EVALUATION OF SUSTAINABLE FORAGE SYSTEMS FOR MEAT GOAT

PRODUCTION IN THE SOUTHERN US

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# EVALUATION OF SUSTAINABLE FORAGE SYSTEMS FOR MEAT GOAT PRODUCTION IN THE SOUTHERN US

Carla E. Hopkins-Shoemaker

A Dissertation

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EVALUATION OF SUSTAINABLE FORAGE SYSTEMS FOR MEAT GOAT PRODUCTION IN THE SOUTHERN US

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# VITA

Carla Elaine Hopkins-Shoemaker, was born on November 23, 1966 in Phenix City, Alabama. She graduated from Beauregard High School in 1985 in Opelika, Alabama. She entered Auburn University, Auburn, Alabama and graduated with a B. S. degree in Animal Sciences in 2000. Upon completion she pursued a Master of Science (M. S.) degree in Animal and Poultry Science at Tuskegee University, Tuskegee, Alabama. Upon graduation in August 2002 she immediately began her program for the degree of Doctor of Philosophy in the Department of Animal Sciences at Auburn University, Auburn, Alabama.

DISSERTATION ABSTRACT

EVALUATION OF SUSTAINABLE FORAGE SYSTEMS FOR MEAT GOAT PRODUCTION IN THE SOUTHERN US

Carla Elaine Hopkins-Shoemaker

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The effect of production systems on growth, carcass traits and carcass quality of 45 Boer wether goat kids was determined and the development of prediction equations for carcass composition was examined using carcasses from 89 goat kids of varying weights and feeding regimes. Forty-five Boer crossbred goat kids were randomly assigned to 1 of 3 production systems. Concentrate diet (CONC), bahiagrass pasture (BG) or mimosa browse (MB). Growth was measured by weighing goats every two weeks for 14 weeks. Goats receiving CONC had higher ($P = 0.001$) average daily gains, heavier ($P > 0.05$) carcass weights, higher dressing and shrinkage percentages, greater body wall fat and more kilograms of total carcass lean than BG or MB goats. Moisture and ash percentages were higher ($P < 0.05$) while fat percentages were lower ($P < 0.05$) in goats

grazing BG and browsing MB carcasses than goats receiving CONC. Total fatty acid concentrations were higher ($P = 0.01$) in CONC goats and fatty acid profiles indicated that goats receiving CONC contained higher ($P = 0.05$) amounts of C18:2 n-6, while goats browsing MB contained higher ($P = 0.001$) amounts of C18:3 n-3, with a lower n-6:n-3 ratio. Retail data indicated that surface discoloration occurs at d 4 of display regardless of production system. Cook loss and sensory attributes were not affected ($P > 0.05$) by production system and WBSF values were within acceptable values for tender meat products. Whole body fat percentages were predicted from the 9-10-11$^{th}$ rib cut and carcass traits with an $R^2$ value of 0.81 and 0.74, respectively.

These results indicated that goat kids receiving a concentrate-based diet produced heavier carcasses with higher fat percentage and more total carcass lean than goat kids receiving a primarily forage-based diet. Managing goats on forage-based systems improved the fatty acid profile and lowered total fatty acid content with no adverse effects on meat quality or palatability traits. These data also indicated that fat percentages in goat carcasses can be predicted accurately utilizing the 9-10-11$^{th}$ rib cut and carcass traits.

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# I. INTRODUCTION

The goat's ability to survive under adverse environmental conditions was possibly one of the reasons they were among the first animals domesticated by man for the production of meat, milk, skins and fiber (Gall, 1981). In the southeastern US, goats are becoming important contributors to the income of limited resource farmers due to the regions forage ecology. The use of a pure grass range or pasture system common to the southeast US (bahaigrass, bermudagrass and infected tall fescue) will not provide an adequate quality diet for optimal growth of goats (Lusigi et al., 1984). Feed accounts for over 70 percent of the total production cost in most livestock operations (Gelaye, 1987); therefore, a forage-based production system may be the key to a profitable meat goat operation. Browsing is an inherent feeding behavior of goats, therefore the development and utilization of alternative production systems that incorporate and utilize the abundant browse species (mimosa, kudzu, honey suckle, locust, willow) available in the southern US may improve production and profitability of meat goats for small farmers.

Goat meat is one of the most widely eaten red meats in the world with production rates of 3.7 million tons in 2001 (Devendra, 1990; Dubeuf et al., 2003). The demand for goat meat has continued to increase in the US with an 11 percent increase in federally inspected harvest numbers from 2000 to 2004 (NASS, 2005). The US Department of Agriculture Economic Research Service (USDA, ERS, 2005) attributes the increased

demand for goat meat to the ethnic diversity within the US population. The growth of the industry has not been easy, and obstacles remain before goat can become as economicly viable as beef, pork or chicken. Public perception and inconsistencies in price and quality are among the problems facing the industry today. In order for producers to maximize profit margins they have to bring a consistently good quality animal to the market. Goat meat value may be increased through production practices, which minimize input costs and increase income per unit. Diet has a significant effect on carcass characteristics and meat quality. Perceptions of meat quality vary from country to country and between ethnic groups within countries (Shorthose and Harris, 1991). Local customs and preferences (Naude and Hofmeyr, 1981) influence the acceptability of meat products. Today's health conscious consumer demands a more healthy diet; therefore, opportunities exist for goat meat because of its dietetic and health qualities. Goat meat is leaner than other red meats and has less saturated fat and lower saturated to unsaturated fatty acid ratios than lamb (Sheridan et al., 2003). However, goat meat is generally unavailable in retail markets and annual consumption is low when compared to other meat products in the US (USDA, 1998). The low consumption rate may be related to the unfamiliarity of goat meat and its intense and inherent aroma and flavor (Rhee et al., 2003). Changes from whole or half carcasses to retail cuts and the production of value-added products that appeal to both traditional and ethnic populations should increase the consumption and profitability of goat meat. However, goat meat is seldom fabricated and displayed in retail stores; therefore little data are available on carcass quality characteristics such as ideal color and shelf life stability.

With the growing popularity of leaner meat products it is important to understand the determinants of carcass composition. Due to the low level of fat in goat carcasses, compositional changes may not affect meat quality unless there are breeds of goats or production systems which encourage favorable fattening of goats (Gaili et al., 1972). The most accurate method of determining carcass composition is by chemical analysis of several muscles within the carcass (Callow, 1962). One of the first methods used to simplify measuring the composition of beef carcasses was to physically separate and chemically analyze the 9-10-11$^{th}$ rib section (Hankins and Howe, 1946). Cole et al. (1960 and 1962) and Ramsey et al. (1962) later related carcass yield traits to the separable carcass muscle and developed equations to predict the amount of separable muscle in beef carcasses. Goats are sold to the consumer as bone-in whole carcasses or bone-in primal cuts. In order to bring value-based marketing to the goat industry, prediction methods based on carcass measurements are needed to determine the amount of saleable product and its quality. Prediction of carcass composition using carcass measurements will allow rapid, precise and cost-effective assessment without total dissection and destruction of the carcass.

# II. LITERATURE REVIEW

## Meat goats

Goats belong, scientifically, to the Bovidae family within the suborder of ruminants. Goats and sheep make up a tribe within the Bovidae family called Caprini. Goats are one of the smallest and earliest domesticated ruminants in the world. Historically, in the United States, goats have been used to produce fiber and milk. The recent increase in demand for goat meat from ethnic and health conscious groups has shifted the emphasis from fiber and milk to meat production. With the exception of the South African Boer goat and the New Zealand Kiko goat, there are no well defined meat goat breeds in the United States.

The introduction of the Boer goat from South Africa offered the opportunity to improve growth and carcass traits through crossbreeding programs using the Boer as a part of the composite breed. The most useful contribution of crossbreeding is to improve specific functions such as milk, meat or fiber production. In introducing improved breeds to indigenous populations, the adoption of criss-cross or rotational crossing may be necessary to keep the proportion of indigenous genes at the level, which maintains viability and reproductive efficiency. Blackburn (1995) conducted a comparative study between the Boer and the Spanish goat breeds in two locations, Texas and Oklahoma. Within the two locations forage quantities ranged from high forage, medium forage and

low forage avaliability. Breeding seasons consisted of fall and year round breeding. The Boer goat produced more sale weight per doe than Spanish goats on the high forage system however, when exposed to the medium or low forage conditions the Boer goat's advantage decreased. In general, as forage avaliability decreased, the Boer's performance ranked below that of the Spanish goat breed. Boer goats reach the optimum carcass weight in half the time as compared to crossbreeds (Newman and Paterson, 1997) however; effective use of the breed will depend on the forage resource base and the producer's ability to provide inputs into the production system. Introduction of the Boer goat stimulated significant interest especially in goat nutrition, health, genetic improvement, and reproduction. Most goats are raised on pasture or native range although small farm flocks are growing in number. Glimp (1995) reported an increase in opportunities for the U. S. and other countries in meat goat production due to ethnic consumer populations that continue to increase faster than goat numbers. Goats are usually managed as part of a multi-species grazing system with cattle and will continue to be valued for their ability to control noxious plants (Glimp, 1995).

## The meat goat industry

Traditionally, the fiber market has driven the goat industry, but meat is of increasing importance and is becoming a viable agricultural enterprise in the southeast United States (US). According to the USDA National Agricultural Statistics Service (NASS; 2005) survey all goat inventory in the United States on January 1, 2005, totaled 2.5 million head. Breeding goat inventory totaled 2.1 million head and market goats totaled 0.4 million head. Meat and all other goats totaled 1.97 million head, milk goats

totaled 283,500 head and Angora goats totaled 274,000 head. The 2004 kid crop was 1.67 million head for all goats. In 2002, Alabama with 47,270 meat goats, ranked eighth in the nation, however according the USDA NASS (2005) survey, Alabama ranked ninth in meat goat numbers with a 25 percent decrease in total goats within the state. The growth of the industry has not been easy, and obstacles remain before goats can become as economicly viable as beef, pork or chicken. Public perception, inconsistencies in price and quality and lack of processing facilities are among the problems facing the goat industry today. The Alabama Department of Agriculture and Industries reported annual harvest goat sales of 46,211 and 42,595 head for 2001 and 2002, respectively. The goat's average price per pound of live weight in Alabama ranged from $1.00 to $1.25 in the same years. In order for producers to obtain good prices for their animals, they have to bring a consistent, good quality animal to the auction.

Chevon (goat meat) is one of the most widely eaten red meats in the world especially in Asia, Africa, and the Far East (Devendra, 1990). The world production of goat meat has risen from 1.1 million tons in 1961 to 3.7 million tons in 2001 (Dubeuf et al., 2003). The demand for goat meat has continued to increase. In 2000 approximately 549,371 head of goats were harvested nationwide in federally inspected plants (USDA NASS, 2005). By 2004, harvest numbers had risen to nearly 611,754 head of goats; an 11 percent increase over the five year period. Goat harvest numbers pale in comparison to harvest numbers of cattle which were 35 million head in 2000 and 31 million head in 2004 resulting in an 11 percent decrease in harvest numbers, the number of lambs were 3 million head in 2000 and 2 million head in 2004 resulting in an 19 percent decrease in harvest numbers and the number of hogs were 96 million head in 2000 and 101 million

head in 2004 resulting in an 5 percent increase. The number of goats harvested in the same years represents approximately 1.7 percent of the cattle, 0.5 percent of the lambs and 20 percent of the hogs. However, of the three species, only the goat numbers have significantly increased over the last five years. Glimp et al. (1986) estimated that up to 20 percent of the goats produced sell directly to consumers and are unaccounted for in market reports for goat sales. Another 20 percent of the goats sold at auction are not harvested at inspected facilities but are sold to retail stores that cater to various ethnic groups. Even with significant increases in domestic harvest, the US is a net importer of goat meat. Approximately 98 percent of goat meat imported into the US originates in New Zealand and Australia (USDA FAS, 2004). In 2003, the US imported nearly 8.46 million kilograms of goat meat valued at 21.5 million dollars (USDA NASS, 2005). According to the USDA market news report, US to Mexico weekly livestock export summary of 2005, goat exports decreased from 3,765 in 2004 to 2,376 in 2005.

The US Department of Agriculture's Economic Research Service (USDA, ERS, 2005) attributes the increased demand for goat meat to ethnic diversity of the US population and extreme fragmentation of the marketplace. This change in demographic characteristics of consumers has led to changes in the demand for red meat products. It is widely accepted that the major demand for goat meat in the US comes primarily from various ethnic groups. There has been a dramatic growth of immigrants to the US and they are coming from countries where goat meat is a central part of their diet. According to the US Census Bureau (2000), 51.7 percent of the foreign-born population was from Latin America, 26.4 percent was from Asia, and 15.8 percent was from Europe. Over the last decade (1991-2000), immigration to the US has increased by 20 percent over the

pervious decade (1981–1990). Along with this major change in the geographic origins of the foreign-born, the US has seen a major change in settlement of these groups. The proportion of foreign-born population living in the West and South rose from 37.7 percent in 1970 to 65.5 percent in 2000 (US Census Bureau, 2000). The majority of end consumers for goat meat are found in major metropolitan areas. The major flow of domestic meat goats originates in Texas and other principle meat goat producing states (Tennessee, Georgia, and Alabama). The flow of meat originating primarily in these states terminates in major metropolitan areas (Northeast California, Texas and Florida) (Pinkerton et al., 1994; Pinkerton et al., 1991). The economic concept of elasticity measures the sensitivity between changes in production and prices, which ultimately determines supply. The supply of goats seems to be elastic (sustained improvements in prices offered would result in an increase in the production of goats because of the potential for producer profits). The supply and demand function for meat goats in the US is shifting upward. These upward shifts are indications of a growing industry.

## Ruminant growth

### *What is growth?*

Growth is defined as the production of new cells. Growth is typically measured as an increase in body mass, which includes not only cell multiplication (hyperplasia) but also cell enlargement (hypertrophy). It is an excess of protein synthesis over breakdown in body tissues simultaneously. Mature size is generally considered to be the point at which muscle mass reaches a maximum. During embryonic development, all tissues grow by hyperplasia; however postnatal growth of muscle mass occurs through

hypertropy and satellite cell replication (Goldspink, 1991). The full compliment of skeletal muscle fibers, in most mammals, is determined at birth. Growth rate can be influenced by factors such as plane of nutrition, hormonal status, and environment resulting in a mature body size that is below the genetically determined maximum (Widdowson, 1980). Hammond (1961) stated that differences between breeds in size are due to differences in skeleton size and in the number but not the size of muscle cells. Tissues such as blood cells, hair follicles, gastrointestinal epithelia and digestive tract organs continue to divide throughout life. Tissues associated with digestion have faster protein and cell turnover than skeletal muscle. The fractional protein synthesis in the ruminant's gastrointestinal tract ranges from 10 to 30 percent daily (McBride and Kelly, 1990). The digestive tract can account for 28 to 46 percent of whole body protein synthesis. Swick and Song (1974) reported the half-life for myofibrillar protein generally ranges from 18 to 50 days. Therefore, skeletal muscle may not be the primary site of protein synthesis.

Organs and tissues do not mature simultaneously. Batt (1980) reported growth rates of various tissues and various sites in animals fed for rapid or slow rates of growth. Based on relative growth rate, a general gradient in organ to muscle formation from head to tail and from extremities to the core is apparent causing the body shape to change over time. The head, brain, metatarsus and kidney fat region develops first followed by the neck, bone, tibia-fibula and intermuscular fat region. The thorax, muscle, femur and subcutaneous fat regions develop at the third level followed by the loin, fat, pelvis and intramuscular fat, which develop later in life. Therefore, body shape and composition change as an animal matures. The correct dietary nutrients must be supplied in order to

maintain optimum growth rates in ruminants. The traditional growth curve for mammals follows a characteristic sigmoid curve composed of prepubertal, self-accelerating, puberty, self-retarding and maturity phases of production. Muscle cell culture studies have suggested that growth inhibition is due to limitation in resources (space, nutrient supply, growth factors) or accumulation of products or inhibitory factors (hormones, steroids, growth factors) that restrict cell division or replication (Dayton and Hathaway, 1991).

***Measurement of growth***

Growth can be measured in animals by many different means. Rate of gain is usually calculated as the change in weight during a specific time interval. Average daily gain is calculated from the initial to the final body weight of the animal. Feed intake and rate of gain change as an animal matures and tends to reach a plateau at the animals mature body weight. Body mass will change over a period of time as the plane of nutrition changes. This is due to both the mass of the digesta within the digestive tract and the expansion or contraction of organs involved with digestion and metabolism. Body mass is composed of salable product plus other components of the carcass (digestive tract, hide, and blood). Olthoff and Dickerson (1989) found that smaller breeds of sheep had a higher percentage of their empty body weight in visceral organs, gastrointestinal tract, and internal fat. A large digestive tract increases the capacity to consume roughage; however, a large digestive tract also carries a high maintenance requirement. Drouillard et al. (1991b) demonstrated that the visceral organ mass varied in weight to the proportion of dietary energy intake. In cattle grazing prior to finishing, reductions in gain to feed ratios were noted when compared to cattle receiving grain prior

to finishing. Grazing ruminants prior to finishing can be detrimental due to expanded internal organs, decreased digestibility, and increased maintenance of the digestive tract. Protein deficiencies have also been noted to reduce performance in cattle when grazed prior to finishing. Ferrell (1988) demonstrated that visceral tissues represent a small portion of body weight (6 percent) but consumes approximately 50 percent of the maintenance energy. Muscle makes up 41 percent of the body weight but consumes only 23 percent of the total energy for maintenance. In the case of grazing ruminants, energy consumed by muscle tissue could be much larger, depending on the amount of work required during forage consumption and processing. Therefore animal weight may not reflect the quantity of salable product. In order to obtain a more reliable estimate of empty body mass animals are often shrunk, prior to weighing, by depriving them of feed and water for a period of time (overnight or 24 hours) or weigh at the same time on several consecutive days in order to estimate full body weight without feed and water restrictions. Feed and water restriction reduces the weight of the digestive tract contents. Transport of animals will decrease weight further.

## Composition of gain

The period of access to a particular diet will determine its effect on the final composition of the body. When ruminants are fed diets that allow growth for long periods of time the rumen microbes proceed to present the tissues with a relatively constant nutrient mixture that do not allow for departures from the average composition for weight gain (Reid, 1972). Composition of gain can be defined as fat and protein accretion as a percentage of empty body weight gain. The relationship between fat and protein mass to

empty body weight indicates that the mass of fat increases quadratically. Weight and protein mass increases more linearly with weight. This is due to an accretion rate for fat that is greater than that for protein. When net energy intake is restricted in growing beef bulls, rate of fat accretion often is reduced although protein growth may continue at nearly normal rates if protein intake is adequate (Anderson et al., 1988). Byers (1980), Old and Garrett (1987), and Slabbert et al. (1992) demonstrated the effect of feed restriction on reducing the rate of gain for fat and protein accretion. If nutrient intake is restricted in growing animals the growth rate will become subnormal. Compensatory gains after weight loss represents a rapid hypertrophy of muscle tissue. Drouillared et al. (1991a) reported larger gains in beef steers following energy restriction rather than protein restriction. This may represent replacement of lost functional tissue, in the digestive tract or liver, or at least redevelopment of these organs to a size commensurate with nutrient flow. Owens et al. (1995) utilized data from Byers (1980), Old and Garrett (1987), and Slabbert et al. (1992) to evaluate the relationship between empty body weight and rates of fat and protein accretion through stepwise regression analysis across different genotypes of cattle. Regression lines indicated that as empty body gain increased to approximately 1.3 kg/day, the rate of fat accretion increased. However with gains higher than 1.3 kg/day fat accretion reached a plateau, indicating that fat accretion was limited by energy intake. Protein accretion did not reach a plateau at higher rates of gain but continued to increase at higher rates of empty body weight gain, indicating that rate of empty body weight gain was related to rate of protein accretion. Correlation between rate of gain and accretion of protein and fat are confounded by other factors such as maturity, gender, genotype, age, and environment.

The continual turnover of protein consumes energy and decreases efficiency of animals. Owens et al. (1995) reported energetic efficiency of fat and protein synthesis and accretion from theoretical data as well as data from chickens, rats, pigs, lambs, calves, and cattle. On a caloric basis, fat accretion averaged 76 percent and protein accretion averaged 47 percent efficiency. Fat accretion was approximately 1.6 times as efficient as protein accretion due to faster and less efficient turnover of protein depots as of fat depots (Bergen and Merkel 1991). In growing ruminants the protein synthesis rate ranges from 5 to 10 times the accretion rate. The large variation in protein accretion efficiency is due to variations in protein turnover rates. Fast protein turnover and increased accretion rates increase heat production and decrease gross energy efficiency.

## Production Systems

### *Production types*

Production systems are developed by man for man and are influenced by the social and economic environment within ecological zones. Many factors influence the development of a production system; however most are based on land capability and intensity of production within the capability of the land. Goat production systems in temperate zones and in developed countries fit into a system classified by the intensity of production. A grazing system integrates animal, plant, soil, and environmental components (Forage and Grazing Terminology Committee; FGTC, 1991). Season of the year, climate, forage species and forage growth potential, as well as, animal species and breed all interact to influence the animal response in the system. The climate of a region is often considered to be the dominating ecological influence. Hot and cold arid climate

zones are predestined to induce a very extensive system (grazing of large areas of relatively unproductive lands) while a temperate humid climate favors a highly intensive system (high density of stock under fairly tight management). Grazing systems usually include the use of several forage species in order to lengthen the grazing season and improve the forage quality offered. Stocking rates and grazing pressure can be managed in order to optimize intake and forage utilization. The production system should provide the quality and quantity of forage or supplementation needed to ensure optimum nutrition for growing animals in order to achieve the target rate of gain. The feed demand of livestock varies with the physiological state of the animal. The feed supply created by the pasture varies according to seasonal temperature, rainfall, and the impact of the animal. The ideal environment is one in which the feed supply from the pasture and the feed demand from the animal are equal throughout the whole year. There is no doubt that increasing stocking rate has been a significant method to increase the farmers production and that increased production is most likely to come from growing more forages and using them more efficiently. The average annual yields of pasture and browse in goat production systems can vary widely across time and place. Pinkerton and Pinkerton (1996) suggested several stocking rates typically applied in goat production. Six mature goats equal one cow on native or improved pastures or ten goats equal one cow on browse or understory brushy areas. Goats have been rotationally grazed at ten to twelve goats per acre of good wheat pastures and twelve to fifteen goats per acre on alfalfa pastures. Texas range lands typically require three to four acres per goat.

## Intensive system

In temperate regions where rainfall is adequate, high levels of pasture production can be achieved. Intensive producers use features such as improved pastures (introduction of forage species, which are fertilized regularly) and rotational grazing, along with supplemental annual forages and concentrates, in order to allocate nutrition to the animals.The term intensive implies a high density of stock under tight management practices. Stocking rates and productivity per animal on such systems are usually high; however the relative profitability is subject to many site-specific variables (price of concentrates, climate considerations and labor costs). The smaller size and greater density of farms in the intensive system allows fertilizers and sprays to be applied to pastures, permits easier control of pastures in order to monitor intake and condition of the animals, and encourages advanced herd management techniques (early identification, control of parasites and diseases, culling of unproductive animals and breed selection) in animal production. The intensive system has been more prevalent in areas where a high price can be commanded for the end product (meat) and involves a high input of management (housing, feeding and breeding programs) to produce a high output of meat throughout the year. Factors associated with intensive management systems are reproductive rate and the efficiency in which the animal utilizes feed products within the system. The ability to control every phase of production from ovulation to parturition as well as market dates are important in this system because revenues in the meat goat industry consist primarily of meat goat kids sold at auction or the sale of cull stock and breeding stock.

### *Intensive system efficiency*

Efficiency of feed conversion has a marked influence on the efficiency of a production system. The efficiency of feed conversion is important in intensive livestock industries where animals are housed and fed because feed costs account for over 70 percent of the total production cost in most livestock operations. Out of every dollar spent on an intensively managed farm, more than 60 cents goes into feed (Gelaye and Amoah, 1987). Holmes (1970) and Large (1973) compared the feed efficiency of different species of domesticated livestock and found that on a concentrate and high energy diet non-ruminant animals were superior in meat production when compared to ruminant animals. Within ruminants, on concentrate and moderate energy diets, dairy cattle were more efficient in meat production over beef cattle, which in turn were more efficient than sheep. Goats generally have lower average growth rates and feed conversion efficiencies than sheep. In a comparative trial involving four breeds of sheep (South African Mutton Merino, Merino, Dorper and Pedi) and the Boer goat, the Boer goat kids grew at 124 g/d while the average gain for the four breeds of sheep were 166 g/d (Casey and Van Niekerk, 1988). Naude and Hofmeyr (1981) concluded that for a given growth rate or feed intake, Boer goat kids are as efficient as lambs. Casey and Van Niekerk (1988) reported average feed conversion efficiency in goats ranged from 8 to 10 kg/kg.

## Forage systems

### *Forage utilization*

Meat goats must depend primarily on forages to meet their nutritional needs in order to be economically viable. Forages commonly utilized in goat production are

grasses, forbs, and browse species. Seasonal small grains, hays and silage may be used to meet their nutrient requirements. Goats will eat all classes of forage but prefer about 60 percent browse, 20 percent grasses and legumes, and 20 percent forbes (Pinkerton and Pinkerton, 1996). Vegetation can be divided into three categories: grasses, forbs, and browse plants. Grasses are monocotyledons and belong to the family, Gramineae and their leaves appear as blades with parallel veins. Forbs are dicotyledons and include individual plants from many families with veins that are netted or branched within their broad leaves. Browse plants include plants other than grasses and forbs and are usually taller plants such as shrubs, vines, trees and others having woody stems. Grasses are often considered to be the desirable type of vegetation for livestock production however; forbs and browse plants often contain higher levels of nutrients. The goat's relative nutrient requirements exceed those of most other livestock species, therefore they need access to a wide variety of plants in order to exercise diet selection because individual plant species increase and decrease in nutritional value as the plant matures and the seasons change throughout the year. Grazing areas with few species of vegetation, such as an all grass pasture, will not provide good nutrition for goats over a long period of time (Lusigi et al., 1984). Leguminous forbs and browse commonly contain more than 25 percent crude protein and are higher in calcium than in phosphorus (NRC, 1981). Addlestone et al. (1999) reported calcium and phosphorus percentages of three different leguminous tree species to be in the range of 1.34 to 1.17 and 0.15 to 0.42, respectively.

In comparison to other domestic animals, goats have unique preferences for shrubs, tree leaves and herbaceous flowering plants. They have a preference for the flowering part or seed head of grasses. Goats have prehensile lips, which allow them to

have exceptional control of their mouth to nip off particular plant parts. Compared with cattle or sheep they select from a wider array of plants. Their pattern of selection compares closely to that of small ruminant game animals. Because of their unusual preferences for leaves of woody plants, they have been used as biological control agents for invading plant species and unwanted regrowth of sprouts following timber harvest. Managing defoliation with goats results in a substantial increase in favorable vegetative cover while reducing or eliminating the unwanted species of vegetation. Hansen et al. (1980) and Child et al. (1985) analyzed diets selected by dairy and meat-type buck kids rotated among four paddocks of upland hardwood forest in Arkansas from July to December. Results showed that more than 65 percent of the goat's diet contained vine species (honeysuckle, greenbriar, kudzu and rattan). Forbs persisted in the diet for several months while grasslike plants increased in importance as the season progressed. As fall and winter approached an increased consumption of acorns, dead leaves and pine needles were noted.

Goats are top down browsers and typically browse along fence lines before moving to the center of a pasture. These browsing characteristics contribute to a more uniform plant height in pastures and effective weed control along fence lines and wooded areas within pastures. Child et al. (1985) estimated that at least 20 million acres in the southeastern United States could benefit from using goats to control shrubs, kudzu, and other viniferous species on pasture lands and in forests. According to Pinkerton et al. (1991) goats can generate $40 to $70 per breeding female per year when utilized in brush control and improved pastures. Using goats at the high stocking rates required to achieve

effective brush control may reduce kidding rates and weaning weights, therefore supplementation of concentrates may be required (Pinkerton et al., 1991).

Experts suggest that browse plants, shrubs and tree leaves should be given more attention in the feeding management for goats. Tree legumes may be utilized to increase intake, digestibility and performance of low quality forages by providing a high protein supplement. Mimosa (*Albizia julibrissin*), honey locust (*Gleditsia triacanthos L.*), willow (*Salix spp.*) and black locust (*Robinia pseudoacacia L.*) are fodder trees that grow in the southeast US.

Bransby et al. (1992) evaluated mimosa (*Albizia julibrissin*) as a woody forage legume in the Southeastern US. Mimosa was planted in1989 in four 3.7 x 6.1 meter plots with 0.91 meters between rows and 0.30 meters between plants within rows. Dry matter yield of Mimosa totaled 4.5 tons/ha with an average 17 percent crude protein content of the leaves. Addlestone et al. (1999) conducted a field study in North Carolina to evaluate the establishment and early growth characteristics of three leguminous tree species (mimosa, honey locust, and black locust). The fodder trees were established in 1995 and 1996 in single row 8-meter plots with intra-row spacing of 50 to100 centimeters. The tree species were evaluated for tree height, root collar diameter, herbage mass, forage quality and goat browsing preference. The extent of regrowth from the onset of the second growing season was most exceptional for mimosa, which increased 115 percent with an average height of 137.7 cm. This increase was greater than the black locust, which increased only 18 percent with an average height of 298.3 cm, and honey locust, which increased 90 percent with a mean of 136.1 cm. Black locust produced the highest

herbage mass with an average yield of 2,390 kg/ha, followed by mimosa (945 kg/ ha) and honey locust (366 kg/ha).

Composite foliage analyses indicated that crude protein values for the leaflets of all species were greater than 20 percent and leaflet acid detergent fiber values ranged between 12.2 to 22.0 percent, an indication of high digestibility. Leaf petioles were of considerably lower nutritive value and if consumed in large quantities would affect diet quality. Defoliation observations ranging from 0 to 10 indicated that black locust and honey locust were the most preferred tree species with defoliation observation scores of nine followed by mimosa with an observed defoliation score of three. Mimosa produced the second greatest herbage mass and has the most favorable branch growth structure (dropping branches) for browsing animals, therefore it may be suitable for integration into a mixed silvopastoral system in the southeast US.

## Forage management

Management for maximum leaf production in order to maximize forage quality is the key in grazing management. Grazing management applies both plant and animal principles to produce the needed nutrients for the animal while maintaining the long term productivity of the pasture. This principle is true for grasses as well as herbaceous forbs and brushy species and is accomplished through intensity and frequency of forage plant defoliation. The selection of the best forage must consider both the adaptability to a specific site and soil type, the nutritional needs of the animal, and the management goal of the producer.The basic unit of forage production is a tiller, which is composed of the leaf blade and sheath, stem, and seedhead. Tillers grow from the base up, and new leaves

(vegetative growth) are pushed up through surrounding sheaths of older leaves. The last leaf to emerge is the flag leaf and precedes the emergence of the seedhead (reproductive growth). Most forage grasses will produce between five and ten leaves per tiller, however, not all tillers are reproductive and produce a seedhead. Individual tillers are relatively short-lived and new tillers originate from basal buds. If the basal buds are removed by grazing or cutting, new tillers will not be produced. Many of the forage grasses that have evolved under grazing systems have basal buds at or slightly below the soil surface. Broadleaf plants, including many of the brushy browse species preferred by goats, have basal buds above ground. Physiological changes occur in forages from vegetative growth to reproductive growth. Typically the plant attempts to place its seedhead up high in order to disperse over a wide area. To hold the seedhead up the stem must become rigid which decreases the digestibility of the forage. The nutrients to fill the seedhead must be translocated from the leaves of the plant. The bottom or oldest leaves on the tiller are the first to have nutrients translocated to the seedhead. This process is complementary to grain products such as corn and wheat but most grass seed are indigestible when fed to animals and merely pass through the digestive tract. Management principles such as grazing or cutting grasses before the seedhead emerges and utilizing forages in a way that increases leaf to stem ratios improve forage quality which can be measured in animal performance.

Forage quantity increases as new leaves emerge. The maximum dry matter yield per tiller occurs between flag leaf and flowering and the maximum digestible nutrient yield occurs at flag leaf or before seedhead emergence. The yield of a forage plant increases as the number of tillers per acre increase. New tillers are produced by removal

of the top growth without damaging the basal bud and with proper fertilization and moisture. Energy, stored in the root system of plants, is used to develop new tillers. Defoliation management to keep root energy reserves replenished will maximize new tiller development and increase yield per acre. This may be accomplished by allowing the forage plant time to grow with no grazing so that energy is moved to and stored in the roots.

In developing a management strategy for meat goat production the producer must realize that both the maximum yield and the best quality of a forage species can not be achieved. The producer must manage the forage for the production status of the goat to be fed. The lactating doe and the growing weanling kid must consume vegetative forage to meet the production requirements of milk production and gain, therefore maximum yield per acre of forage will be unattainable in order to meet the nutrient requirements. Bucks and dry does have a lower nutrient requirement for maintenance and will meet their nutrient requirements on more mature forage or hay allowing the producer to maximize forage yield per acre. Hart et al. (1993) grazed 6 to 8 month old Alpine, Angora and Nubian kids on high quality wheat (*Triticum aestivum L.*) or low quality, dormant bermuda grass (*Cynodon dactylon L. Pers.*) for 54 days. Animals on bermuda grass also received 200 g/day of a 24 percent crude protein supplement. Goats grazed on the wheat pasture gained 50 g/day vs 10 g/day for animals on bermuda grass. Limit grazing has been used as a strategy to extend the grazing season or as an alternative to concentrate feeding in grazing animals. Hart and Sahlu (1995) evaluated two systems of overwintering mature pregnant Angora goats, limit grazing on winter wheat-ryegrass (*Lolium multiflorum*) pasture (2 hours daily) and supplemental feeding of

454 $g \cdot head^{-1} \cdot day^{-1}$ of a protein supplement (16 percent crude protein). Both groups were randomly assigned to pastures of standing dormant forage and fed chopped bermuda grass hay. Supplemented does showed a decrease in body weight during the experiment while limit-grazed does maintained adequate body weights. Limit-grazing of quality seasonal forage could prove to be more economical than supplemental feeding in pregnant and growing goats.

Cultivated herbaceous grass-legume silvopastoral systems have been used to improve meat goat performance. Goodwin et al. (2002) compared three different environments in which grass-legume silvopastoral systems could be developed in north central Texas. The systems consisted of grass only pasture in full sun (FSG), annual grass-pigweed-legume system under full sun (FSM), and annual grass-pigweed-legume system under shade (SM). Stocking rate for each system consisted of two Boer x Spanish does per acre to allow for sufficient herbage growth and selective grazing by the goats. Forage quality and composition was determined for each pasture over a two-year period (1999 and 2000). Goats in the FSM obtained the highest average daily gain (ADG) of 0.10 kg/day followed by goats in the SM system with ADG of 0.07 kg/day and goats in the FSG system had the lowest ADG of 0.05 kg/day. Total end of season DM yields in the FSG, FSM, and SM systems were 4,330, 1,980, and 1,650 kg/ha, respectively. The full sun environments produced a more consistent forage yield however regardless of the level of sunlight, goats in pastures with mixed grass/pigweed/legumes produced greater gains when compared to full sun grass only pastures.

## Forage quality and intake

The goat's feeding strategy is to select grasses when the protein content and digestibility are high, but to browse when the latter overall nutritive value is higher. Goats are able to select highly digestible parts of plants and reject those materials, which are low in quality. The daily dry matter intake of a mature goat ranges between 3 to 5 percent of body weight and is influenced by physiological needs, palatability, dry matter content, digestibility, and rate of passage from the rumen (Pinkerton and Pinkerton, 1996). Palatability is generally associated with lower fiber, higher protein and increased digestibility. Plants are made up of cells, which are composed of cell walls and contents within the cell walls. Neutral detergent fiber (NDF) is the estimate of plant cell wall content and is associated with total potential intake of the forage. Acid detergent fiber (ADF) is the cell wall content minus hemicellulose and is more closely related to the digestibility of the forage. As plants mature the cell wall content increases as a percent of the total plant cell and digestibility or quality of the forage decreases. Forages with a low NDF or ADF content are higher in quality than forage with a high NDF or ADF. Goats can withstand a lower digestibility of nitrogen, NDF, and organic matter than sheep (Hadjigeorgiou et al., 2001). The most usable nutrient in a plant for grazing or browsing animals is the leaf. Low quality forages have a total digestible nutrient (TDN) content of 40 to 55 percent, good quality forages have a TDN of 55 to 70 percent, and concentrates have from 70 to 90 percent TDN. According to the NRC (1981), most pasture grasses contain between 50 to 76 percent TDN depending on maturity and common hays contain between 48 to 62 percent TDN when harvested from 6 to 9 weeks of growth. Forbs and vines vary in TDN but normally average higher than pastures and hays common to the

southern region of the US. The protein and TDN levels of individual forages are dependent on age of the plant, soil fertility, rainfall, harvesting procedures, storage conditions, and variety of forage within the system. High quality forage or browse should be available to does during the last month of gestation, to lactating does, and to weanlings and yearlings. Total digestible nutrient requirements for lactating and growing goats range between 60 and 68 percent (NRC, 1981).

In grazing environments variation exist between plants and with time, in palatability traits and in the density of its distribution over the grazing area. As a result, intake may be limited by the time or energy required to harvest the pasture. Forage intake is a function of digestibility that reflects reticuloruminal rates of fermentation and passage. The capacity of the rumen is one of the main factors affecting differences in turnover rate of digesta and is linearly related to the size of the animal (Van Soest, 1994). Welch and Smith (1969) suggested that rumen space is limited by undigested feed residue in the rumen. Digestion and mastication degrade residue particles so that they are small and dense before they exit the rumen. A decline in forage quality through maturity increases the need for remastication to reduce the particle size of the forage and increase rumination time per unit of forage, which would limit intake. Goats are very active and have a relatively small digestive tract. Goats must consume a higher proportion of their body weight in dry matter each day as compared to sheep and cattle (NRC, 1981). Hadjigeorgiou et al. (2001) noted that goats exhibited a greater degree of selection than sheep when fed ad libitum which resulted in greater intake and a diet of smaller particles, with no subsequent effect on digestibility or passage rate. The ability or desire of goats to be selective may partially substitute the need to remasticate ruminal residues. Houston et

al. (1986) noted that digestibility of the ruminant diet is partially regulated by ruminal turnover rates and rate factors differ among animal species. These researchers noted that rate factors could be important determinants in assessing animal adaptability within habitats.

Digestion can be viewed as a simple balance between what the animal consumes and the amount of dry waste produced. The diet of the grazing or browsing animal contains a large proportion of cell wall material, consisting of structural carbohydrates, which are only partially and slowly digestible and sets a ceiling to voluntary intake. The processes governing digestibility are primarily defined by the forage fed. Intake is influenced by the forage, the animal and the environment. Variability among animals given the same feed is less for digestibility than for intake, therefore digestibility is usually predicted with greater precision than intake. Yet, intake has been suggested to be the more important parameter for estimating forage quality and animal performance (Minson, 1990; Moore, 1994; Coleman et al., 1999). Reid et al. (1990) reported greater intake and digestibility by cattle than by goats and sheep, and greater digestibility by goats than sheep. Cattle exhibited slower passage rates than goats and sheep; however, goats were more efficient at digestion than sheep at the same passage rate. The data of Reid et al. (1990) would suggest that microbial efficiency may be better in goats than in sheep.

On properly managed forages, the first limiting ingredient to gain is energy. When the quantity and quality of available forage or browse are limited, a concentrate supplement may be considered in order to maintain desirable production demands. Data from Osuji (1974) indicates that energy expenditure by grazing sheep can be 30 percent

greater than by confined sheep due to muscular work of eating, standing, and walking. By supplementing energy, the protein content of the forage can be used in the production of lean tissue. If additional energy is not provided the excess nitrogen must be excreted which requires energy and compounds the energy deficiency problem. Providing additional energy in the diet has often produced reductions of intake in grazed forages. Lake et al. (1974) concluded that the nitrogen content of forages is higher in relation to their energy content. Supplementation with corn resulted in a favorable protein to energy ratio by decreasing the forage protein intake and increasing the digestible energy content of the diet. Henning et al. (1980) reported that low levels of corn supplementation (7.8 percent of DMI) increased forage intake in sheep. However, with corn supplementation greater than 23 percent of forage DMI was reduced. Reports that low levels of energy supplementation increase forage intake seems to occur more frequently in sheep than in with cattle. Chase and Hibberd (1987) fed incremental levels of corn to cows consuming low-quality forage and reported linear decreases in forage organic matter intake. Hannah et al. (1990) indicated that reductions in forage intake associated with corn supplementation have been attributed to starch, however, the basal forage quality of pastures and rangelands may also play a role in energy supplementation response. Henning et al. (1980) fed either straw or hay supplemented with corn and showed reductions in hay intake were greater than reductions in straw intake. Matejovsky and Sanson (1995) supplemented lambs with incremental levels of corn while providing basal forages containing 5.2, 10.2, or 14.2 percent crude protein. Results of their work indicated that intake decreased linearly as protein level in the forage increased. Readily degradable fiber sources such as corn gluten, barley, soybean hulls, and wheat middlings

provided additional energy to animals without depressing forage digestion. Ulmer et al. (1990) supplemented steers fed medium quality hay with barley at 0.8 percent of the steers' body weight daily and reported a marginal affect on forage intake and digestibility. Martin and Hibberd (1990) indicated that feeding soybean hulls results in small decreases in forage intake when fed up to 3 kg/cow daily. Supplementation with a readily degradable fiber source has been suggested as an option for maintaining fiber digestion, ruminal pH, and minimizing intake reductions associated with grain supplementation (Horn and McCollum, 1987).

## Carcass characteristics in ruminants

### *Determinants of carcass composition*

With the growing popularity of leaner meat products in today's consumer-oriented market, it is important to understand the determinants of variation in body composition. Body composition tends to be relatively uniform in production animals. The typical body composition of an adult mammal is 60 percent water, 16 percent protein, 20 percent fat and 4 percent mineral matter. Carbohydrates usually amount to less than 1 percent of body tissue (Church and Pond, 1982). Adipose tissue does not contain as much water as muscle or other tissues resulting in an inverse relationship of water with body fat content (Church and Pond, 1982). Mean level of fat in the carcass of goats is highly variable when compared to protein and bone. Body fat content can be influenced by factors such as breed, age, sex, body weight, growth rate and plane of nutrition. The proportion of fat in the carcass of goats tends to increase while the proportion of muscle changes little and bone tends to decrease with increasing age and

weight (Gaili et al., 1972; Owen et al., 1978). Due to the low level of fat in the goat carcass, compositional changes may not be sufficient to affect meat quality unless there are breeds of goat or management systems which encourage fattening (Gaili et al., 1972).

Johnson et al. (1995) reviewed the aspects of breed type and sex on carcass traits, composition and tenderness of Florida native goats, Nubian x Florida native goats and Spanish x Florida native goats. In their study, breed type had minimal effects on carcass composition. Sex class had a more substantial influence on moisture, fat and protein contents of goat kids harvested at 21 to 28 kg. Ruvuna et al. (1992) reported higher lean to fat to bone percents (75:10:15) for intact males than castrated males (68:18:14). These data confirmed the findings of Bayraktarohlu et al. (1988) that castrated males had more mesenteric, kidney, and pelvic fat and lower weights of carcass cuts than intact males. Tahir et al. (1994) showed that an increase in body weight caused a significant increase in carcass protein and fat and a significant decrease in bone as a percentage of chilled carcass weight in Iraqi indigenous black wether goats.

Breed influences animal performance and carcass characteristics. In studies conducted on genotypes of goat breeds, the Boer x Spanish cross had a higher ADG than the Spanish, Angora or the Spanish x Angora cross (Roeder et al., 1997). According to Newman et al. (1997), Boers reach the optimum carcass weight range in half the time as compared to crossbreeds. Cameron et al. (2001a) reviewed the effects of gender and age on performance and harvest traits in Boer x Spanish wether, female, and male goats. Average DMI was lowest among female and ADG was greater for males and wethers. Internal kidney and pelvic fat was lower and carcass percentage of separable bone was greatest for males. Differences in performance among genders were not observed

between 4 and 11 months of age, however, carcass characteristics differed between 4 and 6 months of age.

Oman et al. (1999) conducted a study utilizing the Boer x Spanish and Spanish goat breeds under feedlot and range management conditions and found the Boer x Spanish breed to exhibit higher conformation scores and larger leg circumference than carcasses from Spanish goats. However, the lean, bone and fat were similar in the carcass and wholesale cuts within diet group. Batina and Dhofari are the two important goat breeds in tropical region of Sultanate, Oman. The two breeds differ in mature body size with the Batina weighing 10 to 15 kg more than the Dhofari. In a study conducted by Mahgoub and Lu (1998) on male and female goats of both breeds, Dhofari goats had higher growth rates than Batina goats indicating that small sized goats are not less suitable for meat production than large breeds. Dhofari goats had higher total body fat and muscle than Batina goats with a more pronounced difference in females. This indicated an earlier maturity rate for the smaller Dhofari goat, which enters the fattening stage at a lower weight than the larger Batina goat. Mahgoub et al. (2000) reported that age decreased carcass water and protein, but increased levels of fat with no effect on ash content in carcasses of Omani sheep. Luo et al. (2000) studied the effect of growth on carcass traits during two periods of ad libitum feed consumption in Boer x Alpine crossbred wethers. Phase 1 consisted of 15 to 31 weeks of feeding a 20 percent crude protein diet with a 33 percent neutral detergent fiber content, while phase 2 consisted of 38 to 50 weeks of feeding a 16 percent crude protein diet with a 40 percent neutral detergent fiber content. Their (Luo et al., 2000) results indicated that body weight gain was greater in phase 1 feeding, while carcass bone percent and backfat thickness were

greater during phase 2 feeding. Chilled carcass weight, dressing percent and percent carcass fat were greater during phase 2 with carcass protein percent being similar between phase1 and phase 2 feedings.

The most accurate method of determining carcass composition is by chemical analysis several muscles within the carcass (Callow, 1962). One of the first methods used to simplify measuring the composition of beef carcasses was to physically separate and chemically analyze the 9-10-11 rib section (Hankins and Howe, 1946). Cole et al. (1960 and 1962) and Ramsey et al. (1962) later related carcass yield traits to the separable carcass muscle and developed equations to predict the amount of separable muscle in beef carcasses. Osborn (1995) used two methods to determine the correlation between protein and fat with carcass measurements of crossbred steers. The correlation data obtained from the rib section was higher than correlation data obtained from the specific gravity method. These results indicated that the chemical analysis of the 9-10-11 rib section is a more sensitive method in determining carcass protein and fat. Several researchers have predicted the composition (protein, fat and moisture) of goat carcasses from primal cuts (Dhanda et al., 2003 and Tahir et al., 1994).

***Dietary energy and carcass characteristics***

Energy intake influences body composition suggesting that differences in growth rates are at least partially a function of nutrition. Productivity of a herd depends on the amount and availability of energy in the diet. Pralomkarn et al. (1995) compared growth and feed utilization of Thai native and Anglo-Nubian goats to calculate maintenance and growth requirements for energy and protein. The maintenance energy requirement was calculated to be 376 ± 18.5 kJ ME/kg body weight/day and the metabolizable energy

(ME) requirement for body weight gain was 25.9 ± 2.4 kJ ME/kg gain per day. Results showed that Thai native goats and crosses with Anglo-Nubian goats have similar energy requirements for maintenance and weight gain over a weight range of 15 to 25 kg.

Mahgoub et al. (2000) evaluated the effect of feeding diets containing various levels of ME on growth and carcass composition of Omani intact male lambs. They found an increased daily body weight gain, improved feed conversion ratio; increased carcass weight and dressing percentage in lambs fed a high energy diet over medium and low energy diets. Dietary energy altered the growth rate of muscle. Oman et al. (1999) experimented with two feeding regimens (feedlot and rangeland). The feedlot goats were fed an 80 percent concentrate diet of high protein ad libitum while the rangeland goats were fed no concentrate and browsed on multiple species of native grasses and forbs. The results indicated a heavier live and carcass weight with a higher yield of dissectible fat and protein for the feedlot goats over the rangeland goats. Shahjalal et al. (1992) compared a low energy diet and a high-energy diet fed to British Angora goats. The results showed that the high-energy diet increased carcass weight, dressing percent and cross-section size of *longissimus* muscle area when compared to the low energy diet. Johnson and McGowan (1998) also reported that the goats receiving a diet high in protein had heavier harvest and carcass weights, higher dressing percents and larger *longissimus* muscle area than goats fed a low protein diet.

***Dietary protein and carcass characteristics***

Protein content in diets influences average daily gains (ADG) and feed efficiency (FE). Apart from energy, protein is the most important nutrient in animal production. Crude protein below 6 percent in the diet reduces feed intake which leads to a combined

deficiency in energy and protein (NRC, 1981). Minimum nitrogen requirements for body weight maintenance have been established at 4.40 ± 0.24 g digestible crude protein (DCP)/ kg body weight/day and requirement for body weight gains are set at 0.204 ± 0.033 g DCP/ kg gain (Pralomkarn et al., 1995). Fluharty and McClure (1997) showed diets high in protein increased dry matter intake (DMI), ADG and FE when fed at 125 percent of the calculated NRC (1985) requirement for protein in Hampshire x Targhee crossbred lambs. Results also indicated that lambs allowed ad libitum access to dry matter had greater ADG than lambs fed at 85 percent of ad libitum. Feed efficiency did not differ between ad libitum and 85 percent ad libitum dry matter intake for lambs.

Luginbuhl et al. (1999) found that feeding increased levels of cotton seed meal (CSM) decreased hay intake, which led to a decrease in neutral detergent fiber intake, resulting in poor performance of the Boer x Brush crossbred wether goats. Dietary protein concentrations have positive effects on growth and performance when fed at proper levels. However, high levels of protein supplementation can influence performance negatively when fed levels to exceed the animals requirements. In a study conducted to compare growth rates and carcass traits of Boer x Spanish, Spanish, and Boer x Angora post weaned wether goats, Cameron et al. (2001b) found that feeding a high protein (25 percent crude protein) commercial pelleted diet ad libitum increased growth rate significantly in the Boer crossbreds over the Spanish goats. Average daily gain, DMI and FE were also greater for Boer cross than for Spanish goats. Atti et al. (2004) determined the optimal level of crude protein in concentrate diets for growing goats to be 130 g/kg (13 percent) of dry matter, with no growth improvement in body weight or lean deposition with higher levels of crude protein.

## Factors affecting meat quality characteristics

### *What is quality?*

Perceptions of meat quality vary among countries, between ethnic groups within countries, and between age groups of all ethnicity. Quality is defined as the consumer acceptance or preference of a food or food product. Quality has no boundaries and is often described as having a range within many different planes. Traditionally meat quality is either eating quality or processing quality, therefore quality is directly associated with usage and is a multifaceted concept (Webb et al., 2005). Meat quality characterizes the composition, palatability, and safety of a food product. Each of these characteristics are dependent on factors that are directly linked with the animal (breed, age, sex) and factors external to the animal (diet, weather, harvest procedure) indicated by the term "environmental". Palatability can be greatly influenced by cooking methods and the addition of flavoring ingredients.

### *Tenderness*

Of all the attributes of eating quality, the average consumer presently rates texture and tenderness most important (Koohmaraie, 1992a). There are two main components of meat tenderness, myofibrillar (muscle) and connective tissue (collagen). The degree of tenderness can be related to three categories of protein in muscle, those of the connective tissue (collagen, elastin, reticulin), of the myofibril (actin, myosin, tropomyosin), and of the sarcoplasm (sarcoplasmic proteins, sarcoplasmic reticulum). Maturity and tenderness in beef is attributable to the stabilization and cross-linking of collagen into an insoluble heat resistant form which reduces the amount of collagen that can be solubilized during cooking, resulting in less tender meat (Miller et al., 1983). Collagen crosslinking is

positively related to growth rate and animal maturity rather than chronological age. Hall and Hunt (1982) concluded that cattle fed low-energy diets grew slower than cattle fed high-energy diets and that at any given chronological age the low-energy diet cattle would be physiologically less mature than the high-energy diet cattle. Collagen solubility in cattle with rapid growth rates resulted in more soluble collagen and more tender meat than the slower growing cattle. Carlucci et al. (1998) found that meat from goats grazed and fed a commercial pellet was more tender and juicy than meat from goats fed hay and a commercial pellet, which was stringier with meatier odor and flavor. Gadiyaram et al. (2003) reported no differences in shear force, collagen solubility, or cooking loss of the *longissimus* muscle for dairy goats fed a low and high energy or low and high protein level diet.

The toughness of meat decreases during post-rigor storage and is termed tenderisation. Post mortem tenderisation is due to the enzymatic activity of calpains, which breaks down the structural proteins within muscle fibers and consequently weakens the myofibrillar matrix (Koohmaraie, 1996). Cattle grown rapidly prior to harvest produced more tender meat than their slower growing counterparts due to increased protein turnover which resulted in higher concentrations of proteolytic enzymes in the tissues at harvest (Aberle et al., 1981; Fishell et al. 1985). Shackelford et al. (1994) measured the activity of the enzyme inhibitor calpastatin, the endogenous inhibitor of calpains, and found that calpastatin activity was negatively associated with live weight gain.

The rate and extent of post-mortem proteolysis is temperature and pH dependent (Koohmaraie, 1992b). Glycolysis continues in the tissues of animals following harvest

until the glycogen substrate is exhausted or autolysis of glycolytic enzymes renders glycolysis inoperable. Acidic glycolytic end products accumulate in tissues and the pH declines. Ultimate pH values for goat muscles range from 5.55 to 6.33 (Webb et al., 2005). The excitable nature of goats predisposes them to yield high pH values. Simela et al. (2004b) and Kannan et al. (2002) verified the high pH theory of goats by measuring concentrations of glycolytic metabolites in muscles and blood of Spanish and South African indigenous goats. Glycogen concentrations averaged 33 umol/g among a mixed sex and age group of goats. The minimum concentration required for sufficient lactic acid production to maintain a satisfactory pH value is 50 umol/g. Muscle glycogen concentrations are reduced in stressed or excitable animals reducing the potential for a favorable pH decline from living tissue (7.0) to post-mortem muscle (5.8; Muir et al., 1998). Simela et al. (2004a) indicated that the tenderness and color properties of chevon, from indigenous South African goats, were highly dependent on postmortem pH and temperature. Goat carcasses chilled slowly resulted in a faster pH decline, which improved the tenderness and colorimetric values.

The decrease in tenderness associated with the onset of rigor mortis is gradually reversed as the time of post-rigor conditioning (storage at chilled temperatures for 10 to 14 days) increases. Temperature, carcass size, and carcass fat cover may influence meat tenderness because muscles in larger and fatter carcasses are slower to cool thus prolonging post-mortem proteolysis. Maximum tenderization has been observed in the first four days post-mortem in Spanish goats chilled at 4 °C for 24 hours followed by vacuum packing and continued aging for 12 days. Shear force decreased at eight days accompanied by an increased myofibril index (MFI) with storage time (Kannan et al.,

2002). Warner-Bratzler shear force values were less with six day aging than one day aging of *longissimus, biceps femoris, semimembranosus*, and *semitendinosus* muscles of Omani goats (Kadim et al., 2003). Aging for three days did not improve tenderness, however aging for 14 days decreased shear force of *gluteobiceps* muscles in Boer cross kids weighing 11 kg (King et al., 2004).

***Juiciness***

The organoleptic parameter of juiciness has two components. The first is the impression of wetness during the first few chews and is produced by the release of meat fluids. The second is the sustained juiciness due to the stimulatory effect of fat on salivation (Lawrie, 1998). Many of the physical properties of meat are partially dependent on water holding capacity. Water holding capacity is defined as the ability of meat to retain tissue water present within its structure during application of external forces such as cutting, heating, grinding or pressing. Water within meat is held by means of electrical charges and may exist in the muscle as bound (polarized water molecules associated with amino acids with high electrical charges), immobilized (held by capillary forces between the myofilaments), and free (held by weak surface forces and membranes). Gains or losses of water are important for consumer satisfaction because they affect juiciness, texture, color, and flavor of meat. It has been suggested that juiciness reaches a minimum when the pH level of the meat is about six (Lawrie, 1998).

Water molecules are not electrically neutral but have a positive and negative charge (they are polar) and associate with electrical charges within muscle proteins. Muscle fibers contain tightly packed myofibrils with thin (actin) and thick (myosin) filaments arranged in a hexagonal lattice. Myofibrils are the largest water compartment in

muscle tissue and changes in water holding capacity are linked to changes in the myofibril structure (swelling or shrinking). Three main factors determine shrinkage or swelling of myofibrils. One is the onset of rigor mortis. During rigor mortis myosin heads bind to actin reducing filament space and forms a tight network within the contractile proteins. Rigor bonds in stretched muscle will have little overlap resulting in a small difference in water holding capacity post and pre rigor. Rigor bonds in contracted muscle however, will have considerable overlap and the difference in waterholding capacity post and pre rigor will be greater.

The rate of pH decline is the second factor determining shrinkage or swelling of myofibrils. The iso-electric point of myofibrillar proteins is around pH 5.0 to 5.1. Readings above and below this pH value will result in myofilament repulsion due to negative or positive net charges of ions. This negative or positive net charge allows the myofilaments to expand in volume resulting in a greater waterholding capability. The rate of pH decline will affect the rate of sarcoplasmic protein degradation (phoshorylase and creatine kinase). Upon degradation the sarcoplasmic proteins will precipitate into the myofibrillar protein fraction and cause a decrease in the myofibrillar protein's ability to bind to water (van Laack, 1999). A fast decline in pH results in faster sarcoplasmic protein degradation, more sarcoplasmic proteins precipitate onto myofibrillar proteins (restricting myofibrillar protein binding to water molecules), shrinkage of myofilament space and ultimately less bound water molecules (Lawrie,1998). Protein denaturation affects the structure and charge of proteins. Disintegration of the I band and loss of integrity of the Z-line (costameric, gap, and intermediate proteins) by enzymatic activity (M-Calpain and u-Calpain proteases) allows diffusion of ions into the interfibrillar space

reducing divalent ions (Ca++ and Mg++) of muscle proteins to monovalent ions allowing water to bind to proteins and ultimately increasing the waterholding capacity of the muscle (van Laack, 1999). Greater net charges in protein exist when pH values are within ranges obtained by red meat products (5.2 to 6.8) allowing a greater percentage of bound or immobilized water to be retained within the muscle fibers (Aberle et al., 2001).

A low correlation exists between juiciness and marbling in cattle (Blumer, 1963) and it has been suggested that juicier beef is often associated with older, fatter cattle (Pearson, 1966). Increased age of the Angora and Boer goat was reported to increase drip loss and meat from older animals with permanent incisors and was judged to have lower initial and sustained juiciness than meat from younger animals with no permanent incisors (Schonfeldt et al., 1993). Goat meat and goat meat products have been compared with meat and meat products from pork, beef, and lamb at comparable maturity and fatness. Goat meat had the same juiciness, but less tenderness and less overall satisfaction than the other meat products (Smith et al., 1974). The juiciness of goat meat was reported to be the same in loin chops and leg roasts from Angora and Spanish goats of the same age (Smith et al., 1978). A halo effect exists between tenderness and juiciness whereas a piece of meat judged to be tender would often be judged to be juicy (Shorthose and Harris, 1991).

***Flavor***

There has been a great deal of research over the years into the chemical components of meat flavor. It has been noted that meat flavor increases with the age of the animal at harvest and that the characteristic flavors of meat reside more in the fat content of the animal rather than the lean portion. The animal's age also plays a role in

the amount of fat in muscles. The older the animal, the more time it has had to build up fat pocket energy reserves in the muscles. Schonfeldt et al. (1993a) reported that carcasses from younger Angora and Boer goats, in the range of 10 to 30 kg, had a more desirable flavor than carcasses from older Angora and Boer goats. However, Griffin et al. (1992) reported that the flavor of young goats (Angora and Spanish) and sheep (Rambouillet, Barbados and Karadul) was not as acceptable as the flavor of the older goat and sheep. Smith et al. (1978) reported that flavor in the leg roast from young Angora goats were more intense than from yearling Angora goats.

Flavor is typically associated with two components. Meat flavor precursors, which are low molecular weight water soluble components (free sugars, sugar phosphates, nucleotide-bound sugars, free amino acids, peptides, nucleotides and thiamine) and flavor volatiles, which are derived from non-enzymatic browning reactions between amino acids and carbohydrates and are associated with the fatty acid profiles. Cooking (heat) triggers a series of chemical reactions between proteins and other lesser components to develop flavor. Raw meat is bland; therefore both the method of cooking and browning are keys to flavor. Any browned meat has more flavor than unbrowned meat and food develops more flavor when heated to a high temperature. Fat is an energy source stored in animal muscles and contributes to meat flavor. Flavor and aroma molecules are hydrophobic and dissolve in the animal fat. Meat's fat content varies from animal to animal, and within each animal it varies from area to area. Muscles that are used often (locomotive) consume the fat as an energy source and result in muscles with little fat. Muscles that are not used as much (support) do not use fat as an energy source resulting in an increase of fat. Schonfeldt et al. (1993a) noted that the muscle and the

method of preparation had an affect on the flavor and aroma of sheep and goat meat. Meat from sheep and goat with one to four millimeters of subcutaneous fat had a more acceptable flavor than meat with either more or less subcutaneous fat cover.

Lipid oxidation varies among animal species and is influenced by factors such as animal diet, fatty acid composition, prooxidants and antioxidants in muscles. Hydrolysis of triacylgylcerols and phospholipids as well as oxidation of fatty acids contributes to meat flavor. Ruminal microorganisms hydrogenate dietary lipids, which result in an increase of saturated fatty acids in animal tissues compared to the diet profile. Concentrate-based diets normally have an increased level of unsaturated fatty acids in the fat and as a consequence the fat appears to be softer (Enser et al., 1998). The lipid composition of pasture forages consists largely of glycolipids and phospholipids, with the major unsaturated fatty acids being linolenic (C18:3) and linoleic (C18:2) and are of the cis configuration. Forage plants do not contain a large quantity of lipid material. The normal range of lipid in plant material is less than 2 percent of the dietary dry matter with linolenic acid being the predominant lipid fatty acid (Van Soest, 1994). The fat depot of ruminant animals consists largely of stearic acid (C18:0), trans isomers and branched chain fatty acids. These trans and branched chain fatty acids are not characteristic of plant lipids making it evident that synthesis of these acids must take place in the rumen, the lower gastro-intestinal tract or body tissues (Church, 1976).

Dietary lipid consumed by ruminant animals has two transformation stages that occur in the rumen. The first stage is hydrolysis (lipolysis) of the ester linkage, which is catalyzed by microbial lipases, resulting in the liberation of free unsaturated fatty acids. The second stage is biohydrogenation of the unsaturated fatty acids. Rumen bacteria and

delta-9 desaturase found in the adipose and mammary tissues are responsible for biohydrogenation of unsaturated fatty acids. Forage plants are high in linolenic acid (C18:3) while seed oils are high in linoleic acid (C18:2; Bauman et al., 1999). The biohydrogenation of these two unsaturated fatty acids differ in the ruminant animal. The biohydrogenation of seed oils (C18:2) are dependent on several species of bacteria in the rumen. Ruminal bacteria are symbiotic and exchange intermediates of biohydrogenation between populations; therefore there must be a balance of bacterial groups for complete hydrogenation of unsaturated fatty acids.

Examples of bacteria responsible for biohydrogenation include Fusocillus babrahamensis P2/2, T344, and R8/5, which are gram negative rod bacteria and are responsible for converting oleic acid (C18:1) to stearic acid (C18:0), hydroxystearic acid, and trans-11 C18:1. Butyrivibrio fibrisolvens, which hydrogenate linoleic acid and linolenic acid to trans-11 C18:1. *Selenomonas ruminalium* and *Enterococcus faecalis*, which hydrogenate oleic acid to 10-hydroxysteraric acid (Mosley et al., 2002). The biohydrogenation of forage plants (C18:3) are dependent on bacterial biohydrogenation of C18:3 to C18:0 with trans-11 C18:1 as the intermediate. Trans-11 C18:1 can then be absorbed and taken up by the mammary cells (in lactating animals) or adipose tissues (in meat producing animals) and desaturated to form conjugated dienes by a multienzyme complex that includes nicotinamide adenine dinucleotide (NADH)-cytochrome b5 reductase, cytochrome b5, acyl-CoA synthase, and the terminal delta-9 desaturase (Bauman et al.,1999).

Rumen biohydrogenation of seed oil products containing linoleic acid (C18:2) are initiated by isomerization of the cis-12 double bond to form cis-9, trans-11 conjugated

diene. This initiation step has no cofactor requirement and occurs in the middle of a long hydrocarbon chain by the enzyme linoleate isomerase. The enzyme is bound to the bacterial cell membrane and has an absolute substrate requirement for the cis-9, cis-12 diene system. The second reaction is the reduction of cis-9, trans-11 to trans-11 C18:1 (vaccenic acid) and upon further hydrogenation to stearic acid (C18:0). Vaccenic acid appears to be the rate-limiting step in biohydrogenation within the rumen. Accumulation of cis-9, trans-11 (CLA), vaccenic acid (trans-11 C18:1) or stearic acid (C18:1) in the rumen leads to uptake by mammary or adipose tissues. Rumen biohydrogenation of forage plant products containing linolenic acid (C18:3) are also initiated by isomerization to form cis-9, trans-11, cis-15 conjugated diene. Further reduction reactions occur forming trans-11 C18:1 and stearic acid (C18:0). Trans-11 C18:1 is the predominant intermediate for linolenic acid biohydrogenation in the rumen. This intermediate can be absorbed by mammary or adipose tissue and undergo endogenous synthesis by a multienzyme complex to form cis-9, trans-11 (CLA; Bauman et al., 1999 and Beaulieu, 2000). Endogenous cis-9, trans-11 (CLA) has been shown to predominately originate from the desaturation of trans-11 C18:1 by the delta-9 desaturase enzyme. Species differences in distribution of delta-9 desaturase exist. Growing sheep and cattle have been reported to obtain delta-9 desaturase in their adipose tissues while lactating animals obtain the enzyme in their mammary glands. The activity of delta-9 desaturase can be measured by enzymatic activity assays and is the predominant source of CLA in milk fat of lactating animals and body fat of growing animals.

The end product of lipid oxidation depends on the fatty acid profile of the meat. The more unsaturated lipids will lose a hydrogen atom quicker than saturated lipids

resulting in faster initiation of the oxidation process. Oxidative rancidity (the oxidation of unsaturated lipids) is the main factor of off-flavor in meat products. It is a chemical change in the fat constituent of meat that results in an unpleasant odor and taste during storage. Experiments have shown that removing the intermuscular and intramuscular triacylglycerols resulted in no differences in aroma characteristics after cooking (Mottram, 1998). However, when all lipids were extracted from the meat product (triacylglycerols and phospholipids) results in aroma differed (Mottram, 1998).

A review by Melton (1990) suggested that feed type (grass vs. grain) can modify beef flavor precursors with grass-fed beef having higher levels of saturated and omega-3 polyunsaturated fatty acids and lower levels of monounsaturated and omega-6 polyunsaturated fatty acids than grain-fed beef. Fatty acids in meat from Moxoto goats raised on forage changed with goat age. Steric acid, oleic acid, and cholesterol increased whereas linolenic acid decreased in the lean composite mixtures from carcasses with increased harvest age (Beserra et al., 2004). However Dhanda et al. (2003) reported that oleic and linoleic acids increased in the intermuscular adipose tissue of male goats at 254 days of age when compared with younger goats at 93 day of age. In a study conducted to correlate various energy levels in animal diets to fatty acid content of young Saanen goats, researchers found that diets containing higher energy levels produced fatty acid profiles with higher monounsaturated fatty acids, lower omega-6 to omega-3 fatty acid ratios and lower saturated fatty acid concentrations (Coltro et al., 2005).

The phospholipid layers contain a high proportion of polyunsaturated fatty acids that break down during heating. The products then react in the Maillard reaction and enhance aroma and flavor of the meat. The triacylglycerols contain very small

proportions of polyunsaturated fatty acids and do not break down as readily during the heat process resulting in less aroma and flavor. The flavor of meat is derived from reactions involving heat (Maillard and Strecker browning reactions) and lipid degradation between triacylglycerols and phospholipid bilayers. Aroma of meat products can be contributed to the browning reactions, which produce heterocyclic compounds with long chain alkyl substituents, and lipid degradation, which produce sulfur substituted compounds, which react together and influence the overall aroma and flavor of cooked meat.

Branched chain fatty acids (BCFA) have been implicated in sheep and goat species related flavor (Wong et al., 1975; Johnson et al., 1977). Branched chain fatty acids are derived from ruminal propionate, the main source for liver gluconeogenesis (Kennedy et al., 1994). However, when propionate levels exceed the capacity of the liver to metabolize it normally, there is production of BCFA (Garton et al., 1972). The fact that sheep and goats, in comparison to cattle, accumulate these compounds as a result of restricted roughage and high grain diets, suggest that differences exist in the metabolism of propionate between ruminant species (Van Soest, 1994). The 4-ethyloctanoic acid is associated with a powerful goaty odor and has been detected in goat, lamb and mutton and their cheeses (Ha and Lindsay, 1991). Other BCFA implicated in goat-like flavors are 4-methyloctanoic, 4-ethylheptanoic and 4-methylnanoic (Wong et al., 1975; Ha and Lindsay, 1991). Young et al. (1997) found that male Romney lambs raised in feedlots based on alfalfa and crushed corn had concentrations of BCFA significantly higher when compared to lambs grazed on ryegrass and clover pastures. High-forage diets fed to

lambs and goats could reduce the occurrence of BCFA by increasing the ratio of acetate to propionate.

***Lean meat color***

Meat color is detected by the eye and is affiliated with pigments that absorb and reflect certain wavelengths of light. Hue and chroma are attributes associated with any color. Hue describes the wavelength of light radiation in colors. Chroma (purity or saturation) describes the intensity of a color with respect to the amount of white light mixed with the color. The value of a color is an indication of the overall light reflectance (brightness) of the color. The basic pigment of meat is myoglobin. Myoglobin is purple and is the color of deep (anaerobic) muscle. Exposed to air, myoglobin binds oxygen to form the bright red pigment oxymyoglobin which is attractive to consumers and is associated with freshness. At low partial pressures of oxygen, myoglobin oxidizes to a brown form, metmyoglobin, which is perceived as unattractive to the consumer (Renerre, 1990). Metmyoglobin formation is also affected by the chemically reducing conditions of the muscle, such as pH, and the rate of breakdown of metmyoglobin and the amount of oxygen within the muscles post-mortem (Renerre and Labas, 1987). Metmyoglobin forms typically as the meat ages in exposure to oxygen, UV light or other factors such as metals. Metmyoglobin also coincides with the oxidation of fatty acids in the lipid portion of the meat (Faustman et al., 1998). Kannan et al. (2001) reported that shoulder cuts from eight month old Spanish does appeared redder and contained the highest chroma and lowest hue values than other primal cuts. The surface discoloration of all cuts occurred within four to eight days when displayed at 2° C indicating that shelf life of chevon cuts is comparable to beef, lamb, and pork. Intramuscular fat content could also be responsible

for differences in meat lightness because fat is lighter in color than muscle. Craig et al. (1959) compared color reflectance and muscle pigment concentrations of pasture and grain fed steers and found that animals with more fat within muscles (marbling) had the brightest colored meat (highest reflectance value) however, reflectance did not correlate with muscle pigment concentrations. They concluded variation of fat and moisture rather than the quantity of pigment present caused differences in color of lean meat.

Myoglobin quantity varies with diet, species, age, sex, muscle and physical activity. Priolo et al. (2001) reviewed 35 experiments, which reported the effect of pasture systems and concentrate finishing systems on beef meat color. The experiments concluded that meat from animals finished on pasture was darker than meat from animals finished on concentrate diets. The muscle of immature animals will have lower myoglobin content than those of more mature animals (Lawrie, 1998). Poor nutrition is a primary cause of high ultimate pH in meats because animals do not have the ability to accumulate sufficient glycogen reserves in their muscles (Bray et al., 1989). Pasture systems typically contain forages with high fiber and low starch contents, which increases the ratio of acetate to propionate and in turn causes a higher ultimate pH of the meat (Priolo et al., 2001). Shorthose and Harris (1991) suggested that muscle myoglobin concentrations were greater in free ranging and grazing animals than in feedlot finished animals due to differences in exercise. Vestergaard et al. (2000) reported that Freisian bull calves grazing extensively on summer forage and wintered indoors on dry forage diets had redder *longissimus dorsi* and *semitendinosus* muscles than calves' tie-stalled and fed concentrate ad libitum. Differences in ultimate pH were also noted with higher

pH values, lower residual glycogen and glycolytic potential from animals reared in the extensive pasture system than animals raised in tie-stalls and fed concentrates.

Bowling et al. (1977) suggested that a lower glycolytic potential and a higher disposition to glycogen depletion through stress could be a risk factor for high pH values. Kannan et al. (2003) reported that a two hour transportation stress prior to harvest decreased redness and chroma values in meat from young goats (6 to 12 months), however, older goats (24 to 30 months) were more resistant to transportation stress with no affect seen on redness and chroma values of loin cuts. Metabolism influences postmortem characteristics of the muscle group. Muscle to muscle differences are due to muscle fiber types. Muscles containing a relatively high proportion of red fibers will appear dark red in color. Muscles also differ in their rate of enzyme activity, which regulates the amount of oxygen available to the tissue. An increase in pH and temperature will cause enzymes to become more active reducing the oxygen content in the muscle. Maintaining muscle near freezing minimizes the rate of enzyme activity and oxygen utilization (Aberle et al., 2001). Hood (1980) noted the degree of discoloration in pre-packaged beef following four days of storage was two to five times greater at 10 °C than at 0 °C.

Increased temperatures accelerate pigment oxidation rate by increasing the rate of prooxidant reactions within the tissue. Increased temperature storage also decreases oxygen solubility in meat resulting in dissociation of oxygen from oxymyoglobin yielding a greater proportion of reduced myoglobin in the less stable, deoxy form. Additionally, elevated storage temperatures result in an increase in oxygen consumption by the tissue, enhanced microbial growth, and accelerated lipid oxidation (Faustman and

Cassens, 1990). Oman et al. (2000) reported that lean color score and overall appearance decreased as surface discoloration increased in goat rib chops wrapped in retail overwrap packaging and displayed for four days at 2° C. Oxygen permeable packaging during 4° C storage increased lipid oxidation of raw goat meat patties, however when stored at -20° C the amount of lipid oxidation decreased (Rhee et al., 1997). Vacuum packaging increased the shelf life (28 days) compared with aerobic packaging (3 days) of minced goat meat (Babji et al., 2000).

The objectives of this research were to compare the effect of production systems on:

1. Growth and carcass traits
2. Meat quality, palatability and product shelf life

and to:

3. Identify practical carcass traits related to carcass composition and develop accurate equations for predicting carcass composition and salable bone-in yields from goat carcasses.

# III. THE EFFECT OF PRODUCTION SYSTEMS ON BOER CROSS GOATS I: GROWTH, CARCASS TRAITS, CHEMICAL COMPOSITION AND COMMERCIAL CUTS

**ABSTRACT:** The effect of production systems on growth and carcass traits of high-percentage (**HP**; 87.5) or low-percentage (**LP**; 50.0) Boer wether goat kids was determined. Twenty-four HP (initial BW 23.1 ± 0.74 kg) and twenty-one LP (initial BW 19.0 ± 0.79 kg) goat kids were randomly assigned to 1 of 3 production systems 1) concentrate diet (**CONC**) containing 40 percent protein pellets, 40 percent soybean hull pellets, and 20 percent bermuda grass hay, 2) bahiagrass pasture (**BG**) supplemented with protein pellets, or 3) mimosa browse (**MB**) supplemented with cracked corn. Animals were harvested when a final BW of 35.0 ± 5.0 kg was obtained or when the forage season ended. The performance phase consisted of 98 d. Carcass yield measurements were collected 48-h postmortem. The 9-10-11$^{th}$ rib cut from the right side and the entire left sides of each carcass were used for composition analysis. There were no breed-type differences after adjusting for initial weight, final weight or days to harvest using analysis of covariance. Goats grazing BG had lower ADG ($P = 0.001$) than goats browsing MB, while goats receiving CONC had the greatest ADG ($P = 0.001$). Carcasses from CONC had heavier HCW, and cold carcass weights with greater dressing and shrinkage percentages ($P = 0.001$), greater body wall fat and more kilograms of total carcass lean (*P*

= 0.001) than BG or MB. Carcasses from CONC and MB had larger ($P$ = 0.001) LM areas than BG. Hindlimb circumferences were greater for the CONC and MB carcasses ($P$ = 0.001) than BG, however forelimb circumferences were larger ($P$ = 0.001) for MB and BG carcasses when compared to CONC. Moisture and ash percentages of the 9-10-11$^{th}$ rib cut and half carcass were greater ($P < 0.05$) while fat percentages were lower ($P < 0.05$) in the BG and MB carcasses than CONC carcasses. Production system did not influence ($P > 0.05$) the seven commercial cuts as a proportion of half carcass weight. Carcasses from CONC produced more ($P$ = 0.01) trim weight than MB and BG. These results indicate that goat kids receiving a concentrate-based diet and raised in confinement produced heavier carcasses with greater fat percentage and more total carcass lean than goat kids receiving a primarily forage-based diet. However, goat kids reared on the browse forage system (MB) had greater ADG with more total carcass lean than goat kids reared on the common grass forage system (BG).

## INTRODUCTION

The meat goat industry is one of the fastest growing sectors of agriculture in the United States and has the potential to contribute to the economic sustainability of small farm operations. The growth of the industry has not been easy and obstacles remain in both production systems and product quality before goats can become as economically viable as beef, pork or chicken. Ultimately the success of any meat product depends on consumer acceptance and sustainable production of the product. Feed accounts for over 70 percent of the total production cost in most livestock operations (Gelaye, 1987); therefore, a forage-based economy is the key to a profitable meat goat industry. Goats

offer an alternative for deriving value from vegetation that is otherwise wasted. Goats will normally consume 60 percent browse and 40 percent grass in a mixed plant population (Pinkerton and Pinkerton, 1996). A more diverse forage production system warrants attention in the feed management practices of goats. Bahiagrass (*Paspalum notatum*) is a forage crop commonly used for cattle production in the southern US and mimosa (*Albizia julibrissin*) is a tree legume that grows throughout the southern US. Research has shown (Bransby et al., 1992) that mimosa produces high yields with exceptional forage quality and has an adequate growing season.

Terrill (1993) suggested that in order to maximize profitability in the goat industry, emphasis should be placed on producing a more uniform product. The average market goat weights 18 to 36 kg and reflects a bone-out percentage of 60 to 70 percent of the cold carcass weight (Shoemaker et al., 2005). Producers must develop production systems with quality forages that increase animal weight with minimal input costs. Few studies have reported on the effect of production systems in producing a quality product for the market place. The objective of this study was to compare the effect of production systems on growth performance and carcass traits of goat kids.

## MATERIALS AND METHODS

### *Animals and diets*

Twenty-four high percentage (HP; 87.5 %) Boer goat kids with average initial BW of 23.1 ± 0.74 kg and twenty-one low percentage (LP; 50.0 %) Boer goat kids with average initial BW of 19.0 ± 0.79 kg were used to evaluate potential breed differences that represent the meat goat industry in the southeastern United States. The HP goat kids

were purchased from two farms in Tennessee with known genetics and the LP goat kids were purchased from a local producer in Alabama with mixed genetics of Spanish and Boer breeds. The research was conducted at the Alabama Agricultural Experiment Station E. V. Smith Research Center Beef Unit and the Small Ruminant Research Unit of the Tuskegee University George Washington Carver Agricultural Experiment Station. The Auburn University and Tuskegee University Animal Care and Use Committees (PRN # 2002-0171 and PRN # R027-8-1, respectively) approved the animal care, handling and sampling procedures. Upon arrival, animals were weighed, vaccinated s.c. with Clostridium perfringens type C & D-Tetani Bacterin-Toxoid (Bayer: Bayer Corp., Animal Health, Shawnee Mission, Kansas), dewormed orally with Cydectin (Moxidectin, Fort Dodge Animal Health, Fort Dodge, Iowa) and dusted along the loin area and neck for external parasites using Co-Ral 1% dust (Dale Alley Co., St. Joseph, Missouri). Goats were surgically castrated two weeks prior to the start of the studies followed by a s.c. injection of Liquamycin LA-200 (Pfizer, Animal Health, Exton, Pennsylvania) to prevent the occurrence of infection as recommended by a veterinarian.

Animals were confined indoors for a period of 14 d and fed a 40:60 soybean hull pellets: bermuda grass hay diet on a DM basis. Animals were weighed for two consecutive d, stratified by BW and randomly assigned within breed to one of three production systems (n = 8 HP and n = 7 LP goats per system); 1) concentrate diet (CONC) containing 40 % protein pellets (Alabama Farmers Cooperative, Decatur, AL), 40 % soybean hull pellets (Bunge Corp.; Decatur, AL), and 20 % bermuda grass (*Cynodon dactylon*) hay (Table 1); 2) ad libitum consumption of bahiagrass (*Paspalum notatum*) pasture (BG) supplemented with protein pellets (Table 1 and 2); 3) ad libitum

consumption of mimosa (*Albizia julibrissin*) browse supplemented with 100g·head$^{-1}$·day$^{-1}$ of cracked corn (*Zea mays*; Table 2). Diets were chosen to represent production systems common to the southeastern US. Bahiagrass is the forage crop most commonly used for cattle production in the region and mimosa is a tree legume that grows throughout the southern US. Research has shown (Bransby et al., 1992) that mimosa produces high yields with exceptional forage quality and has an adequate growing season. A concentrate-based diet was chosen as the standard production diet in order to compare animal responses with the forage-based systems.

Table 1. Chemical composition of concentrate-based diet and cracked corn offered to goat kids

| Item[1] | Bermudagrass hay | Soyhull | Protein pellets[2] | Corn |
|---|---|---|---|---|
| DM, % | 88.0 | 89.7 | 92.5 | 87.0 |
| CP, % | 11.7 | 14.2 | 15.5 | 9.0 |
| NDF, % | 66.0 | 60.0 | 25.0 | 9.0 |
| ADF, % | 32.0 | 42.0 | 10.0 | 3.3 |
| $NE_m$, Mcal/kg | 1.26 | 1.11 | 1.74 | 2.15 |
| $NE_g$, Mcal/kg | 0.55 | 0.40 | 1.02 | 1.47 |
| ME, Mcal/kg | 1.94 | 1.71 | 2.67 | 3.22 |

[1] DM basis. Energy values are derived from calculations using NDF values.

[2] Guaranteed analysis: CP minimum 16%, crude fat minimum 2.5%, crude fiber maximum 9%, Ca minimum 1.1%, P minimum 0.6%, NaCl minimum 1.0%, K minimum 0.8&, S minimum 0.2%, Mg minimum 0.2%, Se minimum 0.6 ppm, Co minimum 0.4 ppm, vitamin A minimum 2,597 IU/kg, vitamin $D_3$ minimum 455 IU/kg, vitamin E minimum 99 IU/kg. Ingredients included: Wheat middlings, cracked corn, distiller grain, dehulled soybean meal, corn gluten, alfalfa meal, cane molasses, vitamins A, $D_3$, E, NaCl, dicalcium phosphate, K chloride, Ca sulfate, Mg sulphate, ferrous carbonate, Mg oxidate, Cu sulphate, Co carbonate, Zn sulphate.

Table 2**.** Chemical composition of bahiagrass and mimosa offered to goat kids

| Bahiagrass | | | | | |
|---|---|---|---|---|---|
| Item[1] | June | July | Aug. | Sept. | Oct. |
| Partial DM, % | 31.3 | 30.3 | 33.2 | 33.7 | 39.7 |
| CP, % | 12.1 | 7.50 | 6.56 | 7.13 | 6.98 |
| NDF, % | 68.0 | 69.0 | 70.0 | 76.0 | 68.0 |
| ADF, % | 39.0 | 35.0 | 36.0 | 39.0 | 35.0 |
| $NE_m$, Mcal/kg | 1.24 | 1.22 | 1.20 | 1.14 | 1.24 |
| $NE_g$, Mcal/kg | 0.52 | 0.50 | 0.48 | 0.42 | 0.52 |
| ME, Mcal/kg | 1.90 | 1.87 | 1.84 | 1.74 | 1.90 |
| Mimosa | | | | | |
| | June | July | Aug. | Sept. | Oct. |
| Partial DM, % | 27.5 | 30.5 | 30.2 | 41.9 | 37.4 |
| CP, % | 24.2 | 17.1 | 16.2 | 20.8 | 21.2 |
| NDF, % | 37.0 | 40.0 | 40.0 | 39.0 | 34.0 |
| ADF, % | 27.0 | 29.0 | 29.0 | 25.0 | 23.0 |
| $NE_m$, Mcal/kg | 1.43 | 1.39 | 1.39 | 1.40 | 1.46 |
| $NE_g$, Mcal/kg | 0.71 | 0.67 | 0.67 | 0.68 | 0.74 |
| ME, Mcal/kg | 2.18 | 2.12 | 2.12 | 2.14 | 2.24 |

[1] DM basis. Energy values are derived from calculations using NDF values.

The CONC animals were housed individually in 1.8 x 2.1 m pens with adequate ventilation and raised mesh floors. Fresh water and feed were supplied once daily. Bermuda grass hay was chopped to approximately four to five cm in length using an eight-horse power Tecumseh chipper-shredder (CS8, Sears, Montgomery, AL) and stored in plastic containers. Refusals were collected daily prior to feeding and feed intake was

adjusted weekly. If refusal was more than 10 percent, feed offered was decreased. When refusal was less than five percent, feed offered was increased.

The BG animals were rotationally grazed between two 0.5 ha bahiagrass pastures every 14 d. Bahiagrass was fertilized by broadcasting in May at a rate of 453 kg/ha with N, $P_2O_5$, and $K_2O$ at a 16:16:16 ratio. The BG animals received varying amounts of protein pellets through out the experiment, due to a decrease in protein, an increase in fiber and the low energy content as the available forage matured. The BG animals received protein pellets at a rate of $100g \cdot animal^{-1} \cdot d^{-1}$ during the first seven wk of the performance phase and $200g \cdot animal^{-1} \cdot d^{-1}$ during the last seven wk of the performance phase and throughout the duration of the study.

The MB animals were rotated every 14 d between four 1 ha mimosa plots with trees trimmed to a height of 0.7 m and fed cracked corn once daily at a rate of $100g \cdot animal^{-1} \cdot d^{-1}$ to supplement the energy content of the mimosa. Body weights were recorded after a four h withdrawal from feed and water, for two consecutive d every two wk. The performance phase consisted of a 98 d period beginning in mid June and continuing through September. Individual animal ADG was calculated as the difference between initial and final BW over the interval of the performance phase.

Forage quality for BG and MB systems were collected monthly (June to October 2003) by hand sampling in random transects across each forage system in conjunction with animal weigh days. Samples for the CONC system were collected daily and pooled to form composite samples representing each month (June to October; 2003). Samples from BG and MB systems were weighed and dried for 48 h at 55 ºC in a convection oven (NAPCO; model 420) then re-weighed (after a 24 h equilibration period) to determine

partial DM. Samples were then ground in a Wiley mill (Thomas Scientific; model 4,) to pass through a 1 mm mesh screen, labeled and placed in sealed plastic containers.

Animals were harvested when a final BW of 35.0 ± 5.0 kg was obtained or when the forage season for mimosa and bahiagrass ended. The end of forage season was assessed by monitoring the reproductive growth of the mimosa and bahiagrass. The end of a forage season for mimosa occured when regrowth following defoliation ceased. The forage season ended for bahiagrass pastures when animal weight gains approached zero. Final weights were obtained on two consecutive d, and goats were transported approximately 40 km to the Auburn University Lambert Meat Laboratory. Corresponding average d to harvest for CONC, MB and BG production systems were 104, 127 and 131 ± 1.95, respectively.

***Carcass evaluation and fabrication***

Goats were harvested according to USDA approved guidelines, after an overnight period of feed withdrawal; only water was available on the day of harvest. The Institutional Meat Purchase Specifications (**IMPS**) for fresh goat, series 11, (USDA, 2001) were used by certified USDA graders to report live and carcass selection criteria in this study. According to the IMPS, selection criteria range from No. 1 to No. 3. Selection No. 1 designates the highest proportion of muscle to bone ratio while selection No. 3 designates the lowest muscle to bone ratio evaluated on live animals or carcasses of animals. Hot carcass weight was determined on the day of harvest and carcasses were chilled at 4 ºC. Cold carcass weight (**CCW**), carcass shrink, fat depth over the midpoint of the LM (**Bf**; between the $12^{th}$ and $13^{th}$ ribs), body wall fat (**Bwf**; measured at the lower portion of the12th rib), kidney and pelvic fat weight (**Kpf**), dressing percent (**Dp**), LM

area, hindlimb (measurement taken lateral to the aitch bone) and forelimb (measurement taken midpoint of the foreshank) circumferences were determined by a certified USDA grader 48 h postmortem.

Carcasses were split and the 9-10-11$^{th}$ rib sections were removed from the right side of the carcasses and the entire left sides of the carcasses were used to determine carcass composition. Soft tissue (lean and fat) and bone were dissected from the left side of the carcass and the 9-10-11$^{th}$ rib sections of the right side of the carcass (Hankins and Howe, 1946). Samples were weighed and placed in plastic bags and stored at –20 °C for later analysis. Before dissection, the left side of 18 carcasses were fabricated into standard food service and hotel style retail cuts according to the IMPS for fresh goat, series 11 (USDA, 2001) and weighed. Standard cuts included shoulder with foreshank, breast and neck (Item # 11-X-22, 11-X-10, and 11-X-34), rack (Item # 11-X-30), loin (Item # 11-X-50), sirloin (Item # 11-X-60), hind leg with shank off (Item # 11-X-73), hindshank (Item # 11-X-11), ribs with breast bone off (Item # 11-X-33), and trim (Item # 11-X-90); (IMPS, Section V Appendix C, Item descriptions; USDA, 2001).

***Chemical analysis***

Duplicate feed samples were dried in an air drying oven (Iso Temp, model 655f; Fisher Scientific) at 105 ºC for 24 h and DM was determined. Nitrogen was determined by using a LECO TruSpec (Leco Corp., St. Joseph, MI) and multiplied by 6.25 to estimate CP. Neutral detergent fiber, ADF, and ADL were determined according to Van Soest et al. (1991) and modified (Komarek, 1993) for use in an ANKOM200 fiber analyzer and ANKOM F57 filter bags (Ankom Technology Corp., Fairport, NY).

Soft tissue samples from the 9-10-11$^{th}$ rib section and from the left half of the carcass were thawed at 4 ºC overnight and ground twice with a Hobart (Hobart Corp., Model 4822, Troy, OH) meat grinder utilizing a 9.5 mm grinding plate (C. D. Triump; No. 22). Samples were ground two additional times with a KitchenAid Mixer/Grinder (Model K5SS, KitchenAid, Inc., St. Joseph, MI) utilizing a 5 mm grinding plate. Half-carcass samples were thoroughly mixed and subsampled. Duplicate soft tissue samples were analyzed for moisture by drying a 5-g sample at 100 ºC for 48 h. Ash content was determined on dried samples by ashing in a muffle furnace at 600 ºC overnight. Crude fat percentage was determined on wet samples using the Soxtec System HT (Foss Tecator, Model 1043, Hoganas, Sweden), and results were calculated on a wet basis (AOAC, 1995). Nitrogen was determined by the combustion method (AOAC, 1998) using the Vario EL III CHNOS Elemental Analyzer (Elementar Analyze System, Hanau, Germany), and CP was calculated as N x 6.25 and expressed on a wet basis.

***Statistical analysis***

Analysis was conducted for a 2 x 3 factorial arrangement with breed-type (HP and LP) and production system (CONC, BG and MB) as the main effects. All data were analyzed as a completely randomized design with PROC MIXED (SAS Inst. Inc., Cary, NC). Individual animal was the experimental unit; therefore, residual error was used to test effects of breed-type, production system and the breed-type by production system interactions. Breed-type and the interaction between breed-type and production system was not a source of variation ($P > 0.05$), therefore, only production system effects will be discussed. Differences among means were determined by least square means procedure with the protected F-test ($P < 0.05$). A second model was used for carcass traits, which

included final weight and days to harvest as a covariate in order to compare carcass traits adjusted for differences in final weight and days to harvest. Carcass composition and commercial cuts included final carcass weight as a covariate in order to compare carcass composition and commercial cuts adjusted for differences in final carcass weight. Forage composition was utilized as supportive data only, due to the lack of primary treatment (system) replication.

## RESULTS AND DISCUSSION

### *Animal performance and carcass traits*

Mean BW and ADG of goat kids from different production systems are presented in Table 3. Initial BW of goat kids were similar ($P = 0.22$) among production systems. Goats grazing BG had the lowest final BW and ADG ($P < 0.001$) followed by goats browsing MB ($P < 0.001$). Goats receiving CONC exhibited the highest final BW and ADG ($P < 0.001$) over the 98 d performance phase and reached the harvest end point 23 to 27 d faster ($P = 0.01$) than MB or BG goats, respectively.

Lusigi et al. (1984) suggested that grazing areas with few species of vegetation, such as an all grass pasture, would not provide good nutrition for goats over a long period of time. Goodwin et al. (2002) compared three different grass-legume silvopastoral systems of grass only in full sun and grass-pigweed-legume system under shade or in full sun. Goats in pastures with mixed grass-pigweed-legumes had an ADG that was 0.09 kg/d higher when compared to full sun grass only pastures. Grasses are often considered to be the desirable type of vegetation for livestock production; however, leguminous forbs and browse commonly contain more CP than grasses (NRC, 1981). Bransby et al.

(1992) evaluated mimosa DM yields of 4,081 kg/ha from four harvests with an average 17 percent CP content of the leaves and an estimated invitro digestibility of 66 percent when measured in sheep. Maximum yield was obtained when six to eight weeks were allowed for regrowth between defoliation indicating that under a rotational production system mimosa would be a favorable browse species for livestock. Addlestone et al. (1999) reported herbage mass for mimosa at 945 kg/ha and noted that the branch growth structure (dropping branches) was suitable for integration into a mixed silvopastoral system in the southeastern US. However, no research is available concerning the use of mimosa in diets for growing goats. Richards et al. (1994) investigated varying levels of a tropical tree legume (*Gliricidia sepium*) as a replacement for concentrate in the diets of growing goats. Results showed a linear decrease in digestibility and ADG with increased levels of *gliricidia* indicating that low dietary energy of the *gliricidia* resulted in low nitrogen digestion and assimilation. Results from intensive (feedlot) or semi-intensive (pasture or rangeland) management systems for goats concur with the present data indicating that goats raised under intensive management systems consistently have higher ADG than goats raised under semi-intensive management systems (Johnson et al., 1998; Oman et al., 1999).

Carcass traits and selection grades of goat kids are reported in Table 3. Final BW did not differ ($P = 0.26$) among production systems when the covariant of days to harvest was added to the model. Goats receiving CONC had heavier ($P = 0.001$) HCW and cold carcass weight with higher ($P = 0.001$) dressing and cooler shrink percentages, greater ($P= 0.001$) body wall fat and more ($P = 0.001$) kilograms of total carcass lean from the side than carcasses from BG or MB goats; however, CONC carcasses were not different

($P = 0.38$) from BG or MB carcasses for total lean percentage. No differences were observed in kidney pelvic fat weight ($P = 0.07$), kidney pelvic fat percentage ($P = 0.15$), back fat ($P = 0.11$), or total carcass bone weight ($P = 0.23$) between production systems.

Carcasses from CONC and MB goats had larger ($P = 0.001$) LM areas than carcasses from BG goats. Carcasses from CONC and MB goats had greater ($P = 0.001$) hindlimb circumferences when compared to carcasses from BG goats. Forelimb circumferences were larger ($P = 0.001$) for MB and BG carcasses when compared to CONC carcasses. The difference in hindlimb and forelimb circumference of the MB carcasses may be attributed to the height of the mimosa trees and the manner in which the goats utilized their legs in order to browse.

Total bone percentage was highest in the BG carcasses ($P = 0.03$) followed by the MB and CONC carcasses. Johnson et al. (1998) compared the effect of intensive and semi-intensive diet/management systems on carcass traits of does from the Florida native breeds. The intensive diet/management system produced heavier harvest weights, higher dressing percentages and larger LM areas than goats produced under the semi-intensive system. Oman et al. (1999) reported that feedlot goats produced heavier live and carcass weights with higher fat percentages and lower bone percentages and a more desirable lean to bone ratio than range goats of the Boer x Spanish and the Spanish breeds.

USDA live and carcass selection criteria grades were unaffected ($P > 0.05$) by production system. Goats browsing MB graded in the live animal selection criteria No. 2 by 34 % (100 % would be a perfect selection No. 2) followed by goats grazing BG which graded in the selection criteria No.2 by 29 % and goats receiving CONC which graded in the selection criteria No. 2 by 21 %. Carcasses from the CONC goats graded in the

selection criteria No. 2 by 43 % very similar to carcasses from the BG goats, which graded in the selection criteria No.2 by 40 %. Carcasses from the MB goats graded in the selection criteria No.2 by 22 %. Solaiman et al. (2006) reported USDA live and carcass selection criteria for Boer cross goat kids fed a 70:30 grain:hay diet in the No. 1 selection criteria by an average of 56 % for live animals and 61 % for carcasses and in the No. 2 selection criteria by 4 %. The difference in selection criteria results from the present study and from that of Solaiman et al. (2006) may be attributed to differences in diets, days on feed and breed genetics.

Table 3. Growth performance, carcass traits and selection grades (lsmean ± SE) from pasture-fed, browse-fed and concentrate-fed goat kids

| Trait | Pasture | Browse | Concentrate | *P*-value |
|---|---|---|---|---|
| No. of animals | 15 | 15 | 15 | |
| | | Performance phase (98 d) | | |
| BW, kg | | | | |
| Initial weight | 21.2 ± 0.98 | 21.2 ± 0.98 | 22.9 ± 0.99 | 0.22 |
| Final weight | $25.9^{c}$ ± 0.98 | $29.4^{b}$ ± 0.98 | $35.1^{a}$ ± 0.87 | 0.001 |
| ADG, g/day | $48.9^{c}$ ± 7.12 | $83.0^{b}$ ± 7.11 | $124.9^{a}$ ± 4.53 | 0.001 |
| Avg. Days on Feed | 131 ± 2 | 127 ± 2 | 104 ± 2 | 0.01 |
| Final weight, kg | 29.9 ± 1.94 | 33.1 ± 2.75 | 35.2 ± 2.68 | 0.26 |
| HCW[1], kg | $11.5^{c}$ ± 0.40 | $13.7^{b}$ ± 0.55 | $17.1^{a}$ ± 0.56 | 0.001 |
| CCW[1], kg | $11.3^{c}$ ± 0.39 | $13.6^{b}$ ± 0.53 | $16.0^{a}$ ± 0.55 | 0.001 |
| DP[1] ,% | $38.3^{c}$ ± 0.72 | $44.7^{b}$ ± 0.59 | $46.2^{a}$ ± 0.54 | 0.001 |
| 48 hr cooler shrink, % | $1.73^{b}$ ± 0.60 | $0.63^{b}$ ± 0.59 | $6.69^{a}$ ± 0.82 | 0.001 |
| Kpf[l], kg | 0.14 ± 0.06 | 0.20 ± 0.02 | 0.22 ± 0.02 | 0.07 |

(table continues)

Table 3 (continued)

| Trait | Pasture | Browse | Concentrate | *P*-value |
|---|---|---|---|---|
| Kpf[1] ,% | 1.20 ± 0.18 | 1.48 ± 0.11 | 1.45 ± 0.11 | 0.15 |
| Bft[1], cm | 0.06 ± 0.02 | 0.09 ± 0.02 | 0.06 ± 0.02 | 0.11 |
| Bwf[1], cm | $0.12^{b}$ ± 0.09 | $0.26^{b}$ ± 0.06 | $0.61^{a}$ ± 0.09 | 0.001 |
| LMA[1], $cm^2$ | $6.15^{b}$ ± 0.30 | $7.46^{a}$ ± 0.28 | $7.77^{a}$ ± 0.41 | 0.001 |
| Forelimb, cm | $17.2^{b}$ ± 0.18 | $17.7^{a}$ ± 0.16 | $16.4^{c}$ ± 0.24 | 0.001 |
| Hindlimb, cm | $32.4^{b}$ ± 0.75 | $36.0^{a}$ ± 1.06 | $35.6^{a}$ ± 1.05 | 0.001 |
| Total carcass bone, kg | 3.57 ± 0.16 | 3.85 ± 0.15 | 3.44 ± 0.21 | 0.23 |
| Total bone, % | $31.1^{a}$ ± 1.42 | $28.6^{ab}$ ± 1.32 | $23.1^{b}$ ± 1.91 | 0.03 |
| Total carcass lean, kg | $8.01^{c}$ ± 0.28 | $9.61^{b}$ ± 0.26 | $11.1^{a}$ ± 0.38 | 0.001 |
| Total lean, % | 69.7 ± 1.47 | 72.2 ± 1.36 | 71.0 ± 1.98 | 0.38 |
| | | | | |
| Live grade[2] | 2.29 ± 0.14 | 2.34 ± 0.13 | 2.21 ± 0.19 | 0.55 |
| Carcass grade[2] | 2.40 ± 0.20 | 2.22 ± 0.18 | 2.43 ± 0.28 | 0.83 |

[abc] Means within the same row with different superscripts differ ($P < 0.05$).

[1] HCW=hot carcass weight; CCW=cold carcass weight; DP=dressing percent; Kpf=kidney pelvic fat; Bft=back fat thickness; Bwf=body wall fat; LMA=*longissimus* muscle area.

[2] USDA Selection Criteria range, 1= superior meat type conformation thickly muscled throughout the body; 2= average meat type conformation moderately muscled throughout the body; 3= inferior meat type conformation, narrow in width and very angular in appearance.

***Composition and commercial cuts***

Chemical compositions from half carcass and 9-10-11$^{th}$ rib section of goat kids are shown in Table 4. Soft tissue (lean and fat) of the 9-10-11$^{th}$ rib cut from MB and BG carcasses contained more ($P = 0.001$) moisture and ash ($P = 0.01$) with lower ($P = 0.02$) fat content than lean tissue from CONC carcasses. Production system did not influence ($P = 0.16$) protein percentage of the 9-10-11$^{th}$ rib cut. Similar results for protein content has been reported among different goat genotypes (Dhanda et al., 1999; Cameron et al., 2001;

Dhanda et al., 2003) and when comparing goat and sheep species (Sheridan et al., 2003; Tshabalala et al., 2003; Sen et al., 2004). The proportion of fat in goat carcasses tends to increase while the proportion of muscle remains steady with increasing age and weight (Gaili et al., 1972; Owen et al., 1978). Warmington and Kirton (1990) reviewed eight goat breeds and reported an average fat content of 9.3 percent. Due to the low level of fat content in goat carcasses, compositional changes may not be sufficient to affect meat quality unless there are breeds of goat or management systems which encourage fattening (Gaili et al., 1972).

Ash and Norton (1987) noted that Australian cashmere goats fed a concentrate ration had increased carcass fat deposition when compared to goats browsing or grazing. Similar moisture and fat concentrations have been reported for Boer cross goat kids under intensive management systems of high concentrate diets (Cameron et al., 2001; Sheridan et al., 2003). Gaili and Ali (1985) compared meat from Sudan desert sheep and goats and concluded that goats had more protein and less intramuscular fat than sheep due to different nutritional responses of the two species. Fat depositions in goats tend to be more visceral and less subcutaneous which makes goat meat leaner than mutton and beef (Devendra, 1994). Sen et al. (2004) noted that goats are a tropical breed of livestock and in order to facilitate thermolysis, fat is deposited in the viscera region rather than in the subcutaneous region.

The method of separating and chemically analyzing the 9-10-11$^{th}$ rib section in order to simplify measuring the composition of beef has been performed and validated (Hankins and Howe, 1946; Cole et al., 1960 and 1962; Ramsey et al., 1962; Osborn, 1995). Lean tissue from the half carcass followed the same pattern for moisture and fat as

the 9-10-11$^{th}$ rib cut with MB and BG carcasses containing more ($P = 0.001$) moisture and lower ($P = 0.001$) fat content than lean tissue from CONC carcasses. Protein content from the half carcass analysis did not differ ($P = 0.13$) among production systems. Ash percentage from the half carcass was higher ($P = 0.03$) in the BG carcasses when compared to the CONC carcasses. Tahir et al. (1994) reported that the composition of the whole carcass in Iraqi indigenous black goats could be predicted from the composition of primal cuts. The variation in protein and ash concentrations between the 9-10-11$^{th}$ rib cut and the half carcass may be explained by the mincing of the entire half carcass, instead of analyzing only the LM area.

Table 4**.** Chemical composition (lsmean ± SE) from 9-10-11$^{th}$ rib section and half carcass of pasture-fed, browse-fed and concentrate fed goat kids

| Item[1] | Pasture | Browse | Concentrate | *P*-value |
|---|---|---|---|---|
| No. of animals | 15 | 15 | 15 | |
| 9-10-11$^{th}$ rib section | | | | |
| moisture % | $67.7^{a} \pm 0.80$ | $66.8^{a} \pm 0.65$ | $60.4^{b} \pm 0.75$ | 0.001 |
| fat % | $8.31^{b} \pm 2.27$ | $10.0^{b} \pm 2.54$ | $18.6^{a} \pm 2.69$ | 0.02 |
| protein % | $22.5 \pm 1.15$ | $22.0 \pm 0.42$ | $18.8 \pm 2.47$ | 0.16 |
| ash % | $1.01^{a} \pm 0.02$ | $1.01^{a} \pm 0.02$ | $0.90^{b} \pm 0.02$ | 0.01 |
| Total % | 99.5 | 100 | 98.9 | |
| Half carcass | | | | |
| moisture % | $70.3^{a} \pm 0.88$ | $70.0^{a} \pm 0.87$ | $64.4^{b} \pm 0.95$ | 0.001 |
| fat % | $8.03^{b} \pm 0.75$ | $9.06^{b} \pm 0.61$ | $13.3^{a} \pm 0.71$ | 0.001 |
| protein % | $20.5 \pm 0.51$ | $19.9 \pm 0.42$ | $21.3 \pm 0.49$ | 0.13 |
| ash % | $1.11^{a} \pm 0.07$ | $0.94^{ab} \pm 0.09$ | $0.85^{b} \pm 0.09$ | 0.03 |
| Total % | 99.9 | 100 | 100 | |

[ab] Means within the same row with different superscripts differ ($P < 0.05$).
[1] Reported on as is basis.

The contribution of primal cuts as weight and as percentage of half carcass weight are shown in Table 5. Half carcass weight did not differ ($P = 0.48$) among production systems when the covariate of carcass weight was added to the model. Production system did not influence ($P > 0.05$) the weight of the seven commercial cuts. However, CONC carcasses produced more kilograms of trim ($P = 0.01$) than BG or MB carcasses. The same trend occurred when commercial cuts were expressed as a percentage of half carcass weight with CONC carcasses possessing a higher ($P = 0.05$) percentage of trim than BG or MB carcasses. The average weight from the seven commercial cuts (as a percentage of half carcass side) observed in the present study were similar to those reported by others (Dhanda et al., 1999; Cameron et al., 2001; Tshabalala et al., 2003; Sen et al., 2004). Although proportions of commercial cuts did not differ among production systems it can be observed that the shoulder, foreshank, breast, and neck portion along with the hind leg and hindshank portion make up nearly 60 percent of the goat carcass. In studies comparing goat and sheep carcasses notable differences in muscle distribution have been reported. Tshabalala et al. (2003) reported higher portions of lean in the neck and ventral trunk from Boer goat carcasses when compared to Dorper and Damara sheep carcasses and contributed the difference to the higher fat content of sheep carcasses. Sen et al. (2004) observed similar results when comparing sheep and goat carcasses but contributed the difference in neck and shoulder weights to the erect and extended posture exhibited by goats when browsing shrubs and trees.

Table 5. Commercial cuts (lsmean ± SE) as a proportion of half carcass weight from pasture-fed, browse-fed and concentrate-fed goat kids

| Cut[1] | Pasture | Browse | Concentrate | *P* – value |
|---|---|---|---|---|
| No. of animals | 6 | 6 | 6 | |
| | | kg | | |
| Half carcass weight | 5.44 ± 1.28 | 6.48 ± 1.18 | 7.41 ± 1.15 | 0.48 |
| Shoulder, foreshank, | | | | |
| Breast and neck | 1.79 ± 0.28 | 1.79 ± 0.21 | 1.97 ± 0.23 | 0.81 |
| Rack | 0.50 ± 0.14 | 0.68 ± 0.10 | 0.60 ± 0.11 | 0.63 |
| Loin | 0.57 ± 0.08 | 0.65 ± 0.06 | 0.68 ± 0.07 | 0.66 |
| Sirloin | 0.41 ± 0.11 | 0.56 ± 0.10 | 0.60 ± 0.10 | 0.50 |
| Hind leg, shank off | 1.24 ± 0.17 | 1.37 ± 0.13 | 1.61 ± 0.18 | 0.29 |
| Hindshank | 0.36 ± 0.14 | 0.66 ± 0.11 | 0.53 ± 0.11 | 0.35 |
| Ribs, breast bone off | 0.21 ± 0.28 | 0.39 ± 0.33 | 0.77 ± 0.29 | 0.27 |
| Trim (ground products) | $0.26^{b}$ ± 0.05 | $0.36^{b}$ ± 0.04 | $0.51^{a}$ ± 0.04 | 0.01 |
| | | % | | |
| Shoulder, foreshank, | | | | |
| breast, neck | 31.8 ± 3.40 | 27.4 ± 2.56 | 28.0 ± 2.77 | 0.64 |
| Rack | 9.06 ± 1.93 | 10.3 ± 1.46 | 8.46 ± 1.57 | 0.63 |
| Loin | 10.2 ± 0.72 | 9.82 ± 0.54 | 9.35 ± 0.58 | 0.67 |
| Sirloin | 8.29 ± 0.34 | 8.48 ± 0.25 | 8.19 ± 0.27 | 0.69 |
| Hind leg, shank off | 22.8 ± 1.25 | 20.9 ± 0.94 | 22.4 ± 1.01 | 0.41 |
| Hindshank | 6.17 ± 1.90 | 9.75 ± 1.42 | 7.35 ± 1.54 | 0.33 |
| Ribs, breast bone off | 4.10 ± 2.51 | 5.09 ± 3.73 | 9.41 ± 2.83 | 0.19 |
| Trim (ground products) | $4.55^{b}$ ± 0.86 | $5.68^{b}$ ± 0.64 | $7.19^{a}$ ± 0.70 | 0.05 |

[ab] Means within the same row with different superscripts differ ($P < 0.05$).

[1] Commercial cuts were selected from the International Meat Purchase Specifications (IMPS) for fresh goat meat series 11, 2001; Food service style 4 and Hotel style 5 of Section V; Appedix C.

## IMPLICATIONS

Boer goat kids receiving a concentrate diet produced greater average daily gains and heavier carcass weights with larger *longissimus* muscle areas and more total carcass lean weight than goat kids raised under forage based systems. Forage quality within production system was a component of variation for growth and carcass traits in the present study. The mimosa system produced greater average daily gains and final body weights with heavier carcass weights and more total carcass lean weight when compared to the bahiagrass system. Nutrition has been shown to affect both the rate and composition of growth; therefore, improving nutrition through properly managed systems will increase productivity. The practicality of a system for rearing goats would depend largely on production costs within the system and current market potential of the product.

# IV. THE EFFECT OF PRODUCTION SYSTEMS ON BOER CROSS GOATS

## II: CARCASS QUALITY AND PALATABILITY

**ABSTRACT:** Forty-five Boer cross kids were used to determine the effect of production systems on carcass quality and palatability. Goats were randomly assigned to systems containing concentrate (**CONC**), bahaigrass pasture (**BG**), or mimosa browse (**MB**). Temperature and pH measurements from LM were taken 1, 3, 5, and 24 h postmortem. Carcasses were chilled for 48 h and initial carcass lean Commission Internationale de l'Eclairage (**CIE**) L*, a* and b* color values were recorded. Carcasses were fabricated, vacuum-packed and aged for 14 d at 4 ºC. Fatty acid profile and cholesterol content was measured from the LM. Color characteristics and lipid oxidation were assessed from LM chops held in over wrapped packaging at 4 ºC for 6 d. Cook loss, Warner-Bratzler shear force (**WBSF**) values, and sensory traits were assessed from the semimembranosus (**SM**) and the biceps femoris (**BF**) muscles. Carcasses from BG had greater ($P = 0.002$) pH values and CONC had greater ($P = 0.001$) temperatures at 1 h postmortem. Ultimate pH (24 h) values were lower ($P = 0.002$) for CONC goats. No differences ($P > 0.05$) were observed in 24 h muscle temperatures among production systems. Carcasses from MB and BG had greater ($P = 0.04$) b* values at 48 h postmortem. Goats receiving CONC contained greater ($P = 0.05$) amounts of C18:2 n-6, whereas goats browsing MB contained greater ($P = 0.001$) amounts of C18:3 n-3. The n-6:n-3 ratio was lower

($P = 0.001$) for MB goats, whereas total fatty acid concentrations were greater ($P = 0.01$) in CONC goats. Cholesterol amount did not differ ($P = 0.25$) among systems. Chops from the MB and BG goats had greater ($P = 0.001$) $L^*$ values at 6 d of display and greater ($P = 0.001$) $a^*$, and ($P = 0.04$) $b^*$ values after 4 d of retail display than chops from CONC goats. Color value $a^*$ ($P = 0.001$) and chroma ($P = 0.02$) decreased with increasing display days in all systems. Retail data indicate that surface discoloration occurs at d 4 of display regardless of system. Lipid oxidation was not affected by production system ($P = 0.24$). The WBSF values were greater ($P = 0.01$) in SM and lower ($P = 0.01$) in BF muscles for MB carcasses. Cook loss and sensory attributes were similar ($P > 0.05$) among systems. Managing goats on forage-based systems improved the fatty acid profile and lowered total fatty acid content with no adverse effects on palatability traits. Results indicate that the inclusion of forages in production systems for rearing goats can be achieved without deleterious effects on meat quality.

## INTRODUCTION

Chevon (goat meat) is one of the most widely eaten red meats worldwide with 3.7 million tons produced in 2001 (Devendra, 1990; Dubeuf et al., 2003). The USDA National Agricultural Statistics Service (**NASS**; 2005) reported an 11 percent increase in goats harvested at federally inspected plants from 2000 to 2004. Even with increases in domestic harvest, the US is a net importer of goat meat with 8.5 million kg valued at 21.5 million dollars in 2003 (NASS, 2005). Evolving demographics and increasing concerns regarding nutrition and health have changed the demand for food products, especially red meats. Goat meat is leaner and contains less saturated fat than other red meats, however,

it is generally unavailable in retail markets and annual consumption is low when compared to other red meats in the US (NASS, 2005). The low consumption rate may be related to the consumers' unfamiliarity with goat meat and its intense and inherent aroma and flavor that are undesirable to most American consumers (Rhee et al., 2003).

Public perception and variations in price and quality are problems facing the goat industry. Changes from whole or half carcasses to retail cuts and the production of value-added products should increase the profitability of goat meat and encourage producers to establish production systems that bring consistent high quality products to the market. Meat quality characterizes the composition, palatability, and safety of a food product. These characteristics are dependent on factors directly linked with the animal (breed, age, sex) and factors external to the animal (diet, weather, harvest method). Few studies have compared quality, palatability and product shelf life of goat meat from traditional forage-based and intensive concentrate-based production systems. The objectives of this study were to compare meat quality and palatability from goats consuming a forage- or concentrate-based diet; and to evaluate the effect of production systems on product shelf life.

## MATERIALS AND METHODS

### *Animals and diets*

Twenty-four high percentage (**HP**; 87.5%) and twenty-one low percentage (**LP**; 50.0%) Boer wether goat kids were randomly assigned to one of three production systems (n = 8 HP and n = 7 LP goats per system). Production systems consisted of supplementation with protein pellets (16 percent) or cracked corn (*Zea mays*) in addition

to bahiagrass (*Paspalum notatum*) pasture (BG), mimosa (*Albizia julibrissin*) browse (MB) or a typical concentrate-based diet (CONC). Shoemaker et al. (previous chapter) provides a complete description of the animals and the production systems. The CONC animals were housed individually in 1.8 x 2.1 m pens with adequate ventilation and raised mesh floors. Fresh water and feed were supplied once daily. The BG animals were rotationally grazed every 14 d between two 0.5-ha bahiagrass pastures and supplemented with a 16 percent protein pellet concentrate (Alabama Farmers Cooperative, Decatur, AL) once daily at a rate of 100 $g \cdot animal^{-1} \cdot day^{-1}$ during the first seven wk and 200 $g \cdot animal^{-1} \cdot day^{-1}$ throughout the remaining duration of the study. The MB animals were rotated every 14 d between four mimosa plots (1-ha) with trees trimmed to a height of 0.7 m and supplemented with cracked corn (*Zea mays*) once daily at a rate of 100 $g \cdot animal^{-1} \cdot day^{-1}$. Animals were housed at the Alabama Agricultural Experiment Station E. V. Smith Research Center Beef Unit and the Small Ruminant Research Unit of Tuskegee University George Washington Carver Agricultural Experiment Station and all procedures were approved by the Auburn University and Tuskegee University Animal Care and Use Committees (PRN# 2002-0171 and PRN# R027-8-1, respectively). Animals were harvested when a final BW of 35.0 ± 5.0 kg was obtained or when the forage season for mimosa and bahiagrass ended. The end of forage season was assessed by monitoring forage reproductive growth. The end of a forage season for mimosa occured when regrowth following defoliation ceased.The forage season ended for bahaigrass pastures when animal weight gains approached zero. Final weights were obtained on two consecutive d, and goats were transported approximately 40 km to the Auburn University Lambert Meat Laboratory. Corresponding average days to harvest for

CONC, MB and BG production systems were 104, 127 and 131 ± 1.95, respectively. Goats were harvested according to USDA approved guidelines and carcasses were chilled at 4 °C for 48 h before fabrication.

***Sample collection and preparation***

*Longissimus* muscle pH and temperature were measured between the 12$^{th}$ and 13$^{th}$ rib section of the carcasses right side at 1, 3, 5, and 24 h postmortem using a pH and temperature meter with piercing electrode and temperature probes (Thermo Orion meter, Orion Research, Boston, MA). Carcasses were ribbed at the 12$^{th}$ to 13$^{th}$ rib interface and allowed to bloom for approximately 30 min at 4 °C. Commission Internationale de l'Eclairage (CIE) lean color *L** (muscle lightness), *a** (muscle redness), and *b** (muscle yellowness) values were measured from two readings along the 12$^{th}$ to 13$^{th}$ rib LM area with a Hunter Miniscan XE Plus (HunterLab, Reston, VA; Illuminant D65, 10 ° viewing angle, and a 35 mm viewing area) and averaged to obtain a representative measure of initial lean color. Carcasses were split along the vertebral column and the right halves were fabricated into loin (Item #11-X-50) and hindleg with shank off (Item #11-X-73) cuts according to the Institutional Meat Purchase Specifications (**IMPS**) for fresh goat, series 11 (USDA, 2001). The LM was removed from the 13$^{th}$ rib through the lumbar vertebrae and sliced into 2.5-cm-thick boneless chops. *Semimembranousus* (SM) and *biceps femoris* (BF) muscles were removed from the hindleg and sliced into 2.5-cm-thick cuts. The SM and BF muscles were selected because they were of sufficient size for the desired measurements of cooking loss, WBSF values and sensory evaluation. All cuts were vacuum-packaged and aged at 2 °C for 14 d. Samples for fatty acid and cholesterol analysis were taken across the whole width of the LM at the 13$^{th}$ rib following the 14 d

postmortem aging period. Samples were vacuum-packed and stored at –80 ºC until analyzed. The remaining portions of the LM were utilized for retail display analysis and oxidative stability determination. Samples for cooking loss, WBSF and sensory evaluation were vacuum-packed and stored at –20 ºC until analyzed.

***Fatty acid and cholesterol analysis***

*Longissimus* muscle samples were thawed at 4 ºC and trimmed to remove external adipose and connective tissue. Total lipid was determined following the chloroform-methanol procedure of Folch et al. (1957). Nonadecanoate acid (C19:0; Avanti Polar Lipids, Inc.) was added as an internal standard. Fatty acid methyl esters (FAME) were prepared following the procedure of Park and Goins (1994). The FAME were analyzed using a Agilent Technologies 6890N gas chromatograph (GC), and separated using a 60-m DB-23 capillary column (0.25 mm i.d. and 0.25 um film thickness, Agilent Technologies). The GC oven temperature was programmed at 150 to190 ºC at 10 º /min, held at 190 ºC for 15 min, then ramp to 230 ºC at 4 º/min, and held at 230 ºC for 10 min utilizing a 20:1 split ratio. The injector and detector were maintained at 250 ºC. Helium was the carrier gas at a flow rate of 1 mL/min. Individual fatty acids were identified by comparison of retention times with standards (Nu-Chek Prep, Inc.) and quantified using the internal standard (C19:0).

Cholesterol content was determined following the procedure of Rule et al. (2002). Cholesterol was analyzed using a Agilent Technologies 6890N GC, and separated using a 30-m HP-5 capillary column (0.32 mm i.d. and 0.25 um film thickness, Agilent Technologies) with column temperature at 250 ºC and detector and injector temperatures at 300 ºC. Helium was used as the carrier gas with a 50:1 split ratio. Stigmasterol was

used as the internal standard (Matreya, Pleasant Gap, PA). Cholesterol was identified by comparison of retention time with the standard and quantified using the internal standard.

***Retail color and oxidative stability determination***

Samples were placed on styrofoam trays, overwrapped with polyvinyl-chloride film (MW-4; Filmco, Aurora, OH) and stored in a Tyler (Model M1, Hussmann Corporation, Bridgeton, MO) retail display case under simulated retail conditions at 2 ºC (950 lux; Sylvania F40W/DCWP lighting) for 6 d. Samples were placed randomly throughout the case to allow for even distribution and account for variations in temperature and lighting. The CIE $L^*$ (muscle lightness), $a^*$ (muscle redness), and $b^*$ (muscle yellowness) values were measured daily, through the over-wrap, from two readings with a Hunter Miniscan XE Plus (HunterLab, Reston, VA; Illuminant D65, 10 ° viewing angle, and a 35 mm viewing area) and averaged to obtain a representative measure of color. Muscle chroma (color intensity/saturation; $(a^2 + b^2)^{1/2}$) and hue angle (wavelength of light radiation red, yellow, green, blue and purple; $tan^{-1}(b/a)$) values were obtained utilizing equations as described by Hunt (1980). On d 0 meat samples were allowed to bloom for 2 h before color was determined.

The extent of lipid oxidation was determined by the 2-thiobarbituric acid reactive substances (**TBARS**) assay using the aqueous acid extraction method of Wang et al. (2002). A 10-g portion of each sample was homogenized in 80 mL of an extract solution (7.5% trichloroacetic acid (**TCA**), 0.1% propyl gallate and 0.1% EDTA) using a Kinematica (Model CH-6010, Brinkmann Instruments, Westbury, NY) at speed 3 for 1 min. The homogenate was diluted to 100 mL and centrifuged at 6000*g* for 5 min. A 2-mL aliquot of the supernatant was mixed with 2 mL of an 80 mM 2-thiobarbituric acid

(**TBA**) solution and incubated at 40 ºC for 90 min. The absorbance was measured at 532 nm using a Thermo Spectronic Genesys 10 (Fisher Scientific) spectrophotometer. Lipid oxidation was evaluated in duplicates from LM chops that were displayed for instrumental color. A standard curve was constructed utilizing different volumes (0, 0.25, 0.50, 0.75, 1.0, 2.0, 3.0, 4.0, 5.0) of a 20 nmole/mL malonaldehyde (**MDA**; 1,1,3,3-tetramethoxypropane) with 2 mL of an 80 mM TBA solution with the final volume diluted to 4 ml using a 7.5% TCA solution. Results were expressed on a wet sample basis as milograms MDA equivalents/kg meat sample.

***Shear force determination and sensory evaluation***

Samples for cooking loss and WBSF values were thawed for 24 h at 4 ºC and precooked weights were obtained. A minimum of three chops for both SM and BF muscles were used to determined WBSF values. Samples were cooked using George Foreman Grills (model GRP4, Salton, Inc., Columbia, MO). The grills were allowed to preheat for 5 min and approximate cooking surface temperature was 190 ºC. Chops were cooked to an internal temperature of 71 ºC according to AMSA (1995) guidelines and were not turned during the cooking process. Internal temperatures were monitored using a digital, hand-held thermometer (model AT-600, KOCH Supplies Inc., Kansas City, MO). Chops were weighed and percent loss in weight was recorded as cooking loss. Chops were covered with Saran wrap to prevent evaporation losses and cooled overnight at 4 ºC. Following cooling, chops were allowed to equilibrate to room temperature and three muscle cores (1.3 cm diameter) were removed from each chop parallel to the muscle fiber. All cores were sheared once perpendicular to the muscle fiber utilizing a Warner-Bratzler Shear machine (G-R-Electric Mfg. Co., model 1955, Manhattan, KS)

equipped with a V-notch blade. The peak force for each core was recorded in kg and WBSF values were determined by averaging the three cores from each chop.

An eight-member sensory panel (consisting of departmental faculty, staff and graduate students) was selected and trained according to the procedure of Cross et al. (1978). Randomly selected samples for sensory evaluation (SM and BF muscles) were thawed for 24 h at 4ºC and cooked using the same method as described for WBSF values. Sample ends were squared and trimmed of connective tissue, cut into cubes (1.3 x 1.3 x 2.1 cm) utilizing a plexiglass grid (14 x 12 x 4 cm) and stored in warming pans at 75 ºC for up to 20 min before being presented to the sensory panel. Panelist evaluated two cubes from each sample per session and two sessions were conducted per day with six to eight samples per session. A warm up session was conducted on each evaluation day prior to the first session to ensure consistency among panelist. Unsalted crackers and room temperature water were provided to cleanse the palate between samples. Evaluations were performed in individual booths, under red-filtered incandescent lighting and samples were assigned a two-digit number and randomized prior to presentation. Sensory panelists rated cubes for initial and sustained tenderness and juiciness, flavor intensity, and off flavor on an eight point scale (1 = extremely tough, dry, bland or uncharacteristic and 8 = extremely tender, juicy, intense or characteristic).

***Statistical analysis***

Analysis was conducted for a 2 x 3 factorial arrangement with breed-type (HP and LP) and production system (CONC, BG and MB) as the main effects. All data were analyzed with days to harvest as a covariate in order to compare means adjusted for differences in days to harvest among production systems. Initial color, FAME,

cholesterol, WBSF, cooking loss and sensory attribute data were analyzed using the Proc MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a completely randomized design. The fixed effect was production system and individual animal was the experimental unit; therefore, residual error was used to test effects of breed-type, production system and the breed-type by production system interactions.

Retail data, TBARS values, and muscle temperature and pH were analyzed as repeated measures with breed, production system, time or display day and all two and three way interactions included in the model as a fixed effect using the Proc MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The individual muscle measured was the subject of the repeated statement and first order autoregressive structure with a random effect between animals was chosen as the optimum covariance structure according to Littell et al. (1996). Animal within production system was the subject of the repeated statement. Breed-type and the interaction between breed-type and production system was not a source of variation ($P > 0.05$), therefore, only treatment effects and their interactions will be discussed. Differences among means, for all analyses, were determined by least square means procedure with the protected F-test ($P < 0.05$).

## RESULTS AND DISCUSSION

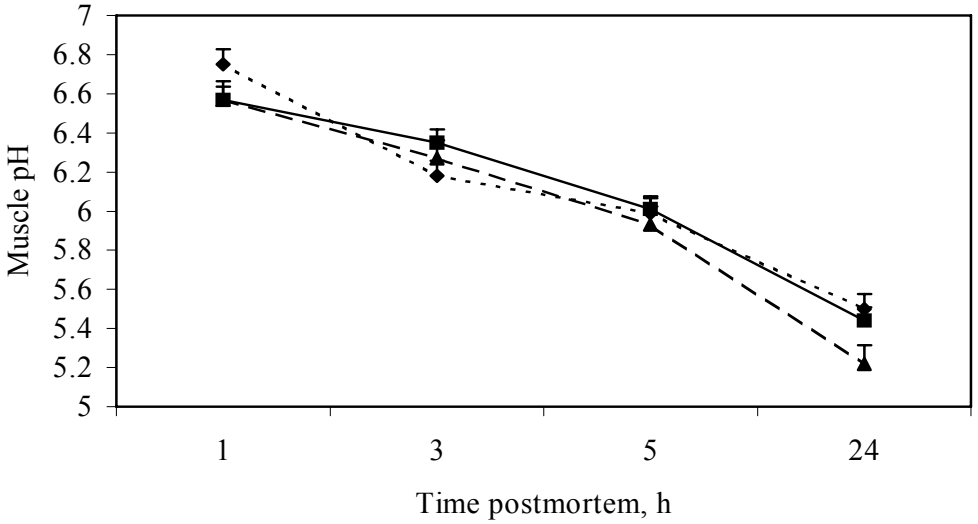
### *Initial carcass and color measurements*

Least square means for LM muscle pH and temperature are presented in Figure 1. Time postmortem affected both muscle pH and temperature decline ($P = 0.001$). The LM from goats grazing BG had greater ($P = 0.002$) pH values at 1h postmortem than goats browsing MB or receiving CONC. No differences ($P > 0.05$) were observed in pH values

from 3 and 5 h values among production systems. Ultimate pH (24 h) values were lower ($P = 0.002$) for CONC goats when compared to BG and MB goats. The LM from goats receiving CONC had greater ($P = 0.001$) muscle temperatures at 1 and 3 h postmortem while LM from goats grazing BG had lower ($P = 0.001$) muscle temperatures at 3 and 5 hours postmortem. No differences ($P > 0.05$) were observed in 24 h muscle temperatures among production systems.

Goat carcasses tend to have small muscles with low amounts of subcutaneous fat cover. These characteristics favor rapid muscle temperature decline prior to the onset of rigor mortis and can initiate cold shortening of the muscles, which affects meat tenderness. There have been many reports on the effects of age, breed, gender, diet, and pre-harvest conditions on muscle pH of goats. The effects of age and weight indicate that older and heavier goats produce carcasses that chill slower and produce a more acceptable ultimate pH value when compared to their younger counterparts. This phenomenon may be attributed to the insulating effect of larger muscles with more fat content (Dhanda et al., 2003; Kannan et al., 2003; Marichal et al., 2003; Kadim et al., 2003; Dhanda et al., 1999). Kannan et al. (2005) reported that feeding diets with varying levels of energy and protein to castrated dairy goats did not affect muscle pH or temperature decline. The rates of muscle pH and temperature decline were comparable to results of the present study and indicate rapid heat dissipation before the onset of rigor mortis. To alleviate the occurrence of cold shortening in goat muscles due to irregular heat dissipation and pH decline. King et al. (2004) experimented with the effect of high voltage electrical stimulation. Results indicate that the response to high voltage electrical stimulation reduced muscle pH below 6.0 at 2 h postmortem with ultimate pH values

[a] $P = 0.33$, [b] $P = 0.69$, [c] $P = 0.001$, [d] $P = 0.95$, [e] $P = 0.002$, [f] $P = 0.69$




[a] $P = 0.35$, [b] $P = 0.001$, [c] $P = 0.001$, [d] $P = 0.75$, [e] $P = 0.001$, [f] $P = 0.62$

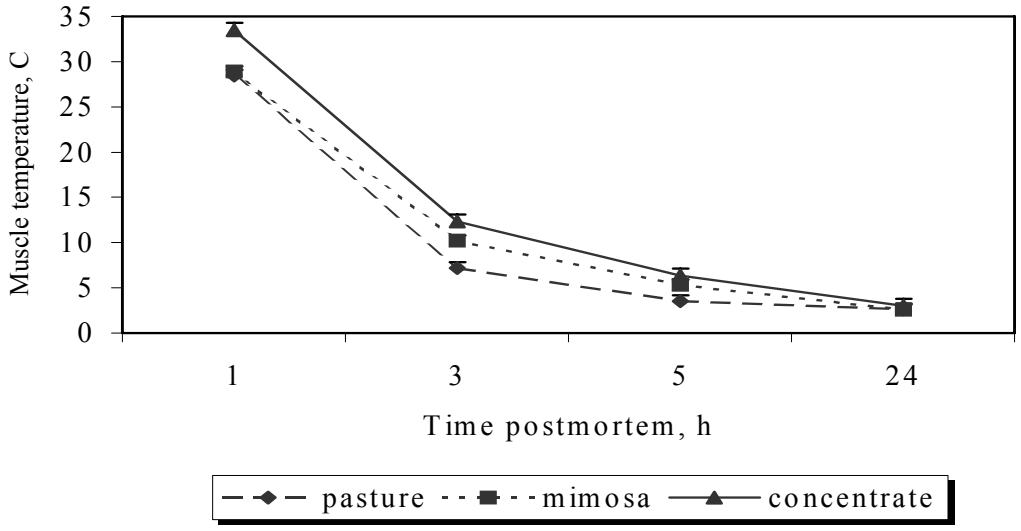



**Figure 1.** Least square means ± SEM for treatment x postmortem time on *longissimus* muscle pH and temperature of goat kids. [a]breed; [b]treatment; [c]hour; [d]breed x treatment; [e]treatment x hour; [f]breed x treatment x hour; n = 15 for each mean.

obtained within 6 h postmortem. These conditions along with proper temperatures at 2 h postmortem contribute to preventing cold shortening in goat carcasses.

Objective color measurements of the LM 48 h postmortem are shown in Table 1. Production system did not affect the lightness ($L^*$; $P = 0.71$) or redness ($a^*$; $P = 0.82$) of the LM among goat carcasses. Carcasses from the BG and MB goats had higher ($P = 0.04$) $b^*$ values indicating more yellowness compared to goats receiving CONC. King et al. (2004) reported muscle color values ($L^*$, $a^*$, $b^*$) of Boer cross goat carcasses that were within the same range as the present study. Goat meat has been reported to be darker and redder than lamb due to the low intramuscular fat content (Babiker et al., 1990). Sheridan et al. (2003b) compared fresh meat color values between Boer kids and Merino lambs receiving diets with varying levels of energy. These researchers reported lighter $L^*$ and lower $a^*$ values in the 28-d harvest group and lower $b^*$ values in the 56-d harvest group for the Boer kids than for Merino lambs.

Table 1. CIE $L^*$, $a^*$ and $b^*$ color parameters (lsmean ± SE) of *m. longissimus* muscle from pasture-fed, browse-fed and concentrate-fed goat kids measured 48 h postmortem (d 0).

| Trait | Pasture | Browse | Concentrate | $P$ - value |
|---|---|---|---|---|
| No. of animals | 15 | 15 | 15 | |
| $L^*$ value[1] | 43.7 ± 2.68 | 43.2 ± 2.90 | 41.9 ± 3.12 | 0.71 |
| $a^*$ value[1] | 13.0 ± 1.36 | 14.3 ± 1.84 | 12.7 ± 1.82 | 0.82 |
| $b^*$ value[1] | 15.9[a] ± 0.52 | 15.9[a] ± 0.42 | 13.6 [b] ± 0.68 | 0.04 |

[ab] Means within the same row with different superscripts differ ($P < 0.05$).

[1] $L^*$ values are a measure of lightness (0 = black, 100 = white); $a^*$ values are a measure of redness; measurement range = 60 to (-60); (positive values = red, negative values = green); $b^*$ values are a measure of yellowness; measurement range = 60 to (-60); (positive values = yellow, negative values = blue).

***Fatty acid and cholesterol analysis***

Fatty acid methyl ester weights (milograms) per 100 g of LM tissue are reported in Table 2. The principle fatty acids in the intramuscular fat of goat LM tissue were, in all production systems, palmitic (C16:0), stearic (C18:0), oleic (C18:1) and linoleic (C18:2). Saturated fatty acids include mainly myristic (C14:0), C16:0 and C18:0; monounsaturated fatty acids are primarily palmitoleic (C16:1) and C18:1; and polyunsaturated fatty acids are mainly C18:2, linolenic (C18:3) and arachidonic (C20:4). Mahgoub et al. (2002) reported similar results in Akhdar goats of different sexes and weights when fed a concentrate diet containing 16 percent protein and Rhodesgrass hay. Beserra et al. (2004) also reported greater percentages of palmitic, stearic and oleic fatty acid in castrated Moxoto' goats and their crosses when fed a diet containing native Brazil grass supplemented with elephant grass and sorghum silage.

Results from the present study demonstrated an influence of production system on the fatty acid profile of Boer goat kids. Goats receiving CONC contained lower ($P$ = 0.001) concentrations of tridecanoate (C13:0) than goats browsing MB or grazing BG. However, there were no differences ($P > 0.05$) in the concentrations of C14:0, myristoleate (C14:1), pentadecanoate (C15:0) or pentadecenoate (C15:1) among production systems. Lower ($P = 0.01$) concentrations of C16:0 were observed in MB and BG goats with similar ($P = 0.64$) concentrations in the trans form of palmitelaidate (C16:1) among production systems. Lower ($P = 0.001$) concentrations in the cis form of palmitoleate (C16:1) were observed in the BG and MB goats. Heptadecanoate (C17:0) was greater ($P = 0.05$) in CONC goats whereas,10-heptadecenoate (C17:1) was lower ($P$ = 0.04) in BG goats. The fatty acids of C18:0, oleate (C18:1 cis-9) and vaccenate (C18:1

cis-7) were greater ($P > 0.05$) in CONC goats compared to MB and BG goats. Elaidate (C18:1 trans-9) concentrations were greater ($P = 0.002$) in MB goats than CONC and BG goats with no differences ($P = 0.71$) in petroselinate (C18:1 cis-11) among production systems. The CONC goats contained greater ($P = 0.05$) concentrations of the n-6 fatty acid linoleate (C18:2 cis 9,12) compared to MB and BG goats, whereas MB goats contained greater ($P = 0.001$) concentrations of the n-3 fatty acid linolenate (C18:3 cis 9,12,15) compared to CONC and BG goats.

Conjugated linoleic acid concentraions (**CLA**; C18:2 c9, t11) were similar ($P = 0.76$) among production systems with weight percentages less than one percent of the total fatty acid concentration. The n-6 long chain fatty acids of eicosadienoate (C20:2 cis-11,14) and homogamma linolenate (C20:3 cis-8,11,14) were similar ($P = 0.95$; $P = 0.18$, respectively) among production systems however, concentrations of the n-6 fatty acid arachidonate (C20:4 cis-5,8,11,14) were greater ($P = 0.04$) in BG goats, whereas docosatetraenoate (C22:4 cis-7,10,13,16) concentrations were greater ($P = 0.004$) in CONC and BG goats. The n-3 long chain fatty acid eicosapentaenoate (EPA; C20:5 cis-5,8,11,14,17) did not differ ($P = 0.73$) among production systems, however docosapentaenoate (DPA; C22:5 cis-7,10,13,16,19) concentrations were greater ($P = 0.001$) in MB goats and lower ($P = 0.001$) in CONC goats. The greater concentration of DPA in MB goats would be expected because DPA is synthesized from the elongation and desaturation of C18:3 which was also greater in MB goats. Desirable fatty acids (**DFA**) are fatty acids (all unsaturated fatty acids and C18:0) that exhibit no adverse implications on human health (Rhee, 1992). In a review by Banskalieva et al. (2000) comparisons were made between fatty acid profiles of goat muscle and that of beef and

lamb muscle. Results indicated that average percentages of DFA in goats ranged from 61 to 80 percent and were greater than percentages reported for beef and lamb (63 to 71 percent).

Total SFA and MUFA levels were affected by production system with CONC goats having greater ($P = 0.03$; $P = 0.001$, respectively) concentrations than MB or BG goats, however total PUFA concentrations were similar ($P = 0.77$) among production systems. Total n-6 concentrations were greater ($P = 0.001$) in CONC goats, whereas total n-3 concentrations were greater ($P = 0.001$) MB goats. The n-6:n-3 ratio was lowest ($P = 0.001$) in MB goats second lowest ($P = 0.001$) in BG and greatest ($P = 0.001$) in CONC goats. The PUFA:SFA ratio was lowest ($P = 0.05$) in CONC goats when compared to MB and the BG goats. Total fatty acid concentrations were greater ($P = 0.01$) in CONC goats compared to MB or BG goats reflecting their greater carcass fatness.

Properly balanced fatty acid profiles have a beneficial effect on human nutrition. Goat meat has been reported to have a beneficial fatty acid profile and is considered ideal for human consumption (Hogg et al., 1992; Mahgoub et al., 2002). Plasma cholesterol concentrations are influenced by the fatty acid profile of dietary fat. Saturated fatty acids (C14:0 and C16:0) cause elevated low density lipoprotein (**LDL**) cholesterol levels in plasma and are considered atherogenic, whereas C18:0 and C18:2 are neutral, and C18:1 reduce LDL cholesterol levels in plasma (Spady et al., 1993) therefore, as the proportion of C18:0, C18:1 and C18:2 increases and C14:0 + C16:0 decreases the effect should be that plasma LDL-cholesterol levels decrease (Grundy and Denke, 1990; Derr et al., 1993). The n-6:n-3 ratio is an index of the role played by fatty acids in human atherosclerosis (Enser, 2001). Consumption of adequate levels of n-3 fatty acids decrease

serum triacylglycerols, increase LDL cholesterol and high density lipoproteins (**HDL**) cholesterol with no effect on total cholesterol (Harris, 1997). However, elevated levels of n-6 fatty acids (C18:2 cis-9,12 and C20:4 cis-5,8,11,14) contribute to the synthesis of eicosanoids with severe thrombotic tendencies that predispose consumers to coronary diseases (Enser, 2001).

In the present study goats browsing MB obtained an acceptable n-6;n-3 ratio, in accordance within the Department of Health's (1994) recommended value of below four, due to elevated concentration of n-3 fatty acids (C18:3 and C22:5) and a decrease in concentration of the n-6 fatty acid C22:4. Goats grazing BG and receiving CONC had reduced concentrations of n-3 fatty acids (C18:3 and C22:5) with elevated concentrations of n-6 fatty acids. The n-6 fatty acid C22:4 was elevated in BG goats and concentrations of C18:2 and C22:4 were elevated in CONC goats causing the n-6:n-3 ratio to exceed the recommended value of below four. These differences are a consequence of the fatty acid profile in the diet. The addition of a concentrate protein pellet in the diet of the BG and CONC goats lead to a decrease in C18:3 and C22:5 concentrations in the muscle tissue. Intramuscular lipids reflect the lipid profile of the diet consumed by the animal with C18:3 (n-3 precursor) being the major fatty acid in grass lipids and C18:2 (n-6 precursor) being a major component in grains (Marmer et al., 1984). Rhee et al. (2000) reported that grain rations contained lower amounts of C18:3 fatty acids and greater amounts of C18:2 fatty acids compared to grasses, forbs and browse.

The PUFA:SFA ratio is used to calculate the risk factor of foods with regard to blood cholesterol rise. The PUFA:SFA ratios calculated for each production system were below the recommended values of 0.45 established by the Department of Health (1994).

Compared with the PUFA:SFA ratio of CONC goats, BG and MB goats had greater C22:5 PUFA and lower C18:0 and C16:0 SFA which were responsible for the greater PUFA:SFA ratios observed. According to French et al. (2000) PUFA:SFA ratios usually increase linearly with increased forage intake. The resulting PUFA:SFA ratios of the present study are in agreement with compiled data reported by Banskalieva et al. (2000) for goat muscle PUFA:SFA (median 0.32) and are greater than compiled data for lamb (median 0.19) and beef (median 0.25). Rule et al. (2002) compared fatty acid profiles from range and feedlot bison and beef cattle with range elk and reported that range bison, cattle and elk have the most beneficial PUFA:SFA and n-6:n-3 ratios than the feedlot bison or cattle. The present study is also in agreement with Johnson et al. (1998) who reported that goat kids reared in an intensive system (grain-fed) contained greater amounts of C18:2 and SFA while goat kids reared in a semi-intensive system (range with supplemental corn) contained greater ratios of unsaturated to saturated fatty acids. Sheridan et al. (2003a) reported no difference in PUFA of goats fed a high energy or low energy diet, however goats had a lower SFA concentration and SFA to unsaturated fatty acid ratio with greater MUFA concentrations when compared to sheep. A possible explanation for species differences can be attributed to the fatty acid profile of the subcutaneous fat between sheep and goats. Goat subcutaneous fat depots are less saturated, with greater MUFA concentrations and less C18:2 and C18:3 than sheep (Banskalieva et al., 2000).

Cholesterol concentration of the LM was not affected by production systems ($P$ = 0.25; Table 2). The cholesterol concentrations in the present study are in agreement with Park et al. (1991) who reported cholesterol values for goat LM at 57.8 mg/100 g muscle

in young dairy goats of the Alpine and Nubian breeds and Beserra et al. (2004) who reported cholesterol values of 69.4 mg/100 g muscle in Moxoto' goats at 8 to10 weeks of age. Results from Sheridan et al. (2003a) indicate that cholesterol values in goat rib cuts (66.8 mg/100 g) were lower than cholesterol values from rib cuts of lamb (99.3 mg/100 g). Results from the present study indicate that goat LM cholesterol values (63.3 to 66.1 mg/100g) are similar to cholesterol values of beef LM (51.7 to 65.8 mg/100g; Rhee et al., 1982 and 45 to 55 mg/100g; Rule et al., 1997). Total cholesterol concentration in goats has been shown to decrease with increased age (Madruga et al., 2001). Werdi Pratiwi et al. (2005) reported that for each kilogram increase in harvest weight, the mean values of total cholesterol concentrations decreased by 0.18 units (mg/100 g) for longissimus, 0.07 units (mg/100 g) for *infraspinatus* and 0.08 units (mg/100 g) for *biceps femoris* muscles.

Table 2**.** Intramuscular fatty acid composition and cholesterol (lsmean ± SE) of *m. longissimus* muscle from pasture-fed, browse-fed and concentrate-fed goats

| Fatty acid | Pasture | Browse | Concentrate | *P* – value |
|---|---|---|---|---|
| 13:0 | 7.42 ± 1.89[a] | 10.24 ± 1.54[a] | 0.70 ± 1.79[b] | 0.001 |
| 14:0 | 30.97 ± 4.75 | 24.57 ± 3.86 | 35.25 ± 4.50 | 0.17 |
| 14:1 cis-9 | 0.70 ± 0.42 | 0.01 ± 0.34 | 0.08 ± 0.40 | 0.46 |
| 15:0 | 4.67 ± 1.30 | 6.78 ± 1.06 | 7.06 ± 1.23 | 0.43 |
| 15:1 cis-9 | 13.78 ± 2.27 | 15.71 ± 1.85 | 14.42 ± 2.15 | 0.77 |
| 16:0 | 296.21 ± 43.92[b] | 299.86 ± 35.69[b] | 474.71 ± 41.59[a] | 0.01 |
| 16:1 trans-9 | 7.87 ± 1.21 | 9.24 ± 0.98 | 9.46 ± 1.14 | 0.64 |
| 16:1 cis-9 | 23.19 ± 4.44[b] | 21.24 ± 3.61[b] | 43.96 ± 4.21[a] | 0.001 |
| 17:0 | 14.33 ± 2.98[b] | 18.59 ± 2.42[ab] | 23.67 ± 2.82[a] | 0.05 |
| 17:1 cis-9 | 10.27 ± 1.67[b] | 13.58 ± 0.95[a] | 14.07 ± 1.10[a] | 0.04 |
| 18:0 | 236.71 ± 36.53[b] | 260.86 ± 29.68[b] | 336.72 ± 34.59[a] | 0.05 |
| 18:1 trans-9 | 2.14 ± 1.13[b] | 5.09 ± 0.92[a] | 0.11 ± 1.07[b] | 0.002 |
| 18:1 cis-11 | 32.86 ± 6.57 | 37.03 ± 5.34 | 45.46 ± 6.22 | 0.71 |

(table continues)

Table 2 (continued)

| Fatty acid | Pasture | Browse | Concentrate | *P* – value |
|---|---|---|---|---|
| 18:1 cis-9 | 537.94 ± 90.14[b] | 571.45 ± 73.14[b] | 1010.39 ± 85.25[a] | 0.001 |
| 18:1 cis-7 | 18.96 ± 2.22[b] | 17.87 ± 1.80[b] | 27.50 ± 2.10[a] | 0.004 |
| 18:2 cis-10,12 | 6.25 ± 5.64 | 1.16 ± 4.58 | 10.84 ± 5.34 | 0.58 |
| 18:2 cis-9,12 | 65.01 ± 8.90 | 63.16 ± 7.23 | 83.54 ± 8.43 | 0.05 |
| 18:3 cis-9,12,15 | 6.17 ± 1.13[b] | 16.68 ± 0.92[a] | 6.14 ± 1.07[b] | 0.001 |
| 18:2 c-9, t-11 CLA[1] | 11.60 ± 2.13 | 13.69 ± 1.73 | 11.85 ± 2.02 | 0.76 |
| 20:2 cis-11,14 | 7.90 ± 0.45 | 8.36 ± 0.37 | 8.80 ± 0.43 | 0.95 |
| 20:3 cis-8,11,14 | 3.51 ± 0.70 | 1.91 ± 0.57 | 2.92 ± 0.66 | 0.18 |
| 20:4 cis-5,8,11,14 | 53.64 ± 3.00[b] | 45.35 ± 2.44[a] | 48.84 ± 2.84[ab] | 0.04 |
| 20:5 cis-5,8,11,14,17 | 6.10 ± 2.47 | 8.89 ± 2.96 | 6.17 ± 3.08 | 0.73 |
| 22:4 cis-7,10,13,16 | 3.16 ± 0.65[a] | 0.94 ± 0.53[b] | 3.36 ± 0.62[a] | 0.004 |
| 22:5 cis-7,10,13,16,19 | 11.36 ± 0.46[b] | 14.80 ± 0.37[a] | 9.01 ± 0.44[c] | 0.001 |
| SFA[1] | 590.31 ± 86.19[b] | 620.89 ± 70.03[b] | 878.12 ± 81.63[a] | 0.03 |
| MUFA[1] | 649.51 ±103.83[b] | 691.83 ± 84.37[b] | 1165.20 ± 98.34[a] | 0.001 |
| PUFA[1] | 171.58 ± 9.37 | 179.92 ± 7.61 | 189.92 ± 8.87 | 0.77 |
| n-6[2] | 138.76 ± 7.58[b] | 125.45 ± 6.16[b] | 158.91 ± 7.18[a] | 0.001 |
| n-3[2] | 21.21 ± 1.86[b] | 40.78 ± 1.51[a] | 19.16 ± 1.76[b] | 0.001 |
| n-6:n-3 | 6.83 ± 0.56[b] | 3.21 ± 0.46[c] | 8.75 ± 0.53[a] | 0.001 |
| PUFA:SFA | 0.34 ± 0.04[a] | 0.32 ± 0.03[a] | 0.23 ± 0.03[b] | 0.05 |
| Unknown-<C16 | 9.90 ± 1.87 | 5.73 ± 1.52 | 5.29 ± 1.77 | 0.31 |
| Unknown-C16-C18 | 22.86 ± 4.52[b] | 27.72 ± 3.68[b] | 38.99 ± 4.29[a] | 0.03 |
| Unknown- >C18 | 8.09 ± 2.24 | 4.68 ± 1.82 | 2.17 ± 2.12 | 0.25 |
| Total fatty acids | 1443.54 ±200.65[b] | 1520.09 ± 63.04[b] | 2279.35 ±190.03[a] | 0.01 |
| Cholesterol | 66.12 ± 2.39 | 60.99 ± 1.94 | 63.28 ± 2.26 | 0.25 |

[abc] Means within the same row with different superscripts differ ($P < 0.05$).

[1] CLA: conjugated linoleic acid, SFA: saturated fatty acids, MUFA: monounsaturated fatty acids, PUFA: polyunsaturated fatty acids.

[2] n - 6 fatty acids include:18:2c10,12, 18:2c9,12, 20:2c11,14, 20:3c8,11,14, 20:4c5,8,11,14, 22:4c7,10,13,16. n - 3 fatty acids include:18:3c9,12,15, 20:5c5,8,11,14,17, 22:5c7,10,13,16,19.

### *Simulated retail display and lipid oxidative stability*

*Longissimus* muscle chop instrumental color measurements (*L**, *a**, *b**) over 6 days of simulated display are shown in Figure 2. Chops from the MB and BG goats had

higher ($P = 0.001$) $L^*$ values than chops from CONC goats during 6 days of display. Goats browsing MB and grazing BG had redder ($a^*$; $P = 0.001$) and yellower ($b^*$; $P = 0.04$) chops than CONC goats after 4 days of display. The overall redness ($a^*$) in the MB goats was higher ($P = 0.002$) than in the BG goats, although the differences were not evident at days 5 and 6 of retail display.

Measurements of hue angle did not differ ($P = 0.12$) among production systems throughout the 6 d retail display (Figure 3). However, color saturation (chroma) decreased over display time with CONC chops having the lowest ($P = 0.02$) chroma values from d 3 to d 6. Kannan et al. (2001) reported negative correlations between percent metmyoglobin and both $a^*$ and chroma values in the shoulder, leg and loin cuts of Spanish does suggesting that as metmyoglobin accumulates in muscle tissue the color values of redness and saturation decrease. Hue angle (true redness) values over retail display days did not differ ($P = 0.12$) among production systems. There is little information on the effect of feed-type on meat color in goats, however Oman et al. (2000) and Kannan et al. (2001) reported surface discoloration of goat meat occurs within 4 to 8 d of retail display. Studies examining the effects of feed-type on fresh beef color in cattle have produced mixed results. Higher lean color values ($a^*$) have been reported when comparing forage and concentrate finishing systems (Realini et al., 2004; Bidner et al., 1981) while others have reported similar lean color values ($a^*$; O'Sullivan et al., 2003; French et al., 2001).

Figure 3 shows lipid oxidation values, as determined by TBARS, for LM chops at different storage days of simulated retail display. Lipid oxidation (TBARS) values were similar ($P = 0.27$) among production systems. In the current study, average oxidation

levels of goat LM chops at d 6 of retail display were higher than average oxidation levels reported at d 6 in LM steaks of cattle (Realini et al., 2004). Park and Washington (1993) reported higher ratios of polyunsaturated to saturated fatty acid ratios in goat meat as compared to beef. A higher degree of unsaturated fatty acids could cause a reduction in oxidative stability, which could reduce the storage life of fresh meat products (Rhee et al., 1997 and Morressey et al., 1998).

Metmyoglobin formation and lipid oxidation are associated with discoloration in retail displayed meats (Sherbeck et al., 1995). The formation of metmyoglobin has been shown to be positively correlated with lipid oxidation and is dependent on the antioxidant status of the meat (Yin and Faustman, 1993; Kannan et al., 2001). Studies have shown that dietary vitamin E supplementation causes accumulation of α-tocopherol in muscle tissue (Arnold et al., 1993; Liu et al., 1996). Target α -tocopherol levels for protection against discoloration have been suggested at 3.5 ug α -tocopherol per g of meat (Arnold et al., 1993). In nature the synthesis of vitamin E is a function of plants. Fresh green forages produce five to ten times the vitamin E of cereal grains or dried hays (Ullrey, 1981; Daly et al., 1999). Research has shown that cattle grazing on good quality forages had higher α -tocopherol concentration within muscle tissues than cattle fed a high concentrate grain diet (Arnold et al., 1993; Realini et al., 2004). Although α -tocopherol levels were not measured in the present study, higher lean color values ($a^*$) associated with forage-based systems (MB and BG) were similar to results reported by Realini et al. (2004) in which cattle background on good quality pastures exhibited higher lean color values ($a^*$) over cattle receiving concentrate.

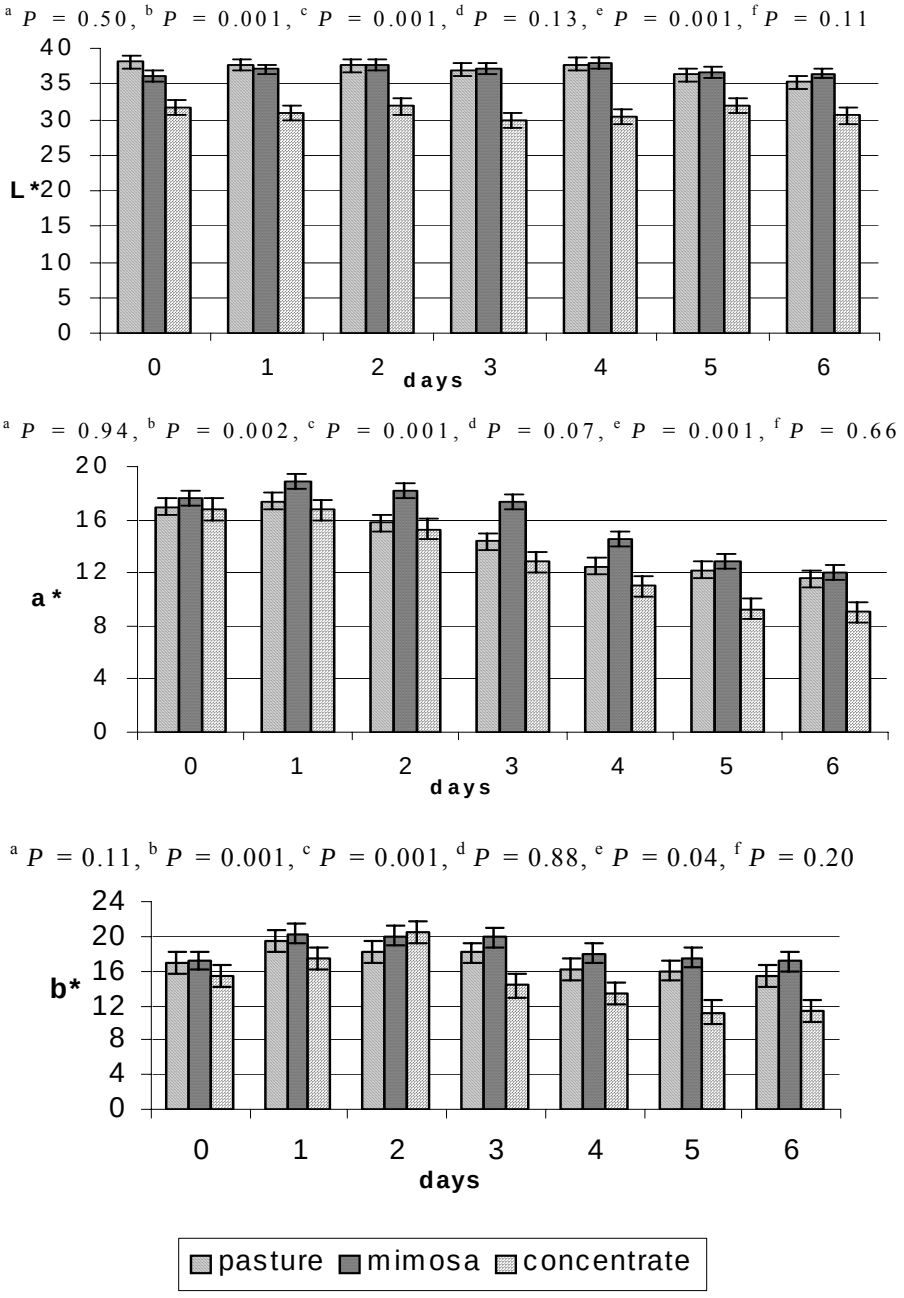



**Figure 2.** Least square means ± SEM for treatment x display day on CIE *L**, *a** and *b** values for *m. longissimus* muscle chops. [a]breed; [b]treatment; [c]day; [d]breed x treatment; [e]treatment x day; [f]breed x treatment x day; n = 15 for each mean.

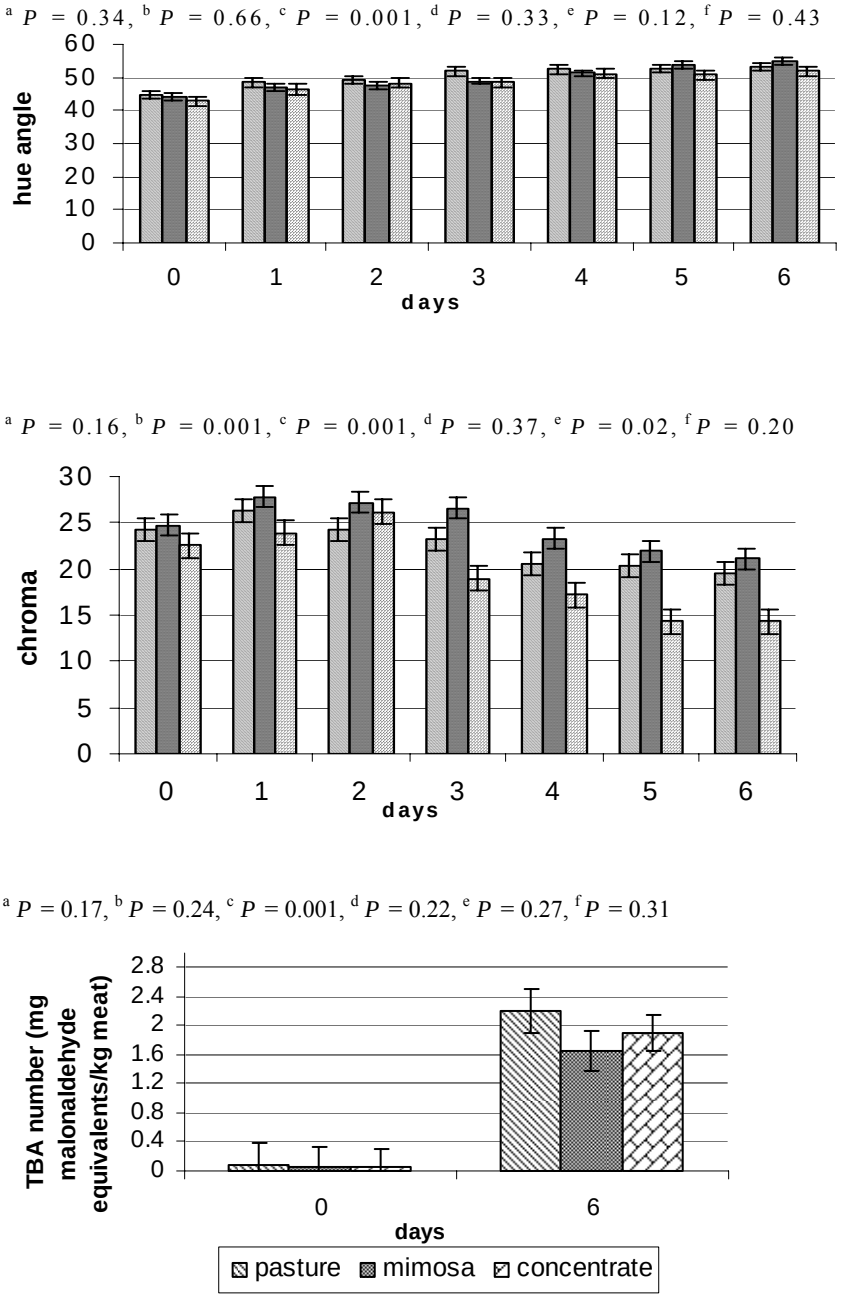



**Figure 3.** Least square means ± SEM for treatment x display day on hue angle, chroma values and thiobarbituric acid reactive substances (TBARS) for *m. longissimus* muscle chops. [a]breed; [b]treatment; [c]day; [d]breed x treatment; [e]treatment x day; [f]breed x treatment x day; n = 15 for each mean.

***Shear force determination and sensory evaluation***

Warner-Bratzler shear force (WBSF) values percent cooking loss and sensory scores over 14 d of aging are presented in Table 3. Cooking time and temperature for SM and BF muscle groups did not differ ($P > 0.05$; data not shown) among production systems. The average cook time and temperature for SM and BF muscles were 5.7 and 3.6 minutes and 69 and 70 ºC, respectively. Goats browsing MB had higher ($P = 0.01$) WBSF values in the SM muscle and lower ($P = 0.01$) WBSF values in the BF muscle than goats grazing BG or receiving CONC. The WBSF values for both muscle groups were within an acceptable tenderness rating of 3 kg for lamb and 4.0 kg for beef muscles (Daly, 2000; Miller et al., 2001). Percent cooking loss from the SM and BF muscles did not differ ($P > 0.05$) among production systems. Cooking loss in the SM and BF muscles ranged from 28.6 to 23.4%, respectively, and was within reported ranges for goat muscles (Schonfeldt et al., 1993a; Kannan et al., 2001; King et al., 2004; Sen et al., 2004). Sensory scores for tenderness, juiciness, flavor intensity and off flavor did not differ ($P > 0.05$) among production systems.

Several authors have reported that goat meat is less tender than other types of red meat (Sen et al., 2004; Schonfeldt et al., 1993b; Griffin et al., 1992). The lower WBSF values in the present study may be due to the extensive postmortem aging period of 14 d as compared to shorter postmortem aging of 1, 2, and 7 d in previous studies (Schonfeldt et al., 1993b; Sheridan et al., 2003b; respectively; Sen et al., 2004;). McKeith et al. (1979) reported improved tenderness of goat muscles when aged for 7 d, while King et al. (2004) reported improved tenderness values when goat carcasses were aged for 14 d as compared to 3 d. Increased tenderness as muscle ages is due to the structural weakening

of the myofibrils by calpain proteases (Muir et al., 1998). Kannan et al. (2002) reported no visible structural changes of the intramuscular connective tissue in goat LM during 12 d of postmortem aging, however myofibril fragmentation increased with aging time for up to 8 d. Weakening of the intramuscular connective tissue structure in beef muscle has been shown to occur after 14 d of postmortem aging based on decreases in mechanical strengths and increases in yield of perimysial fractions (Nishimura et al., 1998).

Production system did not influence sensory evaluation traits in the current study ($P > 0.05$). Sheridan et al. (2003b) reported no difference in organoleptic attributes of Boer goat kids finished on either a high energy or low energy diet. Johnson and McGowan (1998) also reported no effect of diet/management system on sensory traits of juiciness, flavor, tenderness, or off flavor in roasted goat loins. In studies comparing goat and sheep meat, researchers have reported that goat has a stringy texture and is less juicy than lamb and contribute the differences to the lower fat content and larger muscle fiber diameter of the goat muscles (Sheridan et al., 2003b; Tshabalala et al., 2003; Arguello et al., 2005). Rodbotten et al. (2004) conducted a sensory map of meat from different species used for food consumption. Goat meat was described as having an intense "gamey" flavor, toughness and hardness when compared with 14 other species. Branched chain fatty acids have been implicated in sheep and goat species related flavor (Wong et al., 1975; Johnson et al., 1977). Branched chain fatty acids (BCFA) have been found to accumulate in sheep and goat as a result of restricted roughage and high grain diets, which change the favorable acetate to propionate acid ratio in the rumen, and are associated with the undesirable species-related flavor and odor (Van Soest, 1994; Ha and Lindsay, 1991). Young et al. (1997) found that lambs reared on feedlots with alfalfa and

corn had higher concentrations of BCFA when compared to lambs grazed on ryegrass and clover pastures.

Table 3. Warner-Bratzler shear force (WBSF), cooking loss and sensory evaluation (lsmean ± SE) from pasture-fed, browse-fed and concentrate-fed goat kids

| Trait | Pasture | Browse | Concentrate | *P* - value |
|---|---|---|---|---|
| No. of animals | 15 | 15 | 15 | |
| *m. semimembranosus* | | | | |
| WBSF, kg | $2.91^{b} \pm 0.41$ | $3.29^{a} \pm 0.42$ | $2.16^{b} \pm 0.48$ | 0.01 |
| Cooking loss, % | 28.0 ± 1.90 | 31.0 ± 1.88 | 26.6 ± 2.49 | 0.15 |
| Sensory | | | | |
| Initial tenderness[1] | 5.72 ± 0.22 | 5.93 ± 0.26 | 5.24 ± 0.35 | 0.42 |
| Sustained tenderness[1] | 5.44 ± 0.23 | 5.51 ± 0.27 | 5.22 ± 0.36 | 0.87 |
| Initial juiciness[1] | 5.69 ± 0.67 | 6.03 ± 0.51 | 6.09 ± 0.66 | 0.89 |
| Sustained juiciness[1] | 5.58 ± 0.98 | 6.02 ± 0.59 | 6.78 ± 0.79 | 0.64 |
| Flavor intensity[1] | 6.23 ± 0.82 | 6.46 ± 0.44 | 7.44 ± 0.61 | 0.39 |
| Off flavor[1] | 6.22 ± 0.29 | 6.31 ± 0.28 | 6.41 ± 0.33 | 0.32 |
| *m. biceps femoris* | | | | |
| WBSF, kg | $2.69^{b} \pm 0.12$ | $2.34^{a} \pm 0.10$ | $2.76^{b} \pm 0.16$ | 0.01 |
| Cooking loss, % | 25.1 ± 2.53 | 24.4 ± 2.03 | 20.6 ± 3.32 | 0.29 |
| Sensory | | | | |
| Initial tenderness[1] | 5.95 ± 0.62 | 5.89 ± 0.32 | 6.19 ± 0.71 | 0.88 |
| Sustained tenderness[1] | 5.55 ± 0.77 | 6.03 ± 0.62 | 5.57 ± 0.79 | 0.84 |
| Initial juiciness[1] | 5.83 ± 0.68 | 6.64 ± 0.47 | 5.38 ± 0.62 | 0.25 |
| Sustained juiciness[1] | 5.76 ± 0.81 | 6.97 ± 0.54 | 5.29 ± 0.71 | 0.15 |
| Flavor intensity[1] | 6.54 ± 0.27 | 6.48 ± 0.23 | 6.13 ± 0.29 | 0.62 |
| Off flavor[1] | 6.45 ± 0.37 | 6.38 ± 0.30 | 6.11 ± 0.38 | 0.83 |

[ab] Means within the same row with different superscripts differ ($P < 0.05$).

[1] 1-8 point scale, where 1= extremely tough, extremely dry, extremely bland, extremely uncharacteristic and 8= extremely tender, extremely juicy, extremely intense, extremely characteristic.

## IMPLICATIONS

Production system influenced temperature measurements with concentrate carcasses cooling at a slower rate when compared to the mimosa and bahiagrass carcasses. Mimosa-fed goats had greater n-3 fatty acids with a desirable n-6:n-3 ratio. Forage systems produced lower total fatty acids concentrations and greater PUFA:SFA ratios. Cholesterol values were similar among systems and considered to be comparable to other red meat species. Forage goats had greater *a** and chroma values with discoloration decreasing within four days confirming that goat meat is similar to other red meats in shelf life stability. Lipid oxidation increased with days on display; however sensory traits were not affected by production system. Shear force values indicated that goat meat was within an acceptable range for tender meat. Therefore, forage-based systems can improve the fatty acid profile of intramuscular fat in goats, from a human nutrition perspective, without having detrimental effects on meat quality.

# V. DEVELOPMENT OF MULTIPLE REGRESSION EQUATIONS FOR PREDICTING CAPRINE CARCASS COMPOSITION AND CUTABILITY USING CARCASS TRAITS AND RIB SECTION COMPOSITION

**ABSTRACT:** Carcasses from 89-castrated Boer cross goat kids were used to develop prediction equations for carcass composition. Carcasses from 18 of the 89 goat kids were used to determine salable bone-in retail yield. Dressing percentage (**Dp**), hot carcass weight (**HCW**), kidney and pelvic fat (**Kpf**), backfat thickness (**Bf**), body wall fat (**Bwf**) and LM area were measured and used as independent variables in developing regression equations. Carcasses were split, the left half was utilized for total body composition and the 9-10-11$^{th}$ rib section was removed from the right half. Carcass sides and rib sections were dissected into separable lean and bone portions. Lean portions were analyzed for moisture, fat, protein, and ash percents. Prior to dissection, the left sides of 18 carcasses were fabricated into standard food service and hotel style retail cuts and weighed. Whole body moisture and fat percentages were predicted utilizing the rib section moisture and fat percentages with $R^2$ values of 0.78 and .081, respectively. Hot carcass weight and Bwf accounted for the variation in whole body moisture with an $R^2$ value of 0.71. Percent fat in the whole body was predicted utilizing Dp, Bwf and Kpf with an $R^2$ value of 0.74. Bone-in retail yields were correlated ($P < 0.05$) with carcass measurements of live weight, Dp,

HCW, CCW, LM area, boneless lean weight and hindlimb and forelimb circumference. Live weight accounted for the variation in total bone weight with a resulting $R^2$ value of 0.69. Cold carcass weight alone explained 99 percent of the variation in total lean weight. The shoulder, leg, neck and brisket cuts resulted in an $R^2$ value of 0.32 with the LM area accounting for the variation. The loin, sirloin and spare rib cuts were predicted with $R^2$ values of 0.49, 0.55, and 0.55, respectively with HCW as the major variation. Dressing percent accounted for the variation in the roast cut and in the trim with $R^2$ values of 0.29 and 0.72, respectively. These data indicate that moisture and fat percentages in goat carcasses can be predicted accurately utilizing carcass traits. The composition measurements of the 9-10-11$^{th}$ rib section are useful for predicting carcass composition and are highly correlated to the whole body composition measurements. These results also demonstrate the potential use of carcass traits in predicting bone-in retail yields of goat carcasses.

## INTRODUCTION

The ability to estimate carcass composition without sacrificing the entire carcass is a valuable research tool. The typical carcass composition of an adult mammal is 60 percent water, 16 percent protein, 20 percent fat and 4 percent mineral matter (Church and Pond, 1982). Breed, age, sex, body weight, and plane of nutrition can influence carcass fat content. Owen et al. (1978) reported that fat tissues of Botswana and Boer goats did not reach appreciable levels until the body weight of 40 kg was achieved. Tahir et al. (1994) showed that an increase in body weight from 18.5 to 24.5 kg increased the carcass lean and fat content and decreased the bone percentage of Iraqi black kids. The most accurate

method of determining carcass composition is by chemically analyzing the carcass (Callow, 1962). One of the first methods to simplify measuring the composition of beef carcasses was to physically separate and chemically analyze the 9-10-11$^{th}$ rib section (Hankins and Howe, 1946). Cole et al. (1960 and 1962) and Ramsey et al. (1962) later related carcass yield traits to the separable carcass muscle and developed equations to predict the amount of separable muscle in beef carcasses. Goats are sold to the consumer as bone-in whole carcasses or bone-in retail cuts. In order to bring value-based marketing to the goat industry, prediction methods based on live animal and carcass measurements are needed to determine the amount of saleable carcass product. Equations have been developed for predicting percent lean, fat and bone of major cuts in various breeds of goats using dissection methods and ultrasound technology (Tahir et al., 1994; McGregor, 1990; and Arguello et al., 2001). Therefore, the objectives of this study were to identify practical carcass traits related to carcass composition, compare rib section composition to carcass composition, and develop accurate equations for predicting carcass composition and salable bone-in retail yields from carcass traits.

## MATERIALS AND METHODS

### *Animals*

Eighty-nine castrated Boer cross goat kids varying widely in the selection criteria of the Institutional Meat Purchase Specifications (IMPS) and exposed to different feeding systems (concentrate, browse, pastures) were used for this experiment. The Auburn University and Tuskegee University Animal Care and Use Committees approved the animal care, handling and sampling procedures. Upon arrival, animals were weighed,

vaccinated s.c. with *Clostridium perfringens* type C & D-Tetani Bacterin-Toxoid (Bayer: Bayer Corp., Animal Health, Shawnee Mission, Kansas), dewormed with Cydectin (Moxidectin, Fort Dodge Animal Health, Fort Dodge, Iowa) and dusted along the loin area and neck for external parasites using Co-Ral 1% dust (Dale Alley Co., St. Joseph, Missouri) . Goats were surgically castrated four wk prior to the start of the studies followed by a s.c. injection of Liquamycin LA-200 (Pfizer, Animal Health, Exton, Pennsylvania) to prevent the occurrence of infection as recommended by a veterinarian.

***Carcass data collection***

Goats were weighed for two consecutive d, stratified by BW and randomly assigned to several experimental feeding systems. At the end of the studies, final BW was obtained on two consecutive d, and goats were transported approximately 40 km to the Auburn University Lambert Meat Abattoir. Goats were harvested according to USDA approved methods, after an overnight period of feed withdrawal. Hot carcass weight (HCW) was determined on the d of harvest. Cold carcass weight (CCW), carcass shrink percentage, fat depth over the midpoint of the LM (Bf; between the 12th and 13th ribs), body wall fat (Bwf; measured at the lower portion of the$12^{th}$ rib), kidney and pelvic fat weight (Kpf), dressing percent (Dp), LM cross-sectional area as well as hindlimb (measurement taken lateral to the aitch bone) and forelimb (measurement taken midpoint of the foreshank) circumferences were determined by a certified USDA grader 48 h after harvest. Carcasses were split and the 9-10-$11^{th}$ rib sections were removed from the right side and the left sides of the carcasses were used to determine carcass composition. Soft tissue and bone were dissected from the left side of the carcass and the 9-10-$11^{th}$ rib sections of the right side of the carcass (Hankins and Howe, 1946). Samples were placed

in plastic bags and stored at -20 °C for later analysis and bones were weighed. Prior to dissection, the left side of 18 carcasses were fabricated into standard food service and hotel style retail cuts according to the IMPS for fresh goat, series 11 (USDA, 2001) and weighed. Standard cuts included shoulder with foreshank, breast and neck (Item # 11-X-22, 11-X-10, and 11-X-34), rack (Item # 11-X-30), loin (Item # 11-X-50), sirloin (Item # 11-X-60), roast (Item # 11-X-73), hindshank (Item # 11-X-11), spare ribs; with breast bone off (Item # 11-X-33), and trim (Item # 11-X-90); (IMPS, Section V, Appendix C, Item descriptions; USDA, 2001) and weighed. Muscle to bone ratios were calculated as the total weight of the soft tissue divided by the total weight of the bone.

***Chemical analysis***

Soft tissues from the 9-10-11$^{th}$ rib section and the left half of the carcass were thawed at 4 °C overnight and were ground twice with a Hobart meat grinder (Model 4822, Biro Manufacturing. Co., Marblehead, Ohio) utilizing a 9.5 mm grinding plate. Samples were ground an additional two times with a KitchenAid Mixer / Grinder (Model K5SS, KitchenAid, Inc., St. Joseph, Michigan) utilizing a 5 mm grinding plate. Half-carcass samples were thoroughly mixed and duplicate sub-samples were taken. Soft tissue samples were analyzed for moisture by drying 5-g samples at 100 °C for 48 h. Ash content was determined on dried samples by ashing samples in a muffle furnace at 600°C overnight. Carcass fat was determined on wet samples using the Soxtec Avanti System (Foss Tecator model 2055, Hoganas, Sweden) and results were calculated on wet basis (AOAC, 1995). Nitrogen was determined by the combustion method (AOAC International, 1998) utilizing the Leco FP-2000 (Leco Corporation, St. Joseph,

Michigan). Crude protein was calculated as nitrogen x 6.25 and results were expressed on a wet basis.

***Statistical analysis***

Data were analyzed using Pearson correlations to determine significant ($P < 0.05$) relationships between carcass composition, carcass traits and bone-in retail cuts (SAS, 2001). Regression models using carcass traits, carcass composition and bone-in retail cuts were generated utilizing the PROC REG and STEPWISE procedures of SAS. Final equations were selected based on maximizing the $R^2$, optimizing Cp value and minimum root mean square error (**RMSE**). In addition, overall means and ranges of the sampled population were determined.

## RESULTS AND DISCUSSION

***Prediction of carcass composition***

The overall descriptive statistics taken from 89-castrated Boer cross goat kids are presented in Table 1. Wide ranges in the population characteristics illustrate the large variation of the selected population. Pearson correlations for whole body composition and rib section composition are presented in Tables 2. The percentage of moisture, ash, protein and fat in the 9-10-11$^{th}$ rib sections were correlated ($P < 0.05$) with those of the whole body (r = 0.86, 0.51, 0.51, and 0.88, respectively). Hedrick et al. (1981) and Powell and Huffman (1968) observed similar results in cattle. Whole body moisture was negatively correlated with rib section fat (r = -0.84) and positively correlated with rib section moisture (r = 0.86) indicating that the 9-10-11$^{th}$ rib section was likely to be a useful predictor of carcass composition. Based on the magnitude of the correlations, the

independent variables with the greatest potential for prediction are fat and moisture percentages.

Table 1. Population means, standard deviation and minimum and maximum values of goat kids (n = 89)

| Variable | Mean | SD | Min. | Max. |
|---|---|---|---|---|
| Moisture % 9-10-11$^{th}$ rib | 64.72 | 5.83 | 48.39 | 73.79 |
| Ash % 9-10-11$^{th}$ rib | 0.94 | 0.12 | 0.67 | 1.33 |
| Protein % 9-10-11$^{th}$ rib | 20.44 | 2.24 | 14.62 | 25.51 |
| Fat % 9-10-11$^{th}$ rib | 13.91 | 7.58 | 2.23 | 36.08 |
| Moisture % carcass | 67.57 | 3.83 | 56.31 | 74.15 |
| Ash % carcass | 0.88 | 0.08 | 0.61 | 1.10 |
| Protein % carcass | 20.13 | 2.02 | 14.14 | 23.50 |
| Fat % carcass | 11.42 | 4.48 | 4.56 | 25.52 |
| Live weight, kg | 30.20 | 6.30 | 18.00 | 43.76 |
| Dressing % | 45.72 | 7.28 | 32.84 | 70.12 |
| Hot carcass weight, kg | 14.02 | 4.38 | 7.26 | 25.06 |
| Cold carcass weight, kg | 13.36 | 4.14 | 6.80 | 23.00 |
| Carcass shrink, % | 5.07 | 3.61 | 0.00 | 13.84 |
| Kidney and pelvic fat, kg | 0.29 | 0.28 | 0.01 | 1.40 |
| Back fat, cm | 0.08 | 0.15 | 0.00 | 1.27 |
| Body wall fat, cm | 0.36 | 0.27 | 0.00 | 1.27 |
| Longissimus muscle area, $cm^2$ | 7.40 | 2.46 | 3.05 | 13.21 |
| Bone % carcass | 27.64 | 6.59 | 14.91 | 45.56 |
| Lean % carcass | 69.34 | 5.55 | 54.44 | 86.21 |

Table 2. Partial correlation coefficients for carcass composition and 9-10-11th rib section composition of goat kids
(n = 89)

| | Trait | | | | | | |
|---|---|---|---|---|---|---|---|
| Trait | Rib ash % | Rib protein % | Rib fat % | Carcass moisture % | Carcass ash % | Carcass protein % | Carcass fat % |
| Rib moisture % | 0.84* | 0.65* | -0.97* | 0.86* | 0.52* | 0.24* | -0.86* |
| Rib ash % | . | 0.61* | -0.84* | 0.83* | 0.51* | 0.23* | -0.83* |
| Rib protein % | . | . | -0.80* | 0.55* | 0.53* | 0.51* | -0.72* |
| Rib fat % | . | . | . | -0.84* | -0.56* | -0.34* | 0.88* |
| Carcass moisture % | . | . | . | . | 0.61* | 0.06 | -0.89* |
| Carcass ash % | . | . | . | . | . | 0.04 | -0.56* |
| Carcass protein % | . | . | . | . | . | . | -0.50* |

* Significant at $P < 0.05$.

Pearson correlations for whole body composition, rib composition and carcass traits are presented in Table 3. Dressing percent, Kpf, Bwf, HCW and CCW were correlated to whole carcass and rib section moisture and fat composition. These variables were negatively correlated ($P < 0.05$) with whole body moisture (r = -0.68, -0.62, -0.72, -0.72, and –0.71, respectively) and rib section moisture (r = -0.75, -0.68, -0.66, -0.79, and –0.78, respectively) and positively correlated ($P < 0.05$) with whole body fat (r = 0.78, 0.75, 0.66, 0.70, and 0.67, respectively) and rib section fat (r = 0.78, 0.73, 0.66, 0.76, and 0.74, respectively). Adipose tissue does not contain as much water as muscle or other tissues resulting in an inverse relationship of water with carcass fat content (Church and Pond, 1982). Longissimus muscle area was positively correlated ($P < 0.05$) with percent of fat in the whole carcass and rib section (r = 0.64 and 0.67, respectively), which indicates that fatter goats in this population also had greater muscle mass. Fatter goats were more heavily muscled because animals on a higher nutritional plane increase both fat deposition and muscle accretion when compared to animals on a lower plane of nutrition. O'Mara et al., (1998) reported the carcass traits of muscle score and calculated LM area were positively related to total fat percentage in slaughter cows representing four genotypes (British, continental, *Bos indicus*, and dairy) and three body condition classes (thin, moderate, and fat). Live weight at harvest, LM area, HCW and CCW were positively correlated ($P < 0.05$) with lean percentage of the whole carcass (r =0.45, 0.43, 0.48, and 0.49, respectively).

**Table 3.** Partial correlation coefficients for carcass composition, 9-10-11th rib section composition and carcass traits of goat kids (n = 89)

| | Trait | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Trait | Live weight, kg | Dressing % | Hot carcass wt, kg | Cold carcass wt, kg | Carcass shrink % | Kidney-pelvic fat, kg | Back fat, cm | Body wall fat, cm | LM area, $cm^2$ | Bone % carcass | Lean % carcass |
| Rib moisture % | -0.62* | -0.75* | -0.79* | -0.78* | -0.08 | -0.68* | -0.26* | -0.66* | -0.69* | 0.61* | -0.42* |
| Rib ash % | -0.52* | -0.66* | -0.69* | -0.67* | -0.20 | -0.64* | -0.28* | -0.63* | -0.66* | 0.48* | -0.24* |
| Rib protein % | -0.22* | -0.65* | -0.49* | -0.44* | -0.34* | -0.68* | -0.31* | -0.47* | -0.43* | 0.44* | -0.21* |
| Rib fat % | 0.55* | 0.78* | 0.76* | 0.74* | 0.16 | 0.73* | 0.29* | 0.66* | 0.67* | -0.63* | 0.39* |
| Carcass moisture % | -0.56* | -0.68* | -0.72* | -0.71* | -0.13 | -0.62* | -0.21* | -0.72* | -0.65* | 0.56* | -0.30* |
| Carcass ash % | -0.16 | -0.31* | -0.29* | -0.28* | -0.18 | -0.30* | -0.31* | -0.54* | -0.18 | 0.30* | -0.27* |
| Carcass protein % | 0.05 | -0.42* | -0.18 | -0.13 | -0.34* | -0.48* | -0.11 | -0.09 | -0.18 | 0.26* | -0.07 |
| Carcass fat % | 0.46* | 0.78* | 0.70* | 0.67* | 0.27* | 0.75* | 0.24* | 0.66* | 0.64* | -0.61* | 0.29* |
| Live wt, kg | . | 0.47* | 0.89* | 0.92* | -0.27* | 0.48* | 0.05 | 0.30* | 0.82* | -0.57* | 0.45* |
| Dressing % | . | . | 0.82* | 0.76* | 0.36* | 0.81* | 0.17 | 0.54* | 0.77* | -0.67* | 0.39* |
| Hot carcass wt, kg | . | . | . | 0.99* | 0.03 | 0.74* | 0.12 | 0.47* | 0.93* | -0.70* | 0.48* |
| Cold carcass wt, kg | . | . | . | . | -0.09 | 0.70* | 0.12 | 0.46* | 0.92* | -0.68* | 0.49* |
| Carcass shrink % | . | . | . | . | . | 0.29* | 0.03 | 0.15 | -0.01 | -0.07 | -0.13 |
| Kidney-pelvic fat, kg | . | . | . | . | . | . | 0.19 | 0.39* | 0.72* | -0.59* | 0.26* |
| Back fat, cm | . | . | . | . | . | . | . | 0.29* | 0.09 | -0.13 | 0.08 |
| Body wall fat, cm | . | . | . | . | . | . | . | . | 0.38* | -0.41* | 0.27* |
| LM area, $cm^2$ | . | . | . | . | . | . | . | . | . | -0.67* | 0.43* |
| Bone % carcass | | . | . | . | . | . | . | . | . | . | -0.65* |

- Significant at $P < 0.05$.

Table 4 represents the stepwise regression procedures used to predict carcass composition from the 9-10-11$^{th}$ rib section. Moisture in the rib section accounted for 74 percent of the variation in whole body moisture. Adding ash in the rib to the model accounted for only 4 additional percent of the variation in predicting whole body moisture. Fat in the rib section accounted for 78 percent of the variation in whole body fat and adding ash in the rib accounted for only 3 additional percent of the variation. Protein in the rib section accounted for only 26 percent of the variation in predicting the whole body protein while fat in the rib section explained only 32 percent of the ash in the whole body. Adding moisture in the rib section to the model could only account for 1 percent more of the variation in whole body ash. The best predictor of moisture and fat in the whole body was the rib section measurement of that same variable (i.e., moisture in the rib section predicted whole body moisture and fat in the rib section predicted whole body fat).

Table 5 represents the stepwise regression procedures for predicting whole body composition using carcass traits. Hot carcass weight and Bwf accounted for 52 and 18 percent of the variation in whole body moisture and the addition of Bwf improved the $R^2$ value to 0.70. Adding kidney and pelvic fat to predict whole body moisture increased the accountability by only 1 percent. For percent fat in the whole body, Dp was the first variable to enter the model and accounted for 60 percent of the variation. Body wall fat and Kpf entered the model accounting for 9 and 5 percent more of the variation, respectively. Therefore, the best model for predicting fat percentage in the carcass using carcass traits was the model containing Dp, Kpf, and Bwf with an $R^2 = 0.74$. Kidney and pelvic fat accounted for only 23 percent of the variation in predicting the whole body protein while CCW explained only 4 percent and Dp explained only 3 percent of the

variation. Percent ash in the whole body could best be explained by the independent variable of Bwf, which accounted for 29 percent of the variation. Adding Bf to the model could only account for 2 percent of the variation. Cold carcass weight accounted for 24 percent of the variation in lean percentage of the whole body. Hodge and Oddie (1984) predicted boneless lamb meat yields from carcass weight with an accountability of 5 percent. These predictions were improved when Bf and Kpf were included with carcass weight (r = 0.54). Compared with the study of McGregor (1990), lamb carcasses contained 16 percent more fat than goat carcasses.

Table 4. Regression equations for predicting carcass composition using the 9-10-11$^{th}$ rib section of goat kids (n = 89)

| Dependent variable and equation number | Independent variable[1] | Intercept | b–value | $R^2$ | Cp | RMSE[2] |
|---|---|---|---|---|---|---|
| % moisture in carcass | | | | | | |
| 1 | Mrib | 30.93 | 0.57*** | 0.74 | 17.53 | 1.94 |
| 2 | Mrib | 33.29 | 0.36*** | 0.78 | 2.57 | 1.79 |
| | Arib | | 11.62*** | | | |
| % ash in carcass | | | | | | |
| 1 | Frib | 0.96 | -0.01*** | 0.32 | 3.48 | 0.07 |
| 2 | Mrib | 1.57 | -0.01 | 0.33 | 3.31 | 0.07 |
| | Frib | | -0.01** | | | |
| % protein in carcass | | | | | | |
| 1 | Cprib | 10.65 | 0.46*** | 0.26 | 1.67 | 1.75 |
| % fat in carcass | | | | | | |
| 1 | Frib | 4.16 | 0.52*** | 0.78 | 12.22 | 2.11 |
| 2 | Arib | 16.17 | -10.66** | 0.81 | 2.85 | 1.99 |
| | Frib | | 0.38*** | | | |

[1] Mrib = moisture % in the rib section; Arib = ash % in the rib section; Cprib = protein % in the rib section; Frib = fat % in the rib section.
[2] Root mean square error.
* $P < 0.05$ ** $P < 0.01$ *** $P < 0.001$

Table 5. Regression equations for predicting carcass composition using carcass traits of goat kids (n = 89)

| Dependent variable and equation number | Independent variable[1] | Intercept | b–value | $R^2$ | Cp | RMSE[2] |
|---|---|---|---|---|---|---|
| % moisture in carcass | | | | | | |
| 1 | HCW | 76.37 | -0.63*** | 0.52 | 65.31 | 2.67 |
| 2 | HCW | 76.03 | -0.43*** | 0.70 | 9.73 | 2.11 |
| | Bwf | | -6.85*** | | | |
| 3 | HCW | 75.31 | -0.34*** | 0.71 | 8.88 | 2.09 |
| | Kpf | | -1.92 | | | |
| | Bwf | | -6.75*** | | | |
| % ash in carcass | | | | | | |
| 1 | Bwf | 0.94 | -0.16*** | 0.29 | 9.46 | 0.07 |
| 2 | Bf | 0.94 | -0.09 | 0.31 | 8.15 | 0.07 |
| | Bwf | | -0.15*** | | | |
| % protein in carcass | | | | | | |
| 1 | Kpf | 21.13 | -3.43*** | 0.23 | 16.78 | 1.78 |
| 2 | CCW | 19.22 | 0.19** | 0.31 | 7.98 | 1.69 |
| | Kpf | | -5.48*** | | | |
| 3 | Dp | 23.38 | -0.12* | 0.36 | 3.73 | 1.64 |
| | CCW | | 0.28*** | | | |
| | Kpf | | -3.77** | | | |
| % fat in carcass | | | | | | |
| 1 | Dp | -10.43 | 0.48*** | 0.60 | 43.46 | 2.84 |
| 2 | Dp | -7.22 | 0.36*** | 0.69 | 18.23 | 2.53 |
| | Bwf | | 5.68*** | | | |
| 3 | Dp | 0.51 | 0.15* | 0.74 | 2.25 | 2.31 |
| | Kpf | | 6.43*** | | | |
| | Bwf | | 6.17*** | | | |
| % lean in carcass[3] | | | | | | |
| 1 | CCW | 60.50 | 0.66*** | 0.24 | 3.89 | 4.86 |

[1] HCW = hot carcass weight; CCW = cold carcass weight; Bwf = body wall fat; Kpf = kidney and pelvic fat; Bf = back fat; Dp = dressing %.

[2] Root mean square error.

[3] Untrimmed lean tissue.

* $P < 0.05$

** $P < 0.01$

*** $P < 0.001$

***Prediction of saleable bone-in meat yield***

The second objective of the study was to develop practical prediction equations for use in saleable bone-in retail yields for goat meat. It is expected that heavier goats would produce carcasses with higher meat yields. McGregor (1990) indicated that for every 1 kg increase in live weight, HCW increased 427g in wether cashmere goats. Tahir et al. (1994) also reported that an increase in BW caused an increase in carcass lean and fat from Iraqi black kids. The overall descriptive statistics taken from 18 of the 89-castrated Boer cross goat kids are presented in Table 6. Mean yield of boneless goat meat was 70.6 percent on a HCW and 72.5 percent when calculated on a CCW. The muscle to bone ratio was 2.7 and trim represented 2.6 percent of HCW while bone waste represented 25.7 percent. McGregor (1990) reported similar results of lean meat yields, fat trim and muscle to bone ratios utilizing 90 wether cashmere goats. Goat carcasses had proportionally more weight distributed in the hind section (roast and hind shank) and fore section (shoulder, leg, neck, and brisket) representing 13.8 and 13.2 percent of the CCW, respectively. The middle section (rack, loin, and sirloin) represented 12.5 percent of the CCW.

Pearson correlations between carcass traits and total kilogram of bone and lean are given in Table 7. Based on simple correlations, live weight at harvest, as well as, HCW and CCW had the highest correlation ($P < 0.05$) to total bone weight (r = 0.79, 0.73, and 0.73, respectively) and to total lean weight (r = 0.94, 0.98, and 0.98, respectively) than any other variable. The LM area was highly correlated ($P < 0.05$) to the total lean weight, hindlimb and forelimb circumference (r = 0.92, 0.74, and 0.87, respectively). The LM area has been used as an indicator of carcass muscling in many species (Jones, 1989). The high correlation of the LM area with total lean weight and hindlimb and forelimb

circumference indicates this measurement is an acceptable indicator of carcass muscling in goats. Stanford et al. (1995) reported a correlation of the hind leg with the carcass LM area (r = 0.84) and also reported hip height as a significant regression coefficient ($R^2$ = 0.22) for the prediction of the LM area in Alpine kids.

Table 6. Population means, standard deviation and minimum and maximum values of goat kids (n = 18)

| Variable | Mean | SD | Min. | Max. |
|---|---|---|---|---|
| Live weight, kg | 32.55 | 5.93 | 21.00 | 42.00 |
| Dressing % | 44.10 | 4.45 | 36.71 | 50.39 |
| Hot carcass weight, kg | 14.51 | 3.61 | 7.71 | 20.86 |
| Cold carcass weight, kg | 14.13 | 3.54 | 7.71 | 19.95 |
| Carcass shrink, % | 2.76 | 2.44 | 0.00 | 7.41 |
| Kidney and pelvic fat, kg | 0.20 | 0.08 | 0.01 | 0.32 |
| Back fat, cm | 0.08 | 0.04 | 0.00 | 0.13 |
| Body wall fat, cm | 0.38 | 0.29 | 0.05 | 1.02 |
| Longissimus muscle area, $cm^2$ | 7.39 | 2.20 | 3.30 | 11.43 |
| Bone, kg | 3.73 | 0.86 | 2.18 | 4.99 |
| Lean, kg | 10.24 | 2.87 | 5.08 | 15.42 |
| Muscle : bone ratio | 2.66 | 0.56 | 1.78 | 3.65 |
| Hindlimb, cm | 35.88 | 3.04 | 29.85 | 40.01 |
| Forelimb, cm | 17.41 | 1.97 | 13.65 | 20.32 |
| Shoulder; leg; neck; brisket, kg | 1.87 | 0.48 | 1.00 | 2.63 |
| Rack, kg | 0.59 | 0.20 | 0.32 | 1.04 |
| Loin, kg | 0.64 | 0.17 | 0.41 | 0.95 |
| Sirloin, kg | 0.54 | 0.13 | 0.32 | 0.73 |
| Roast, kg | 1.42 | 0.29 | 1.00 | 1.95 |
| Hind shank, kg | 0.53 | 0.29 | 0.14 | 1.04 |
| Spare ribs, kg | 0.53 | 0.19 | 0.23 | 0.86 |
| Trim, kg | 0.38 | 0.14 | 0.14 | 0.63 |

**Table 7**. Partial correlation coefficients for carcass traits of goat kids (n = 18)

| | Trait | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trait | Dressing % | Hot carcass wt, kg | Cold carcass wt, kg | Carcass shrink % | Kidney-pelvic fat, kg | Back fat, cm | Body wall fat, cm | LM area, $cm^2$ | Bone wt, kg | Lean wt, kg | Lean:bone ratio | Hindlimb, cm | Forelimb, cm |
| Live wt, kg | 0.62* | 0.94* | 0.96* | -0.27 | 0.59* | 0.60* | 0.46 | 0.87* | 0.79* | 0.94* | 0.46 | 0.87* | 0.95* |
| Dressing % | . | 0.83* | 0.80* | 0.30 | 0.43 | -0.03 | 0.77* | 0.83* | 0.46 | 0.80* | 0.59* | 0.57* | 0.60* |
| Hot carcass wt, kg | . | . | 0.99* | -0.07 | 0.58* | 0.38 | 0.64* | 0.94* | 0.73* | 0.98* | 0.57* | 0.83* | 0.90* |
| Cold carcass wt, kg | . | . | . | -0.15 | 0.59* | 0.42 | 0.62* | 0.94* | 0.73* | 0.98* | 0.57* | 0.83* | 0.92* |
| Carcass shrink % | . | . | . | . | -0.06 | -0.39 | 0.13 | -0.08 | -0.11 | -0.12 | -0.08 | -0.10 | -0.28 |
| Kidney-pelvic fat, kg | . | . | . | . | . | 0.28 | 0.19* | 0.48* | 0.49* | 0.58* | 0.31 | 0.72* | 0.59* |
| Back fat, cm | . | . | . | . | . | . | -0.26 | 0.36 | 0.66* | 0.35 | -0.15 | 0.61* | 0.68* |
| Body wall fat, cm | . | . | . | . | . | . | . | 0.56* | 0.14 | 0.68* | 0.75* | 0.32 | 0.33 |
| LM area, $cm^2$ | . | . | . | . | . | . | . | . | 0.65* | 0.92* | 0.56* | 0.74* | 0.87* |
| Bone wt, kg | . | . | . | . | . | . | . | . | . | 0.67* | -0.11 | 0.86* | 0.84* |
| Lean wt, kg | . | . | . | . | . | . | . | . | . | . | 0.64* | 0.79* | 0.88* |
| Lean:bone ratio | . | . | . | . | . | . | . | . | . | . | . | 0.19 | 0.33 |
| Hindlimb, cm | . | . | . | . | . | . | . | . | . | . | . | . | 0.88* |

* Significant at $P < 0.05$.

Pearson correlations between carcass traits and bone-in retail yields are presented in Table 8. The mean level of fat in the goat carcass is much lower than fat tissues in the carcass of pigs, sheep and cattle. As goats generally lack significant fat deposits (Colomer-Rocher et al., 1987), carcass measurements could be a more accurate predictor of carcass retail yields. Simple correlation results indicate the lowest relationship with bone-in retail yield of goat carcasses were with the measurements of Kpf, Bf and Bwf. Bone-in retail yields, with the exception of the thoracic region, were highly correlated ($P < 0.05$) with carcass measurements of live weight at harvest, Dp, HCW, CCW, LM area, boneless lean weight and hindlimb and forelimb circumference due to their direct relationship to the size and weight of the animal. Correlations among these variables ranged from r = 0.37 to 0.81 with bone-in retail yields. McGregor (1990) also reported live weight as the best single indicator of boneless meat yields in wether cashmere goats.

Table 9 represents the stepwise regression procedures used to predict kilograms of total bone and lean utilizing carcass traits. The actual weight of an animal may be considered as a function of the amount and distribution of the lean and fat tissues in the carcass. In this study, the live and carcass weights were good predictors of total carcass bone and lean weight. Live weight at harvest explained 63 percent of the variation in total bone weight. The addition of Bwf to the equation could only explain an additional 6 percent of the variation in total bone weight and was not a significant ($P > 0.05$) indicator in the model. Cold carcass weights alone explained 98 percent of the variation in total lean weight. The addition of live weight at harvest, Bwf and Bf explained an additional 1 percent of the variation; however, Bwf and Bf were not significant ($P > 0.05$) indicators in the model.

**Table 8.** Partial correlation coefficients for carcass traits and bone-in retail cuts of goat kids (n = 18)

| | Trait | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Trait | Shoulder, leg, neck, brisket, kg | Rack, kg | Loin, kg | Sirloin, kg | Roast, kg | Hind shank, kg | Spare ribs, kg | Trim, kg |
| Live wt, kg | 0.49* | 0.14 | 0.60* | 0.65* | 0.38 | 0.61 | 0.63* | 0.38 |
| Dressing % | 0.47 | 0.23 | 0.64* | 0.68* | 0.53* | 0.55* | 0.71* | 0.81* |
| Hot carcass wt, kg | 0.55* | 0.19* | 0.70* | 0.74* | 0.49* | 0.66* | 0.74* | 0.59* |
| Cold carcass wt, kg | 0.55* | 0.18 | 0.70* | 0.73* | 0.50* | 0.64* | 0.73* | 0.56* |
| Carcass shrink % | -0.08 | 0.12 | -0.02 | -0.03 | -0.10 | 0.10 | 0.01 | 0.23 |
| Kidney-pelvic fat, kg | 0.35 | 0.03 | 0.33 | 0.47 | 0.28 | 0.43 | 0.33 | 0.19 |
| Back fat, cm | 0.10 | 0.11 | 0.12 | 0.17 | -0.04 | 0.30 | 0.09 | -0.12 |
| Body wall fat, cm | 0.28 | 0.02 | 0.43 | 0.48* | 0.48* | 0.30 | 0.53* | 0.63* |
| LM area, $cm^2$ | 0.56* | 0.19 | 0.66* | 0.66* | 0.45 | 0.55* | 0.67* | 0.67* |
| Bone, kg | 0.43 | 0.18 | 0.50* | 0.49* | 0.23 | 0.58* | 0.40 | 0.17 |
| Lean, kg | 0.53* | 0.14 | 0.66* | 0.71* | 0.50* | 0.60* | 0.73* | 0.57* |
| Lean:bone ratio | 0.23 | -0.02 | 0.32 | 0.41 | 0.40 | 0.18 | 0.54* | 0.57* |
| Hindlimb, cm | 0.43 | 0.33 | 0.65* | 0.69* | 0.39 | 0.69* | 0.53* | 0.26 |
| Forelimb, cm | 0.53* | 0.16 | 0.55* | 0.61* | 0.36 | 0.61* | 0.60* | 0.37 |
| Shoulder, leg, neck, brisket, kg | . | -0.09 | 0.58* | 0.64* | 0.69* | 0.30 | 0.76* | 0.40 |
| Rack, kg | . | . | 0.55* | 0.52* | 0.33 | 0.63* | 0.33 | 0.25 |
| Loin, kg | . | . | . | 0.92* | 0.77* | 0.69* | 0.75* | 0.52* |
| Sirloin, kg | . | . | . | . | 0.81* | 0.75* | 0.88* | 0.55* |
| Roast, kg | . | . | . | . | . | 0.33 | 0.80* | 0.49* |
| Hind shank, kg | . | . | . | . | . | . | 0.64* | 0.27 |
| Spare ribs, kg | . | . | . | . | . | . | . | 0.59* |

* Significant at $P < 0.05$.

Table 9. Regression equations for predicting kilograms of total bone and lean using carcass traits of goat kids (n = 18)

| Dependent variable and equation number | Independent variable[1] | Intercept | b–value | $R^2$ | Cp | RMSE[2] |
|---|---|---|---|---|---|---|
| Total Bone, kg | | | | | | |
| 1 | Live weight | -0.05 | 0.12*** | 0.63 | 3.10 | 0.54 |
| 2 | Live weight | -0.37 | 0.14*** | 0.69 | 1.98 | 0.51 |
| | Bwf | | -0.88 | | | |
| Total Lean, kg | | | | | | |
| 1 | CCW | -1.09 | 0.80*** | 0.98 | 19.79 | 0.44 |
| 2 | CCW | -0.74 | 0.75* | 0.98 | 11.98 | 0.38 |
| | Bwf | | 1.01** | | | |
| 3 | CCW | -1.76 | 0.52** | 0.99 | 9.41 | 0.36 |
| | Bwf | | 1.57* | | | |
| | Live weight | | 0.12 | | | |
| 4 | CCW | -2.79 | 0.44** | 0.99 | 7.71 | 0.33 |
| | Bwf | | 1.05 | | | |
| | Live weight | | 0.21* | | | |
| | Bf | | -6.66 | | | |

[1] CCW = cold carcass weight; Dp = dressing %; Bwf = body wall fat, cm; Bf = back fat, cm.
[2] Root mean square error.
* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

Stepwise regression equations for predicting bone-in retail yields using carcass traits are presented in Table 10. The shoulder, leg, neck and brisket cuts resulted in a $R^2$ value of 0.32 with the LM area accounting for the variation. Hot carcass weight accounted for the variation in the loin, sirloin and spare rib cuts with $R^2$ values of 0.49,

0.55 and 0.55, respectively. The roast and trim were predicted with $R^2$ values of 0.29 and 0.72, respectively with dressing percent accounted for the majority of the variation.

Table 10. Regression equations for predicting bone-in retail cuts (kg) using carcass traits of goat kids (n=18)

| Dependent variable and equation number | Independent variable[1] | Intercept | b–value | $R^2$ | Cp | RMSE[2] |
|---|---|---|---|---|---|---|
| Shoulder, leg, neck, brisket | | | | | | |
| 1 | LMA | 0.96 | 0.12** | 0.32 | -9.21 | 0.41 |
| Lumbar | | | | | | |
| 1 | HCW | 0.15 | 0.03** | 0.49 | 8.96 | 0.13 |
| Sacral | | | | | | |
| 1 | HCW | 0.14 | 0.03** | 0.55 | -4.69 | 0.09 |
| Roast | | | | | | |
| 1 | DP | -0.12 | 0.04* | 0.29 | -5.14 | 0.25 |
| Rear Shank | | | | | | |
| 1 | Hindlimb | -1.91 | 0.07** | 0.48 | -8.96 | 0.22 |
| Spare ribs | | | | | | |
| 1 | HCW | -0.06 | 0.04** | 0.55 | -8.51 | 0.14 |
| Trim | | | | | | |
| 1 | DP | -0.81 | 0.03*** | 0.66 | -9.08 | 0.09 |
| 2 | DP | -0.55 | 0.03*** | 0.72 | -7.95 | 0.08 |
| | Hindlimb | | -0.01 | | | |

[1] HCW = hot carcass weight; Dp = dressing %.

[2] Root mean square error.

* $P < 0.05$

** $P < 0.01$

*** $P < 0.001$

## IMPLICATIONS

Prediction of carcass composition using carcass traits should allow rapid, precise and cost-effective assessment of goat carcasses without total dissection of the carcass and destruction of the loin area. Independent variables with the greatest potential for prediction were moisture and fat percentages and the best predictor of these variables in the whole body were the rib section measurements of the same variables. Dressing percent, kidney and pelvic fat, body wall fat, hot carcass weight and cold carcass weight accounted for the largest variation in moisture and fat percentage of the whole body. Live weight and cold carcass weight best predicted total kilograms of bone and lean. These results demonstrate the potential use of carcass traits in predicting bone-in retail yields and should be a helpful tool in assessing carcass value.

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