01$) day effects between day 1 and day 14.

Table 5.8. Least squares means of flavor intensity of loin and ground shoulder from lambs in Trial 2.

	Diet [1]				Age [2]			Sex		
Item	**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**SEM [3]**	**Lamb**	**Long-fed**	**SEM [3]**	**Ewe**	**Wether**	**SEM [3]**
Longissimus dorsi										
Lamb flavor intensity	43.3	42.6	38.6	3.65	38.7 [f]	44.3 [e]	3.57	41.9	41.2	3.57
Off-flavor intensity	12.8	13.9	11.5	2.78	11.4 [d]	14.1 [c]	2.73	12.8	12.7	2.73
Ground shoulder patty										
Lamb flavor intensity	38.1 [b]	44.3 [a]	35.7 [b]	3.48	36.7 [f]	42.1 [e]	3.36	40.7	38.1	3.37
Off-flavor intensity	11.3	10.8	11.0	2.59	9.2 [f]	12.9 [e]	2.53	12.1	10.1	2.53

[a, b] Diet means within a row without a common superscript letter differ ($P < 0.01$).

[c, d] Age means within a row without a common superscript letter differ ($P < 0.05$).

[e, f] Age means within a row without a common superscript letter differ ($P < 0.01$).

[1] Dietary treatments: Ad libitum access to whole shell corn diet, Ad libitum access to alfalfa pellet diet, Whole shelled corn diet fed at 85% of Ad libitum whole shelled corn diet.

[2] Age treatments: Refers to the maturity of the sheep.

[3] The reported standard error of the mean is the greatest between the levels within the treatment.

Table 5.9. Frequency of off-flavors identified by panelists in loin samples from lambs in Trial 2.

	Total	Diet			Sex		Age	
Item		**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**Ewe**	**Wether**	**Lamb**	**Long-fed**
Sweet	2.96	4.97	2.94	0.99	2.89	3.03	2.54	3.42
Sour	4.39	4.97	4.90	3.29	4.00	4.76	3.59	5.24
Salty	1.43	1.32	0.98	1.97	1.33	1.52	1.06	1.82
Bitter	8.88	8.94	10.46	7.24	7.78	9.96	8.03	9.79
Umami/meaty	17.32	17.55	14.71	19.74	16.89	17.75	16.70	18.00
Browned	12.06	11.26	13.07	11.84	12.22	11.90	12.47	11.62
Metallic	8.66	9.60	10.13	6.25	7.78	9.52	8.25	9.11
Livery	7.68	6.62	9.15	7.24	7.33	8.01	6.13	9.34
Bloody	4.82	5.63	3.92	4.93	5.56	4.11	4.02	5.69
Grassy	5.48	5.96	6.21	4.28	4.89	6.06	4.65	6.38
Fecal/Barnyard	5.59	3.97	7.84	4.93	5.11	6.06	3.81	7.52
Urinary/Ammonia	4.61	4.97	4.25	4.61	5.11	4.11	3.59	5.69
Others	1.64	1.66	1.62	1.64	2.21	1.08	2.32	0.91

Table 5.10. Frequency of off-flavors identified by panelists in shoulder samples from lambs in Trial 2.

	Total		**Diet**		**Sex**		**Age**	
Item		**Ad lib. WSC**	**Ad lib. Alfalfa**	**Limit-fed WSC**	**Ewe**	**Wether**	**Lamb**	**Long-fed**
Sweet	7.92	7.46	6.99	9.43	7.23	8.55	8.51	7.35
Sour	1.94	1.32	2.62	90.89	1.89	1.99	2.74	1.18
Salty	8.07	7.89	7.86	8.49	6.92	9.12	7.90	8.24
Bitter	4.33	4.39	3.49	5.19	3.14	5.41	3.95	4.71
Umami/meaty	18.54	14.91	17.47	23.58	18.55	18.52	17.33	19.71
Browned	12.86	12.28	11.35	15.09	12.89	12.82	12.77	12.94
Metallic	10.61	10.53	10.48	10.85	11.95	9.40	10.03	11.18
Livery	9.27	7.02	9.61	11.32	11.32	7.41	6.99	11.47
Bloody	1.20	1.32	0.87	1.42	1.26	1.14	1.82	0.59
Grassy	11.21	11.84	12.23	9.43	10.69	11.68	11.85	10.59
Fecal/Barnyard	8.67	7.02	10.04	8.96	10.06	7.41	5.47	11.76
Urinary/Ammonia	7.32	9.65	5.68	6.60	6.60	7.98	6.99	7.65
Others	4.78	5.70	3.49	5.19	5.35	4.27	2.13	7.35

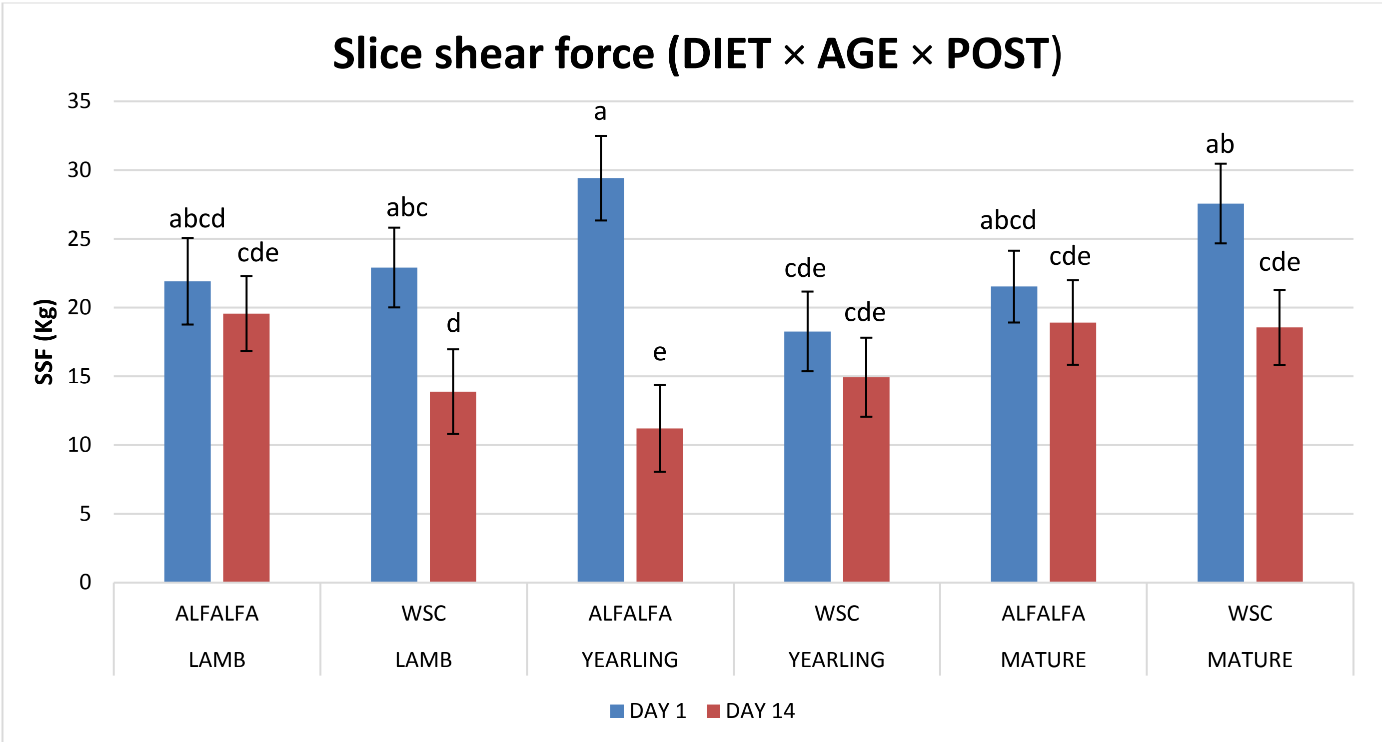

Figure 5.1 Diet × Age of the sheep × Postmortem aging interaction for slice shear force of loins aged 1 or 14 days postmortem from sheep (lamb, yearling, mature) of different ages. WSC is ad libitum access to a WSC diet and Alfalfa is the ad libitum access of alfalfa pellets. Treatment least squares means without a common letter (a, b, c, d, e) are significantly different ($P < 0.05$).

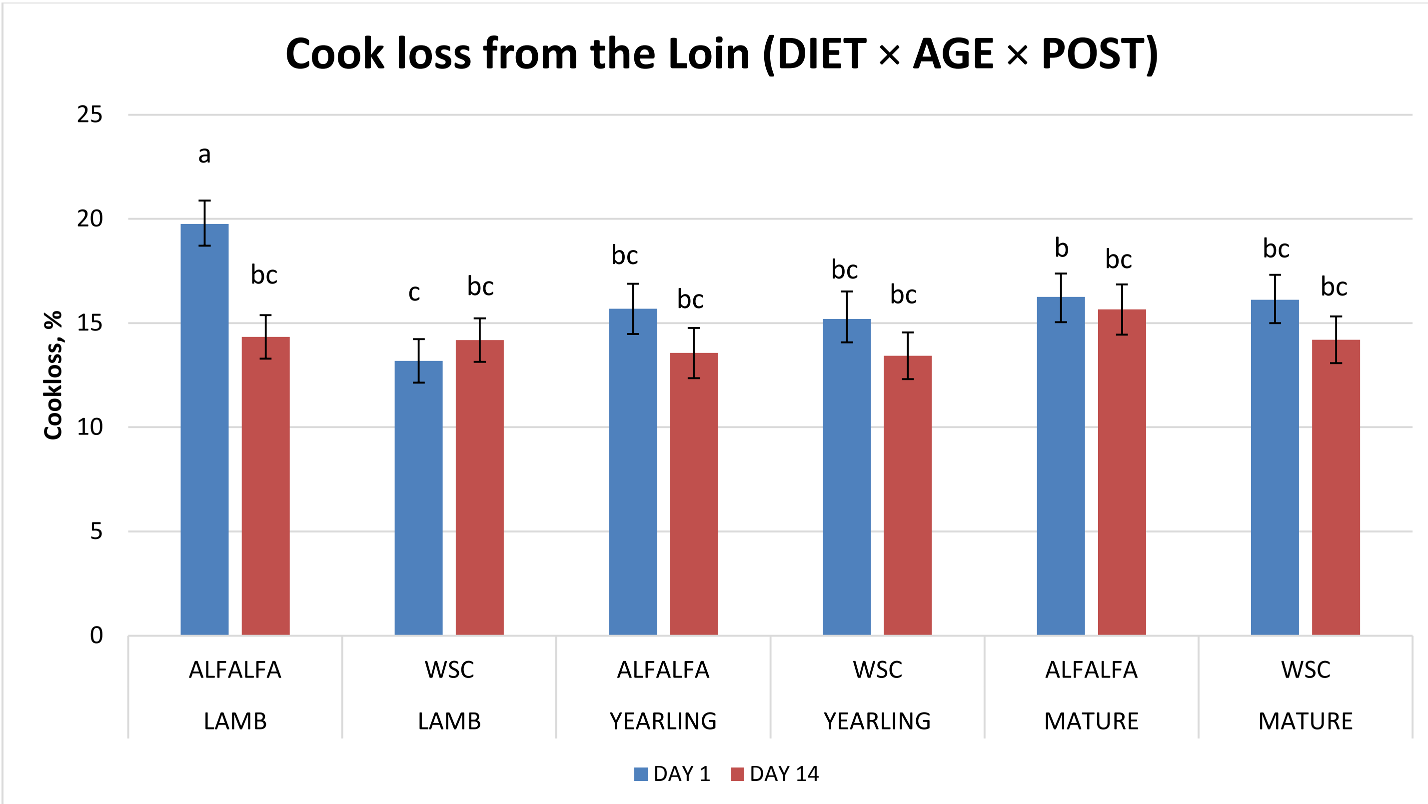

Figure 5.2. Diet × Age of the sheep × Postmortem aging interaction for the cook loss from loins aged 1 or 14 days postmortem from sheep (lamb, yearling, mature) of different ages. WSC is ad libitum access to a WSC diet and Alfalfa is the ad libitum access of alfalfa pellets. Treatment least squares means without a common letter (a, b, c) are significantly different ($P < 0.05$).

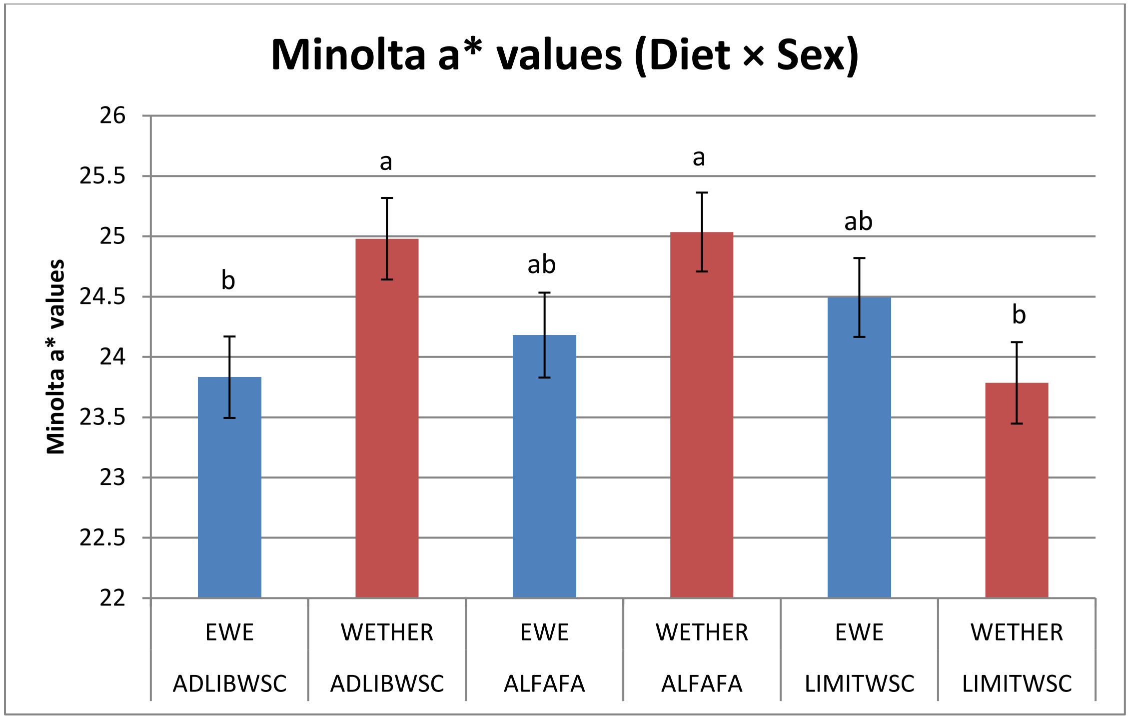

Figure 5.3. Diet × Sex interaction for Minolta a* values taken from the lean of lambs in Trial 2. Treatment least squares means without a common letter (a, b) are significantly different ($P < 0.05$).

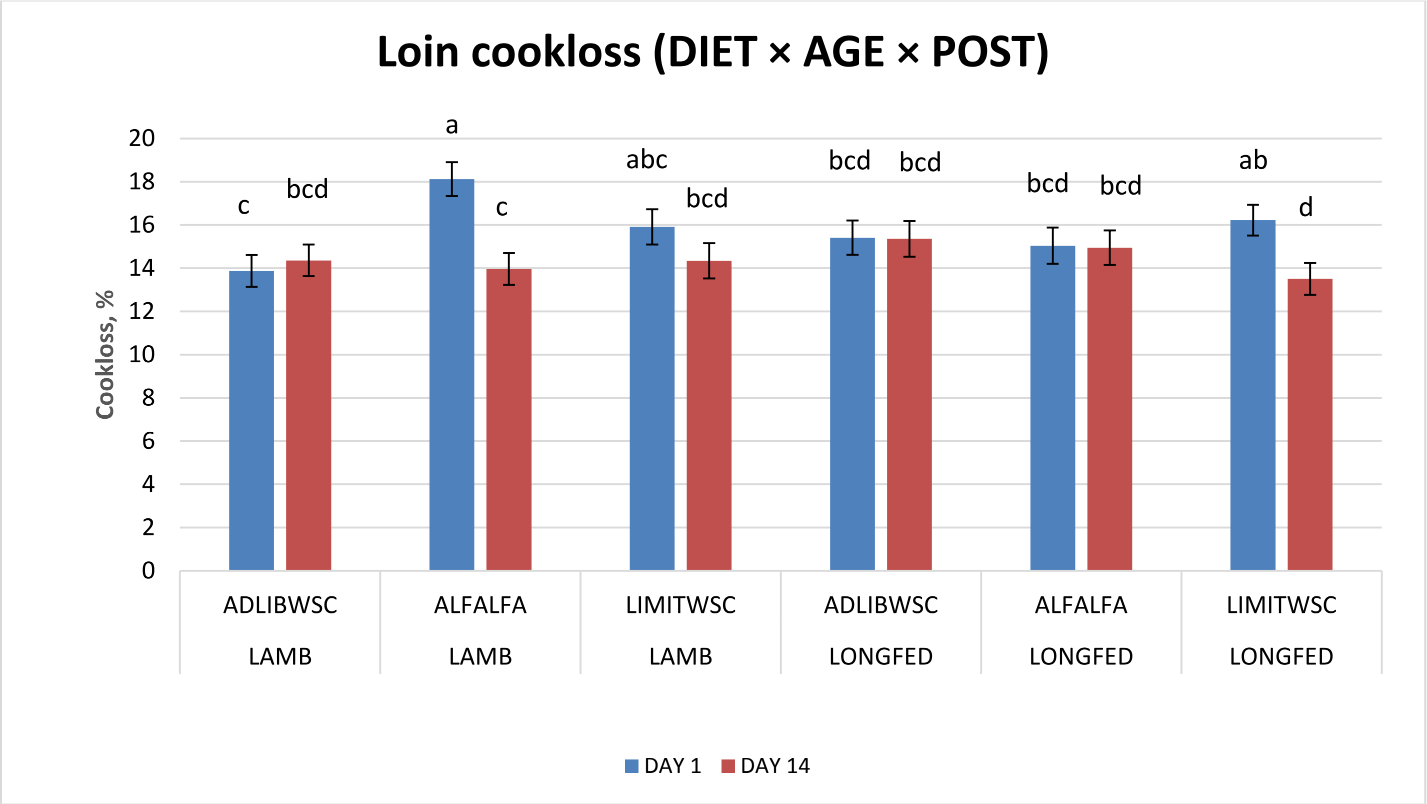

Figure 5.4. Diet × Age of the sheep × Postmortem aging interaction for the cook loss from loins aged 1 or 14 days postmortem from lambs of different ages. ADLIBWSC is ad libitum access to a WSC diet, LIMITWSC is 85% access to the WSC diet, and ALFALFA is ad libitum access of alfalfa pellets. LAMB refers to lambs from Chapter 2 and LONGFED refers to long-fed lambs in Chapter 3. Treatment least squares means without a common letter (a, b, c, d) are significantly different ($P < 0.05$).

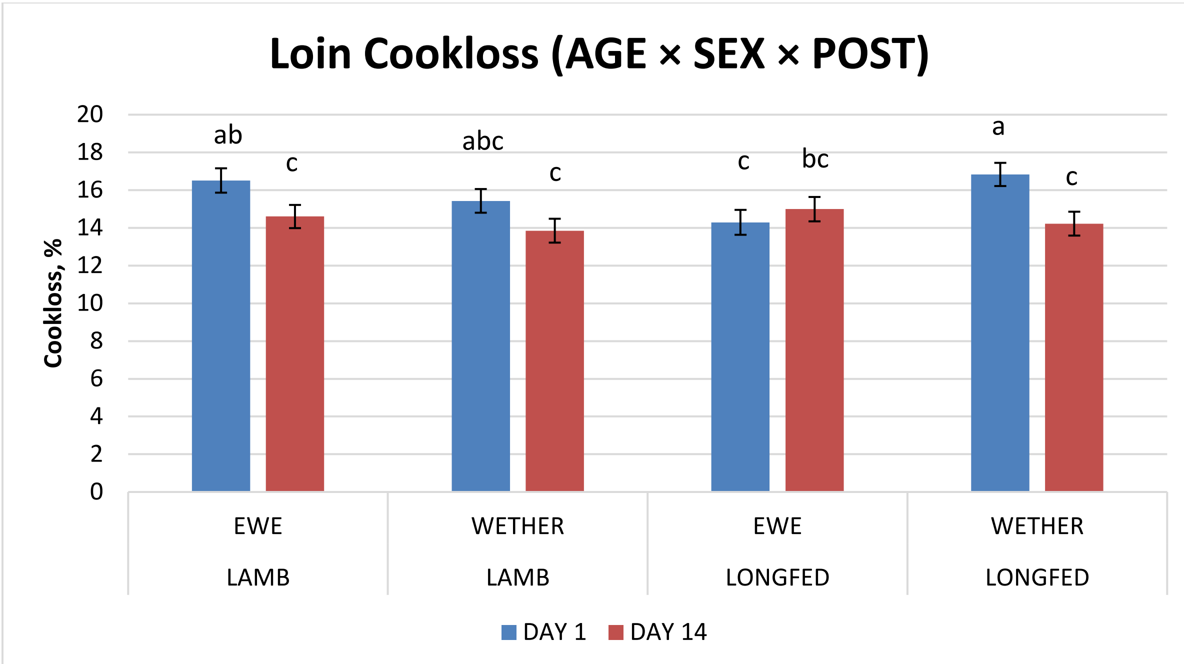

Figure 5.5. Age of the lamb × Sex of lamb × Postmortem aging interaction for the cook loss from loins aged 1 or 14 days postmortem from lambs of different sexes (ewe and wether lambs). LAMB refers to lambs from Chapter 2 and LONGFED refers to long-fed lambs in Chapter 3. Treatment least squares means without a common letter (a, b, c, d) are significantly different ($P < 0.05$).

Chapter 6.

Concluding Thoughts

Conclusion

The American lamb board is trying to identify means to improve four main areas within the American sheep industry; product characteristics, demand creation, productivity improvement, and industry collaboration (American Lamb Industry Roadmap, 2013). The overall goal of this research was to investigate the influence of diet, sex, and age on sheep meat flavor and determine how sheep meat can be marketed to consumers and provide them with a positive eating experience every time. However, in the process of working on this task, we were also able to re-investigate the growth, performance, and carcass characteristics of lambs, as much of the literature is from the 1970's and is becoming outdated.

The main problems the American sheep industry faces are heavy weight lambs, excessively fat lambs, consistent flavor profile, and seasonal demand for lamb. In the American sheep industry, producers and lamb feeders are paid based on the live weight of the sheep marketed. Therefore, a larger sheep will bring the producer or feeder more money. Different breeds of sheep have different frame sizes and therefore reach a desirable level of finish or fatness at a heavier weight (Snowder et al., 1994). Since sheep of different genetic backgrounds mature at different rates and have different body compositions, it is not practical for the sheep industry to necessarily penalize sheep producers for heavy lambs. However, as body weight increases and sheep mature, sheep begin to deposit greater levels of carcass fat. The American sheep industry faces a problem with a low level of demand that is seasonal throughout the year. Increases in the demand for lamb are seen around the times of the holidays for example: Easter, Thanksgiving, Christmas, and other ethnic holidays. Due to the drop in the demand for lamb at other times of the year lamb packers are unable to move lambs through the processing plant. Therefore, the lamb packers are not buying lambs from producers and lamb feeders. This forces lambs to remain in the feedlot on feed until they are able to be sold. Extra days on feed, as demonstrated by the long-fed lambs in our study, reach excessively fat levels that could eventually compromise the welfare of these animals.

Our research investigated the use of three diets; ad libitum alfalfa pellets, ad libitum whole shelled corn (WSC), and limit-fed WSC. Offering lambs ad libitum access to a WSC diet results in the greatest average daily gain (ADG), gain to feed ratio (G:F), and least feed cost per unit of gain (COG) when compared to lambs offered ad libitum access to alfalfa pellets and lambs offered only 85% WSC of ad libitum WSC lambs. Lambs offered limited amounts of WSC resulted with performance results just shy of lambs offered ad libitum access to WSC. However, taking the Dorset × Hampshire lambs to 59.0 and 63.5 kg (ewe and wether lambs, respectively) while offering WSC resulted in greater amounts of carcass backfat (0.96 and 0.89 cm) when compared to lambs offered ad libitum access to alfalfa pellets (0.52 cm). I would recommend that producers and feeders offer WSC diets to their lambs due to the greater performance at a feed cost 4 times cheaper than offering alfalfa pellets. In order to manage greater levels of carcass fatness, offering WSC at a greater restriction than the 15% in this experiment, can decrease the level of fat deposition (Murphy et al., 1994) while maintaining low feed costs. Lambs that are forced to remain on feed in the feedlot due to the low demand of lamb at times, can still add body weight with cheap COG on a WSC diet. However, offering ad libitum access of a WSC diet only causes excessive amounts of fat to be deposited (backfat = 1.74 cm). Offering WSC at 85% of the ad libitum WSC diet to lambs resulted in the lowest increase in the amount of fat and a lower COG between shorter-fed lambs and long-fed lambs when compared to lambs offered ad libitum access to alfalfa pellets or WSC. Once again, offering WSC at a greater at a restriction than in this experiment may allow producers and lamb feeders the cheapest diet while having a greater ratio of lean tissue gain to the least amount of stored carcass fat when compared to offering ad libitum WSC and ad libitum alfalfa pellets.

Preferences for lamb flavor intensity vary with location and past experiences (Prescott et al., 2001). Our experiment utilized an untrained taste panel comprised of typical lamb consumers in the Midwest. We asked taste panel participants to rate sheep meat samples for lamb flavor intensity, and off-flavor intensity if experienced on a scale from very mild to very intense. Due to differences for what each participant recognized mild or intense, there was variation among results. However, the results exhibit patterns for greater lamb flavor and off-flavor intensities from sheep offered alfalfa pellets when compared to sheep offered WSC. The results also exhibited greater lamb flavor and off-flavor intensities from older sheep (long-fed lambs, yearling lambs, mature sheep) when compared to younger sheep (lambs). The frequency of off-flavors noted by taste panelists was also greater for sheep offered alfalfa pellets when compared to WSC and older sheep when compared to younger sheep. The off-flavors most commonly noted with sheep offered alfalfa pellets and older sheep were umami/meaty, livery, and fecal/barnyard flavors.

The American sheep industry can start to improve lamb flavor consistency by encouraging producers and feeders to offer sheep WSC for a period of time before market and to make sure to differentiate lamb from yearling mutton and mutton. Further research needs to be investigated towards an on-line approach for use in the packing plant to segregate quality (lamb flavor) between carcasses. Although, this research didn't use Selected Ion Flow Tube – Mass Spectrometry (SIFT-MS), it may be able to detect flavor differences in sheep meat and provide the American sheep industry with a tool to market sheep meat and provide consumers with a more consistent eating experience every time.

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