THE EFFECTS OF SEX, BREED, AND SLAUGHTER WEIGHT ON GROWTH, CARCASS,

AND SENSORY CHARACTERISTICS OF LAMB

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State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

American lambs are often over-finished and lack consistent quality. It has been suggested that the use of intact ram lambs can decrease USDA YG and improve growth efficiency. However, ram lamb carcasses are underutilized because of potential issues, the most crucial being off-flavor development. Our hypothesis for this study is that U.S. producers can take advantage of intact ram lamb growth and performance with no detriment to product quality, as long as lambs are slaughtered before the attainment of puberty. Three breeds (Hampshire, Dorset, and Columbia), three slaughter weights (light, medium, and heavy) and two sexes (rams and wethers) were evaluated. Results indicate that ram lambs can provide a satisfactory eating experience, however, in one of our studies compounding of maturity and slaughtering intact rams increased incidence of off-flavors. It remains undetermined whether the small differences in sensory characteristics would be detectable by everyday consumers.

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LIST OF ABBREVIATIONS

ADG..Average daily gain

BCFA...Volatile branched chain fatty acid

BF...12th rib backfat

BW ....Bodywall fat thickness

d..Day

EOA ....4-ethyloctanoic acid

H_2S ....Hydrogen sulfide

HCW ....Hot carcass weight

h..Hour

JAR ....Just-about-right scale

LAM..Labeled affective magnitude scale

LSMEANS ....Least squared means

MNA ....4-methylnonanoic acid

MOA ....4-methyloctanoic acid

NDSU...North Dakota State University

Ng/ml ....Nanogram/milliliter

NLQA ....National Lamb Quality Audit

PUFA ....Polyunsaturated fatty acid

QG..Quality Grade

REA..Ribeye area

SEM ....Standard error of the mean

U.S. ....United States

USDA..United States Department of Agriculture

WBSF..Warner-Bratzler shear force

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CHAPTER 1. LITERATURE REVIEW

Lamb flavor

Flavor is an important factor in consumer acceptability of meat products, especially lamb and sheep meat. Lamb is a product that is consumed because of its unique flavor, but it is also rejected because of its flavor. The 2015 Lamb Quality Audit (**NLQA**) data found the leading factor defining lamb quality and consumer palatability was flavor. About 72% of consumers mentioned that they were willing to pay a premium for guaranteed eating satisfaction (Woerner et al., 2016). Although disagreements may be made on which attribute; either flavor or tenderness is the most important for overall lamb palatability, flavor is vital in ensuring a desirable eating experience. Meat acceptability of other species may be based on different criteria, such as beef based on tenderness; and pork and turkey on juiciness (Batcher et al., 1969). Eating quality of lamb and sheep meat has been examined by many researchers throughout the years (Weller et al., 1962; Dransfield et al., 1979; Crouse et al., 1981; Jeremiah et al. 1993; Braggins, 1996; Young et al., 2003; Gkarane et al. 2017) and has been shown to be affected by many pre- and post-slaughter factors such as gender, castration, diet, maturity, breed, processing methods, aging, freezing, and packaging. However, the method of action and influence of these factors and their possible interactions on lamb eating quality have frequently remained unclear. Much of the variability in lamb eating quality can be explained due to the variability in sheep production systems that are found in countries such as the U.S. and European countries compared to Australia or New Zealand (Sanudo et al., 2007). The variability of production systems, breeds, and nutrition can be attributed to local environmental conditions and availability of feed, and therefore, results in different management styles. The U.S commercial sheep production consists of two primary types of operations: range sheep operations that graze native

pastures, and farm flock operations, that consist of smaller flocks which graze on improved pastures or are fed in feedlots (NRC, 2008). Comparatively, Australian sheep operations are generally larger and graze on native pastures. Australian lambs are then typically finished on grass or grass/grain-based diets (Ryan, 2017).

Lamb flavor profile and fat characteristics

Meat flavor is a complex topic as it is influenced by hundreds of compounds (Calkins and Hodgen, 2007). The basic, *meaty* flavor of red meat originates from a non-lipid source while specie specific flavor has been shown to reside primarily in the fat (Hornstein, 1971). One animal that stands out in terms of flavor and fat formation is the sheep. General lamb flavor is attributed largely to medium-length (8-10 carbons) branched-chain fatty acids (Jamora and Rhee, 1999). The *mutton* or *sheepmeat* flavor that is often associated with lamb has been attributed to carbonyls or other polar compounds in the form of volatile branched-chain fatty acids (**BCFA**) that occur as triacylglycerols found in adipose tissue (Hornstein and Crowe 1963; Watkins et al., 2010).

Lamb meat provides a unique aroma and flavor profile that some consumers find unpleasant, especially when those flavors are intense. Research has shown that lamb flavor intensifies as the animal ages, and the term *mutton* is a common descriptor of lamb meat (Sink and Caporaso, 1977). An additional flavor that is characteristic of lamb is a *pastoral* flavor, which has been identified in the meat of lambs who were pasture-finished (Young et al., 2003). The flavors that are categorized as *pastoral* include, *sheepy, gamey, animal, grassy,* and *milky* (Schreurs et al., 2008). Pastoral flavor of lamb has been attributed to 3-methylindole (skatole) and indole, which are both formed in the rumen from degradation of tryptophan (Young et al.,

2003). Indole and skatole are stored and accumulate in adipose tissue when excessive amounts are produced, which is usually seen in pasture finished lambs (Priolo et al., 2001).

A 1980 study (Chen, 1980) looked at breed, sex, and three different weights to determine the variation in flavor profiles. Results from gas chromatography indicated that 21 out of 124 possible flavor compounds showed differences. Rambouillet lambs had the greatest proportion of flavor compounds, followed by Targhee, Columbia, and Suffolk crossbred lambs with the lowest proportion of flavor compounds. When examining sex effects, ram lambs had the greatest concentration of compounds, which indicates that they may have the most expression of flavor. However, there were no differences between ewe and wether lambs. Interestingly, light weight lambs had a greater concentration of flavor volatiles when compared to medium and heavy lambs, with heavy lambs having the least number of volatiles (Chen, 1980).

Volatile branched-chain fatty acids have been found to originate from ruminal propionate. Ruminal propionate is the main source for liver gluconeogenesis in ruminant animals. Rumen fermentation is a process that ferments indigestible carbohydrates to volatile fatty acids in the rumen (Kaneko, 2008). One of the volatile fatty acids formed in the rumen fermentation process, propionate, is the only fatty acid that continues to contribute to gluconeogenesis. It has been found that propionate can contribute up to 80-90% of the glucose synthesized in sheep who are primarily fed roughage-based diets (Cridland, 1984). Occasionally the propionate levels exceed the capacity of the liver for normal metabolism and therefore BCFAs form. Although it is not proven, there seems to be a different method of propionate metabolism between ruminant species, as we do not see high concentrations of BCFAs in cattle (Garton et al., 1972), even if the cattle are managed and fed the same way as sheep.

As previously mentioned, *mutton or sheepmeat* flavor is one of the most common off-flavors found in lamb meat. Mutton flavor has been described by panelists as sweaty, sour, urinary, fecal, barnyard, oily, sharp and acrid (Wong 1975a). The compounds associated with these aromas and flavors have been identified as branched-chain and unsaturated fatty acids having 8 to 10 carbons (Wong et al., 1975a, 1975b). The compounds associated with mutton flavor identified by Wong et al. (1975a) were 6-methylheptanoic acid, n-octenoic acid, 4-methyloctanoic acid, 6-methyloctanoic acid, 2-octenoic acid, n-nonenoic, 4-methylnonanoic acid (**MNA**) and 8-methylnonanoic acid. Wong (1975a) stated that 4-methyl branched C8 acid (4-methyloctanoic acid) was mainly associated with a *sweaty* flavor and later concluded that the 4-methyl-substituted C9 to C10 fatty acids such as 4-methyloctanoic (**MOA**) and 4-methylnonanoic acids were primarily responsible for the characteristic aroma and flavor of lamb (Wong et al. 1975b). More recent research confirms that increased concentrations of MNA and MOA along with another BCFA, 4-ethyloctanoic acid (EOA) are largely responsible for more intense lamb flavor and is sometimes described as *mutton* flavor (Watkins et al., 2014).

Another feature that changes perceived flavor and palatability is lipid melting point. Lamb fat is known to be harder than the fat on other meat animals, this is due to higher levels of saturated fatty acids (Tichenor et al., 1970), as we know the melting point of saturated fatty acids is significantly higher than that of unsaturated fatty acids of the same length. Ruminant animals, such as sheep, have a very low content of polyunsaturated fatty acids (**PUFA**), and a high content of saturated fatty acids. The high saturated fatty acid concentration is a result of the hydrogenation of unsaturated fatty acids found in the diet by the rumen microorganisms as well as the existence of a variety of fatty acids specific to ruminants, such as trans-unsaturated fatty acids, odd-chain fatty acids and BCFAs (Kim et al., 2009).

The increase in saturated fatty acids shown above may explain why consumers find lamb fat undesirable. It is also noted that heavy ram lambs tend to develop "soft" or oily fat. This type of fat is still harder than that of the other meat producing animals but since consumers are accustomed to eating hard lamb fat it may seem undesirable. Soft lamb fat can be caused by weather changes and high energy diets (Shelton et al., 1972) which in turn decrease the length of carbon chains or increase the amount of unsaturation in the fatty acids in the lipids. Reports have correlated yellow fat with softer lamb fat (Busboom et al., 1981). Additionally, consumers may find lamb fat undesirable because lamb fat contains a higher percentage of stearic acid, compared with the other meat type animals, which leads to a higher melting point and causes the "mouth-coating" or "waxy" feel which commonly occurs when eating lamb (Cramer and Marchello, 1964). High levels of oleic acid and low levels of linoleic and linolenic acids make up lamb fat. As the lamb matures, the proportion of triacylglycerides to phospholipids increases as levels of synthesized fatty acids (myristic, palmitic, stearic and oleic acids) increase. Wood (1984) hypothesized that fat might decrease in quality as the animal became leaner due to a decline in the proportion of triacylglycerides to phospholipids. This decline occurs due to declining levels of saturated fatty acids and increased levels of phospholipids and polyunsaturated fatty acids. Interestingly, as total lipid in muscle decreases from as little as 5% down to 1% the percentage of phospholipid in the total lipid increases from less than 10% to about 70% (Dugan, 1971)

Pre-slaughter effects on lamb flavor

Maturity

It is a generally accepted fact that meat animal flavor intensity increases with maturity (Sink and Caporaso, 1977). Additionally, Jamora and Rhee (1999) stated that a dislike of lamb meat increases with maturity of the live animal. An example of maturity decreasing consumer

satisfaction is illustrated with a common preference of lamb meat (under 1 year of age) compared to the meat from an aged sheep (mutton). Although the literature is limited, the concentration of BCFAs in lamb carcass fats appears to increase with age (Sutherland & Ames, 1996; Watkins et al., 2010). A trial using ram and wether lambs of multiple ages showed an increasing trend with age in the levels of the short-chain branched fatty acids, 4-methyloctanoic and 4-methylnonanoic acid (Young et al., 2003). Brennard et al. (1989) found that 4-methylnonanoic acid had a *mutton* odor whereas descriptors for 4-methyloctanoic acid were more variable with odors such as *waxy, goaty, muttony, and sweaty.* However, 4-methyloctanoic acid was present at a significantly greater concentration than 4-methylnonanoic acid. Additionally, Young et al. (2003) hypothesized that *sheepmeat* odor was most likely due to 4-methyloctanoic acid. The results from their study indicated that BCFAs were more abundant in rams and 4-methylnonanoic acid was the most abundant in all animals, but older animals had greater concentrations of both fatty acids. The authors conclude that the castration and maturity effects found in this study concur that older ram lambs possess more *mutton* flavor. Additionally, the increase in the proportions of pentadecanoic and heptadecanoic acids with an increase in maturity may be consistent with the increases in BCFAs. Pentadecanoic and heptadecanoic acids are odd-chain fatty acids that account for small proportions of the total saturated fatty acids in lamb meat and are uncommon because almost all animal fatty acids contain an even number of carbon atoms (Pfeuffer and Jaudszus, 2016). The formation of these odd-chain fatty acids stems from rumen microbial fermentation similarly to BCFAs and can serve as minor precursors for gluconeogenesis (Ha & Lindsay, 1990).

It has been found that the flavor from older lambs can possess more lamb flavor intensity (Sink and Caporaso, 1977). Misock et al. (1976) and Paul et al. (1964) found that lamb was

considered most flavorful at 12 months of age while Field et al. (1978) reported that heavier ram

lambs (68 vs 41 kg live weight) produced meat that was less desirable than lighter wethers.

Corbett et al. (1973) stated that there were no differences in flavor intensity of meat from rams,

wethers and cryptorchids ranging in age from 3 to 42 months. Similarly, Wilson et al. (1970)

found no differences in organoleptic qualities of meat from rams, wethers, and cryptorchids at 46

to 49 kg live weight and 149 to 173 days of age. The authors of both of these studies offer no

explanation of why there were no sensory differences detected. Both Wiese et al. (2005) and

Pethick et al. (2005) investigated maturity on eating quality of sheep meat. Pethick et al. (2005)

examined meat from ewes in six maturity groups (8.5, 20, 32.5, 44.5, 56.5, and 68.5 months of

age). Consumer taste panel scores for tenderness, juiciness, liking of flavor, and overall liking

did not decrease until after 20 months of age. After 20 months the consumer preference scores

decreased slightly until 68.5 months. Similarly, Wiese et al. (2005) looked at meat from ewes

and wethers placed in 3 dentition categories: fully erupted, erupted but not in wear (below the

central lateral milk teeth), and not erupted. Trained and consumer taste panels were conducted by

Wiese, and found no differences in tenderness, juiciness, or flavor, but consumers rated overall

liking higher for the younger maturity group lambs. Both Wiese and Pethick concluded that the

eating quality differences between maturity groups are small, and sheep maturity classifications

in Australia could potentially be rebuilt. Interestingly, research by Weller et al. (1962) found that

trained taste panelists actually preferred the meat flavor from older lambs (200-245 days) than

younger lambs (150 days). Descriptive terms such as "more natural" were given to the flavor of

the older lambs in this particular study (Weller et al., 1962).

Weller's findings are interesting; however, the ideal lamb flavor is hard to pinpoint as it

varies with geographical location and consumer background (Prescott et al., 2001) and the ideal

flavor has evolved throughout the years. Consequently, the flavor profile that was preferred to an early 1960s consumer, may not be preferred by the modern-day lamb consumer (Watkins et al., 2013). Additionally, in central and south-eastern Asia, lamb is commonly disliked because of its strong flavor. In the Middle East and Northern Asia, lamb is a large part of the diet, as they enjoy the stronger flavor of lamb. In Europe, much like the U.S., more intense flavored lamb is rejected, especially by younger consumers. In Africa, the fat of mutton is sought after, and the greater lamb flavor intensity is liked. In Oceania, lamb and mutton make up a large amount of the diet, and a stronger flavor is preferred. Lastly, in North America, strong lamb flavor is not generally accepted, and it is the flavor of lamb that can be a deterrent against its consumption (Rubino et al. 1999).

Research by Ames and Sutherland (1999) showed that 30-week-old (210 day) Suffolk ram lambs had greater scores for flavors described as *lamby, meaty, roast, stale, urine,* and *barnyard* compared to 12-week-old (84 day) ram lambs. Contrasting, Young et al. (2006) analyzed fat and lean of Romney ram and wether lambs slaughtered at 7 different maturity levels (4, 7, 10, 13, 17, 20, and 23 months of age) and found no significant effect of maturity on *barnyard* odor and flavor in both fat and lean. The results of the contrasting studies may not be able to be explained by breed or diet because the slower maturing Romney lambs were fed a pasture-based diet when compared to the faster maturing Suffolk lambs on a high energy diet. The lambs in the study by Young et al. had the potential to have increased off-flavor intensity, due to breed and diet but no differences were observed. Campion et al. (1976) found that aroma of cooked fat from intact ram lambs became less desirable as hot carcass weight (**HCW**) increased in a range from 16 to 51 kg. However, flavor of rib roasts was not influenced by weight. Misock et al. (1976) compared ram and wether lamb carcasses of 29, 39 and 43 kg.

Results indicated that flavor and aroma scores were lower and less desirable for rams than wethers. A *bucky* odor was noticed in the 39 and 43 kg (over 183 days of age) carcass groups and the authors note that 10 percent of the carcasses from the two heaviest weight groups were returned as being "unfavorable" to the University meat lab where they were purchased by consumers.

Maturity or chronological age plays a huge role in flavor intensity as well as off-flavor development. Compounding of maturity and other pre-slaughter factors greatly affect lamb flavor.

Breed

The effect of breed on lamb flavor has been a topic of interest for many years (Jacobson and Koehler, 1963; Duckett et al., 1999; Elmore et al., 2000; Sanudo et al., 2000) many of which have reported no differences in lamb flavor due to breed or sire breed in crossbred studies (Fox et al., 1962; Dransfield et al., 1979; Mendenhall and Ercanbrack, 1979; Crouse et al., 1981).

Researchers who have found significant differences in flavor based on breed or sire breed have hypothesized why breed may or may not have an influence on flavor. Cramer (1983) suggested that wooled sheep might possess a mechanism for sulphur (S) storage, because wool is abundant in the amino acid cysteine. It is known that cysteine contains disulfide bonds between their thiol groups which in theory would cause sheep to have a higher S requirement than other meat producing livestock. The most dominant sulphur compound in cooked meat is hydrogen sulfide (H_2S) (Nixon et al. 1979). H_2S has its own distinct odor, which is commonly described as *rotten eggs* and can also be a precursor for other odor compounds. Lamb contains much more H_2S than beef, which may account for the increased flavor intensity of lamb meat. The H_2S stores in lamb fat have been hypothesized to supply compounds that would make the odor of

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lamb different and maybe even stronger than the meat from other species (Kunsman and Riley, 1975). This leads to the common belief that sheep with finer wool produce more undesirable flavors in the meat than meat from sheep with coarser wool. Cramer et al. (1970) completed a study comparing breeds with flavor composition. He found that Rambouillet sheep, a fine-wool breed, possessed more intensely flavored meat, compared to two coarser wool breeds (meat type), Columbia and Hampshire. This study also concluded that Hampshire lambs had the least amount of *mutton* flavor. An interesting study performed by Martinez-Cerezo et al. (2005) looked at the sensory characteristics of three breeds (Spanish breeds) and three slaughter weights (10-12, 20-22, and 30-32 kg live weight). This research concluded that Spanish Merino lamb meat in the intermediate and heavy weight groups had the best quality flavor when evaluated by a trained taste panel. This result is inconsistent from what we typically see in lamb sensory panels, which may be because the lambs were slaughtered at considerably lighter weights than typically seen in United States or Australian production systems.

A more current study (Young et al. 1993) compared the flavor of meat of two breeds, the Coopworth, a dual purpose (meat and wool) and the Merino, a wool breed. Results from a sensory panel show differences in odor which were described as *tallow* for Merino lamb meat, and *sweet* for Coopworth lambs. Sensory effects observed in this study such as breed effects for *sheepmeat* flavor and foreign flavor are speculated to be caused by differences in final pH. High final pH has been shown to evoke negative flavor reactions and increase off-flavors in beef (Dutson et al., 1981; Fjelkner et al., 1983). Interestingly, Johnson and Vickery (1964) suggested that as meat pH increases the expression of H_2S at cooking is increased. A 0.1 increase (ex. 5.6 to 6.6) in pH would increase the expression of H_2S by 60 percent. In the study by Young et al. (1993) the mean final pH (Coopworth, 5.77; Merino 6.16) of the lambs differed significantly.

The authors mention that some sheep breeds or genetic lines may be more susceptible to pre-slaughter stress than others, explaining the high final pH of the Merino lambs. Literature suggests that maturity may play a bigger role in flavor formation than breed. A good example of this is through the Merino sheep breed. Merino sheep have been shown to have a higher flavor intensity, however they also are a slower growing and slower maturing breed. Merino lambs are usually lighter and/or older at slaughter than other breeds. Additionally, Merino sheep which are common in Australia, typically graze on native pasture, so their diets are likely to differ from those of other breeds that commonly graze on improved pasture or are grain finished.

A recent U.S. breed study (Leymaster et al., 2006) evaluated nine breeds on growth, carcass, and meat quality traits. The effects of sire-breed were non-significant for meat quality traits of flavor intensity and off-flavor. The authors note that it may be beneficial for producers to select within breeds and not among breeds when aiming to improve meat quality characteristics. A 2012 study evaluated three types of common South African sheep breeds (wool, dual-purpose, and mutton) for meat quality characteristics. Results indicated that there were no differences in flavor based on breed type. The authors note that this finding was expected as the lambs on the trial were fed and treated the same way throughout the trial, and diet plays a huge role in fatty acid formation (Cloete et al., 2012).

The effect of breed on the flavor of other species have been noted. Flavor intensity differences have been evident between dairy breeds of cattle and beef breeds (Ramsey et al., 1963) although differences between specific breeds within these types have not been observed. Ziegler et al. (1971) reported flavor preferences for beef from British breed cattle compared to Continental breeds, however later studies failed to see the same results. Differences in flavor between breeds of swine have been observed (Jensen et al., 1967).

Overall, the results of various breed comparisons suggest that breed or genetic effects on flavor are minor, especially compared to other factors such as maturity, diet, and final pH.

Diet

Diet or nutrition plays one of the biggest roles in meat flavor formation across all species. It is noted that grass finishing lambs has a significant effect on flavor, more so even than that of beef cattle (De Brito et al., 2016). In sheep, the flavor from grass-finishing is mostly determined by BCFAs and 3-methylindole (skatole). The role that skatole plays in cattle flavor formation is less crucial than that of sheep because cattle lack the BCFAs that sheep possess. Several products of the oxidization of linoleic acid also play an important role in lamb flavor formation (Priolo et al., 2001).

It is widely known that propionate is one of the leading sources of glucose in grass-fed ruminants. Feeding grain-based diets to ruminant animals generally increases the amount of propionate in the rumen. However, livestock on grain-based diets do not require propionate as extensively for a glucose source (Berthelot et al., 2002). This is because grain-fed animals get their glucose straight from the feed. We know that increased levels of propionate lead to BCFA formation, because when propionate levels exceed the capacity of the liver to metabolize it normally there is the production of BCFAs (Garton et al., 1972). Therefore, the fat of grain-fed animals will generally contain more BCFAs than grass-fed animals (Busboom et al., 1981). Despite this, meat from grain-fed lambs is known to have a milder flavor with less off-flavor than grass-fed lambs (Rousset-Akrim et al., 1997; Young et al., 2003). This observation concurs with flavor formation in grain-fed beef, as grain-finished beef is significantly more palatable to consumers compared to grass-finished beef (Elswyk and McNeil, 2014).

Although the majority of the literature examines pasture fed lambs versus grain fed lambs, comparisons between pasture type and lamb flavor show that flavor can differ between pasture types. In certain regions, such as the Pacific Northwest it is common for operations to finish lambs on perennial ryegrass or clover. Cramer et al. (1967) evaluated these two pasture types when used as a finishing feed for lambs. He reported more intense lamb flavor intensity from lambs who were finished on clover compared to ryegrass before slaughter. In 1970, a similar study was conducted, and concluded that lamb flavor intensity in the clover grazing group of lambs was higher than the ryegrass lambs as soon as three weeks of grazing (Shorland et al., 1970). Further studies involving untrained taste panels described lamb that grazed alfalfa prior to harvest as having an intense lamb flavor, with more foreign flavors, which in turn reduced overall liking (Nicol and Jagusch, 1971; Park et al., 1972).

Beef flavor has been highly related to diet and significant differences in beef flavor have been found between samples taken from grass finished steers versus corn finished steers (Melton, 1983). For U.S. beef consumers grass-finished or forage-finished beef has a less acceptable flavor than grain-finished beef (Mandell et al., 1998; Melton, 1990; Xiong et al., 1995). Meat from grass-finished beef has been given descriptors for its flavor such as *grass, milky, fishy, barnyard* and even *rancid* (Bailey et al., 1988). A 2001 review found 16 U.S. experiments looking at the effect of grass vs grain-finishing on beef consumer acceptability. Two of these studies resulted in consumer taste panels rating grass-finished beef more acceptable in terms of flavor than grain-finished beef. The authors note that if similar experiments were conducted in other countries that the results would most likely differ (Priolo et al., 2001). Similar to what is observed with lamb, the literature states that it takes at least three months of concentrate feeding

to reverse the often-negative flavors produced by grazing (Melton et al., 1982; Larick et al., 1987).

Overall, nutrition has a large impact on fat composition and flavor. Flavor intensity has been shown to increase with the grazing of clover and alfalfa but can be combatted by grazing ryegrass pastures for 2 weeks before slaughter (Priolo et al., 2001). Most importantly, finishing lambs on grain diets alters fatty acid composition and results in milder lamb flavor.

Sex/castration

When examining the effect of sex on flavor of lamb meat, the effect of castration has proven to be the most important factor. Numerous studies have focused on males versus females (Wise, 1978; Alvi, 1980; Butler-Hogg et al., 1984; Dransfield et al., 1990; Jeremiah et al., 1997; Lind et al., 2011), but overall the results are conflicting and the differences between sexes are small. Research performed by Busboom (1981) determined that fat from ram lambs contained more BCFAs and shorter chain fatty acids, specifically those with odd numbers of carbon atoms than fat from wether lambs. Interestingly, it was found that fat firmness decreased in heavy weight ram lambs, but the opposite with wether lambs. Fat firmness is one of the criteria that often warrant a discount for heavy ram lamb carcasses, as these carcasses have shown to possess soft, oily subcutaneous fat. As mentioned earlier, fat firmness or melting point is one factor that greatly influences palatability. Batcher et al. (1969) found no differences in flavor liking between meat from ram lambs and wether lambs (7 to 8 months old), however there was greater flavor intensity in broth from ram lamb meat. Interestingly, further differences were found between ram and wether lamb meat when 20% additional fat was added into a ground product. A Canadian retail acceptability study found that over 50% of the participants indicated that lamb chops from all genders (ram, wether, ewe) and all slaughter weight groups (40.5-49.5 kg, 50-58.6 kg, 58.9-

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67.7, and 68.2-76.8 kg live weight) were unacceptable with the exception of chops from ram lambs up to 58.6 kg live weight which were rated as acceptable. The authors speculate that these findings are because all chops in the study were from overfat lambs except for chops from ram lambs up to 58.6 kg (Jeremiah et al., 1993).

When evaluating age and sex as variables, Rousset-Akrim et al. (1997) performed a study on 7-month old ram lambs and 3-month old ram lambs and concluded that the younger lambs had more desirable meat quality characteristics. This suggests that age and the onset of puberty are likely to influence the meat quality when comparing sex of the lamb. Okeudo & Moss (2008) determined that castrated wethers and intact ram lambs that were slaughtered at the same slaughter weight (32, 36, 40, 44, 48, 52, and 56 kg) and ages ranging from 180 to 390 days of age were found to have no difference in meat quality.

Many studies have found little to no differences in eating quality between rams and wethers (Bradford and Spurlock, 1964; Batcher et al., 1969; Rhodes, 1969; Jacobs, 1970), including a review by Field et al. (1971) which concluded that there were only minor differences between eating quality and sex, and no trends favoring one effect were found throughout the review. An interesting study evaluated thirty-six crossbred lambs of full and half-brother ram/wether pairs using a trained taste panel and found no difference in flavor (Usborne et al., 1961). The study by Usborne and others is especially intriguing because of the full and half-brother pairs of wethers and ram lambs. This experimental design eliminates the genetic variability observed with most sensory studies.

A recent study using British breeds (Texel and Scottish Blackface) indicated that meat from ram lambs scored lower for intensity of *roast* aroma and flavor, and higher for intensity of *lamb* aroma than meat from castrated lambs when evaluated by a sensory panel. Although there

were statistical differences found, the differences were small numerically, suggesting that this small of an effect might not be noticeable by consumers. Additionally, ram lambs scored higher for undesirable aromas and flavor attributes. The authors speculate that the aroma and flavor differences may be due to the greater amount of BCFAs found in ram lamb fat. Overall, the study found very little gender x breed and age x breed interactions, which may indicate that gender and age effects that were observed are found in both breeds. Furthermore, this study was accomplished by a trained taste panel, and the differences detected may not be detectable by everyday consumers (Gkarane et al. 2017).

The intact male from several species have shown negative flavor attributes. In swine, boar taint is a negative flavor attribute. Boar taint is caused by the presence of androstenone, a sex steroid, along with skatole (3-methylindole) (Babol et al., 2004). Swine skatole is produced from tryptophan by large intestine bacteria (Zamaratskaia et al., 2004). Sheep rumens also produce skatole, which indicate that ram lambs have the potential for off-flavors similar to boar taint. So far, there is no research to prove that off-flavors in lamb meat is indeed a 'ram taint.' Skatole levels have been found to vary with maturity of the animal, but the major increase is seen close to the onset of puberty (Babol et al., 1999; Doran et al., 2002). This is hypothesized to be caused from the involvement that sex steroids have in the regulation of skatole metabolism at the liver. Fat skatole in measurable amounts has not been found in castrated or female pigs, which further suggest that sex steroids regulate skatole levels (Babol et al., 1999). Albaugh et al. (1975) observed no differences in flavor liking between bulls, cryptorchids, and steers. Similarly, Glimp et al. (1971) found some differences in tenderness between steers and bulls, however, trained taste panelists were unable to find differences in flavor, juiciness, or overall acceptability of cooked steaks. Current research has shown that overall palatability of 105-day old castrated goats

was greater than that of intact male goats (Madruga et al., 2000). Conversely, Bayarktaroglu et al. (1983) and El-Hag et al. (2007) found no differences in flavor liking between intact males and castrated goats.

In conclusion, the effect of sex on the flavor of meat is strongly related to the chronological age of the animal in that its expression is generally not observed before pubertal onset.

Slaughter effects on lamb flavor

As mentioned earlier, pH has been shown to effect sheep meat odor and flavor. In a study by Braggins (1996), sheep meat with a moderate or high final pH (6.26 and 6.81, induced by pre-slaughter adrenaline injection) had a lower flavor intensity than sheep meat of a more normal final pH (5.66). As pH increased, sensory panelists found that undesirable flavor and odor scores increased. Trap gas chromatography/mass spectrometry of cooked fat identified 57 (of a total of 325 possible) volatile compounds which decreased in concentration as pH increased. Within the volatile compounds, aldehydes were the most common. Additionally, gas chromatography identified 54 odor-active compounds of which 10 were found to be responsive to changes in meat ultimate pH. Most of these compounds were also aldehydes. Therefore, these results show that lamb aroma and flavor are significantly affected by elevated meat pH. This supports the hypothesis that pH, rather than breed, may be the main factor affecting sensory characteristics of lamb meat. The effects of pre-slaughter stress on lamb meat quality are frequently attributed to an increased incidence of dark-cutting high pH meat that occurs when pre-slaughter stress causes muscle glycogen depletion (Eldridge, 1989). Additionally, some studies have reported that pre-slaughter stress may lead to an increase in off-flavors caused by an increase in stress hormones

(Braggins, 1996; Warner et al., 2007) whereas others have reported no differences based on stress (Brown et al., 1997; Liste et al., 2011).

Post slaughter effects on lamb flavor

Fat

The flavor of meat is connected to water soluble compounds in the muscle, such as sugars, amino acids and nucleotides, where the amount and types differ between species. The characteristic flavor of meat for each species is determined by the proportions of different fatty acids in the lipids, particularly by the unsaturated fatty acids. Unsaturated fatty acids contribute the most to flavor profiles because they are more susceptible to oxidation of volatile compounds of low molecular weight, such as aldehydes, ketones, hydrocarbons and alcohols, which contribute to the aroma and flavor of meat (Mottram, 1998). The reaction that causes the oxidation of volatile compounds and ultimately the flavor of cooked meat is the Maillard reaction.

Maillard reaction

The Maillard reaction is a reaction that occurs between amino acids and reducing sugars during cooking, and this reaction is what gives "browned" meat its distinctive flavor. The Maillard reaction has been shown to be largely responsible for the development of the flavor of red meat. Furthermore, the similarity in amino acid profiles and carbohydrate composition of the red meat animals (beef, pork, lamb) may account for the similarity in flavor, or the "meat" flavor that is common with these species (Hornstein, 1971). The compounds that come from lipid oxidation include straight chain aldehydes, ketones, hydrocarbons, alcohols, and alkylfurans. The volatiles produced from Maillard reactions include heterocyclic nitrogen and sulphur compounds

such as pyrazines, thiophenes, thiazoles, furanoses, furfurols and also non-heterocyclic compounds (Elmore et al., 2000).

What determines tenderness?

Meat tenderness is a trait which can be hard to predict, but it is very important to meat quality and palatability. Tenderness is often evaluated mechanically with the use of Warner-Bratzler Shear Force (WBSF) through determining the maximum shear force, but can also be determined with sensory panels, although these tend to be more subjective. However, the relationship between mechanical and sensory evaluation tend to be non-linear (Tornberg, 1996). For consumers, tenderness can be described by the ease of chewing, which is also contributed to by many factors. Some of these factors include animal maturity, age, days on feed, activity of tenderizing enzymes, as well as many post-slaughter factors. Among these factors, the fibrous make-up of muscle contributes to chewing resistance (Gerrard and Grant, 2003). Single muscle fibers are composed of myofibrils that are arranged parallel across the muscle fibers, this leads to more strength for muscles but also decreases muscle tenderness. There are many components that construct muscle fibers, but the proteins can be considered the most important. Muscle proteins are categorized in one of three categories based on their solubility: sarcoplasmic, myofibrillar, and stromal. Sarcoplasmic proteins are extracted with water or solutions with low ionic strength. Myofibrillar proteins are extracted by salt solutions and require higher ionic strength, called salt-soluble proteins. Stromal proteins include proteins of connective tissues, which have a fibrous and insoluble nature (Aberle et al., 2001). Stromal proteins are collagen, elastin, and reticulin.

The type and amount of connective tissue both affect meat tenderness. Connective tissues lead to strength of muscle but in turn lead to decreased tenderness. The amount, distribution, and

composition of connective tissue in the muscle is shown to differ based on muscle type and animal maturity (Purslow, 2005). The strength of connective tissues comes from its collagen fibers. Therefore, meat tenderness is most definitely influenced by collagen of the muscle. However, it has been documented that WBSF values are more closely related to the myofibrillar components than connective tissue (Bouton et al., 1975). Connective tissues can be categorized into two main categories: loose and dense connective tissues based on density and organization of fiber bundles. The dense connective tissues are common in tendons and are much tougher than loose connective tissues, just as the name implies.

Additionally, there have been seven types of collagen identified in intramuscular connective tissue, where types I and III are the most abundant. Cross-linking between the different types of collagen especially in more mature animals has been identified as a major cause of toughness (Purslow, 2005). When looking at collagen content younger animals will produce more tender meat than a more mature animal (Gerrard and Grant, 2003). Another considerable muscular factor is muscle types. The ratio of type I and type II muscle fibers highly influence meat tenderness. This ratio varies among individual animals of the same breed and crosses of breeds. Beef tenderness has been shown to be positively related to type I muscle and negatively related to the other types of muscles. The differences found between muscle types are hypothesized to be from a greater ratio of protein turnover in tender muscle and greater level of calpains (Lawrence and Fowler, 2002). Calpains are a cysteine protease which play an important role in protein degradation, and therefore impact final meat tenderness (Koohmaraie and Geesink, 2006).

Tenderness

As previously mentioned, tenderness is disputed as one of the most important attributes of meat palatability (Tornberg, 1996). The majority of consumers consider lamb to be palatable in regard to tenderness, with variation in tenderness being more moderate than other meat producing species, while other reports show that attitudes toward lamb are mixed (ALMC, 1997; Safari et al., 2002). In a 1990s Australian consumer survey, only 40% of consumers agreed that lamb was tender, juicy, and highly palatable (AMLC, 1997; Bennett, 1997; Yann et al. 1994). Overall, shear force values reported throughout the literature for lamb are lower than most beef values. Beef tenderness has a threshold value for shear force at about 4.5 kg. This value indicates that any value that falls below 4.5 kg would suggest that consumers would rate the meat slightly tender (Shackelford, 1991). Although threshold values are not currently available for lamb meat, reported shear force measurements for lamb and levels acceptable for beef indicate that consumers would consider lamb to be more palatable in terms of tenderness than beef. Some lamb is more tender than others, but extreme toughness is rare. Research has indicted that postmortem factors such as sarcomere length, temperature, pH, and proteolysis play a key role in meat tenderness. These factors along with pre-slaughter factors such as breed, genotype, diet, and gender may also play a role in influencing tenderness.

Genotypic effects are one of the biggest influences when looking at post-mortem effects of tenderness in sheep. The most common genotypic effect on tenderness is the callipyge gene. The callipyge gene is a mutation which causes muscular hypertrophy. The mutation is associated with superior leanness, improved feed efficiency, along with improved conformation seen in the hind limbs and loin muscle (Cockett et al., 2009). Inopportunely, the callipyge gene leads to a reduction of consumer satisfaction due to increased toughness and decreased juiciness in the loin

(*longissimus*) and leg muscles (Shackelford et al., 1997). Selection for high muscle depth, which is not including callipyge gene, has shown conflicting responses to tenderness effects. Navajas et al. (2008) determined that using genetics and selecting for increased muscularity doesn't have any negative impacts on palatability.

When examining gender as an effect on lamb tenderness there have been conflicting reports. Jacobson et al. (1962) and Lloyd et al. (1981) found no differences in tenderness attributable to gender. Conflicting, Wise (1978) suggested that ewe lamb carcasses had lower, more desirable shear force values than wether carcasses. Purchas et al. (1979) found higher shear force values in certain muscles of rams than wethers. Although many are dated, other reports have shown differences in tenderness between ewe and wether lambs (Summers et al., 1978; Butler-Hogg et al., 1985; Dransfield et al., 1990), rams and wethers (Fox et al., 1962; Garrigus et al., 1962; Gates et al., 1964; Pattie et al., 1964; Batcher et al., 1969; Alvi, 1980; Kemp et al., 1972; Campion et al., 1976; Misock et al., 1976), and ewes and rams (Alvi, 1980). A 1990 experiment determined that ram lamb carcasses possessed higher intramuscular collagen content (Dransfield et al. 1990), than wether and ewes. It is reported that castrated animals have reduced intramuscular collagen deposition (Boccard at al., 1979), although this does not always influence meat tenderness. Furthermore, Butler-Hogg et al. (1985) reported chops from wethers were juicier than chops from ewe lambs. Shelton and Carpenter (1972) examined tenderness on meat from rams, ewes, and wethers at live weights of 38 to 68 kg and found no differences in WBSF values due to weight or sex. Research by Kemp et al. (1981) agreed with Shelton and Carpenter and found no difference in tenderness based on sex (ram, wether, and ewe) or slaughter weight (41 and 50 kg). It is interesting to note that Shelly et al. (1970) reported that USDA QG, juiciness, tenderness, and overall liking of rib roasts from ram and wether lambs improved as

lamb slaughter weight increased from 36 to 54 kg. However, Campion et al. (1976) concluded that as lambs slaughter weight increased their meat became less tender as tested by WBSF and sensory panel tenderness scores.

Sensory characteristics, especially tenderness have been a focus of research in meat producing species for decades. Many sensory type studies have shown that bull meat has acceptable tenderness ratings, but these ratings were numerically lower and less desirable than steer meat (Glimp et al., 1971; Albaugh et al., 1975; Arthaud et al., 1977; Ntunde et al., 1977). A report from Hunsley et al. (1971) suggests that bull meat tenderness is more heavily influenced by maturity than beef from steers. In agreement, Hedrick et al. (1969) reported that shear force values and sensory evaluation indicated that tenderness was the same for meat from bulls, steers, and heifers less than 16 months of age. Johnson et al. (1995) observed differences in tenderness based on goat sex but not breed. Female goat carcasses had lower and more tender WBSF values than intact and castrated male goat carcasses. These results concur with earlier research that found meat from female goats was more tender than that of castrates (Hogg et al., 1992). For reference, average WBSF values were below 5.5 kg for all muscles except the *semitendinosis* muscle in female goats, and above 5.5 kg for all muscles in castrate and intact male goats (Johnson et al., 1995).

It is known that as an animal ages, the crosslinking and types of collagen change. Lowe (1948) reported that an animal's maturity at slaughter was one of the major factors of meat tenderness. Ramsey (1984) concluded with early research and reported that maturity had a large influence on palatability, especially when examining tenderness. Interestingly, a study by Lloyd et al. (1981) found a slaughter weight by breed interaction for tenderness, but tenderness scores consistently favored lambs in the heavyweight group regardless of breed. Tenderness has been

reported to decrease in the first two years of an animal's life (Woodhams et al., 1966; Jeremiah et al., 1971; Corbett at al., 1973; Campion et al., 1976) although other studies have found no differences based on maturity (Weller et al., 1962), and interestingly, some have found an increase in tenderness with greater weights and increased maturity (Kemp et al., 1976; Field et al., 1978). Additionally, tenderness is affected by post-slaughter factors such as cooking methods, muscle type, carcass fat, and pre-rigor temperature which all can cause variability between tenderness scores.

In addition to pre-slaughter factors, post-slaughter factors have been associated with effects on tenderness. Aging time has proven to be most important when looking at tenderness (Shorthose et al., 1986; Wheeler & Koohmaraie, 1994). An increase in aging time on lamb *Longissimus dorsi* muscles from 1 to 7 days resulted in more tender meat, based on sensory taste panel (Jamie et al., 1992). Martinez-Cerezo et al. (2005) similarly concluded that tenderness and juiciness of lamb steaks increased with aging.

In conclusion, carcasses from younger animals are generally more likely to have lower WBSF, and more desirable tenderness scores on consumer taste panels than more mature animals. More mature animals have been reported to have a lower moisture content in their carcasses (Jeremiah et al., 1997; Reagan et al., 1976), however differences in juiciness based on chronological age or maturity have not been observed.

Use of intact males for meat production

Hormones

The use of intact male lambs in meat production systems have been examined for close to a century. Intact male animals are known to reach greater mature weights, have increased growth rates, be more feed efficient, and possess leaner carcasses than their castrate counterparts (Glimp,

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1971; Seideman, 1982; Purchas and Grant, 1995). These traits can be attributed to the most well-known, and primary androgen, testosterone (Harper, 1969). The testicles produce androgens and estrogens that work to promote muscle growth by increasing nitrogen retention. Research by Schanbacher (1980) proved that testosterone is the principle testicular hormone responsible for these characteristics. In Schanbacher's experiment, castrated lambs were given exogenous testosterone during their finishing stage. The testosterone was administered at a dose that was similar to what was observed in the intact ram lambs. The comparable performance of the intact rams and wethers receiving testosterone indicated that testosterone is the single most important androgen. Additionally, when male animals are castrated, the production of testosterone and estrogen are greatly reduced (Unruh, 1986).

The natural endogenous concentrations of androgens and estrogens in intact male animals is remarkable because they allow for near maximal expression of growth (Unruh, 1986). Bavera and Penafort (2005) reported that bulls had approximately 7-8 percent more muscle than steers which is attributed to the increase of muscle hypertrophy caused by testosterone. Testosterone is also involved in collagen synthesis, accumulation and maturation which may be responsible for some of the observed tenderness differences between intact males and castrated males (Unruh, 1986). McCarty et al. (1979) stated that testosterone and estradiol-17b which are incredibly pronounced at puberty and sexual maturation causes bulls to mature physiologically faster than steers. In this case, physiological maturity was based on bone ossification.

Performance

Early research concluded that ram lambs grew faster and produced a leaner carcass when compared to wether and ewe lambs, although wethers were found to have the highest dressing percentages (Hammond, 1932). Most reports indicated ram lamb superiority, however, in

reviews by Turton (1962; 1969) rams gained weight faster than wethers and ewes but reports were conflicting when looking at loineye area. Additionally, Field (1971) concluded that ram lambs had greater retail yields, but they had lower and less desirable QG than wethers, but still averaged QG of USDA Choice. Unfortunately, ram lambs have also been attributed with difficult pelt removal, oily or yellow appearing carcasses (Crouse et al., 1978; 1981) as well as an increase in lower value cuts and lower dressing percentages (Kemp et al., 1970). Rams have less fat cover than wethers which contributes to decreased dressing percentages. Additionally, and arguably most importantly, the biggest challenge with ram lamb carcasses is the potential for off-flavors, most commonly described as *mutton* or *bucky* flavor (Reineccius, 1979).

Ewe and wether lambs usually result in more desirable flank streaking and USDA QG scores compared to ram lambs (Ho et al., 1989). Jeremiah et al. (1997) found that ewe lambs had greater carcass conformation scores when compared to wethers, and both were greater than rams.

Although bulls generally spend slightly more time on feed, they have proven to yield significantly more carcass weight, trimmer carcasses, and a greater percent lean than steers (Ntunde et al., 1977). Bull carcasses have been shown to contain roughly 8 percent more muscle, and 38 percent less fat than steer carcasses (Jacobs et al., 1977). Additionally, only small differences in percentages of bone have been observed, but steer carcasses have much lower muscle to bone ratio than bulls (Berg and Butterfield., 1968). Consequently, bull carcasses have been shown to yield close to six percent more boxed beef than steers, and waste from trimming fat can be up to 17 percent less for bulls compared to steers (Jacobs et al., 1977).

Most reports conclude that meat quality from castrated male animals is superior to intact males, however this advantage is dependent on many factors such as maturity, live weight, and nutrition program.

Conclusion

Overall, the literature on lamb flavor and eating quality of lamb is outdated and results are conflicting. Updating eating quality research is important because consumer preference is continuously changing. Additionally, over the past 100 years researchers have been looking at eating quality of sheep, but farmers have changed the genotypes, phenotypes and function of many different sheep breeds (Blair and Garrick, 2007). For example, the Hampshire sheep breed of the 1970's is much different than present day Hampshire sheep. The effect that specific breed genetic progress or transformations has on carcass and sensory characteristics of lamb meat is unclear. Furthermore, lamb slaughter weight has changed significantly over time. The current average live weight of U.S. slaughter lambs is 136 pounds (USDA, 2018) and the average weight of a slaughter lamb in 1987 was 120 pounds (USDA, 2011). The following research will update the current literature on breed and slaughter weight differences and determine if ram lamb growth and performance can be beneficial for the U.S. sheep industry.

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CHAPTER 2. CARCASS AND SENSORY CHARACTERISTIC DIFFERENCES BETWEEN RAM AND WETHER LAMBS OF THREE BREEDS

Abstract

Farm flock and small operations make up a substantial portion of U.S. sheep production, approximately 73% of all operations. Farm flocks show potential for the most growth and expansion of all sectors, especially those in the mid and upper Midwest, as surveys indicate that 55% of these operations plan on expanding in the next five years. Therefore, the need for continued research on common farm flock breeds is necessary to match the growth seen in these operations. To determine carcass composition and eating quality of common U.S farm flock breeds, three breeds were used: Hampshire, Dorset, and Columbia. Additionally, the effects of castration on growth, carcass, and sensory characteristics were studied to determine if ram lamb growth and efficiency can be advantageous without providing detriment to eating satisfaction. Twenty-four spring-born Columbia (n = 8), Hampshire (n= 8), and Dorset (n= 8) lambs were assigned randomly as either rams or wethers (12 rams, 12 wethers), where lambs assigned to the wether group were castrated at weaning (approximately 65 days of age). Lambs were harvested at an average age of 192 ± 7.5 days of age. Following harvest, carcasses were chilled for two days at 2 °C, fabricated, and primal cut yields were recorded. Boneless legs were wet aged for 14 days, ground and formed into 1 oz. patties for sensory analysis. Sensory analysis was conducted and evaluated ground leg samples for flavor, tenderness, juiciness, and texture attributes. The MIXED procedure of SAS was used to evaluate fixed effects of sex (n = 2), breed (n = 3), and their interaction as well as random effects of sensory characteristics including panelist, day, and sample. As hypothesized, ram lambs had greater ($P < 0.05$) ADG throughout the trial period compared to wethers. Hampshire lambs had greater ($P < 0.05$) ADG than Columbia and Dorset

lambs. Dressing percentage was not affected ($P > 0.05$) by sex but was greater ($P < 0.05$) in Hampshire and Dorset lambs compared to Columbia lambs. Interestingly, neither breed nor sex had a significant ($P > 0.05$) influence on backfat thickness or USDA Yield Grade. Hampshire lambs had larger REA ($P < 0.05$), and better leg conformation score ($P < 0.05$) than Columbia lambs. Hampshire and Columbia lambs had less ($P < 0.05$) bodywall thickness than Dorset lambs. There were no ($P > 0.05$) differences in flank streaking based on breed or sex. Overall, there were no ($P > 0.05$) USDA Quality Grade (QG) differences based upon sex, but there were USDA QG differences ($P < 0.05$) based on breed where Hampshire lambs had better ($P < 0.05$) USDA QG when compared to Columbia lambs. When examining subprimal weights, there was a sex by breed interaction ($P < 0.05$) for bone-in shoulder weights, no ($P > 0.05$) differences in bone-in rack weights, and bone-in leg weight tended ($P = 0.054$) to be affected by sex. Bone-in loin weights were not affected ($P > 0.05$) by breed but were affected ($P < 0.05$) by sex where ram lambs had greater loin weight than wether lambs. When looking at sensory characteristics, the interaction of sex and breed only influenced juiciness intensity scores ($P < 0.05$). Overall liking, flavor liking, texture liking, juiciness just-about-right (JAR) toughness intensity, toughness JAR, and off-flavor intensity were not ($P > 0.05$) affected by sex or breed. Lamb flavor intensity was not affected by sex ($P > 0.05$) but was affected by breed ($P < 0.05$) where Columbia lambs had more lamb flavor intensity than Hampshire lambs. Flavor JAR was affected ($P < 0.05$) by breed where Columbia lambs were placed closer to the JAR point than Hampshire lambs. Overall, intact ram lambs excelled in growth, and resulted in greater subprimal yields without providing any detriment to eating quality. Selecting breeds of sheep for increases in growth and performance may prove useful, as we see that Hampshire lambs had improved performance measures. However, selecting breeds for meat eating quality may not be beneficial.

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Key Words: Sheep, Breed, Castration, Lamb Flavor, Sensory

Introduction

Lamb meat in the United States is generally derived from two production systems; Western range sheep operations and farm flock operations. Range sheep operations consist of large flocks that graze on native pastures in the western United States, and farm flock operations are smaller flocks (less than 100 head) which are raised in feedlots or improved pastures (National Research Council, 2008). Farm flock operations are common in the Midwest and Eastern states and according to the most recent U.S Sheep Industry Survey, small operations make up 73% of the U.S operations. It is important to note that fifty-five percent of farm flock operations in the mid and upper Midwest plan on expanding in the next five years (Miller et al., 2016). Because of the nature of farm flock operations, heat, cold, and drought tolerant breeds of sheep are generally not needed, and gregarious sheep breeds are not essential as the sheep in these production systems are not expected to flock. Therefore, fine-wool breeds (e.g. Rambouillet, Debouillet, Merino) are generally not used on farm flock operations, but medium-wool (e.g. Columbia, Corriedale, Targhee) and meat-type (e.g. Dorset, Hampshire, Suffolk) breeds are used instead. This research will investigate the effects of three popular farm flock breeds of Hampshire, Columbia, and Dorset on meat quality characteristics.

Many trials have evaluated sheep breeds for carcass traits and growth characteristics (Clarke et al., 1984; Freking & Leymaster., 2004; Notter et al., 2004). However, limited research has looked at common U.S. farm flock breeds regarding meat quality characteristics. Furthermore, the literature is becoming outdated, while sheep breeds continue to change, leading to a gap in the knowledge in this area. Overall, the effect of breed on lamb flavor characteristics is conflicting and outdated. Cramer et al. (1970) compared breeds and flavor composition. He

found that Rambouillet sheep had more intensely flavored meat, compared to Columbia and Hampshire. This study also concluded that Hampshire lambs had the least amount of *mutton* flavor. A more current study, performed by Young et al. (1993) compared the flavor of meat of two breeds, the Coopworth, a dual purpose breed, and the Merino, a fine-wool breed. Results from the study showed small aroma and flavor differences that the authors speculated could be explained by differences in final carcass pH. Research has indicated that maturity may play a bigger role in flavor formation than breed. A good example is the Merino sheep breed. Merino sheep have been shown to have greater flavor intensity, however they also are a slower growing and slower maturing breed. Merino lambs are usually lighter and/or older at slaughter than other breeds. Additionally, Merino sheep, which are common in Australia, typically graze on native pasture, so their diets are likely to differ from those of other breeds that commonly graze on improved pasture or are grain finished.

The effect of breed on the flavor of other species have been noted. Flavor intensity differences have been evident between dairy breeds of cattle and beef breeds (Ramsey et al., 1963) although differences between specific breeds within these types have not been observed. Ziegler et al. (1971) reported flavor preferences for beef from British breed cattle compared to Continental breeds, however later studies failed to see the same results. Differences in flavor between breeds of swine have been observed (Jensen et al., 1967). The results of the various breed comparisons suggest that breed or genetic effects on flavor are minor, especially compared to other factors such as maturity, diet, and final pH.

Additionally, small operations may benefit from direct marketing intact ram lambs of these breeds. The effect of sex and breed on carcass and meat quality characteristics may be important to farm flock producers wanting to give their customers more information about their

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product. Flavor is an important factor in consumer acceptability of meat products, especially lamb and sheep meat. Lamb is a product that is consumed because of its unique flavor, but it is also rejected because of its flavor. The 2015 Lamb Quality Audit (NLQA) data found the leading factor defining lamb quality and consumer palatability was flavor. Additionally, 72% of consumers mentioned that they were willing to pay a premium for guaranteed eating satisfaction (Woerner et al., 2016). Although disagreements may be made on which attribute flavor or tenderness is the most important for overall meat palatability, flavor is vital in ensuring a desirable eating experience. Eating quality of lamb and sheep meat has been examined by many researchers throughout the years and has been shown to be affected by many pre- and post-slaughter factors. However, the degree and method of the influence of these factors, and their possible interactions on lamb eating quality have frequently remained unclear.

We hypothesize that if ram lambs of three common U.S. farm flock breeds are processed before they hit puberty, the positives for feeding them may be economically advantageous and provide no detriment to product quality, including consumer palatability. Therefore, the objectives of this study are to: 1) identify the effect of breed and sex on meat quality characteristics, and 2) determine product yield, carcass cutability, and sensory characteristics for ram and wether lambs from three common farm flock breeds.

Materials and methods

All procedures were approved by the North Dakota State University (NDSU) Animal Care and Use Committee (IACUC number A17036). Animals were housed and fed at North Dakota State University's Sheep Unit. A total of 24 spring-born Columbia (n = 8), Hampshire (n = 8), and Dorset (n = 8) lambs were acquired from the NDSU Sheep Unit for this research. Lambs were assigned randomly as either rams or wethers (12 rams, 12 wethers), where lambs

assigned to the wethers group were castrated at weaning (approximately 65 days of age). Lambs were weighed, and average daily gain (ADG) was calculated on a weekly basis starting in May 2016. The 24 lambs were penned together for the duration of the study and fed the same grain-based diet. All lambs were left unshorn for the trial.

Blood samples for analysis of plasma testosterone concentrations were collected biweekly starting when the lambs averaged 45 kg body weight until slaughter. Blood was collected via jugular venipuncture. Blood samples were centrifuged at 4 °C at 3000g for 20 minutes. The plasma was decanted into micro centrifuge tubes and kept frozen until analysis. Serum testosterone concentrations were measured using a chemiluminescent enzyme immunoassay (Immulite/Immulite 1000 Total Testosterone, Siemens Medical Solutions Diagnostics, Los Angeles, CA). Due to inconsistent time of day at blood collection (e.g. 8:00 am collections for week 1, and 9:00 am collections on week 2) and daily fluctuations in testosterone, inconsistent and inconclusive data were collected. In rams, up to 10 peaks of testosterone have been observed in a 24-hour period, with the levels fluctuating from <1 to 25 ng/ml (Sanford et al., 1974; Illius et al., 1976). Unfortunately, this factor was not accounted for with the design of this research and results from the testosterone portion of this study will not be included in this manuscript.

Lambs were harvested in two different groups, group 1 on 8/9/2016 and group 2 on 8/31/2016 with an even distribution of rams and wethers in each group. Average harvest weights based on breed and sex are shown in table 2.1. All lambs were less than 225 days (7 months) of age at harvest and averaged under 200 days of age (Table 2.1). Lambs in both slaughter groups were taken off feed 24 h prior to slaughter and harvested at the NDSU Meats Laboratory. Hot carcass weights (HCW) were recorded and used for calculation of dressing percentage. Carcass

characteristics, including 12th rib backfat (BF), bodywall fat thickness (BW), ribeye area (REA), leg score, flank streaking, and USDA Yield and Quality Grade were recorded 24 h after harvest. Carcasses were chilled for two days at 2 °C, product was fabricated into primal cuts, and wet aged for a total of 14 days. Bone-in legs (IMPS #233A), loins (IMPS #242), racks (IMPS #204) and shoulders (IMPS #206) were weighed with loins and legs collected for further analysis. Boneless legs were ground and made into 1 oz. patties for sensory analysis.

Table 2.1. Mean age and live weight of lambs based on breed and sex at slaughter.

	Breed			Sex	
Traits	Hampshire	Dorset	Columbia	Ram	Wether
Age, d	190.9 ± 7.5	196.6 ± 7.5	189.5 ± 7.5	192.3 ± 6.1	192.3 ± 6.1
End live weight, kg	74.8 ± 2.3	66.2 ± 2.3	74.1 ± 2.3	75.3 ± 1.9	68.1 ± 1.9

Evaluation of meat sensory characteristics, which included flavor profile, juiciness, tenderness, and overall liking was completed with assistance from the University of Minnesota's Sensory Center, Dept. of Food Science and Nutrition (St. Paul, MN), in order to utilize a large number of experienced taste panelists for lamb sensory characteristics. Panelists evaluated lamb samples based on two different scales: 1) liking and intensity ratings were evaluated on a 120-point labeled affective magnitude (**LAM**) scale (Table 2.2) and characteristics on this scale included overall liking, flavor liking, texture liking, lamb flavor intensity, juiciness, toughness and off-flavor intensity, and 2) flavor intensity, juiciness, and toughness ratings were evaluated on a 150 point just-about-right (**JAR**) scale (Table 2.3).

Table 2.2. Reference captions and point values of the labeled affective magnitude (LAM) scale.

Reference Caption	Point Value
Greatest imaginable disliking	0
Dislike extremely	13
Dislike very much	25
Dislike moderately	39.5
Dislike slightly	53
Neutral	60
Like slightly	67
Like moderately	81
Like very much	93
Like extremely	104
Greatest imaginable liking	120

Table 2.3. Reference captions and point values of the just-about-right (JAR) scale.

Reference Caption	Point Value
Not nearly (attribute) enough	0
Just about right	75
Much too (attribute)	150

Sensory panelists (n = 98), who consumed lamb at least once within the past year were recruited from students and staff of the University of Minnesota. The panel was held over a two-day period and required panelists to consume nine samples of ½ oz. lamb patties per day. Pre-formed patties (1 oz.) were cooked in a conventional oven to an internal temperature of ~71°C and cut in half, to form ½ oz. patties. The patties were served plain (no seasonings) in 60 ml sample cups and nested in insulated foam trays to maintain temperature. Panelists were able to cleanse their palate between samples with water. Within the nine samples served each day were two treatments (rams and wethers) and three breeds (Columbia, Hampshire, Dorset) and serve order was randomized.

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Cary, NC, USA) for fixed effects of castration (n = 2), breed (n = 3), their interaction and random effect of harvest date. In addition to fixed effects, sensory characteristics included panelist, day, and sample as a

random effect in the model. Non-significant interaction ($P > 0.05$) for a given trait were removed from the model. Significance of pairwise comparisons between least squares means of fixed effects were controlled for experiment-wise error rate using the Tukey-Kramer procedure.

Results

Average daily gain

There were no significant breed by sex interactions when investigating ADG ($P > 0.05$). Average daily gain was affected by both sex ($P < 0.0001$; Figure 2.1) and breed ($P = 0.0007$; Figure 2.1) where Hampshire lambs had greater ADG than Columbia and Dorset lambs (0.39 ± 0.01 kg, 0.35 ± 0.01 kg, 0.31 ± 0.01 kg, respectively; $P = 0.019$ and $P = 0.0002$). Additionally, Columbia lambs possessed greater ADG than Dorset lambs ($P = 0.03$). Ram lambs outperformed wethers in ADG by 0.09 kg/d throughout the trial.
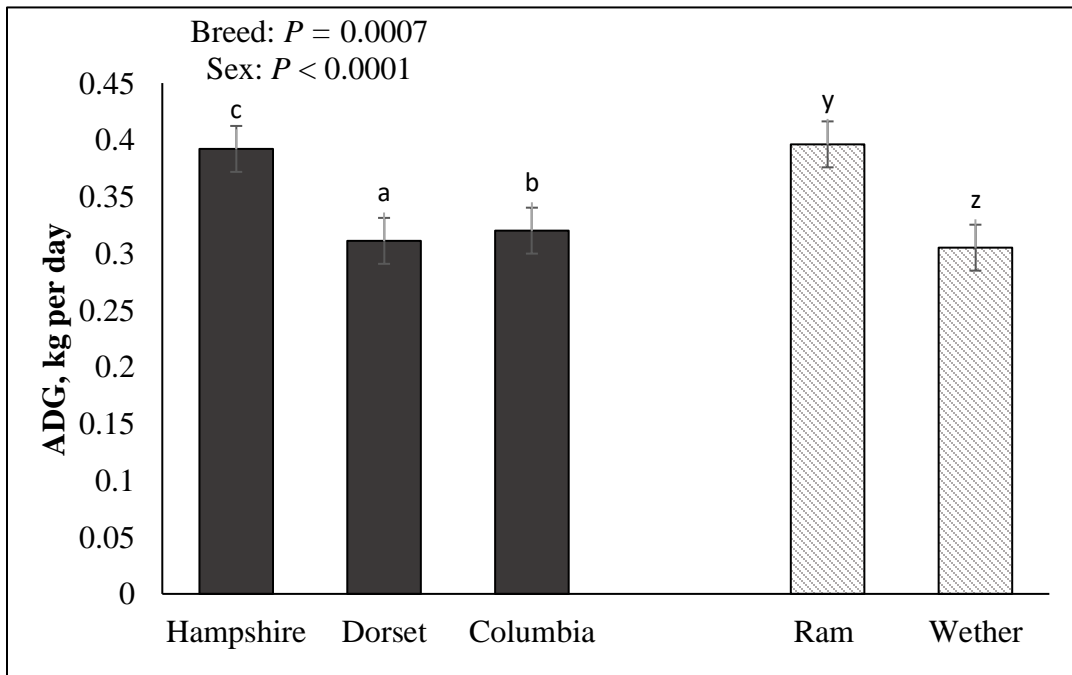
Figure 2.1. ADG for trial period based on breed and sex. [abc]Means in the same class not sharing a common superscript are different ($P < 0.05$). [yz]Means in the same class not sharing a common superscript are different ($P < 0.05$).

Carcass characteristics

There were no observed breed by sex interactions ($P > 0.05$) for all carcass

characteristics. There was a tendency for ram lambs to have heavier HCW than wethers ($P =$

0.05; Table 2.4), and there were no differences based on breed ($P = 0.12$; Table 2.5).

Table 2.4. Least square means and standard errors of carcass characteristics based on lamb sex.

Carcass characteristics	Sex		SEM	*P*-Value
	Ram	Wether		
HCW, kg	36.31	33.28	1.03	0.05
Dressing percentage[1], %	49.66	50.40	0.51	0.32
12th rib backfat depth[2], cm	0.45	0.53	0.01	0.13
Leg conformation score[4]	12.37	12.20	0.24	0.62
Flank streaking[4]	11.31	11.32	0.15	0.95
Ribeye area[3], cm^2	17.70	16.69	0.54	0.22
Body-wall thickness[5], cm	2.08	2.11	0.07	0.75
Quality Grade (QG)[4]	11.44	11.69	0.13	0.18
Yield Grade (YG)[6]	1.78	1.97	0.12	0.30

[1]Determined from the HCW and live weight taken prior to slaughter.
[2]Measured to the nearest centimeter between the 12th and 13th rib over the middle of the ribeye muscle (average of both sides).
[3]Measurement of the cross-sectioned area of the ribeye muscle, taken between the 12th and 13th rib.
[4]Average choice = 11, choice plus = 12, low prime = 13.
[5]Measured between the 12th and 13th rib, 11.45 cm from the center of the spine.
[6]Calculated as YG = 0.4 + (10 x backfat thickness).

Table 2.5. Least square means and standard errors of carcass characteristics based on lamb breed.

Carcass characteristics	Breed			SEM	P-Value
	Hampshire	Dorset	Columbia		
HCW, kg	36.94	33.06	34.39	1.26	0.12
Dressing percentage[1], %	50.81[b]	51.41[b]	47.86[a]	0.62	0.002
12th rib backfat depth[2], cm	0.43	0.56	0.51	0.05	0.15
Leg conformation score[4]	12.73[b]	12.50[b]	11.63[a]	0.29	0.04
Flank streaking[4]	11.57	11.13	11.25	0.18	0.26
Ribeye area[3], cm^2	19.01[b]	17.64[b]	14.93[a]	0.66	0.001
Body-wall thickness[5], cm	1.88[a]	2.33[b]	2.08[a]	0.09	0.006
Quality Grade (QG)[4]	11.93[b]	11.50[ab]	11.25[a]	0.16	0.02
Yield Grade (YG)[6]	1.75	2.00	1.88	0.15	0.52

[1]Determined from the HCW and live weight taken prior to slaughter.
[2]Measured to the nearest centimeter between the 12th and 13th rib over the middle of the ribeye muscle (average of both sides).
[3]Measurement of the cross-sectioned area of the ribeye muscle, taken between the 12th and 13th rib.
[4]Average choice = 11, choice plus = 12, low prime = 13.
[5]Measured between the 12th and 13th rib, 11.45 cm from the center of the spine.
[6]Calculated as YG = 0.4 + (10 x backfat thickness).
[ab]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

Although there was no sex effect on dressing percentage ($P = 0.31$; Table 2.4), there was a difference between breeds ($P = 0.0016$; Table 2.5), where Dorset and Hampshire lambs had higher dressing percentages than Columbia lambs. Neither breed nor sex had a significant influence on backfat thickness ($P = 0.15$, $P = 0.13$, respectively; Tables 2.4 and 2.5) or USDA Yield Grade ($P = 0.52$, $P = 0.30$, respectively; Tables 2.4 and 2.5). There were breed differences in REA, bodywall fat thickness, and leg score ($P = 0.0011$, $P = 0.0058$, $P = 0.036$, respectively; Table 2.5) with Hampshire lambs having the most desirable characteristics in all three categories. However, there were no differences when looking at flank streaking based on breed and sex ($P = 0.26$, $P = 0.95$, respectively; Tables 2.4 and 2.5). Overall, there were no USDA QG differences based upon sex ($P = 0.18$; Table 2.4) but there were USDA QG differences based on breed ($P = 0.02$; Table 2.5). Hampshire lambs had higher USDA QG when compared to Columbia lambs (P

= 0.007). When examining primal cut-out weights there were sex and breed differences for bone-in shoulder weights (P = 0.03, P = 0.029, respectively; Tables 2.6 and 2.7). Columbia and Dorset lambs had comparable shoulder weights (P = 0.615), and Hampshire lambs had greater shoulder weights than both Columbia and Dorset lambs (P = 0.036, P = 0.013, respectively). Bone-in rack weights were not affected by sex, or breed (P = 0.11, P = 0.62, respectively; Tables 2.6 and 2.7). Bone-in leg weight was not affected by breed (P = 0.10; Table 2.7) but tended to be affected by sex (P = 0.05; Table 2.6), where ram lambs had greater leg weights than wether lambs. Bone-in loin weights were not affected by breed (P = 0.13; Table 2.7) but was affected by sex (P = 0.028; Table 2.6), where ram lambs had greater loin weights than wether lambs.

Table 2.6. Least square means and standard errors of bone-in subprimal cuts based on lamb sex.

Carcass characteristics	Sex		SEM	P-Value
	Ram	Wether		
Shoulder, kg	7.83	7.07	0.23	0.03
Loin, kg	3.26	2.88	0.11	0.03
Leg, kg	11.34	10.38	0.33	0.05
Rack, kg	2.80	2.55	0.10	0.11

Table 2.7. Least square means and standard errors of bone-in subprimal cuts based on lamb breed.

Carcass characteristics	Breed			SEM	P-Value
	Hampshire	Dorset	Columbia		
Shoulder, kg	8.13[b]	7.00[a]	7.21[a]	0.29	0.03
Loin, kg	3.22	3.17	2.83	0.14	0.14
Leg, kg	11.53	10.20	10.85	0.42	0.1
Rack, kg	2.72	2.58	2.72	0.13	0.6

[ab]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

Sensory characteristics

The interaction of sex and breed only influenced juiciness scores ($P = 0.029$; Figure 2.2), all other sensory characteristics only looked at main effect differences as the interactions were found to be insignificant ($P > 0.05$) and therefore dropped from the model. Columbia ram lambs were rated to have greater and more desirable juiciness scores than Dorset ram lambs ($31.61\pm$ 1.40 and 29.71 ± 1.41, respectively; $P = 0.02$). Overall liking, flavor liking, texture liking, juiciness JAR, toughness, toughness JAR, and off-flavor intensity were not affected by sex or breed ($P > 0.05$; Tables 2.8, 2.9, 2.10, and 2.11). Lamb flavor intensity was not affected by sex ($P = 0.45$; Table 2.8) but was affected by breed ($P = 0.03$; Table 2.9) where Columbia lambs had more lamb flavor intensity than Hampshire. Flavor JAR was not affected by sex ($P = 0.46$; Table 2.11) but was affected by breed ($P = 0.049$; Table 2.10) where Columbia lambs were placed closer to the just-about-right point than Hampshire lambs ($P = 0.04$).
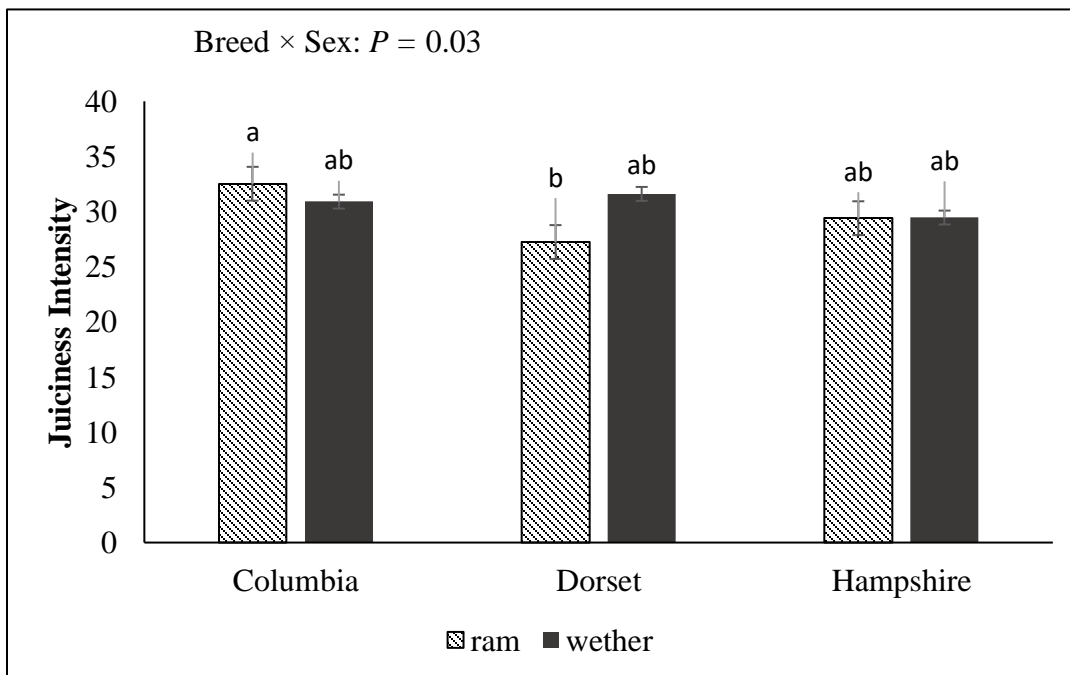

Figure 2.2. Juiciness scores measured on the LAM scale based on the interaction of lamb breed and sex. [ab]Means not sharing a common uperscript are different ($P < 0.05$).

Table 2.8. Least square means for sensory attribute scores in lamb burgers by sex.

Sensory Attributes	Sex		SEM	*P*-Value
	Ram	Wether		
Overall Liking	72.02	72.50	1.41	0.66
Flavor Liking	70.64	72.56	1.45	0.08
Texture Liking	72.05	71.92	1.31	0.90
Lamb Flavor Intensity	30.81	29.98	1.61	0.45
Toughness Intensity	27.23	27.21	1.69	1.0
Juiciness Intensity	29.87	30.51	1.32	0.48
Off Flavor Intensity	22.14	21.93	1.86	0.87

Table 2.9. Least square means for sensory attribute scores in lamb burgers by breed.

Sensory Attributes	Breed			SEM	*P*-Value
	Hampshire	Dorset	Columbia		
Overall Liking	72.66	72.05	72.06	1.56	0.9
Flavor Liking	72.25	71.52	71.04	1.60	0.72
Texture Liking	72.73	70.87	72.36	1.42	0.3
Lamb Flavor Intensity	28.24 [a]	30.68 [ab]	32.26 [b]	1.77	0.03
Toughness Intensity	28.95	25.46	27.25	1.90	0.16
Juiciness Intensity	29.25	29.71	31.61	1.41	0.09
Off Flavor Intensity	21.42	21.15	23.53	2.10	0.40

[ab]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

Table 2.10. Least square means for just-about-right (JAR) scores in lamb burgers by sex.

Sensory Attributes	Sex		SEM	*P*-Value
	Ram	Wether		
Flavor JAR	65.82	65.15	1.49	0.46
Juiciness JAR	63.86	64.16	1.29	0.75
Toughness JAR	76.48	76.34	1.22	0.89

Table 2.11. Least square means for just-about-right (JAR) scores in lamb burgers by breed.

Sensory Attributes	Breed			SEM	*P*-Value
	Hampshire	Dorset	Columbia		
Flavor JAR	63.98[a]	65.77[ab]	66.70[b]	1.56	0.05
Juiciness JAR	62.88	64.02	65.12	1.39	0.17
Toughness JAR	78.03	75.58	75.63	1.40	0.17

[ab]Least squares means in the same row lacking a common superscript differ (*P* < 0.05).

Discussion

Ram lambs outperformed wethers in ADG, consistent with previous studies (Walker, 1950; Jacobs, 1970; Kemp et al., 1970; Arnold et al., 1988) who found up to a 5 kg increase in ADG in rams over wethers. It is common knowledge that intact male animals are known to reach greater mature weights, have increased growth rates, be more feed efficient, and possess leaner carcasses than their castrate counterparts (Seideman, 1982; Glimp, 1971). These traits can be attributed to the most well-known, and primary androgen, testosterone (Harper, 1969). A study by Schanbacher (1980) proved that testosterone is the principal testicular hormone responsible for these characteristics. In Schanbacher's experiment, castrated lambs were given exogenous testosterone during their finishing stage. The testosterone was administered at a dose that was similar to what was measured in the intact ram lambs. The comparable performance of the intact ram lambs and wethers receiving testosterone indicated that testosterone was the driving factor for the increased performance seen in wether lambs.

However, we found only a tendency for ram lambs to have greater HCW than wether lambs. Additionally, there were no differences between sexes based on dressing percent. Previous research has indicated that post pubertal ram lambs often have lower dressing percentages when compared to similar aged wether lambs (Kemp et al., 1970). Based on dressing percent, we can hypothesize that the ram lambs from all three breeds had not reached their

physiological growth peak or puberty and did not possess the undesirable "bucky" characteristics (heavy pelts, heads, and testes) that a post-pubertal ram would possess. Often, HCW doesn't correlate to high retail cut yields in rams because of the tendency for rams to have decreased dressing percentages (Johnson et al., 2007). Literature indicated that observed decreases in dressing percentage in rams is due to teste weight, heavy pelts, and heads (Bradford and Spurlock, 1964; Lirette et al., 1984).

Hampshire lambs had greater shoulder weights than Dorset and Columbia lambs, but did not differ in loin, leg, or rack weights. Hampshire lambs are famed for producing a heavy, lean carcass with heavy muscling. We do see an advantage in muscling in the Hampshire lambs over the Columbia lambs when looking at leg conformation score and ribeye area but not for bone-in leg weight. These findings could be affected by ratio of lean-to bone which is measured as pounds of lean per pound of bone. This measure is considered highly genetic (Whiteman et al., 1966) and was not measured in the current study but has been found to differ between breeds (Sanudo et al., 1997). Previous studies have found that progeny from black-faced sired lambs produced carcasses with more lean but also more bone than white-faced ram's progeny (Whiteman et al., 1966). When looking at sex, ram lambs had greater shoulder and loin weights than wether lambs. Additionally, ram lambs tended to have greater leg weights than wethers. Rams and wethers were found to have no difference in rack weights. These findings partially disagree with previous work. Kemp et al. (1970) reported that ram lambs have a greater proportion of lower value cuts such as the shoulder and neck when compared to wether or ewe lambs.

A brief economic analysis of the subprimal cuts showed that ram lambs quantified a $3.70 increase in bone-in loin value (IMPS #242), $7.98 increase in bone-in leg (IMPS #233A)

value, $5.50 increase in bone-in rack (IMPS #204) value, and $4.42 bone-in shoulder (IMPS #206) value when compared to wether lambs. Overall, ram lambs quantified a $21.60 increase in value when looking at the total of the four subprimal cuts. Total subprimal cuts from Hampshire lambs were valued at $19.26 greater than Dorset lambs, and $12.72 greater than Columbia lambs. However, Hampshire lambs only quantified $0.02 more bone-in rack value when compared to Columbia lambs. Further research is warranted to determine feed efficiency economics of the three breeds and two sexes. All numbers are based on the national 5-day rolling average boxed lamb cuts for fresh American lamb provided by USDA market news from May 2018.

An interesting finding is that although Hampshire lambs excelled in the growth and carcass categories, they did not result in more retail cut yields. They also rated lower on the JAR scale when compared to Columbia lambs. This is an interesting finding but does concur with previous literature stating that finer wool breed sheep generally have more pronounced lamb flavor intensity than coarser wool breeds (Cramer, 1983). Columbia sheep have medium-wool fleeces that are typically between 23-30 micron, which is slightly finer than the wool from Dorset (26-33 micron) and Hampshire (25-33 micron) sheep (Mathis, 2002). This finding is hypothesized to be caused by maturity, as finer wool breed sheep are usually older at slaughter. However, this is not the case with our study, as the Columbia lambs, on average, were numerically younger (Table 2.1) at slaughter than the two other breeds.

The lack of differences between breeds and sex when looking at sensory characteristics are interesting because previous studies have found little to no differences in this category (Fox et al., 1962; Crouse et al., 1981). There was not one sensory characteristic that was influenced by sex as a main effect. The authors hypothesize these findings to be caused by the fact that the

lambs on this study were young and fairly light in body weight. Maturity and body weight are both traits that have been linked to changes in sensory characteristics (Misock et al., 1976; Sink and Caporaso, 1977; Jamora and Rhee, 1999).

This study confirms that no single breed of sheep excels in all traits, which highlights the importance of crossbreeding systems to optimize economic performance. The breeds used in this study may excel in crossbreeding systems to produce offspring that excel in multiple traits, including palatability. However, no particular breed can be selected for palatability alone. Comparison of the current study to the literature is complicated because of the different production systems and multitude of breeds used in breed comparisons. It is doubtful that all previous studies have been completed under the same production conditions (i.e. diet, maturity, etc.).

The use of ram lambs in U.S. lamb production systems has the potential to increase growth rates, and muscularity as well as decrease USDA yield grades without impacting sensory characteristics. Although an investigation of the economic benefits of rearing ram lambs is needed, the authors speculate that the use of ram lambs would function to increase the profits of sheep producers and packers without increasing the costs of production. Also, breed selection may have a minor impact on palatability of lamb meat. It remains undetermined whether the small differences in sensory characteristics would be detected by typical consumers.

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CHAPTER 3. CARCASS AND SENSORY CHARACTERISTIC DIFFERENCES BETWEEN RAM AND WETHER LAMBS OF LIGHT, MEDIUM, AND HEAVY SLAUGHTER WEIGHTS

Abstract

American lambs are often over-finished and lack consistent quality (Hoffman, 2014). It has been suggested that leaving male lambs intact can decrease USDA Yield Grade (carcass fatness) and improve growth efficiency. However, ram lamb carcasses are underutilized because of potential issues, the most crucial being potential off-flavor. We studied the effects of castration and slaughter weight on growth, carcass, and sensory characteristics to determine if ram lamb growth and efficiency can be advantageous without detriment to eating satisfaction. Dorset lambs (n = 20) were randomly assigned to either ram or wether treatment group (10 rams, 10 wethers). Lambs assigned to the wether group were castrated within the first 7 d after birth and all lambs were fed the same grain-based diet for the duration of the study. Animals were balanced for mean age and 90 d weight and assigned to appropriate slaughter group. Targeted end live weights for slaughter designation were light (55 kg), medium (66 kg), and heavy (77 kg). Lambs were harvested in three weight groups, light (55 ± 1.5 kg; n = 6), medium (66 ± 1.3 kg; n = 8), and heavy (78 ± 1.5 kg; n = 6), with an even distribution of ram and wether in each group. Following harvest, carcasses were chilled for two days at 2 °C, fabricated, and primal cut yields were recorded. Boneless legs were wet aged for 14 days, ground and formed into 1 oz. patties for sensory analysis. Untrained panelists (n = 107) evaluated meat sensory characteristics. The Mixed procedure of SAS was used to evaluate fixed effects of sex (n = 2), slaughter weight (n = 3), and their interaction as well as random effects of sensory characteristics including panelist, day, and sample. Supporting our hypothesis, ram lambs exhibited greater ($P < 0.05$)

ADG throughout the trial period when compared to wethers, and lambs in all three weight groups had similar ($P > 0.05$) ADG. Ram lambs had more desirable ($P < 0.05$) leg scores, larger ($P < 0.05$) ribeye areas and less ($P < 0.05$) backfat than wethers. Ram lambs also had lower ($P < 0.05$) USDA Yield Grades and better ($P < 0.05$) USDA Quality Grades than wethers. Sensory evaluation determined that meat from ram lambs had greater ($P < 0.05$) lamb flavor intensity than wethers, and meat from wether lambs had greater ($P < 0.05$) overall liking than ram lambs. Interestingly, the more intense lamb flavor found in ram lambs aligned closer ($P < 0.05$) to the preferred lamb flavor profile for consumers. Lamb originating from rams had greater ($P < 0.05$) off-flavor intensity scores than wethers, and heavy weight lambs had greater ($P < 0.05$) off-flavor intensity scores than light/medium weight lambs. Furthermore, there were no ($P > 0.05$) texture liking or juiciness intensity differences based on sex or slaughter weight. Intact ram lambs provide the sheep industry an opportunity to improve growth, increase muscularity, and decrease USDA Yield Grade while providing a satisfactory eating experience. Ram lamb flavor intensity was more preferred by consumers, yet, compounding of advanced physiological maturity and harvesting intact rams increased incidence of off-flavors.

Key Words: Sheep, Ram Lambs, Castration, Lamb Flavor, Sensory

Introduction

The American Sheep Industry Association's goal is to produce lamb carcasses that are Yield Grade 2 (0.4 - 0.64 cm [0.16-0.25 inches] backfat thickness). Recently, less than 35 percent of U.S. lamb carcasses grade YG 2, which means about 65 percent of lambs do not meet the desires of consumers (Thomas, 2013). The American lamb industry continuously produces overly finished lambs with an average around 0.89 cm [0.35 inches] of backfat (Harris et al., 1990), which approaches Yield Grade (YG) 4. Leaving male lambs intact has been proven to

reduce carcass fatness and improve growth efficiency (Walker, 1950; Jacobs, 1970; Arnold et al., 1988), thereby providing an opportunity to improve carcass characteristics and YG in American lamb. However, producers are hesitant to incorporate this strategy because of potential behavioral issues and economic penalties. It has been documented in processing that post pubertal ram lambs can cause problems such as difficult pelt removal, oily or yellow appearing carcasses (Crouse et al., 1978; 1981) as well as an increase in lower value cuts and lower dressing percentages (Kemp et al., 1970). One of the biggest challenges with ram lamb carcasses is the potential for off-flavors, most commonly described as *mutton* or *bucky* flavor (Reineccius, 1979). Although it is proven that diet has an effect on off-flavors (Melton, 1990), minimal work has been performed on the effect of castration on off-flavor development. Despite these concerns, ram lambs have been shown to grow faster, grow more efficiently, and become leaner than wethers (Kemp et al., 1970; Dickerson, 1972). We hypothesize that if ram lambs are processed before they hit their physiological peak, the positives for feeding them may be economically advantageous and provide no detriment to product quality, including consumer palatability. Therefore, the objectives of this study are to: 1) identify the effect of castration and slaughter weight on meat quality characteristics, and 2) determine product yield, carcass cutability, and sensory characteristics for ram and wether lambs.

Materials and methods

All procedures were approved by the North Dakota State University (NDSU) Animal Care and Use Committee (IACUC number A17036). A total of 20 fall-born (Sept. to Oct. 2016) Dorset lambs were acquired from the NDSU Sheep Unit. At birth, the lambs were randomly assigned to one of two groups, either rams or wethers (10 rams, 10 wethers), where lambs assigned to the wether group were castrated within 7 d of birth. Early castration was used to

simulate commercial sheep management practices and ensure lamb well-being (Mellor and Stafford, 2000). The 20 lambs were penned together for the duration of the study and fed the same grain-based diet. All lambs were weighed on a weekly basis starting in December 2016, with ad libitum access to feed and water, and growth data (ADG) was calculated. All lambs were left unshorn for the trial.

Blood samples for analysis of plasma testosterone concentrations were collected biweekly starting when the lambs averaged 45 kg body weight until slaughter. Blood was collected via jugular venipuncture. Blood samples were centrifuged at 4 °C at 3000g for 20 minutes. The plasma was decanted into micro centrifuge tubes and kept frozen until analysis. Serum testosterone concentrations were measured using a chemiluminescent enzyme immunoassay (Immulite/Immulite 1000 Total Testosterone, Siemens Medical Solutions Diagnostics, Los Angeles, CA). Due to time of day and order of draw at blood collection as well as daily fluctuations in testosterone, inconsistent and inconclusive data were collected. In rams, up to 10 peaks of testosterone have been observed in a 24-hour period, with the levels fluctuating from <1 to 25 ng/ml (Sanford et al., 1974; Illius et al., 1976). Unfortunately, this factor was not accounted for with the design of this research and results from the testosterone portion of this study will be included in Appendix B. A line graph of ram testosterone levels over time is included in the appendix (Figure C.1).

Lambs were harvested in three different weight groups, light (n = 6), medium (n = 8), and heavy (n = 6) with an even distribution of ram and wether in each group. Animals were balanced for mean age and 90 d weight and assigned to appropriate slaughter group. Targeted end live weights for slaughter designation were light (55 kg), medium (66 kg), and heavy (77 kg) classifications. Light lambs were slaughtered at d 42 of the trial, medium lambs on d 56 and

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heavy lambs on d 90, to represent different degrees of maturity and weight. Actual harvest
weights are shown in table 3.1. All lambs were less than 215 days (7 months) of age at harvest
and averaged well under 200 days of age (Table 3.1).

Table 3.1. Mean age and live weight of lambs based on weight group and sex.

	Weight Group			Sex	
Traits	Light	Medium	Heavy	Ram	Wether
Age, d	147.5 ± 3.0	166.6 ± 2.6	197.7 ± 3.0	168.6 ± 2.3	172.6 ± 2.3
End live weight, kg	55.5 ± 1.5	66.3 ± 1.3	77.6 ± 1.5	72.1 ± 1.1	60.8 ± 1.1

Lambs in all slaughter groups were taken off feed 24 h prior to slaughter and then
harvested at the NDSU Meats Laboratory. Hot carcass weights (HCW) were recorded and used
for calculation of dressing percentage. Carcass characteristics, including 12th rib backfat (BF),
body wall thickness (BW), ribeye area (REA), leg score, flank streaking, and Yield (YG) and
Quality Grade (QG) were recorded 24 h after harvest. Carcasses were chilled for two days at 2
°C, product was fabricated, and then wet aged for a total of 14 days. Bone-in legs (IMPS
#233A), loins (IMPS #242), racks (IMPS #204) and shoulders (IMPS #206) were weighed with
loins and legs collected for further analysis. Boneless legs were ground and made into 1 oz.
patties for sensory analysis.

Evaluation of meat sensory characteristics, which included flavor profile, juiciness,
tenderness, and overall liking, was completed with assistance from the University of Minnesota's
Sensory Center, Dept. of Food Science and Nutrition (St. Paul, MN), in order to utilize a large
number of experienced taste panelists for lamb sensory characteristics. Panelists evaluated lamb
samples based on two different scales: 1) liking and intensity ratings were evaluated on a 120-
point labeled affective magnitude (LAM) scale (Table 3.2) and characteristics on this scale
included overall liking, flavor liking, texture liking, lamb flavor intensity, juiciness, toughness

and off-flavor intensity, and 2) flavor intensity, juiciness, and toughness ratings were evaluated

on a 150-point just-about-right (JAR) scale (Table 3.3).

Table 3.2. Reference captions and point values of the labeled affective magnitude (LAM) scale.

Reference Caption	Point Value
Greatest imaginable disliking	0
Dislike extremely	13
Dislike very much	25
Dislike moderately	39.5
Dislike slightly	53
Neutral	60
Like slightly	67
Like moderately	81
Like very much	93
Like extremely	104
Greatest imaginable liking	120

Table 3.3. Reference captions and point values of the just-about-right (JAR) scale.

Reference Caption	Point Value
Not nearly (attribute) enough	0
Just about right	75
Much too (attribute)	150

Pre-screened sensory panelists (n = 98), who consumed lamb at least once within the past

year were recruited from students and staff of the University of Minnesota. The panel was held

over a two-day period and required panelists to consume nine samples of 0.5 oz. lamb patties per

day. Pre-formed patties (1 oz.) were cooked in a conventional oven to an internal temperature of

~71°C and cut in half, to form 0.5 oz. patties. The patties were served plain (no seasonings) in 60

ml sample cups and nested in insulated foam trays to maintain temperature. Panelists were able

to cleanse their palate between samples with water. Within the nine samples served each day

were two treatments (rams and wethers) and three breeds (Columbia, Hampshire, Dorset), and

serve order was randomized.

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Cary, NC, USA) for fixed effects of castration (n = 2), breed (n = 3), and their interaction as well as a random effect of harvest date. Non-significant interaction (P > 0.05) for a given trait was dropped from the model. In addition to fixed effects, sensory characteristics included panelist, day, and sample as a random effect in the model. Significance of pairwise comparisons between least squares means of fixed effects were controlled for experiment-wise error rate using the Tukey-Kramer procedure.

Results

Average daily gain

There was no significant castration by slaughter weight interaction ($P = 0.893$) when investigating ADG. Supporting our hypothesis, ram lambs exhibited significantly greater ADG ($P < 0.001$; Figure 3.1) ADG throughout the trial period when compared to wethers. Ram lambs outperformed wethers in ADG by 0.09 kg/d throughout the trial and continued to gain weight steadily up to 83 kg. Average daily gain between weight groups showed no differences ($P = 0.262$; Figure 3.1).
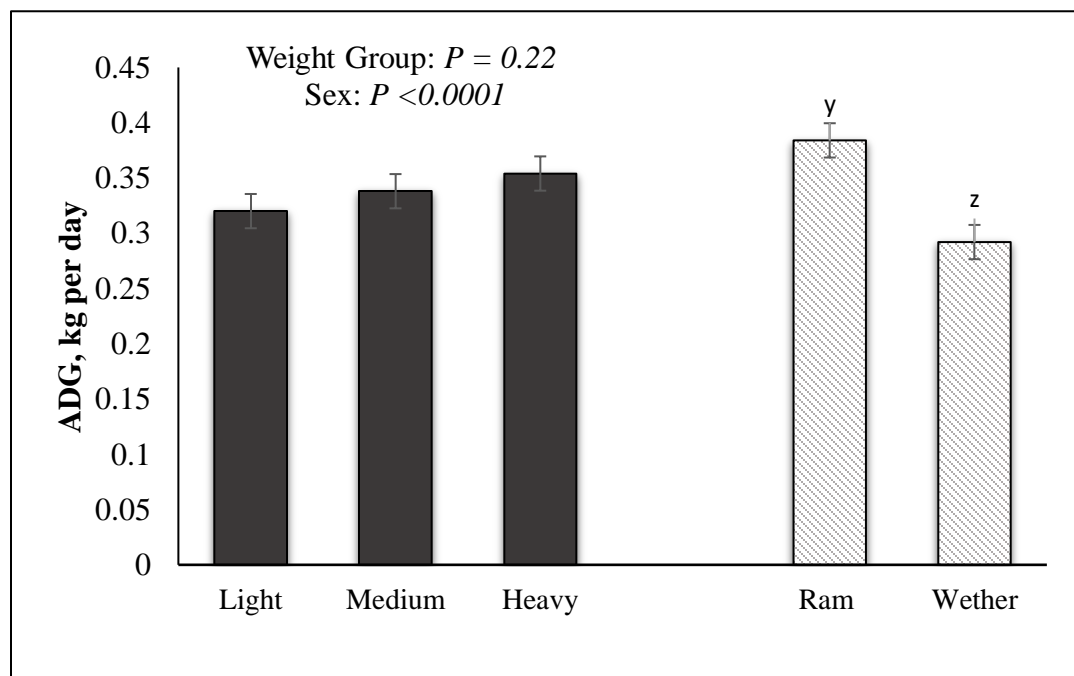
Figure 3.1. ADG for trial period based on slaughter weight group and sex. [y,z]Means in the same class not sharing a common superscript are different (P < 0.05).

Carcass characteristics

Hot carcass weight had an observed slaughter weight by castration interaction ($P = 0.03$: Figure 3.2). As expected, heavy weight ram lambs had greater HCW compared to all other sex by weight group comparisons. Medium weight ram lambs had the same HCW as heavy weight wether lambs and greater HCW than medium weight wether lambs. Ram lambs across all weight groups quantified a 5.6 kg increase in HCW over wethers. Although there was no sex effect ($P = 0.21$; Table 3.4) on dressing percentage, there was a difference ($P = 0.02$; Table 3.5) between weight groups, where as anticipated, heavier lambs had greater dressing percentages. Wethers had greater ($P = 0.02$: Table 3.4) backfat thickness when compared to ram lambs, but there were no differences ($P = 0.24$; Table 3.4) in bodywall thickness between sexes. As expected, when lambs grew heavier their backfat thickness and bodywall thickness increased significantly ($P = 0.004$, $P < 0.0001$, respectively; Table 3.5). Ram lambs averaged 0.30 cm less backfat than wethers (Table 3.4), and the variance in backfat thickness quantified close to one YG difference

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between sexes. Ram lambs had significantly lower ($P = 0.02$; Table 3.4) YG than wethers and

heavy weight lambs had greater ($P = 0.0004$; Table 3.5) YG compared to light and medium

weight lambs. Ram lambs showed significantly improved values in the carcass characteristic

data, with greater ($P = 0.03$; Table 3.4) and more desirable leg scores, larger ($P = 0.01$; Table

3.4) REA and less ($P = 0.02$; Table 3.4) backfat than wethers, regardless of slaughter weight.

Additionally, there was no sex difference ($P = 0.17$; Table 3.4) when looking at flank streaking.

These characteristics ultimately led to a greater ($P = 0.015$; Table 3.4) and more desirable QG in

ram lambs. When looking at carcass characteristics based on slaughter weight, there were no

differences ($P = 0.06$, $P = 0.07$, respectively; Table 3.5) in leg conformation score or REA.

There were differences in flank streaking with medium and heavy lambs having greater ($P =$

0.007; Table 3.5) flank streaking scores than light weight lambs. Heavy and medium weight

lambs had greater ($P = 0.0004$; Table 3.5) and more desirable QG when compared to light weight

lambs.

Figure 3.2. HCW based on the interaction between lamb sex and slaughter weight group.
[abcd]Means not sharing a common superscript are different ($P < 0.05$).

Figure 3.3. Bone-in rack weight based on the interaction between lamb sex and slaughter weight group. [abc]Means not sharing a common superscript are different ($P < 0.05$).

Figure 3.4. Bone-in shoulder weight based on the interaction between lamb sex and slaughter weight group. [abcd]Means not sharing a common superscript are different ($P < 0.05$).

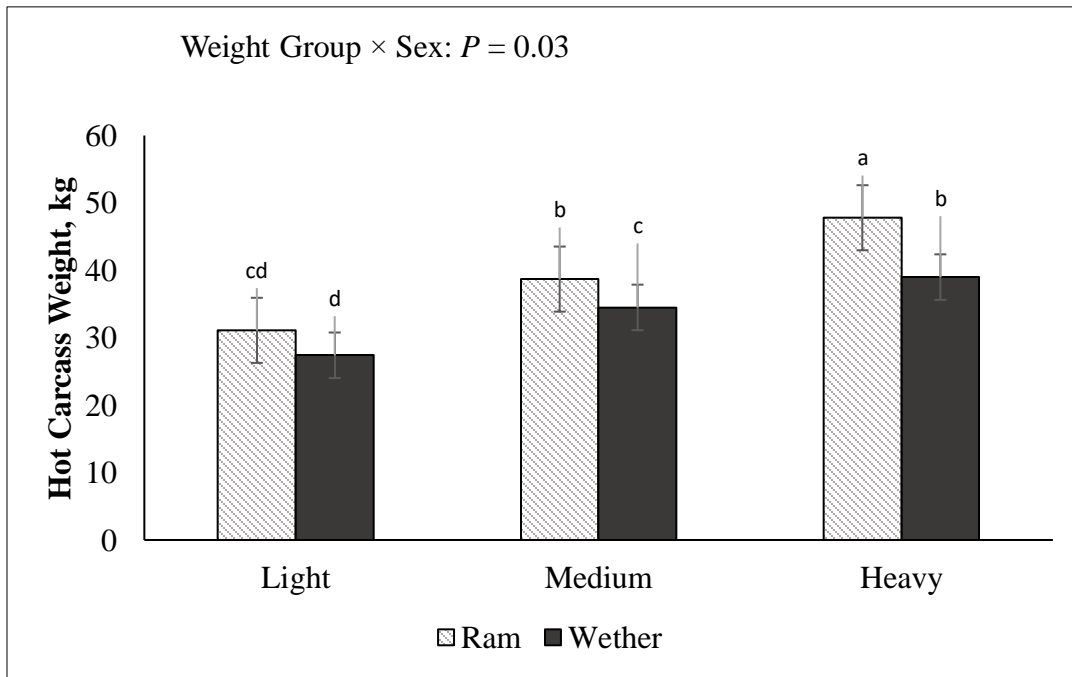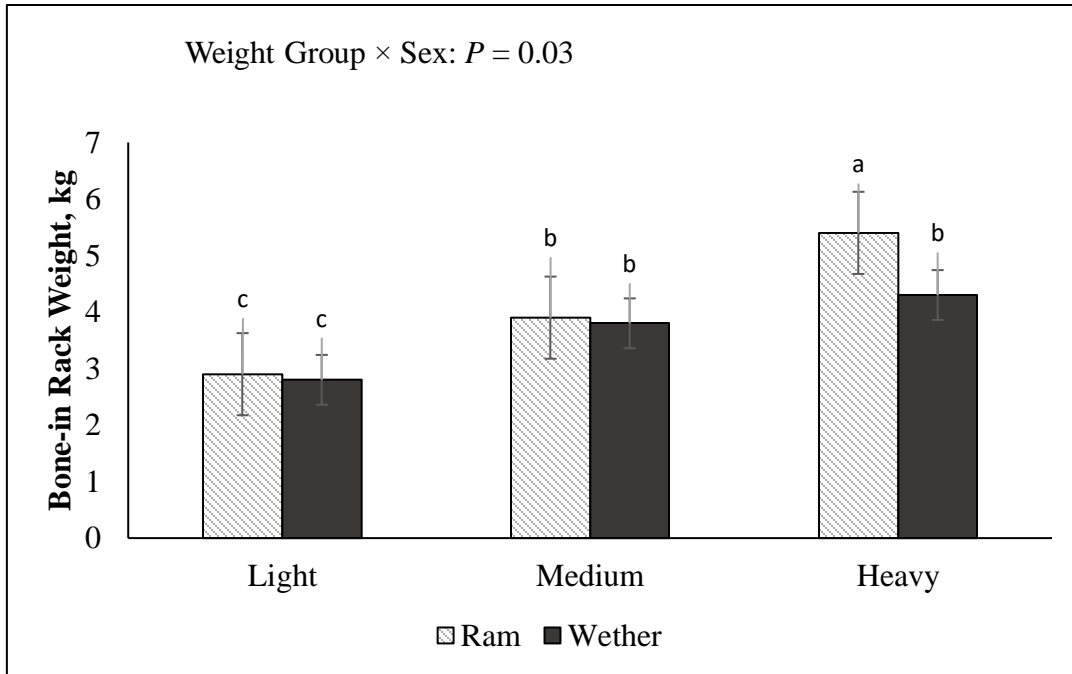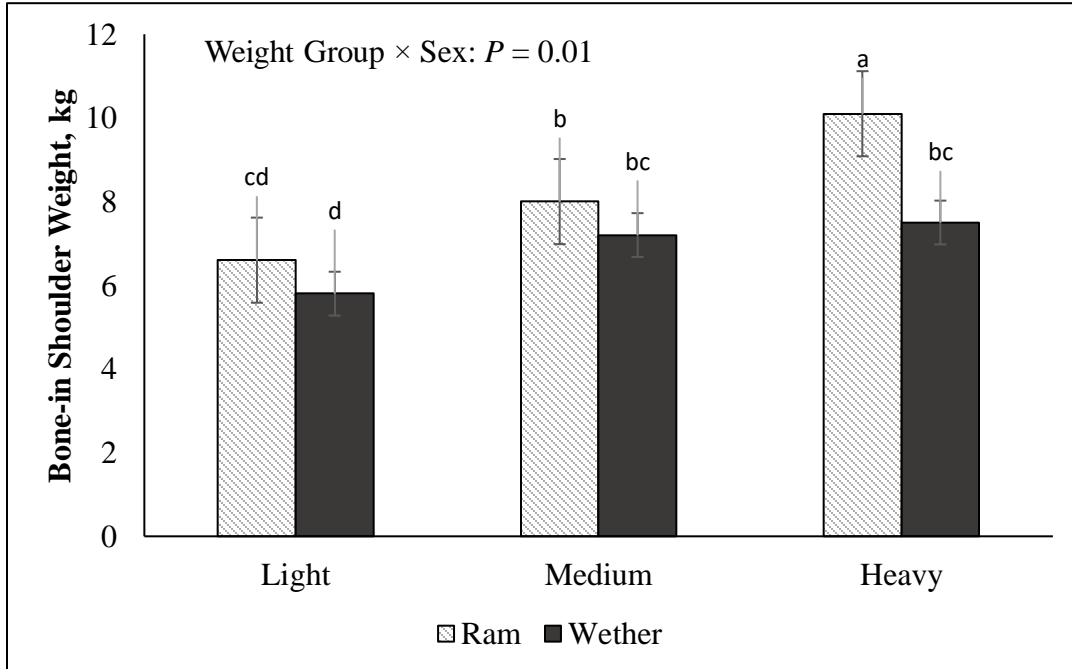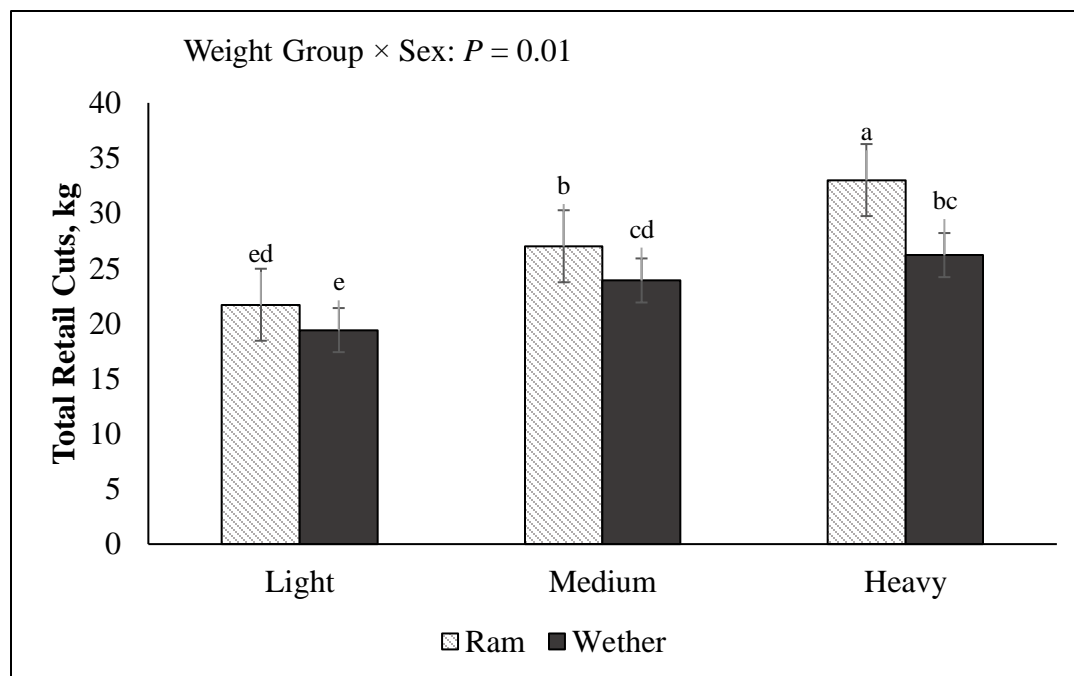**Figure 3.5.** Weight of bone-in total retail cuts based on the interaction between lamb sex and slaughter weight group. [abcde]Means not sharing a common superscript are different ($P < 0.05$).

Table 3.4. Least square means and standard errors of carcass characteristics based on lamb sex.

Carcass characteristics	Sex		SEM	*P*-Value
	Ram	Wether		
Dressing percentage[1], %	54.1	55.2	0.57	0.21
12th rib backfat depth[2], cm	0.74	1.05	0.08	0.02
Leg conformation score[4]	12.8	12.0	0.23	0.03
Flank streaking[4]	12.7	12.1	0.30	0.17
Ribeye area[3], cm^2	19.4	17.0	0.54	0.01
Body-wall thickness[5], cm	2.70	2.90	0.11	0.24
Quality Grade (QG)[4]	12.8	12.0	0.20	0.01
Yield Grade (YG)[6]	3.3	4.6	0.32	0.02

[1]Determined from the HCW and live weight taken prior to slaughter.

[2]Measured to the nearest centimeter between the 12th and 13th rib over the middle of the ribeye muscle (average of both sides).

[3]Measurement of the cross-sectioned area of the ribeye muscle, taken between the 12th and 13th rib.

[4]Average choice = 11, choice plus = 12, low prime = 13.

[5]Measured between the 12th and 13th rib, 11.45 cm from the center of the spine.

[6]Calculated as YG = 0.4 + (10 x backfat thickness).

Table 3.5. Least square means and standard errors of carcass characteristics based on lamb slaughter weight group.

Carcass characteristics	Weight Group			SEM	*P*-Value
	Light	Medium	Heavy		
Dressing percentage[1], %	52.8[a]	55.3[b]	55.9[b]	0.72	0.02
12th rib backfat depth[2], cm	0.58[a]	0.78[a]	1.3[b]	1.0	0.0004
Leg conformation score[4]	11.8	12.9	12.5	0.30	0.06
Flank streaking[4]	11.3[a]	13.3[b]	12.7[ab]	0.38	0.007
Ribeye area[3], cm^2	17.0	19.4	18.3	0.69	0.065
Body-wall thickness[5], cm	2.1[a]	2.7[b]	3.6[c]	1.40	<0.0001
Quality Grade (QG)[4]	11.3[a]	13.1[b]	12.8[b]	0.26	0.0004
Yield Grade (YG)[6]	2.7[a]	3.5[a]	5.7[b]	0.41	0.0004

[1]Determined from the HCW and live weight taken prior to slaughter.
[2]Measured to the nearest centimeter between the 12th and 13th rib over the middle of the ribeye muscle (average of both sides).
[3]Measurement of the cross-sectioned area of the ribeye muscle, taken between the 12th and 13th rib.
[4]Average choice = 11, choice plus = 12, low prime = 13.
[5]Measured between the 12th and 13th rib, 11.45 cm from the center of the spine.
[6]Calculated as YG = 0.4 + (10 x backfat thickness).
[ab]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

Finally, there was an observed castration by slaughter weight effect when examining shoulder and rack weights ($P = 0.013$, $P = 0.03$, respectively; Figures 3.3 and 3.4), where in both cases heavy rams showed the greatest yields compared to the other treatment groups ($P < 0.005$). Ram lambs had heavier ($P < 0.0001$, $P < 0.006$; Table 3.6) bone-in leg and loin weights than wethers. Ram lambs quantified a 3.98 kg increase in total bone-in subprimal cut weights (leg, loin, rack, shoulder) over wether lambs and there was an interaction ($P = 0.01$; Figure 3.5) between sex and slaughter weight when examining total subprimal cuts.

Table 3.6. Least square means and standard errors of bone-in subprimal cuts based on lamb sex, slaughter weight group, and sex × weight group interaction.

Carcass characteristics	Sex		Weight Group			SEM	P-Value		
	Ram	Wether	Light	Medium	Heavy		Sex	Weight Group	Sex × Weight Group
Loin, kg	3.51	3.02	2.78^a	3.48^b	3.52^b	0.12	0.01	0.006	0.50
Leg, kg	11.4	9.69	8.74^a	10.54^b	12.43^c	0.15	<0.0001	<0.0001	0.20
Shoulder, kg	8.21	6.82	6.17	7.57	8.79	0.23	<0.0001	<0.0001	0.01
Rack, kg	4.07	3.87	2.85	3.87	4.84	0.14	0.01	<0.0001	0.03
Total subprimal cuts[1], kg	27.18	23.21	20.55	25.46	29.59	0.49	<0.0001	<0.0001	0.01

[1]Sum of four bone-in subprimal cuts: loin, leg, rack, and shoulder.
^{abc}Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

Sensory characteristics

There was no ($P > 0.05$) significant interaction between castration effects and slaughter weight for all sensory characteristics. Meat from wether lambs had the greatest ($P = 0.040$; Table 3.7) flavor liking and light lambs were favored ($P = 0.030$; Table 3.8) over heavy lambs, but there were no ($P = 0.24$: Table 3.8) differences between heavy and medium weight groups and light and medium weight groups ($P = 0.47$; Table 3.8). Ram lambs were rated to have greater ($P < 0.001$; Table 3.7) lamb flavor intensity than wethers and heavy lambs were preferred ($P = 0.02$; Table 3.8) over medium weight lambs. The higher flavor intensity found in ram lambs was rated closer to the flavor JAR point than wethers ($P = 0.003$; Table 3.9) and heavy weight lambs were closer ($P = 0.02$; Table 3.10) to the flavor JAR point compared to light weight lambs. Even so, panelists rated both ram lambs and wethers as not having enough lamb flavor intensity. Lamb originating from rams had greater ($P < 0.001$; Table 3.7) off-flavor intensity scores than wethers, and heavy weight lambs had greater ($P = 0.02$; Table 3.8) off-flavor intensity scores than light weight lambs. Furthermore, there were no ($P > 0.05$; Tables 3.7 and 3.8) texture or juiciness differences based on sex or slaughter weight. However, there were differences in toughness based on sex, where meat from ram lambs was tougher ($P = 0.03$; Table 3.7) than wether meat, but no ($P = 0.19$; Table 3.8) differences based on weight group. When looking at toughness JAR, wethers were rated closer ($P = 0.001$; Table 3.9) to the JAR point than rams, and light/medium weight lambs were rated closer ($P = 0.01$; Table 3.10) to the JAR point than heavy lambs. There were no ($P = 0.27$, $P = 0.35$, respectively; Tables 3.9 and 3.10) differences in juiciness JAR based on sex and weight group. Overall, meat from wether lambs had greater ($P = 0.001$; Table 3.7) overall liking than ram lambs, and there were no ($P = 0.075$; Table 3.8) differences between weight groups.

Table 3.7. Least square means for sensory attribute scores in lamb burgers by sex.

Sensory Attributes	Sex		SEM	P-Value
	Ram	Wether		
Overall Liking	70.6	73.5	1.44	0.0008
Flavor Liking	70.4	70.4	1.45	0.0004
Texture Liking	70.8	72.2	1.39	0.085
Lamb Flavor Intensity	34.6	30.3	1.62	<0.0001
Toughness Intensity	28.2	26.5	1.44	0.03
Juiciness Intensity	26.5	27.0	1.50	0.55
Off-Flavor Intensity	24.7	20.7	1.83	<0.0001

Table 3.8. Least square means for sensory attribute scores in lamb burgers by slaughter weight group.

Sensory Attributes	Weight Group			SEM	P-Value
	Light	Medium	Heavy		
Overall Liking	73.4	71.9	70.9	1.62	0.08
Flavor Liking	73.2[a]	72.0[ab]	70.3[b]	1.64	0.04
Texture Liking	72.4	70.9	71.2	1.53	0.3
Lamb Flavor Intensity	31.9[ab]	31.3[a]	34.2[b]	1.80	0.03
Toughness Intensity	26.4	27.4	28.5	1.58	0.2
Juiciness Intensity	26.6	25.7	27.9	1.80	0.05
Off-Flavor Intensity	21.0[a]	22.5[ab]	24.6[b]	2.05	0.02

[ab]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

Table 3.9. Least square means for just-about-right (JAR) scores in lamb burgers by sex.

Sensory Attributes	Sex		SEM	P-Value
	Ram	Wether		
Flavor JAR	68.7	64.3	1.55	<0.0001
Juiciness JAR	57.2	58.2	1.89	0.27
Toughness JAR	77.1	74.6	0.99	0.0008

Table 3.10. Least square means for just-about-right (JAR) scores in lamb burgers by slaughter weight group.

Sensory Attributes	Weight Group			SEM	*P*-Value
	Light	Medium	Heavy		
Flavor JAR	66.6[ab]	64.7[a]	68.1[b]	1.72	0.02
Juiciness JAR	57.7	56.8	58.5	2.20	0.35
Toughness JAR	75.2[a]	74.9[a]	77.5[b]	1.12	0.001

[ab]Least squares means in the same row lacking a common superscript differ (*P* < 0.05).

Discussion

Ram lambs outperformed wethers in ADG, consistent with previous studies (Walker, 1950; Jacobs, 1970; Kemp et al., 1970; Arnold et al., 1988), who found up to 5 kg increase in ADG in rams over wethers. Similar to ADG, HCW of ram lambs were significantly greater than wethers. Often, HCW doesn't correlate to high retail cut yields in rams because of the tendency for rams to have decreased dressing percentages (Johnson et al., 2007). Based on dressing percent of the rams in our study we can hypothesize that the ram lambs in all weight groups had not reached their physiological growth peak and did not possess the undesirable "bucky" characteristics (heavy pelts, heads, and testes) that a post-pubertal ram would have. Literature indicated that the observed decrease in dressing percentage in rams is due to teste weight, heavy pelts, and heads (Bradford and Spurlock, 1964; Lirette et al., 1984). Our data shows no differences in dressing percent between wethers and ram lambs but does show an advantage in HCW for ram lambs. High HCW and increased dressing percentages result in higher retail cut yields and more end product. More importantly, ram lambs had significantly lower backfat thickness, which correlated with lower, more desirable YG scores. In contrast to prior studies, which have reported greater QG scores for wether lambs when compared to ram lambs (Crouse et al., 1981); we reported greater QG scores in ram lambs. Additionally, in previous research

rams had lower leg and overall conformation scores (Ho et al., 1989; Jeremiah et al., 1997) when compared to wether and ewe lambs. Results from our research indicate that ram lambs had greater leg conformation scores than wethers. Ram lambs in this study possessed superior muscling when compared to wether lambs, which could be attributed to testosterone although testosterone was not tested in this particular study. Testosterone has been proven to be the principle testicular hormone responsible for increased muscularity in intact male animals (Schanbacher, 1980).

Literature indicates that ram lambs have the tendency to deposit lean weight differently than wether and ewe lambs. Kemp et al. (1970) reported that ram lambs have a greater proportion of lower value cuts such as shoulder and neck when compared to wethers. The authors speculate that this increased proportion of shoulder weight is caused by stimulation of muscle growth in the shoulder and neck caused by testosterone. If carcasses possess too much or "prominent" neck and shoulder muscles, they are described as having "bucky" conformation and are not eligible to be graded USDA Choice or Prime. We did not identify carcasses with a "bucky" conformation, and there was no effect of sex on shoulder weight but there was a sex by weight interaction for shoulder primal weights. The heavy weight ram lambs possessed heavier shoulder weights than all other sex and weight combinations. This may indicate that the ram lambs did not start displaying "bucky" conformation until the heaviest weight group. But the heavy weight ram lambs also had the heaviest rack weights, and as we know the rack is one of the most desirable and expensive cuts of lamb ($9.23/lb. bone-in rack, May 2018). Although the heavy weight ram lambs had an increase in lower value cuts, they also had the largest amount of high value cuts. When looking at retail yields and carcass characteristics of the lambs on our study, the four subprimal cuts appear to have different inherent properties and are influenced

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differently by sex and weight. A brief economic analysis of the subprimal cuts showed that ram lambs quantified a $4.30 increase in bone-in loin value (IMPS #242), and $14.60 increase in bone-in leg (IMPS #233A) value when compared to wether lambs. Heavy weight ram lambs saw a $22.30 increase in bone-in rack (IMPS #204) value, and $17.70 increase in bone-in shoulder (IMPS #206) value when compared to heavy weight wether lambs. All numbers are based on the national 5-day rolling average boxed lamb cuts for fresh American lamb provided by USDA market news from May 2018.

Many studies have been performed regarding lamb meat characteristics (Jacobs, 1970; Kemp, 1970; Busboom, 1981), most of which show the relationship between diet, breed, slaughter age, and genetics on carcass characteristics and some sensory traits. The majority of these studies are outdated and have not utilized a full sensory taste panel. However, this study provides vital sensory characterization of lamb meat quality through sensory differences, which is a critical tool to improve meat quality (Issanchou, 1996) and update outdated literature on lamb flavor. Furthermore, the higher lamb flavor intensity of ram lambs in this study was found to be closer to the JAR point ("just-right" flavor, based on consumer preference) than wethers, which is important because lamb's distinctive flavor is the most important decider for lamb consumers (Hoffman, 2015). Garrigus (1967) stated that a majority of consumers prefer to have lamb that is relatively lean, tender, juicy, and mild in flavor. These results showed that ram lamb scores were similar in palatability to wether lambs based on these four consumer criteria (leanness, tenderness, juiciness, and mild flavor). Flavor profile characteristics showed that ram lambs, especially light and medium weight (55 kg – 66 kg) ram lambs provide a high degree of palatability to consumers. Furthermore, based on the sensory characteristics determined in this study, we can suggest that intact lambs up to around 200 days of age (6 months) and 83 kg will

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produce a carcass that could result in a satisfactory eating experience. Further research in consumer familiarity and satisfaction is needed to determine the cause of off-flavor scores attained by ram lambs and heavy weight lambs in this study.

The results of this study clearly show that the use of intact male lambs will result in efficient growth, increased muscularity, and decreased USDA YG scores. Although the heavy rams possessed heavier lower value cuts, they also had heavier high value cuts, and medium weight ram lambs had similar retail cut weights to heavy wether lambs. Additionally, our results lead to the conclusion that intact lambs up to at least 6.5 months of age (198 d) provide little to no detriment to consumer palatability. More importantly, results place ram lamb flavor intensity closer to the JAR point, which indicates that not only is ram lamb meat palatable, but actually favored over wether lamb meat in this case. Finally, these findings showed that the use of intact male lambs is a simple method of increasing American lamb quality, where additional investigation is warranted to demonstrate the economic benefits of this method.

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APPENDIX A. THE EFFECT OF SEASON OF BIRTH ON LAMB SENSORY ATTRIBUTES

It has been suggested that season of birth and season of harvest may affect eating quality attributes of ram lambs. A study performed by Yalcintan and others (2017) evaluated sensory characteristics of lambs from three rearing seasons (winter, spring-summer, and fall) and found that spring reared lambs had the lowest acceptance in terms of flavor intensity, flavor quality and overall acceptability in the sensory evaluation panel. We hypothesize that spring born ram lambs harvested in the fall/winter may have increased lamb flavor or off-flavors due to increased androgens, as it is common knowledge that sheep are short-day breeders and short days stimulate breeding activity (Chemineau et al., 1992). Previous research has shown that testosterone peaks increase from the non-breeding to the breeding season (Schanbacher & Ford, 1976; Wilson and Lapwood, 1978; Pelletier et al., 1982). We used our research (experiment 1 and experiment 2) to test this hypothesis.

Analysis of all lambs in experiment 1 (n = 24) compared to medium weight lambs in experiment 2 (n = 8) were used for this comparison. Exclusion of light and heavy weight lambs from experiment 2 were to ensure lambs from both experiments were compared at a similar backfat thickness. We believe that the increased fat content of heavy weight lambs is part of what is driving the increased lamb flavor intensity found in lamb burgers from experiment 2. Previous research shows us that species-specific flavor (i.e. lamb flavor) is stored primarily in the fat (Hornstein, 1971; Mottram, 1998) and Sañudo et al. (2000) and Muela et al. (2010) reported that lamb meat from fattier carcasses had higher flavor intensity. Therefore, for the current comparison we wanted to single out season of birth without flavor being affected by fat content.

Season of birth/slaughter in the present study appears to have little to no influence on sensory characteristics of lamb meat. The results indicate that the only differences found between rams of each season were in juiciness intensity and juiciness JAR (Table A.1). There were differences found between rams and wethers of the same season (Table A.1) which was expected, although that was not the focus of this comparison. If there was an increase in off-flavors found in spring born/fall slaughtered ram lambs, then producers may want to consider out-of-season breeding if looking to direct market ram lambs with a high level of eating satisfaction. However, this small comparison found only minor differences in sensory characteristics between the two seasons, and the differences found may not be caused by season of birth/slaughter. Further research is warranted on season of birth and its effect on ram lamb sensory characteristics. For producer application, this research shows that ram lambs born in either the spring or fall season will provide satisfactory eating quality up to 0.30 inches of backfat thickness, and 6 months of age. Backfat thickness is an important quality to note, as it has been shown that increased backfat thickness is correlated with increased lamb flavor intensity, and in some cases, the detection of off-flavors.

Table A.1. Least square means for sensory attribute scores in lamb burgers when comparing spring vs. fall born ram and wether lambs.

Sensory Attributes	Season of birth/ sex				SEM	*P*-Value
	Fall Born		Spring Born			
	Ram	Wether	Ram	Wether		
Overall Liking	71.7	72.9	71.6	72.3	0.92	0.5
Flavor Liking	70.4	72.8	71.8	72.2	0.95	0.08
Texture Liking	72.0	72.0	71.6	70.2	0.92	0.4
Lamb Flavor Intensity	31.4[ab]	29.4[ab]	32.6[a]	30.0[b]	0.98	0.04
Toughness Intensity	27.4	27.1	28.5	26.3	0.87	0.3
Juiciness Intensity	29.7[a]	30.7[a]	26.1[b]	25.3[b]	0.89	<0.0001
Off-Flavor Intensity	23.4[a]	20.7[b]	23.5[ab]	21.4[ab]	1.03	0.03
Flavor JAR[1]	65.7	65.3	66.6	62.8	1.1	0.08
Juiciness JAR[1]	63.6[a]	64.4[a]	57.3[b]	56.4[b]	1.0	<0.0001
Toughness JAR[1]	76.5[a]	76.3[a]	76.5[a]	73.3[b]	0.8	0.006

[2]Measured on a 150 point just-about-right (JAR) scale. Used to identify whether an attribute us present at a level that is too high (150 points), too low (0 points), or "just-about-right" (75 points).

[ab]Means not sharing a common superscript are different (P < 0.05).

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APPENDIX B. PLASMA TESTOSTERONE AND RAM TESTICULAR BLOOD FLOW MEASUREMENTS

Materials and methods

Testosterone

Blood samples for plasma testosterone concentrations were collected biweekly starting when the lambs averaged 45 kg body weight until slaughter. Samples were collected for all 20 lambs, although the wether lambs were found to have no plasma testosterone (as expected). Blood samples were centrifuged at 4 °C at 3000g for 20 minutes. The plasma was decanted into micro centrifuge tubes and kept frozen until analysis. Serum testosterone concentrations were measured using a chemiluminescent enzyme immunoassay (Immulite/Immulite 1000 Total Testosterone, Siemens Medical Solutions Diagnostics, Los Angeles, CA).

Ultrasonography

Measurements of testicular blood flow were measured on three dates (2/14/17, 2/28/17, 4/4/17) and the means of the three dates were averaged for use in this experiment. Ram lambs (n = 7) from the phase 2 lamb flavor study (fall 2016-spring 2017) were randomly selected for ultrasonography. The supratesticular artery (STA) and the pampiniform plexus were used to determine testicular blood flow parameters (Figure 4.1), which were assessed using a duplex B-mode (brightness mode) and D-mode (Doppler spectrum) program of the color Doppler SSD-3500 ultrasound instrument fitted with a 5.0-MHz finger transducer (UST-995; Aloka). All color-Doppler scans were performed at a constant gain setting, filter setting, and velocity range setting. For each ultrasonography examination, rams were placed in an elevated crate and Aquasonic gel was applied to the probe before placing on the scrotum. Cardiac cycle waveforms were plotted in D-mode by velocity (in cm/sec; y-axis) and time (sec; x-axis). Peak systolic

velocity (PSV), pulsatility index (PI), resistive index (RI), end diastolic velocity (EDV), Mean

velocity (MnV), flow volume (FV), cross-sectional area (CSA), cross sectional diameter (CSD),

systolic/diastolic ratio (S/D ratio), and heart rate (HR) were calculated using preset functions on

the ultrasound instrument. The average angle of insonation for the STA was 50°. Equations are

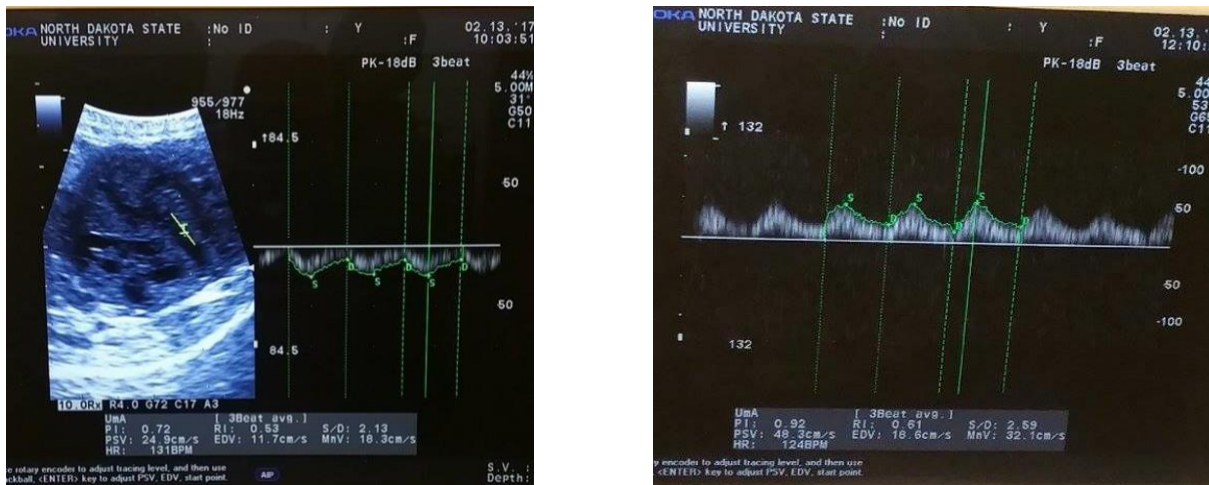as follows: *PI = [PSV – EDV]/MnV and RI = [PSV-EDV]/PSV.*

Figure B.1. Ultrasonography images of data collected from pampiniform plexus of ram lambs to obtain blood flow measurements.

Statistical analysis

In this study, individual lamb was used as the experimental unit, and serum testosterone

level, testicular blood flow, and weight were examined as fixed effects. Testosterone and

testicular blood flow measures were tested as discrete variables (e.g. low, medium, high level

groups). To designate these groups, summary statistics were run using the univariate procedure

in SAS where any value under the 25% quantile was designated as "low" group, 25%-50%

quantile was designated "medium", 50%-75% quantile was "medium-high, and above 75%

quantile was "high". Data were tested for normality of the residuals for each variable. Data were

analyzed using the GLM Procedure of SAS. The Tukey-Kramer test was used to quantify the

associations between the traits evaluated ($\alpha = 0.05$).

Results and discussion

Results indicate that ram lamb weight influences plasma testosterone concentrations, where medium weight (70 kg) ram lambs displayed higher plasma testosterone levels than light (60 kg) and heavy (86 kg) ram lambs (Table B1). Ram weight did not significantly influence any testicular blood flow measures ($P > 0.05$; Table B.1).

Table B.1. Least square means for ram lamb testicular blood flow measures based on body weight groups.

Measures	Ram Weight			P-Value
	Light[1]	Medium[2]	Heavy[3]	
Testosterone	0.71 ± 0.67^b	2.44 ± 0.80^a	0.92 ± 0.23^b	0.02
Scrotal Circumference	31.33 ± 1.07^b	31.88 ± 1.07^b	36 ± 0.93^a	0.03
Pulsatility Index	1.01 ± 0.22	0.90 ± 0.03	0.89 ± 0.04	0.43
Resistive Index	0.62 ± 0.08	0.61 ± 0.02	0.61 ± 0.02	0.97
Peak Systolic Velocity	35.64 ± 3.5	41.93 ± 11.5	41.49 ± 20.08	0.81
End Diastolic Velocity	13.32 ± 3.84	14.14 ± 1.81	15.89 ± 7.1	0.78
Flow Volume	31.96 ± 5.57	30.37 ± 3.19	34.29 ± 9.12	0.72

[1]Light average weight of 60 kg.
[2]Medium average weight of 70 kg.
[3]Heavy average weight of 86 kg.
[ab]Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

Previous research has indicated that non-pubertal ram lambs produce consistently low plasma testosterone concentrations, averaging about 0.90 ± 2 ng/ml. A significant increase in testosterone concentrations at the time of pubertal onset will be observed. As lambs attain puberty, testosterone concentrations will spike to approximately 2.6 ± 0.5 ng/ml (McNatty et al., 1998). The spike of testosterone concentrations at the attainment of puberty may explain the significant difference in testosterone levels between medium weight ram lambs versus light and heavy ram lambs in this study. Furthermore, up to 10 peaks of testosterone have been observed in a 24-hour period in post-pubertal ram lambs, with levels ranging from <1 ng to 25 ng/ml plasma testosterone. Additionally, seasonal variability in testosterone levels have been reported

(Purvis et al., 1974; Sanford et al., 1974). The daily and seasonal spikes in testosterone levels can make it difficult to quantify the actual testosterone levels in ram lambs.

When looking at scrotal circumference, heavy weight ram lambs had larger scrotal circumferences than light or medium ram lambs (Table B.1). This agrees with Dyrmundsson (1973) who determined that body weight is highly correlated to scrotal circumference. Relationships between scrotal circumference and sperm production have been reported in rams (Lino & Braden, 1972). It is recommended that mature rams used for breeding have a minimum scrotal circumference of 33 cm, where 30 cm is acceptable for ram lambs. All of the lambs in the study fall within the acceptable breeding scrotal circumference, indicating that they may have attained puberty during the study.

Additionally, correlations were examined, and positive correlations were found between testicular blood flow measures of PI and RI ($P = 0.0004$; Table B.2). A positive correlation between PSV and EDV were also shown ($P = 0.0010$; Table B.2). This data may prove useful as a reference in future research.

Table B.2. Pearson correlation coefficients (*P*-Value) for testosterone, scrotal circumference (SC), pulsatility index (PI), resistive index (RI), peak systolic velocity (PSV), end diastolic velocity (EDV), and flow volume (FV).

	Testosterone	SC	PI	RI	PSV	EDV	FV
Testosterone	—	-0.52 (0.12)	-0.13 (0.72)	0.07 (0.84)	-0.02 (0.95)	-0.07 (0.85)	-0.05 (0.88)
SC		—	-0.27 (0.44)	-0.18 (0.62)	0.43 (0.21)	0.39 (0.27)	0.18 (0.61)
PI			—	0.90 **(0.0004)**	-0.23 (0.52)	-0.45 (0.19)	-0.45 (0.20)
RI				—	-0.13 (0.71)	-0.35 (0.32)	-0.48 (0.16)
PSV					—	0.87 **(0.001)**	0.17 (0.64)
EDV						—	0.50 (0.14)
FV							—

In conclusion, testicular blood flow measures and plasma testosterone levels are greatly dependent on seasonality and time of day. It has been proposed that using testosterone levels and blood flow parameters could be useful in predicting attainment of puberty and therefore potential off-flavor development in ram lambs. However, blood flow measurements and testosterone may not be an effective way of determining sensory characteristics of ram lambs. This study may provide a better understanding of testicular blood flow parameters and how they correlate with weight and each other. The blood flow measures from this study may be used as reference ranges for blood flow parameters in rams, where there is little to no references. This data adds to the knowledge on Doppler ultrasound techniques used for testicular blood flow, which is a non-invasive technique for monitoring the development and function of the accessory sex organs. Further research is warranted to determine how blood flow parameters can predict the attainment of puberty and its relationship to sensory characteristics of ram lamb meat.

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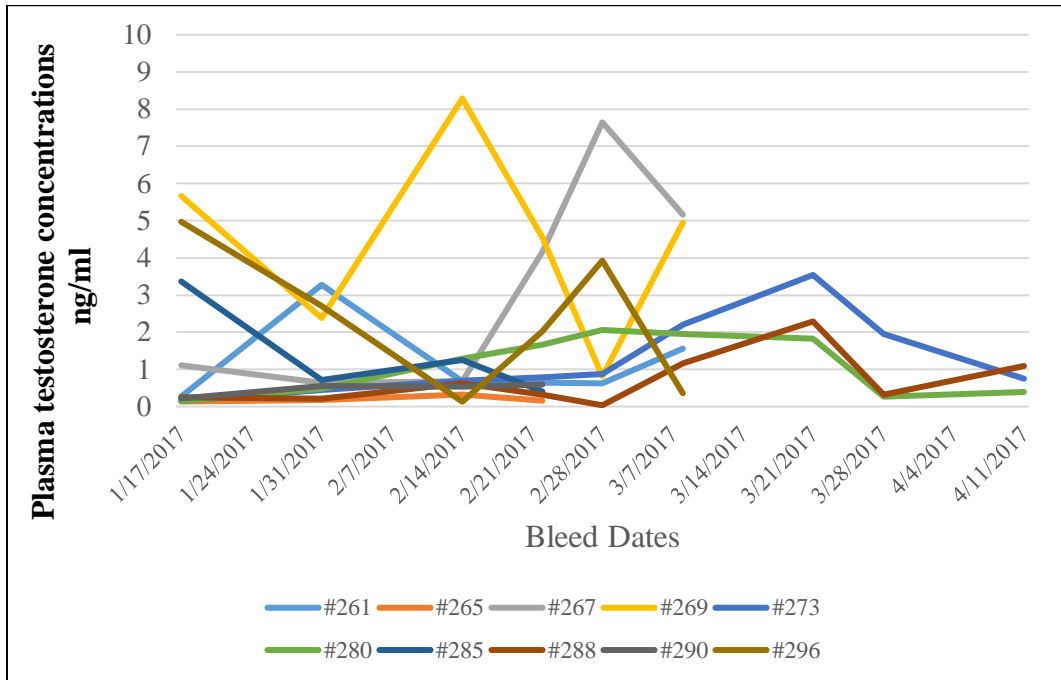
APPENDIX C. SUPPLEMENTARY GRAPHS

Figure C.1. Plasma testosterone levels (ng/ml) over time for individual ram lambs.