EFFECT OF LEVEL OF ENERGY AND PROTEIN ON CASHMERE PRODUCTION BY GOATS

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INTRODUCTION

Cashmere yield and fiber characteristics are influenced by several factors. The principal non-genetic ones are age, sex, nutrition, physiological status, disease, shearing regime, animal origin, and management practices (Sumner and Bigham, 1993). Body size, fleece weight, percent yield, fiber diameter, fiber length, fiber density, fiber color, and completeness of cover are important characteristics in the selection of cashmere goats. Cashmere production should be considered as complementary to meat production in the goat industry of the U.S. (Shelton and Lupton, 1992). Cashmere can be produced by most non-Angora breeds of goats (Teh, 1989).

Nutritional supplements may enhance goat and cashmere production in several ways. First, for kids to reach a marketable carcass weight in a reasonable time period, supplements are needed. Second, the cashmere producing organs, the secondary follicles, normally are active only from mid summer to late autumn or early winter and depend on age and sex of the animal (Restall et al., 1994); their numbers or activity might be altered by supplements. Third, the goat's ability to adjust to changes in weather is enhanced by feeding a supplement. Fourth, improving nutritient status by feeding a supplement can increase fiber production in sheep and mohair in goats (Reis and Sahlu, 1994). However, in several studies with cashmere-producing goats, nutritional supplements have failed to increase cashmere fiber production (Ash and Norton, 1984; Johnson and Rowe, 1984; McGregor, 1988; Restell et al., 1994; Jia et al., 1995). And fifth, supplements may increase reproduction rate.

Fetuses often are rejected at an early stage of gestation in nutritionally starved sheep and goats. When such animals are undernourished during early or mid gestation, fetus weight is reduced (Bell, 1984). When they are undernourished in late gestation, birth weights are reduced (Robinson, 1977). A low protein intake is exacerbated by a low energy intake (Slykes and Field, 1972). Effects on birth weight are more consistent for twins and triplets than with single births. Dams which have high rates of producion are more responsive to changes in nutrient supply. Thus, goat owners who synchronize estrus and breeding with steroid hormones or related chemicals to increase ovulation rate and multiple births, must adequately supplement during late gestation.

Cashmere is produced seasonally by secondary follicles. The fleece requires protection by the longer guard hair. Change in nutrient density during the cashmere growth season may influence cashmere yield and fiber characteristics. Genetically, goats have a finite number of secondary follicles. Cashmere production may be limited by the number of follicles becoming active. However, the seasonality of production relates to both activity of the follicle and changes in the number of secondary follicles (Ryder, 1966). Follicle density changes as animals grow, primarily due to change in size of the animal.

Fiber production takes precedence over fetal development, especially during periods of nutritional stress (Van Rensgurg, 1971). Therefore, animals selected for high rates of fiber production have higher abortion rates. Huston (1980) showed that increasing caloric intake of Angora kids increased fiber growth. Nixon et al. (1991) examined secondary follicle development in Australian cashmere goats and found that nutrition could affect follicle development and cashmere production. Does fed low quality diets may be unable to consume sufficient dry matter to meet requirements for fetal growth due to the physical limit of rumen expansion space. Thereby, the plane of nutrition can affect fetal growth and may alter follicle numbers of the kid. If an animal is deprived of nutrients during a critical stage of follicle maturation, the number of follicles is reduced (Black and Reis, 1979). Because twin-bearing does are more likely to be nutritionally stressed than does bearing single kids, their offspring may differ both in development and in capacity to produce cashmere. Consequently, the effects of nutrient supplementation on follicle numbers of young and growing kids needs to be studied

OBJECTIVES

Our aim was to evaluate responses of cashmere-producing Spanish goat to various levels of energy and protein when fed above maintenance. Specific objectives were 1) to evaluate the effect of supplemental protein and (or) energy on doe and kid performance by Spanish goats, 2) to determine if supplemental protein and (or) energy alter fiber composition and cashmere characteristics, 3) to determine the optimal amounts of protein and energy for growth and fiber production by cashmere-producing Spanish goats, and 4) to quantify secondary follicle number in kids from cashmere producing does fed several different amounts of energy and protein.

CHAPTER II

REVIEW OF LITERATURE

This chapter will outline the literature relevant to cashmere and outline current knowledge and past research efforts to enhance cashmere production. Attention will be focused on the roles of energy and protein and their direct or indirect impact on cashmere fiber production. Emphasis will be placed on the prenatal and postnatal growth and reproduction of goats.

Cashmere Fiber

Cashmere is a luxurious fiber used for making high quality knitwear and woven apparel. Its fine fibers usually are white although some animals produce brown or gray fibers. Cashmere, as defined by the Camel and Cashmere Institute of America, is the fine down undercoat fibers produced by cashmere goats (*Capra Hircus laniger*). These fibers should have no medullation, a scale width to length ratio of 2:3, and a mean diameter from 15 to 19 micron (Smith, 1987). The internal cortical cell structure is predominantly ortho and meso; this differs from mohair which has 100% ortho cells and wool which has ortho plus para cells. Cashmere is straight with no crimp; in contrast, wool is highly

(Langley and Kennedy, 1981).

The fleece of cashmere goats consists of an outer coat of long coarse fibers and the fine, inner coat which has value commercially. The inner coat is produced by secondary follicles; cashmere growth is cyclical with growth rate increasing in autumn and hair shedding in spring (McDonald et al., 1987; Nixon et al., 1991). The usually longer and coarser outer coat is derived from the primary follicles; it grow mainly in the summer and never is completely shed although it is molted continuously. Because cashmere is shed completely in spring and new growth occurs in autumn and winter, cashmere goats frequently are considered to have two coats each year. The diameter of the fiber is the principal means for classifying the quality of cashmere (Couchman, 1986; Ryder, 1986; Ryder and Gabra-Sanders, 1988; Teh, 1990). In general, goats that produce secondary fibers with an average diameter of 15 to 19 micron and have long guard hairs to protect these fiber are classified as cashmere-producing goats (Smith, 1987).

Factors Affecting Cashmere Production

The Cashmere Growth Cycle

Cashmere growth follows a distinct annual cycle (McDonald et al., 1987; Nixon et al., 1991). Production is highest in fall and winter whereas growth is minimal or nil in spring and summer (McDonald and Hoey, 1987; Welch et al., 1990). The initiation of cashmere growth, which coincides with the start of the mating season in goats, is driven by photoperiod. This means that for mature female goats (does), gestation coincides directly with the period of cashmere growth. Optimum cashmere production requires an adequate supply of nutrients for the animal. The energy requirement of the animal is affected by its needs for maintenance and production (Blaxter, 1989). In pregnant ewes, the recommended level of feeding during late gestation ranges from 1.5 times maintenance for ewes bearing singles to 2.2 times maintenance for ewes bearing twins (Bell, 1993).

Several physiological (age, sex, body weight, body condition, breed or origin, productivity), environmental (hours of daylight, weather), and nutritional (available forage, supplement supply) factors affect the quality and quantity of cashmere produced. Sumner and Bigham (1993) suggested that the prominent non-genetic factors affecting fleece and fiber characteristics in goats are age, nutrition, physiological status, disease and shearing regime. Goats of different ages produce cashmere with specific identifying characteristics, that is, fiber diameter, fiber length and percentage cashmere yield (Pattie et al., 1987). Mature male goats (bucks) produce cashmere that has a larger fiber diameter and length and a higher yield percentage than either yearling bucks or does (McGregor et al., 1991; Walkden-Brown et al., 1994).

Environmental factors such as moisture and temperature intensity and duration also can influence production. Most Chinese breeds of cashmere goats produce fiber that has a finer diameter in the winter and spring than in the summer or autumn. Indeed, most of the cashmere produced in the world comes from geographic regions that have dry, hot summers when feed is sparse and winters that are relatively cold (Shelton and Lupton, 1992). Various manipulations and adaptive farming techniques can help to minimize the impact of environment on production.

The nutrient requirements listed by NRC (1981) are different for goats of different body weights and at various stages of gestation or lactation. For sheep, nutrition alters the strength and diameter of fiber in sheep. In general, for both sheep producing wool and for goats producing mohair, greater feed (energy) intake increases diameter of the fiber being produced (Shelton and Menzies, 1968; Sahlu and Fernandez, 1992). In contrast, for cashmere production, the impact of feed (energy) intake on characteristics of the fiber has not been determined clearly. In some studies, reducing feed intake (both energy and other nutrients) during the peak cashmere growing season reduced the diameter of the cashmere produced (McGregor, 1988; McGregor et al., 1991; Shelton and Lupton, 1992); this agrees with effects noted for wool and mohair.

Feed Intake and Gender

Voluntary feed intake by sheep and goats normally is much lower in autumn and early winter than during other seasons of the year. This has been attributed to the animal's response to hormones or chemical messages relayed by photoperiod which also signal the mating season (Walkden-Brown et al., 1990). The effects of season and diet on LH, FSH and testosterone concentrations (reproductive hormones), sebaceous gland volume and male odor were examined by Walkden-Brown et al. (1994). They fed mature cashmere bucks diets of either a low (6.9% CP 1.58 Mcal/kg ME) or a high (17.6% CP; 1.98 Mcal/kg ME) quality for 16 months under natural daylight conditions. Diet significantly influenced reproductive hormone concentrations, sebaceous gland volume and male odor. Peak values in hormone concentrations, sebaceous gland volume, and odor score occurred at mid-autumn for both dietary groups. However, for bucks fed the higher quality diet, seasonal changes in these measurements began earlier in the year, they lasted longer, and the magnitude of the change was greater. Follicle stimulating hormone concentration peaked in either in the late spring (for those fed the higher quality diet) or in the summer (for those fed the lower quality diet) and reached its nadir in early winter.

These results demonstrate that the male cashmere goat, like the female, exhibits seasonality in reproductive traits and that nutrition can modulate the seasonal cycle. Luteinizing hormone secretion, which is under strong seasonal control, was altered by nutrition when the photoperiodic inhibition was waning. However, seasonal regulation of testes mass, and therefore sperm production, appears to depend primarily on changes in voluntary feed intake and growth, not on photoperiod directly (Walkden-Brown et al., 1994). Both voluntary feed intake and growth rate of young male goats varies seasonally, especially for goats on a high plane of nutrition. Modifying appetite might help to optimize the quantity and quality of cashmere produced.

The effects of increasing daily feed intake on fleece growth, and on concentrations of prolactin and thyroxine in the plasma of cashmere-producing goats were examined by Kloren et al. (1993a). They detected no effect of feeding level or animal age on cashmere weight, cashmere diameter or hair weight at shearing. However, animals treated with a thyroxine implants were less responsive to reduction in cashmere diameter when feed intake was restricted to a maintenance level as compared to animals free choice fed the same ration. In sheep, implanting with thyroxin reduces wool production when feed intake is limited but does not alter wool characteristics (Kloren et al., 1993a). The timing of initiation of cashmere growth varies with gender. Growth begins earlier in the year for female than male goats; cashmere growth of castrates begins after females but before males (Kloren et al., 1993a).

Effects of Pregnancy on Fiber Growth

Fiber growth during pregnancy has been studied extensively in sheep but not in goats. Sheep have served as a guide toward understanding fiber production; sheep are used frequently for reproductive research with ruminants. Results of studies of fiber production during pregnancy in sheep should be helpful to aid the interpretation of current knowledge and to plan future studies with goats. Hence, fiber growth during pregnancy in sheep has been reviewed.

Wool production rates for pregnant-lactating versus non-pregnant-non-lactating Merino ewes were measured by Oddy (1985). Wool production for lambing ewes was measured 2 months before mating, during pregnancy, and 3 months after lambing; for dry ewes, wool production was measured during these same time intervals. Production of clean wool by dry ewes increased linearly with digestible organic matter intake. Growth rate of clean wool was significantly less for pregnant than dry ewes when pregnant ewes were at the later stages (4th and 5th month) of gestation and when they were lactating. Ewes bearing twin fetuses produced 27% less wool than ewes bearing single fetuses. Wool production also decreased as milk production increased, but wool follicle density was not altered by the number of progeny. Sulfur content of the wool was greater for pregnant than dry ewes; but not different for dry versus lactating ewes (Oddy, 1985).

During pregnancy and lactation, earlier workers also have noted that wool growth is depressed when compared with other times of the year (Corbett, 1979; Masters et al., 1993). Competition for nutrients between wool follicles, other maternal tissues, and the gravid uterus may be responsible for these changes. Feeding additional energy or nutrients during pregnancy and lactation often has avoided this drop; in some cases, it has increased wool production (Williams et al., 1978; Oddy, 1985). Changes in the concentrations of individual free amino acids in plasma of ewes during late pregnancy and early lactation were measured by Masters et al. (1993). Concentrations were compared during pregnancy and lactation between the reproducing ewes and a group of non-pregnant ewes maintained under the same conditions. During the last three weeks of pregnancy, concentrations of total, free essential amino acids in plasma were 31% lower in reproducing than non-pregnant ewes when wool growth rate was lowest. Concentrations of these amino acids all increased during the first three weeks of lactation. Reproducing ewes had less wool growth, smaller fiber diameter, lower staple strength and less sulfur in wool than the non-reproducing ewes (Masters et al., 1993).

Follicle Initiation and Development

Follicle development prenatally and postnatally can alter the animal's potential to produce fiber (Bigman and Sumner, 1993). Density (number per square cm) of secondary follicles of an animal may be determined at very early stages of fetal growth. If follicle initiation is influenced by nutrient supply, and if does bearing twin have greater nutrient needs than does bearing singles, then kids born as singles should have more follicles than kids born as half of a pair of twins. Thus, increasing the twinning rate could have negative effects on potential cashmere production if does are deprived of necessary energy or nutrients during pregnancy In sheep, follicle growth is reduced when nutrient supply is restricted during the critical stage of follicle maturation (Black and Reis, 1979), so nutrient deficiencies also may be important for cashmere goats. The effect of nutrient supply on follicle initiation by the cashmere goat fetus needs further study.

Effects of nutrition on wool follicle and cell kinetics in sheep that differed in efficiency of wool production were measured by Hynd (1989). The rate of division of follicle bulb cells and the total volume of the germinative region of the follicle was estimated by image-analysis of bulb sections in skin biopsy samples. When the diet was changed from a low to a high protein content, rate of clean fleece production increased by 33% due to increases in both fiber diameter (8%) and length (26%) of fibers; the volume of the germinative region of the average bulb increased by 30% and the rate of bulb cell division increased by 35%. The average proportion of fiber cross-sectional area occupied by paracortical cells increased from 0.21 to 0.35. The proportion of dividing cells entering the fiber cortex ranged from 0.25 to 0.42 (mean 0.31) for sheep fed the low-protein diet, and from 0.22 to 0.39 (mean 0.32) for sheep fed the high-protein diet. There was no effect of diet on the number of cells present in the fiber and inner root sheath (Hynd 1989).

Effects of Nutrient Supply on Growth and Properties of Fibers

Estimating dietary protein requirements for ruminants is complicated by the fact that both ruminal microbes and animals respond to changes in dietary protein (Orskov, 1992). When forage quality is low, supplementing forage with a concentrate often becomes necessary in order to meet the animal's energy requirement. Ideally, the supplement should complement the forage so that the total diet will meet the animal's nutrient requirements. Reis and Sahlu (1994) reviewed the impact of nutrient status on growth rate and properties of wool and mohair fibers. They reported that nutrient availability was the major factor influencing wool growth. Although the need for energy for wool growth is small, demand for essential amino acids, in particular the sulfur-containing amino acid, is large and often limits wool growth. Nutrient supply also probably limits mohair production through a similar but not identical mechanism (Reis and Sahlu, 1994). Supplementation with energy and protein has influenced clean fleece weight and mohair characteristics (Huston et al., 1993). However, the separate roles of energy and protein remains unclear.

That protein rather than energy is limiting was suggested by Sahlu and Fernandez (1992) who noted that mohair growth increased when methionine was administered intraperitoneally. In contrast, rate of growth of cashmere fleece was increased by an energy but not a protein supplement in a study (McGregor, 1988). Ash and Norton (1987a) detected no response in growth rate of fleece or in fiber diameter to supplemental protein or energy by growing cashmere goats.

The relative importance of methionine and other nutrients needs clarification. Based on their observation that fleece growth was not increased by supplementation with DL-methionine, Ash and Norton (1987b) concluded that methionine supply was not the limiting amino acid for cashmere growth. However, these workers did not measure methionine absorption following supplementation. Perhaps the processes of trans-sulfuration and the metabolism of methionine and cystine may differ with species, that is, goats versus sheep (Ash and Norton, 1987b).

In addition to quantity of fiber produced, quality of fiber may be altered, often adversely, by a change in the supply of nutrients (Reis and Sahlu, 1994). The major nutritional limitation to wool production by sheep is the amount and composition of amino acids available to the tissues (Reis, 1979). In contrast, altering the supply of energy-yielding nutrients usually has failed to alter wool growth (Reis et al., 1992). When sheep are fed diets providing more energy than needed for maintenance, wool growth may increase if the supply of dietary protein is increased simultaneously. Therefore, wool growth could be increased by combination of energy and amino acids. For wool, length and diameter change proportionally with nutrient supply (amino acids in particular) so that the ratio of length:diameter remains approximately constant. In contrast, for mohair fibers, length may not increase with dietary protein supply; if so, increases in production would be due primarily to increases in fiber diameter, a change that decreases the usefulness of the fiber for manufacturing. Yet, exactly how length and diameter of mohair change with nutrient supply and season are not fully clear. Because rate of fiber growth is considerably greater for mohair than wool, the energy requirements for fiber growth must be greater for goats than for sheep (Reis and Sahlu, 1994).

Weight Gain and Cashmere Growth

Management practices which alter the live weight of cashmere goats also affect cashmere growth and fiber diameter (McGregor, 1992). Although kidding and lactation affect live weight and fiber production of goat, the magnitude of the effect depends on breeding strategy, time of kidding and lactation. Weight loss during lactation is lowest when kidding occurs at a time that forage availability is high (Robertson et al., 1992). Nevertheless, body weight and fiber production both often decrease during the last 2 months of pregnancy and the first month of lactation. This time period coincides with the period during which cashmere fiber growth should be highest.

Energy and protein supplementation increased body weight gain and clean fleece weight and also influenced mohair traits in studies by Huston et al. (1993) and McGregor (1992). In the latter study, goats were ranked on the basis of cashmere growth potential and were not supplemented or were supplemented to gain body weight during the cashmere growing season. Live weight change was closely correlated ($r^2 = .77$) with cashmere yield. Cashmere fleece yield was 3.2% higher for animal gaining weight continuously during the trial. Animals fed supplement grew 11 to 15% more cashmere than those not supplemented. For each 1 kg change in mean live weight, cashmere yield increased by 4.7 g (41%) and fiber diameter increased by 0.08 micron (74%).

Effects of energy and protein supplementation or energy restriction on cashmere growth by highly productive cashmere wethers were studied by McGregor (1988). He fed cashmere goats and sheep diets that differed in metabolizable energy so that animals either lost, maintained, or gained weight during the cashmere growing season. Based on his studies, the daily metabolizable energy requirement to maintain live weight of cashmere goats was determined to be 60 kcal/kg $BW^{.75}$. However, to maintain body condition, more energy was needed, that is, 1.25 times maintenance or 75 kcal/kg $BW^{.75}$. Both cashmere growth and fiber diameters were greater for goats fed to gain weight than for goats fed below maintenance.

The relative importance of protein was examined by Kloren et al. (1993b). Fiber growth was lower for goats fed at a maintenance level of energy and a high level of protein compared to animals fed above maintenance. Higher protein intake increased wool production by 40%. Similar increases were not observed for cashmere goats. This difference suggests that the fiber growth response to added protein in sheep differs from that in cashmere-producing goats. Perhaps energy is more important for fiber growth by goats than by sheep. When given ad libitum access to feed so that they gained weight, high-producing cashmere goats had higher yield even though the percentage of cashmere (cashmere/total fleece weight) decreased and the percentage of guard hair increased (McGregor, 1988). When more energy was provided to goats previously fed below maintenance, cashmere fiber diameter increased within four weeks. Results from measurement of mid-side patches suggested that energy-deprivation to the point that goats lost weight resulted in diversion of more nutrients toward growth of cashmere; in contrast, goats fed ad libitum partitioned nutrients toward growth of guard hair. Nevertheless, feeding goats sufficient energy to gain live weight during the cashmere growing period results in maximum yield of cashmere fiber (McGregor, 1988).

Effects of Supplementation on Goat Performance

Intake and Digestibility

Few reports have described the effects of supplementation on digestibility and animal performance in cashmere goats. In contrast, extensive literature is available from studies with other fiber-producing ruminants. Because goats differ from sheep in their grazing behavior, goats are classified as intermediate between concentrate and grass/roughage selectors whereas sheep are considered to be grass/roughage selectors (Hofmann, 1988). Within the goat species, breeds also differ widely in their grazing behavior (Hart et al., 1993; Sahlu et al., 1993). Cashmere can be produced by most breeds of goats (Teh, 1989). The following discussion relates to goats in general.

Increasing the dietary concentration of CP did not change body weight gains and nutrient digestibility even though it increased dry matter (DM) intake by goats (Sahlu et al., 1992b). Concentration of ammonia nitrogen in the rumen, and of urea N and total protein concentration in plasma both increased when dietary CP concentration was increased. Judkins et al. (1994) studied the effect of ruminally degraded methionine supplements on wool growth, digesta kinetics and ruminal fermentation. Although added methionine did not affect rumen pH, total concentration of total volatile fatty acids (VFA), or molar proportions of individual VFA or the acetate:propionate (A:P) ratio, it increased ruminal ammonia nitrogen concentration, perhaps due to an increase in the number of ruminal protozoa which are known to be proteolytic.

Huston (1994) studied stimulative, additive, and substitutive effects of supplements on forage. Supplements were fed to Angora goats at three different stages of maturity, that is, as kids, yearlings, and adults. The first level of supplement increased forage intake, gastrointestinal tract fill, mean particulate turnover, mean particulate whole-tract transit time, fecal output, and forage DM digestibility. However, both intake and DM digestibility of the forage both decreased quadratically in pregnant goats as digestible DM intake was increased further; forage intake and DM digestibility in goats are influenced by gestation. Yearling goats had less gastrointestinal tract fill and lower intake than either kids or adults (based on metabolic body weight); this may explain why reproductive efficiency is lower for young than for adult goats.

Feeding supplement generally increases intake of digestible DM (Huston et al., 1993). Although forage intake usually is not changed significantly by feeding supplement, it often tends to increase. Total digestible DM intake was significantly greater for supplemented goats, but digestible DM intake was not affected by type of protein being fed, high levels of rumen degradable protein verses high levels of rumen undegradable protein. The impact of supplementation at different stages of growth requires further study. The level and composition of the supplement, its feeding frequency, the intake and quality of the forage all must be considered if one attempts to optimize use of a supplement.

Badamana (1992) fed wethers and lactating does diets composed of a 1:1 ratio of hay to concentrate at two energy levels and two concentrations of CP. Digestibilities of DM, organic matter, nitrogen and acid detergent fiber all were reduced at the higher level of feeding. This digestibility depression was significant with the lower protein diet but not with the higher protein diet. In another experiment, goats received a mixed diet of hay and concentrate containing CP at either 11.2, 15.2 or 18.5% of DM. Digestibility of DM organic matter, acid detergent fiber and total nitrogen were significantly greater with the highest than the lowest protein diet; this resulted in a significant linear response to protein (Badamana, 1992). Supplementation with ruminally undegraded protein has failed to increase roughage intake in either sheep or goats (Al-Jassim et al., 1991).

Level of Supplementation

Grease and clean mohair weights were greater by goats fed 19% CP diets than by goats fed diets containing 12% CP (Sahlu et al., 1992b). Clean mohair weight was higher for goats fed diets containing expelled, heat-treated soybean meal than those fed diets containing solvent-extracted soybean meal. An inverse relation between the quality and quantity of mohair fiber was detected (Sahlu et al., 1992b). In contrast, wool fiber characteristics (diameter and length) were not altered when ruminal degraded methionine was supplemented (Judkins et al., 1994). The effects of supplements on growth rate, and fleece production by growing Angora does on pastures was studied by Huston et al. (1993). Feeding supplement increased both body weight and clean fleece yield.

Goats and sheep differ in digestion and retention of nutrients. Al-Jassim et al. (1991) fed sheep and goats a basal straw diet plus a concentrate that contained protein which should have been degraded in the rumen to either a low or a high degree. Digestibility of all constituents tended to be reduced with the less degraded protein supplement, but this decrease was significant only for neutral and acid detergent fiber. Goats digested forage more efficiently than lambs, but lambs were more efficient in digestion of nitrogen; digestibility values were significantly higher for the low ruminally degradable protein diet than the higher degradable protein for both species. Nitrogen retention was increased with low degradable protein supplement and lambs retained more nitrogen than goats (Al-Jassim et al., 1991).

Su and Yun (1990) examined dietary protein sources for doelings. The doelings were fed isonitrogenous diets containing either urea, soybean meal, heat-treated soybean meal, or heat-treated soybean meal plus urea. Postruminal microbial protein yields, amino acid composition, and the digestibility of the neutral and acid detergent fiber fractions were estimated using a continuous fermentation system. No significant differences in daily feed intake and amino acid composition were detected. However, goats fed diets containing heat-treated soybean meal plus urea gained more body weight and had better feed efficiencies than goats fed the other diets. In contrast to the results of Al-Jassim et al. (1991), Su and Yun (1990) found no differences among protein sources in digestibility of either NDF or ADF. Yield and quality of amino acids was lower for the diet containing urea than for the other diets. Soybean meal and heat-treated soybean meal plus urea diets had higher microbial amino acid yields than the diet composed of heat-treated soybean meal. These results indicate that a mixture of heat-treated soybean meal plus urea was utilized most efficiently because the increased ruminal amino acid escape was being combined with an adequate amount of degraded protein to provide ammonia for production of microbial protein in the rumen (Su and Yun, 1990).

Cronje (1992a) compared plasma glucose concentrations in goats selected for fiber (Angora) and for meat (Boer) production. Plasma glucose concentration was 7% lower in the Angoras. Although the glucose flux rate increased with an increased energy intake, it remained slower in the Angoras. The amount of glucose in the metabolic pool was 8% greater for the Angoras; this was distributed in a 17% larger volume of fluid. Pool size and volume of distribution increased as feed intake was increased. Glucose clearance rate did not differ between types, and there was no evidence of impaired adrenal function in fiber goats following glucose loading. Acetate clearance rate was 20% slower in Mohair-producing than in meat goats. There was a positive linear relationship between acetate clearance rate and energy intake. These results would be consistent with an impaired capacity for glucose production, but no evidence of adrenal hypofunction was detected (Cronje, 1992a). Results suggest that genetic selection for hair production results in a shifted in amino acids metabolism that favors hair-protein synthesis over gluconeogenesis. This could mean that Angora goats are unable to mobilize sufficient endogenous protein reserves for gluconeogenesis during times of sudden demand (Cronje, 1992b). Cashmere goats generally are utilized for meat production; therefore, they may utilize glucose differently from Angora goats. Because annual cashmere growth is cyclical, nutrient needs will fluctuate with season; furthermore, nutrient utilization will dependent more heavily on hormonal status than in animals with more continuous wool or mohair growth.

Effect of Supplements on Forage Intake

An ideal supplement for grazing goats complements the nutrients obtained from the forage in order to satisfy the animal's nutrient needs. Milk production by goats fed 750 or 1500 g/d of a supplement from day 30 postpartum to four months into lactation was evaluated by Landau et al. (1993). Feeding more concentrate decreased grazing time but increased milk production. Although differences in total production of fat, protein and solids were not significant, plasma non-esterified fatty acid concentrations were lower with the higher supplement intake. Energy balance, which was calculated from plasma non-esterified fatty acid values, was negative in all periods for goats fed 750 g/d of concentrate but positive for those fed 1500 g/d after day 85 of the study (Landau et al., 1993).

In another study, goats received hay ad libitum plus 1000 g concentrate per day which contained either 11.7, 15.2 or 18.5% CP until week fifteen of lactation (Badamana et al., 1990). Hay intake and milk yield were highest for the group fed 18.5% CP. As CP content of the supplement was increased, hay intake increased linearly from 1.20 to 1.37 kg/day. Protein content of the supplement had no effect on the concentrations of solids-not-fat, total nitrogen, or casein in milk. Digestibilities of organic matter, acid-detergent fiber, and nitrogen were greater with the 18.5% than with 11.7% CP; values for 15.2% CP were intermediate; digestibilities of each increased linearly with protein content of the diet. These results indicate that milk production by lactating goats can be increased by supplying an 18.5% CP supplement when fed at one-third of the total diet (Badamana et al., 1990).

Badamana and Sutton (1992) studied the effects of various levels of CP (11.2, 18.2 or 25.5%) in a concentrate fed at 1,000 g/day with free choice hay. Hay intake and milk yield were increased by adding CP up to 18.2%; further responses to 25.5% protein were small and non-significant. Milk composition was not affected by the protein content of the supplement. The digestibility of neutral-detergent fiber and acid-detergent fiber all tended to increase with dietary CP; this increase was significant only for nitrogen. With increased nitrogen intake, nitrogen output in feces, urine, and milk all increased linearly as did apparently digested nitrogen; nitrogen retention showed no consistent pattern. Although ruminal volatile fatty acids and pH were not affected, concentrations of rumen ammonia and blood urea and ruminal fluid dilution rate all increased with CP level. In contrast to these findings, lactating does fed a concentrate containing soybean showed only a slight increase in milk production when CP levels exceeded 14.5% of the ration (Badamana and Sutton, 1992). Extra supplemental protein (153 vs 187 g/d) included with mixed diets (1:1 ratio of hay to concentrate) for wethers and lactating goats increased total intake and digestibility of hay but only at a higher intake of energy (3.77 vs 1.88 Mcal/kg $BW^{.75}$; Badamana, 1992). Digestibilities of DM, organic matter, nitrogen and acid detergent fiber all were reduced by the higher level of feeding although the reduction in digestibility caused by the increased feed intake was significant only with the lower protein diet.

Effect of Supplements on Milk Composition

Cashmere growth is minimal or nil during the season of the year that Spanish does lactate; this suggests that milk production may compete with fiber growth for available nutrients. Fiber serves as a sink for cysteine and methionine as well as several minerals including sulfur. For cashmere production, an ideal supplement or method of feeding is needed to increase milk production or improve the composition of milk available for the suckling offspring. Follicle growth and development which occurs early in life also requires nutrient to be provided to the young via milk. Follicle development during this crucial stage of follicle maturation may determine the ultimate potential for cashmere production. Hence, supplementation during lactation, even though not increasing cashmere production of the doe, may increase transfer of nutrients to the hair follicles of the young and ultimately increase the potential for cashmere production by the next generation.

Morand (1993) compared effects of providing a supplement in the morning verses the evening on milk yield of goats. Time of feeding the supplement had no effect on milk yield. Under most practical situations, time intervals between supplement feedings longer than 24 h are customary.

Lactation relies on an adequate nutrient status for building body reserves prior to parturition. Both yield and fat content of milk were increased when dairy goats were fed a diet with higher nutrient density prior to parturition (Cerny et al., 1993). Although composition of milk may depend on the quality of dietary nutrients supplied during gestation or lactation, literature findings are conflicting. Typically, supply and type of protein have limited effects on milk composition. However, increasing the energy density of the lactation diet usually reduces the percentage fat increases the percentage protein in goat milk (Morand et al., 1991) similar to responses typically observed for dairy cattle.

Composition and Source of Supplement

The source of energy in the ration may affect the composition of goat milk indirectly through its impact on energy intake. Generally, adding fat to goat rations increases lipid but decreases protein content of milk, the latter being simply due to greater dilution (Morand et al., 1991). Guevara et al. (1991) supplemented grazing goats with similar amounts of energy and protein that provided either 0, 35 or 70 g of fat per day. Protein content of milk was not significantly different although milk fat percentage was significantly greater for animals that received supplemental fat.

Sahlu et al. (1993) studied the effects of dietary protein source and level on milk production using a totally mixed ration with different amounts and sources of CP. Isoenergetic diets were fed free choice for the entire trial. Milk fat, milk protein, milk lactose and milk solids-non-fat did not differ between dietary treatments, perhaps due to the high DM intake (4.7% of body weight) which supplied protein in excess of requirements. Andrighetto and Bailoni (1994) examined the effect of different sources of animal protein on digestive and metabolic parameters and milk production in goats. Diets containing corn silage and concentrates (1:1, DM basis) were prepared with either meat meal or hydrolyzed feather meal plus blood meal. Values for digestibility of DM, protein, and fiber fractions and for total volatile fatty acids and ammonia-N concentrations in ruminal fluid were significantly lower for goats given hydrolyzed feather meal plus blood meal concentrates. Ruminal pH, ruminal acetate:propionate ratio, and nitrogen excretion in milk were higher for goats fed the hydrolyzed feather meal plus blood meal diet. Milk production was similar for does fed the two diets, but protein and casein concentrations in milk were higher for goats given hydrolyzed feather meal plus blood meal.

Effects of protein source on intake, milk yield, milk composition, body weight change and rumen metabolites of lactating goats was studied by Hadjipanayiotou and Photiou (1995). Animals were fed an amount of energy to meet their maintenance needs plus 60% of the additional need for milk production together with one of three sources of protein at either 13, 15 or 18% CP. Goats fed to meet the energy level of maintenance plus 60% of milk production had the lowest milk yield. Supplementing with a protein of low ruminal degradation did not alleviate this reduced milk yield due to the energy deficiency, although it increased mobilization of body reserves which subsequently were used for milk production (Hadjipanayiotou and Photiou, 1995). Protein source or concentration had no significant effect on milk yield, milk composition, body weight change or ruminal metabolites. Protein source did not affect ruminal ammonia nitrogen or total VFA concentration, but the higher dietary protein level significantly increased rumen NH_3-N concentration.

Increasing the CP concentration from 13.8 to 18.6% increased milk yield by 15% without changing its chemical composition in a study with goats by Andrighetto et al. (1989). Blood metabolites were similar at both protein intake levels. In another study, Andrighetto et al. (1992) gave goats free choice access to mixed diets of differing energy

(2.62 and 3.1 Mcal/kg ME) and CP content (15 to 20%) from 50 to 190 days postpartum. Daily intake of mixed feed and hay averaged 1.5 and .2 kg. No metabolic or digestive disorders resulted from this low intake of hay. Neither milk yield nor efficiency of milk production differed with protein level. However, the dietary energy to protein ratio affected milk composition. Efficiency of N utilization was greater with higher energy diets but decreased as dietary protein increased. Nitrogen requirements for maintenance of goats were estimated by Brun-Bellut et al. (1991) as 1.9 to 3.7 g digestible CP/kg $BW^{.75}$ with efficiency of conversion of digested protein to milk protein being .70.

Nutrient Requirements for Maintenance and Growth

Lu and Potchoibia (1990) studied the influence of dietary energy and protein levels on daily DM intake and nutrient utilization for growth of goats. Dry matter intake decreased curvilinearly as dietary ME was increased. In contrast, DM intake was increased linearly by added dietary CP. By regression analysis, they calculated that for each gram of weight gain, goats required 4.6 kcal metabolizable energy and .236 g CP. This estimate for growth is 33% lower than the value proposed in 1981 by the National Research Council. The protein requirement for maintenance of wethers was estimated as 4.1 and 2.6 g/kg $BW^{.75}$ for total protein and digestible CP, respectively (Singh and Mudgal, 1991).

Protein and energy requirements for maintenance of goats also were studied in two experiments by Prieto et al. (1990). Two diets, based on pelleted lucerne hay alone or lucerne hay and barley, were fed individually once daily at a maintenance level of intake.

Maintenance requirements for nitrogen were calculated as 409 mg total nitrogen/kg $BW^{.75}$. Equivalent to 2.56 g CP/kg $BW^{.75}$, this is only 62% of the estimate of Singh and Mudgal (1991) mentioned above. Fasting heat production per day was 77 kcal/kg $BW^{.75}$. The daily energy requirement for maintenance was calculated to be 106 kcal/kg $BW^{.75}$. The overall efficiency of utilization of metabolizable energy for maintenance was .73 (Prieto et al., 1990).

Daily maintenance requirements for lactating does were estimated as 57.0 kcal and 4.8 g CP for each kg $BW^{.75}$ (Kessler, 1989). During the first two months of lactation, does rearing kids had reduced time to eat or graze; thereby, their feed intake is reduced just when nutrient and mineral requirements are highest. To meet these higher requirements, good-quality forage and concentrate supplements usually are provided. Later in lactation, it becomes relatively simple to meet the animal's nutrient and mineral requirements. However, during the fourth and fifth month of gestation, the goat must be prepared for parturition and lactation. Inadequate feeding during this period can lead to pregnancy toxemia and lower milk yield during the subsequent lactation. Grass and preserved forages generally are the staple for economical feeding of goats (Kessler, 1989).

Sanz et al. (1988) studied the energy requirements for maintenance of young nursing goats. Total energy retention, energy retained as protein, and energy retained as fat, all increased as intake was increased from 1.25 to 2.5 times maintenance energy requirements. When compared with a milk substitute, goat milk resulted in greater energy retention and more energy retained as fat at the highest level of intake (2.5 times maintenance). Metabolizable energy requirements for maintenance and for growth, metabolizable energy efficiencies for growth, as well as metabolizable energy partial efficiencies and energy costs of protein and fat deposition were estimated by regression analysis. For goat milk and the milk substitute, the respective daily ME requirements were 106 and 101 kcal/kg $BW^{.75}$; 3.85 and 4.28 kcal/g empty body weight gain; .73 and .58; .91 and .78; .65 and .57 kcal intake/kcal retained (at the 3 feeding levels); 6.26 and 7.24 kcal/g protein retained and 14.62 and 16.68 kcal/g fat retained (Sanz et al., 1988).

In a separate trial to evaluate body composition of goat kids during suckling, Sanz et al. (1990) slaughtered kids at birth or at 15 or 30 days of age. Kids slaughtered at 15 or 30 days old were fed goat's milk or a milk-substitute at two levels of intake. Voluntary feed intake (ME/kg $BW^{.75}$) was equal to 2.42 and 2.44 times the energy needed for maintenance for kids fed goat milk and milk-substitute, respectively. There was a high correlation between the empty-body concentrations of DM, fat, and energy, and empty-body weight and age. The relations between empty body composition and empty body weight were independent of type of milk or plane of nutrition. The results show that goats of a given body weight will have a specific composition, but at what age a specific body weight and composition is reached depends on the diet and level of voluntary feed intake (Sanz et al., 1990).

Morphological development from early post-natal life was found to be different in goats than in lambs (Sanz et al., 1994). They compared food intake and performance of milk-fed lambs and kids from birth through 60 days. Although apparent energy digestibilities were similar, DM and metabolizable energy intake per kg $BW^{.75}$ were lower for goats than lambs. Young goats retained less energy and deposited less energy as fat than did lambs. One primary characteristic of the carcass from young goats is its low adipose tissue content; lack of fat is detrimental to eating quality (Sanz et al., 1994).

Yan et al. (1993) conducted experiments to determine the effect of feeding milk on intake of concentrates and growth of young castrated goats slaughtered at 28 kg live-weight. Goats were fed diets containing a milk substitute from 2 days of age to 28 or 39 d of age at intakes of .140, .176 or .272 kg/d; kids had free choice access to concentrate. Increasing intake of the milk substitute did not reduce intake of concentrate prior to weaning (28 or 39 d old), but it did reduced intake of concentrate from weaning through to slaughter. Weaning at 39 compared to 28 d reduced intake of concentrates. However, there was no difference in average daily feed intake when the level of milk substitute fed was similar for kids weaned at 39 or 28 d. Increasing daily intake of the milk substitute increased daily live weight gain prior to weaning, but tended to increase the time needed for kids to regain their weaning weight following weaning. Milk substitute level and weaning age did not significantly affect overall daily live weight gain or length of time taken to reach 28 kg. There were no significant differences in final body composition, in carcass weight, or in body composition between groups of animals slaughtered at 28 kg.

Milk normally is fed to kids from birth until they reach 4 weeks to several months of age. In a newborn kid, the digestive tract and enzymes are adapted to digest and absorb nutrients from milk. During this pre-ruminant period, kids gradually become able to digest solid feed. Colostrum should be fed ad libitum to all kids as soon as possible after birth to provide immunity and attain a positive energy balance. Liquid feeds for kids include whole milk from goats or cows, skim milk or whey. Skim milk can be fed as the only source of milk beyond 4-5 wk of age and whey beyond 2 months of age (1-2 L/d). Milk substitutes should contain 15-25% high-quality fat and 20-25% protein on a dry basis. Replacement of milk proteins by soybean and fish protein in milk substitute may reduce kid growth, particularly for kids under 3 or 4 wk of age. Natural rearing is preferred in meat-producing herds. In dairy herds, early weaning or part sucking is practiced when the price of goat milk substitute is high, when no milk substitute is available, or if management is poor. Restricting milk intake will increase solid feed intake and reduce the post-weaning growth check (Havrevoll et al., 1991).

To evaluate the effect of suckling frequency on maximum milk intake and nitrogen balance in artificially reared kids, Fernandez et al. (1994) fed whole goat's milk to satiety at either 4, 6 or 12-h intervals. Daily total milk intake was not affected by feeding frequency. Milk ingestion per meal decreased linearly as the number of meals/day increased. Weight gain, feed efficiency and protein efficiency rate showed positive linear responses to an increased number of meals/day. Suckling frequency did not affect nitrogen balance. Although milk protein digestibility was high, urinary nitrogen excretion also was high; consequently, retention of the digested nitrogen was low. These results suggest that the nitrogen:energy ratio in goat milk exceeds the kid's requirements. When animals met their energy needs, nitrogen intake was excessive; consequently, enriching milk with energy (e.g., fat), especially when coupled with a greater number of meals/day should improve efficiency of use of milk (Fernandez et al., 1994).

Production rates and physiological responses of Angora goat kids fed acidified milk replacer or goat milk were examined by Sahlu et al. (1992a). Although final weights and plasma glucose concentrations were similar, kids fed goat's milk produced 13.8% more mohair than those given a milk substitute. Kids fed high concentrate diets reached maturity earlier and a had higher lifetime output of milk (Hadjipanayiotou, 1990). To eliminate metabolic or digestive disturbances, good quality roughage should be offered during periods of high concentrate consumption. An appropriate concentrate mixture should be tailored to balance the roughage in terms of energy, protein, minerals and vitamins. Addition of $NaHCO_3$ to the concentrate can help avoid metabolic disorders and improve efficiency of feed utilization. Cereal grains need not be ground; grinding increases cost and induces both acidosis and the low milk fat syndrome. Pelleted concentrate mixtures for kid have resulted in better feed conversion efficiencies than whole, ground or rolled cereal grains, presumably due to reduced feed separation and sorting of ingredients by kids. Early weaning of kids (7 weeks old) and restricted sucking increases commercial milk yields (Hadjipanayiotou, 1990).

Physiological Factors Affecting Cashmere Growth

Hormones

Isolated hair follicles have been used to determine the effects of prolactin and melatonin, two hormones considered to influence hair follicle growth and activity in vivo, on hair shaft elongation (Ibraheem et al., 1994). DNA synthesis was observed autoradiographically using freshly isolated follicles incubated for 6 h in the presence of [methyl-^{3}H]-thymidine. Similar measurements before and after 96 h of maintenance indicated that incorporation of [methyl-^{3}H]-thymidine was reduced by reducing energy intake. However, prolactin and melatonin stimulated hair shaft elongation of secondary follicles during 24 h measurements and cumulatively over 120 h. Although the number of follicles remaining viable during each 24 h measurement period was not affected by prolactin, it was reduced by melatonin treatment after 96 h of maintenance. These results suggest that prolactin and melatonin may act directly on the cashmere secondary hair follicle to stimulate elongation of the hair shaft and that melatonin may reduce the viability of follicles.

Nixon et al. (1993) studied the sequence of structural changes in goat hair follicles by using melatonin implants to advance and synchronize spring hair growth. Cashmere wethers that received a controlled release formulation of 70 mg of melatonin in late winter had plasma melatonin levels greater than normal 14 days after implants were administered. In untreated animals, daytime plasma melatonin averaged 19.9 pg./ml compared with 914 pg/ml for implanted wethers. Examination of skin biopsies revealed that primary hair follicles had begun to grow fiber in the treated goats only. Structural reorganization of follicles began in treated animals between days 6 and 12 post-treatment, and fibers emerged by day 24. Normally, fiber growth increases in spring when plasma prolactin concentration remains suppressed below normal levels. Although prolactin levels increased in control goats from 7.4 to 12.8 ng/ml in 14 day, they declined in melatonin-treated animals from 6.3 to 2.2 ng/ml during this period (Nixon et al., 1993).

The effect of continuous melatonin administration on prolactin secretion in goats kept under controlled environmental conditions was studied by Emesih et al. (1993).

Plasma prolactin concentrations were greater for goats maintained under long-day photoperiods than for those maintained under short-day photoperiods although there was a day-length by time interaction. A nocturnal peak in circulating concentrations of prolactin was seen in goats exposed to long-day but not to short-day photoperiods. There also was a day-length by gender interaction. Plasma prolactin concentrations were higher for female than for male goats exposed to short-day photoperiods. Prolactin secretion was lower in goats receiving melatonin than in those not receiving melatonin implants. They also showed that nocturnal rise in prolactin secretion in goats subjected to long-day photoperiods continued after melatonin implants. Therefore melatonin administered by means of implants near the end of the normal breeding season, did not influence prolactin secretion in goats (Emesih et al., 1993).

Circulating prolactin profiles also exhibit seasonal variation (high in summer, low in winter) both in pinealectomized and control wethers (Foldes and Maxwell, 1993). There was no difference in wool production between pinealectomized and control wethers when the diet of both groups contained similar amounts of nutrients. Hence, melatonin's role in the regulation of wool growth remains unclear. This hormone may have a transient effect on wool production in young wethers under conditions of limited nutrition but not at higher nutritional levels. This would indicate that melatonin may be involved in partitioning of nutrients between wool follicle growth and other functions.

Effects of feeding level and animal age on fleece growth and plasma concentrations of prolactin and thyroxin were studied using cashmere goats (Kloren et al., 1993b). Serum prolactin concentrations in groups fed at higher intake levels increased during the study; prolactin remained low at the lower feed intake level. However, feeding level had no impact on cashmere production. Cashmere fiber quality characteristics are associated with animal age. Prolactin secretion may partition nutrients away from fleece growth. This antagonism between prolactin secretion and fleece growth rate may be responsible for seasonal changes in fleece production and composition; hormone secretion in turn may depend on level of energy intake. Kloren and Norton (1993) investigated the effect of prolactin on the initiation, maintenance and cessation of cashmere growth. Their results showed that either naturally or artificially induced alterations in prolactin concentrations coincided with the initiation (falling prolactin concentrations) and possibly also with the cessation of cashmere growth (rising prolactin concentrations).

The influence of season on the pattern of fiber growth and hormone concentrations in plasma of cashmere goats was examined by Kloren et al. (1993a). Cashmere length increased more in summer than in winter. Initiation of cashmere growth consistently began earlier for female than males goats; initiation time for castrates was intermediate. The initiation of cashmere growth progressed in a wave from the hip to the shoulder. There were no significant effects of gender on maximum length of cashmere grown. Prolactin secretion also was seasonal, increasing from a minimum value in winter to a peak level in summer. Thyroxin concentrations were higher in summer than winter, but seasonal changes were not as distinct as those for prolactin. Growth hormone concentrations did not change with season, but decreased as animals aged. Peak levels of prolactin in summer signaled the initiation of cashmere growth, but after initiation, rate of cashmere growth increased as prolactin level declined. Neither thyroxin nor growth hormone had a regulatory impact on the cashmere growth cycle.

Nutrient Effects on Follicle Growth

Effect of level of nutrition on the ratio of length:diameter ratio of wool was tested by Hynd (1994). Sheep were grouped by fiber diameter and rate of fiber elongation. Sheep were fed at maintenance for 8 weeks followed by a high plane of nutrition for 7 weeks. Nutrient intake significantly influenced the dimensions of the follicle bulb and dermal papilla, the rate of division of follicle bulb cells, the dimensions of the cortical cells and the production ratio (the ratio of fiber area to fiber-plus-inner root sheath area). The high and low fiber diameter sheep differed in bulb and papilla dimensions and in the rate of bulb cell division. The high and low fiber length sheep differed only in papillary length and cortical cell length. Stepwise multiple regression analysis showed that a model including terms for nutrition, phenotype group and cortical cell length could account for 60% of the variation in fiber elongation. Fiber diameter was best accounted for by a regression equation that included nutrition, phenotype group, cortical cell volume and papillary area ($R^2 = 0.88$, $P < 0.001$). The differential dependence of the fiber dimensions on follicle characters means that the shape of the fiber being produced by a follicle changes when cortical cell length, cortical cell volume and papillary size are altered. Several hormonal, nutritional and selection regimes are known to alter the ratio of length:diameter, but the simple nutritional changes in this study failed to change this ratio.

Secondary Follicle Development in Goats

Kids achieved maximum secondary follicle development at about 20 weeks after birth. Cashmere percentage was found to be a good approximation of the proportion of secondary follicles of these animals born in spring. No difference in S:P ratio or rate of secondary follicle maturity was found between male and female kids. If S:P ratio measurements are to be made, samples should be taken during the summer months when the follicles are active. Fiber diameter was greatest during the summer, narrowing again in winter immediately before shedding. Follicles in goats and sheep are arranged in characteristic fashion in the skin with a primary follicle surrounded by several secondary follicles (Margolena 1959, 1966; Burns 1965)

In sheep, primary follicles are formed first and secondary follicles are formed later (Lyne 1966). Schinckel (1955) pointed out that follicle development should be considered to occur in two stages, e.g., initiation and maturation. The animal age at which all secondary follicle development is completed also varies with breed in sheep; all breeds continue to undergo secondary follicle maturation after birth. Dreyer and Marincoriz (1967) found the same to be true for goats, with secondary follicle numbers continuing to increase until kids were six months old. Assessment of production potential from secondary follicles may be made in two ways. It may be expressed as a ratio of secondary:primary follicles, or as the number of follicles per unit of skin area. The S:P ratio often is measured because it is independent of skin expansion which changes as the animal grows, and of shrinkage of skin during processing. Thus, the S:P ratio has been used extensively both to compare sheep breeds and as a means of measuring secondary follicle development. This is particularly important when the commercially valuable fiber is produced only by secondary follicles as is true for cashmere. Although it has been shown that nutritional changes can alter fiber diameter in sheep (Schinckel 1962), the seasonal variation in fiber diameter was found to be independent of any nutritional effect. Rudall (1956) suggested that changes in the dimensions of the papillae are the principal cause of variation in fiber output and might be useful in selecting replacement animals. Because producers must select replacement at an early age, being able to assess productive potential early in life has an advantage.

Producers need to know the timing and extent of the growing season to properly manipulate nutrition and breeding to maximize production. For winter, a dense fine coat which traps air for winter warmth is desirable; a less dense coat in the spring and summer allows air circulation and evaporative cooling. Henderson and Sabine (1992) measured secondary follicle activity and concluded that the cashmere growing season lasted 10 to 11 months. Fiber diameter was narrowest from spring to early summer and broadest in autumn. In determining the exact timing frequency and duration of the molt, histological studies at the follicular level are essential (Ryder, 1964: Ryder and Stephenson 1968). In tracing the annual growth cycle of cashmere fiber, Henderson and Sabine (1992) described a gradual increase in both the percentage and the diameter of the fiber. A maximum of about 84% cashmere fiber was reached in mid-summer which was maintained until late winter when cashmere fibers began to be lost from the coat. Because the new season's fiber is produced before the old coat is completely shed, cashmere is always present in the coat. Males retain more cashmere fibers than females do. Fiber diameter reached a maximum of 17.68 micron in autumn but decreased during the winter. The decrease in follicle activity in early autumn did not alter fiber diameter. However, the gradual decrease in follicle activity thereafter resulted in a decrease in fiber diameter.

The number of cell produced within the follicle bulb per unit of time is closely related to the rate of fiber growth in sheep (Schinckel 1961; Hynd 1989). Differences in the number of cortical cells appear to contribute more to variation in fiber size than do differences in cortical cell size (Schinkel 1961). The proportion of dividing cells in the follicle bulb which contribute to either fiber cortex or inner root sheath is an inherent characteristic of individual animal (Hynd 1989). A strong correlation has been reported between the rate of bulb cell division and fiber growth. The proportions of dividing cells entering the fiber cortex remains constant.

Skin follicle parameters and body weight measurement were collected sequentially in cashmere-producing goats, at birth, 57, 107 and 301 days of age (Parry et al., 1992). All primary follicles, but few secondary follicles, were mature at birth; follicle number increased 10-fold between birth and 57 days of age. The number of primary follicles declined between 57 and 107 days of age. The number of secondary follicles, but not their density, increased until weaning and then declined to 301 days of age. Single-born kids had a higher secondary follicle number than twin-born kids at all ages except at birth; the secondary:primary ratio remained higher for singles than twins at 57 d old. At 107 and 301 d old, males had higher numbers of both primary and secondary follicles than females. For secondary:primary follicle ratio there were no differences between genders.

Skin follicle parameters, weaning body weight and wool growth of sheep were evaluated by Thomas et al. (1993). Weaning weight and skin follicle density were correlated with yearling fleece parameters. However, follicle density at weaning was not correlated with the secondary:primary follicle ratio.

Woods and Orwin (1988) using a radiolabelling technique to label short regions of growing wool fibers by injecting ^{3}H-cystine intradermally. This technique allowed them to measure emergence time and dimensional changes of individual wool fibers. Fiber dimensions changed with season for sheep fed at maintenance over a 12 month period. Fiber diameter, length and growth rate varied with season with maximums occurring in summer and minimums in winter. Amplitude and timing of each cycle differed between sheep and fiber type. The cyclical change in wool growth rate with season was the result of changes in both fiber diameter and rate of elongation. Monthly measurements of wool diameter and elongation were not related, suggesting that the cellular and physiological mechanisms determining these parameters in the follicle are complex.

Skin follicle and fiber parameters in two generations of Angora goats were examined by Eppleston and Moore (1990). Large differences were detected between the two generations for all traits except for primary follicle density. Female goats had a lower incidence of medullated fibers, a greater density of primary and secondary follicles, and a lower fiber diameter than males goats. Fleece quality compared favorably with that of Texas and South African Angoras, but total unwashed fleece (greasy fleece) weight from Angoras was inferior. Greasy fleece weight was correlated positively with body weight and secondary:primary follicle ratio. Follicle density, fiber diameter and body weight were not related to greasy fleece weight (Eppleston and Moore. 1990).

Tsenkova (1988) attempted to predict wool production of sheep at an early age based on skin samples. Samples were obtained from 32 ram and 45 ewe lambs of the Thrace Finewool breed at 4 and 18 months of age. At the two ages, follicles for rams and ewes, which had averages in their secondary:primary ratio of 9:16 and 9:15, were similar. The correlation between the secondary:primary ratio at the two ages was 0.98 and 0.59 for the two genders. Correlation of the secondary:primary ratio with fiber diameter and length were low and not different between genders.

Alternative Uses for Goats Raised for Cashmere Production

The supply of absorbed energy and protein usually limit the rate of meat production by goats. Higher intakes of both energy and protein by meat goats typically increases muscle development and increases dressing percentage. The plane of nutrition affects growth rate and muscle composition as well as the amount of energy deposited as carcass fat and its distribution. Feed-conversion efficiency typically dictates the economic efficiency of meat production. Additional nutritional strategies that can reduce production costs include 1) greater use of economical crop residues, agroindustrial by-products, and non-conventional feeds, 2) increased use of dietary nitrogen sources, 3) use of urea-molasses block licks, 4) strategic use of supplementary proteins, and 5) increased cultivation and utilization of protein-rich forages. These strategies can enhance efficiency of use of feed resources; in addition, innovative feeding systems can stimulate increased goat meat production in Asia and elsewhere (Devendra and Devendra, 1988).

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CHAPTER III

EFFECTS OF DIETARY PROTEIN AND ENERGY LEVEL ON PERFORMANCE OF CASHMERE-PRODUCING SPANISH GOATS.

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Abstract

To study the effects of concentrations of dietary protein and energy on cashmere production, thirty-six Spanish goats (wethers) were housed in individual metabolism crates and maintained at constant temperature (21°C) with 9 h of light and 15 h of darkness each day. Animals were blocked by body weight (**BW**) into six groups and used in a completely randomized block design with a 2 x 3 factorial arrangement of diets. These included two concentrations (10 and 15%) of crude protein (**CP**) and three concentrations (2 (**L**), 2.35 (**M**), 2.7 (**H**) Mcal/kg) of metabolizable energy (**ME**). Dry matter intake

(DMI) was greater for goats fed the 15% than for those fed the 10% CP diet in g/d ($P <$ .05),.but DMI did not differ with dietary energy levels ($P > .29$). Metabolizable energy intake (**MEI**; Mcal/kg/d) was greater for goats fed H energy diet than for goats fed the other energy levels ($P < .01$). Average daily gain was 48% greater for the 15% than for the 10% CP diet ($P < .02$). Body weight at the end of the trial was heavier for goats fed the higher protein diet ($P < .03$). The higher protein diet increase both MEI and DMI ($P < .04$). Feed efficiency (g gain/kg feed) was 28% greater for those fed the 15% than for those fed the 10% CP diet ($P < .04$). Ruminal ammonia-N, valerate and isovalerate concentrations were greater ($P < .01$) with the higher protein diet. However, ruminal pH and A:P ratio both declined linearly ($P < .01$; $P < .03$) as diet energy level increased. Propionate increased linearly ($P < .03$) as ME of the diet increased. Energy concentration of the diet had a quadratic effect on total fleece weight ($P < .01$); goats fed the M diet produced more fleece than goats fed the other diets. Cashmere diameter was 4% greater ($P < .05$) with the 15 than the 10% CP diet. Results indicate that both quantity and quality of cashmere are influenced by dietary concentrations of energy and protein.

Key words: Cashmere production, Spanish goat, Energy, Protein

INTRODUCTION

The principal non-genetic factors influencing yield and quality characteristics of cashmere include age, gender, nutrition, physiological status, disease, shearing regime, animal origin, and management practices (Sumner and Bigham, 1993). For young non-castrated male goats, growth rate, cashmere yield, and cashmere quality all vary in a seasonal pattern which parallels the quantity of feed consumed (Walkden-Brown et. al., 1990). Presumably, these seasonal effects are controlled by photoperiod. Secondary follicles, those from which cashmere fibers develop, are active from mid summer to late winter. Age and gender of the animal can modify the time of year that cashmere growth begins (Restall et al., 1994). Nutrient status also alter an animal's response to hormonal messages that relay photoperiod and initiate cashmere growth (Walkden-Brown 1990). More detailed knowledge about control of appetite regulation will aid to optimize feed intake. If energy intake were increased, perhaps intact males could produce a quality and quantity of cashmere similar to that produced by wethers.

McGregor (1988) observed that cashmere goats produced fleece which was coarser (cashmere plus guard hair) when fed at 100 versus 80% of maintenance energy intake. When feed intake restriction was removed, cashmere diameter increased within two months. The increase in cashmere production from goats fed 100 versus 80% was closely correlated with an increased cashmere fiber diameter (McGregor, 1988). Hence, the increase in quantity of cashmere produced with energy supplementation was due to a decrease in cashmere quality, that is, increased fiber diameter. Cashmere growth generally increases when an energy supplement is provided to goats grazing poor pasture (McGregor, 1988). However, which specific nutrient(s) impact cashmere characteristics remains to be identified (Restall et al., 1994). Protein supplemented during the cashmere growing season did not increased production (Ash and Norton, 1984; Johnson and Rowe, 1984). However, supplemental protein increased BW.

Body size, fleece weight, percent yield, fiber characteristics and completeness of cover are the primary characteristics used for selecting goats for cashmere production. On an economic basis, cashmere production is considered a byproduct of meat goat production in the US (Shelton and Lupton, 1992). Most non-Angora breeds of goats in the US can produce cashmere (Teh, 1989). Where existing range conditions are inadequate to support the desired rate of growth, supplement of the proper composition should be provided. Management practices which alter nutrient availability enough to affect BW gain of goats will affect cashmere growth and fiber diameter (McGregor, 1992). Supplemental protein is the nutrient which limits tissue growth in young animals. Nutritional status of the animal and nutrient supplementation can influence fiber production in both sheep and mohair goats (Reis and Sahlu, 1994). However, for cashmere-producing goats, several studies have failed to detect any relationship between nutrient intake and cashmere fiber production (Ash and Norton, 1984; Johnson and Rowe, 1984; Jia et al., 1995).

The objectives of this study were 1) evaluate the effects of supplemental protein and energy on animal performance and cashmere production, 2) determine if these supplemental nutrients influence fiber composition and cashmere characteristics, and 3) quantify the optimum energy to protein ratio required for growth and fiber production.

Materials and Methods

Thirty-six wether cashmere-producing Spanish goats were housed in individual 1.2 m by 1.2 m pens. Room temperature was held at 21°C with a light:dark cycle of 9:15 with light beginning at 0800. Wethers were placed in individual pens at 195.7 ± 12.9 d of age with an average BW of 17.5 ± 4.6 kg. Animals were blocked into six weight groups and assigned randomly within each weight group to one of six treatments. Wethers were given free access to their diets during the 84 d experimental period. The treatments, arranged in a 2 x 3 factorial, consisted of two concentrations of CP (10 and 15%) and three concentrations of energy (2.0, 2.35 and 2.7 Mcal ME/kg). To increase protein content of the diet, soybean meal replaced rolled oats and a small amount of ground corn. To increase energy content of the diet, ground corn replaced cottonseed hulls. Diets were completely mixed (Weigh-Tronix Fairmont, MN) to avoid feed sorting. Ingredient and nutrient composition of the diets are shown in Table 1.

Before the experiment began, goats were allowed 3 wk to adapt to a basal diet (10% CP; 2.35 Mcal/kg ME) and were sheared completely. Fresh feed was added at 0900 each day with the amount offered being adjusted to allow no more than 10% orts. Feeders were emptied twice per week to remove orts. Water was available continuously. Samples of feed and orts, collected weekly and composited monthly, were analyzed to determine nutrient intake. Body weight was measured on two consecutive days at 14 d intervals during the trial, and once at the beginning and the end of the 84 d trial.

Measurement and Analysis

Samples of feed and orts were dried at 65°C overnight, allowed to air equilibrate, and ground in a Wiley mill through a 1 mm screen. Dry matter was determined by drying a 1 g sample overnight at 105°C. Ground feed samples were analyzed for N (Technicon, Tarrytown, NY). Energy content (GE) was measured using a Parr adiabatic oxygen bomb calorimeter (Parr Instrument, Moline, IL). Dietary fiber (ADF and NDF) were measured by the method of Goering and Van Soest (1970).

Blood was sampled at 14 d intervals during the trial. Prior to feeding, blood was collected by jugular venipuncture directly into 10 mL vacuum tubes (Becton Dickenson Vacutainer Systems, Rutherford, NJ) containing either K_3EDTA or potassium oxalate with sodium fluoride (a glycolysis inhibitor). Blood sample tubes were chilled immediately in an ice bath, transported to the laboratory, and centrifuged at 1500 x g and 4°C for 20 min. Aliquots of plasma were stored at -20°C until analyzed. Concentrations of urea-N, glucose, and total protein in plasma were assayed colorimetrically using a Technicon Autoanalyzer II System (Technicon Instrument, Tarrytown, NY).

Ruminal samples, obtained via stomach tube, were taken 4 h postprandially during wk 10 of the trial. Each sample was collected by inserting a tube with a strainer tip into the rumen and applying mild vacuum with a 60 cc syringe. The first 20-30 mL of ruminal fluid obtained was discarded to reduce contamination with saliva. Thereafter, 20 mL was collected for analysis. Ruminal fluid pH was measured using a pH meter (SA-720, Orion Research, Boston, MA) immediately after sampling. For VFA measurements, 1 mL of 25% (wt/wt) metaphosphoric acid was added to 4 mL of ruminal fluid; the mixture was stored at -20°C until analyzed with a gas chromatograph (Hewlett Packard CO, Avondale, PA). Total ruminal ammonia N was analyzed by using the method of Broderick and Kang (1980).

Goats were sheared at the beginning and end of the experiment. Total fleece weight was recorded; a representative fleece sample was retained. These fleece samples were used to determine the weight of cashmere, guard hair, and total 'corrected' fleece yield after three passes through a Shirley Analyzer (ASTM 1990). For each animal, two fleece samples (1.00 g) drawn randomly were separated manually into cashmere and non-cashmere fibers. Cashmere length was measured under a microscope to the nearest .5 mm. Diameter was measured using 100 fibers from each cashmere sample using a projection microscope at a magnification of 500 x (ASTM 1988).

Statistical Analyses.

Statistical analyses were calculated using the GLM procedure of SAS (1985). Data were analyzed as a 2 x 3 factorial arrangement of treatments in randomized complete blocks (Cochran and Cox, 1957). Least squares means were calculated and are reported to adjust for the unequal number of observation per cell. The model included effects of protein, energy, protein x energy interaction, and the residual error. Main effects and interactions were tested using the residual error mean square. Each animal was considered as a separate experimental unit. Orthogonal contrasts were used to detect linear and quadratic responses to supplemental energy. Exact probability values will be presented. When interactions between protein and energy were detected at $P < .05$, individual means will be presented; otherwise treatment means will be presented and discussed.

Results and Discussion

Differences in age, BW, and fiber parameters obtained at the start of the experiment are listed in Table 2. Effects of protein, energy, and the interaction between energy and protein on initial animal measurements were not significant except for effect of energy level on age. Kids fed the highest ME diet by random chance were five days younger ($P < .05$) than other groups. All animals were fed their specified diets for 84 days. Using initial values as a covariate did not significantly alter interpretation of any variable measured except for BW. Initial BW analyzed as covairate was considered significant ($P <.06$). Consequently final BW values were adjustment for differences in initial BW; other variables were analyzed without adjustment.

Dry matter intake (DMI), average daily gain (ADG), final BW and weight gain:feed intake ratio for wethers showed no protein x energy interactions. Data are presented as responses to protein (Table 3a) and to energy (Table 3b). Dry matter intake, expressed either as g/d, % BW, or g/kg $BW^{.75}$, all were altered ($P > .05$) by starting weight of the wethers; larger wethers consumed more feed (g/d) than smaller animals did. Dry matter intake as % BW and g/kg $BW^{.75}$ showed identical response patterns to initial weight, with the heavier wethers having the lower DMI values. Dry matter intake was greater goats fed the 15% than for goats fed the 10% CP diet in g/d ($P < .05$). Values for DMI measured as % BW or g/kg BW$^{.75}$, were numerically greater for those fed the 15% CP, but this difference was not significant ($P = .09$). Dry matter intake for goats has been reported to be greater with higher dietary CP (Ash and Norton, 1984; Huston et al., 1988; Lu and Potchoiba, 1990; Cheema et al., 1991; Jia et al., 1995). Values for indigestible DMI in g/d differ for the protein diets ($P < .02$) and were directly related to DMI g/d. The level of indigestible dry matter intake (UNDMI) in grams per day (Tables 3a) shows varied with dietary protein levels (227.8 vs 260.1; $P < .05$). Metabolizable energy intake (Mcal/kg/d) was not different for the two protein levels despite a 5% greater mean value for goats fed the 15% CP diet.

Dry matter intake (g/d) did not differ for dietary energy. However, DMI expressed as % BW or g/kg BW$^{.75}$ showed a declined linearly ($P < .01$) as ME of the diet increased. Presumably, animals fed the lower energy diet consumed more feed in order to reach satiety. Intake of DM was greater for animals offered the 2.0 ME diet than for the other two diets. Thus, satiety, not fill, probably limited energy intake of goats fed the two higher energy levels.

Indigestible dry matter intake responded similarly to DMI when expressed as % of BW, decreasing linearly ($P < .001$) as ME level of the diet increased. Calculated MEI (Mcal/kg/d) was significantly greater for the 2.7 ME diet than the other levels ($P < .01$). For the three energy levels, UNDMI were 44.2, 35.2 and 24.9% of DMI with values of 329.9, 233.6 and 168.3 g/d ($P < .001$) for low medium and high energy diets, respectively.

Although DMI as % BW or g/kg $BW^{.75}$ was greater for the lowest energy diet, MEI was superior for the 2.7 ME diet due to the higher percentage of UNDMI (44 and 35%) for low and medium energy diets.

Live weight gain, positive for all treatments, ranged from 4.13 to 8.05 kg. Wethers fed the 15% CP diet gained 6% more weight than wethers fed 10% CP diet. Average daily gain did not differ between wethers irrespective of starting weight ($P > .24$), but was 48% greater for those fed the 15% than for those fed the 10% CP diet ($P < .02$). Similar results have been documented for cashmere doelings fed 8 or 16% CP diet (Jia et al., 1995). Increased BW gain for goats fed higher protein diets also has been reported by others (Johnson and Rowe, 1984; Ash and Norton, 1984; McGregor, 1988). Results would confirm the NRC estimate that 10% protein is not adequate for maximum growth rate for goat kids.

Level of dietary energy did not alter ($P > .10$) ADG (Table 3b). However, BW gain in g/d increased from the lowest to highest ME diet (58.29 to 78.36). In several studies, BW gain for goats has increased when dietary energy concentrations were increased (Ash and Norton 1984; McGregor, 1988). However, Lu and Potchoiba (1990) observed that ADG was not influenced by dietary energy density for growing Alpine and Nubian breeds of goats. At the end of the trial individual BW ranged from 19.4 to 35.7 kg. Body weights at the end of the trial, adjusted for initial BW as covariate, were heavier for those fed the 15% CP diet ($P < .03$). This greater BW observed for higher protein diets is consistent with the greater ADG; similar responses have been observed by others

(Lu and Potchoiba 1990). Final BW did not differ with ME level of the diet (*P* > .89), but values were increased numerically by the higher energy diets.

Live weight gain expressed as (g/kcal) MEI, (g/g) CPI, or g/kg DMI were not affected by the initial BW of wethers. The higher protein diet produced greater MEI and DMI (*P* < .04). The DMI was higher (P < .02) for those fed the 2.7 ME diet than for those fed other diets. Feed efficiency (g/kg) was 28% greater (*P* < .04) with the 15% than with the 10% CP diet. Jia et al. (1995) reported that feed efficiency was 100% greater for cashmere goats fed a 16% versus an 8% CP diet. In their study, DMI was 28% greater and BW gain 150% greater with higher CP diet. In this study, feed intake was 12% greater and BW gain was 48% greater with the 15% than the 10% CP diet. Increasing ME content of the diet linearly (*P* < .02) improved efficiency, with the 2.7 ME diet producing 43% greater feed efficiency than the lowest ME diet.

Ruminal fluid parameters were not changed due to initial weight of the wethers. (*P* > .18). A significant protein x energy interaction was detected for isobutyrate concentration; this is depicted graphically (Figure 1). Data for all other ruminal fluid parameter are presented in separately (Table 4a) as effects of dietary protein and (Table 4b) dietary energy. Ruminal total volitile fatty acids (VFA), acetate propionate butyrate and A:P ratio were not affected by dietary protein levels (*P* > .29). Similar results have been reported by others (Hart et al., 1993; Sutton et al., 1988). Valerate and isovalerate concentrations were greater (*P* < .003) with the higher dietary CP. Branched chain VFA were higher with the 15% CP diet. Ruminal pH was 6.01 versus 6.14 (*P* = .07) for low and high protein diets, respectively. Ruminal ammonia-N was higher with the 15% than the 10% CP diet ($P < .01$), directly reflecting the supply of protein available for ruminal degradation. There were no differences between dietary energy levels for total VFA, acetate, butyrate, valerate, isovalerate or ammonia-N concentrations in ruminal fluid ($P > .07$). However, ruminal pH and A:P ratio both declined linearly ($P < .01$; $P < .03$) as diet ME level increased. Propionate concentration increased linearly ($P < .03$) as ME of the diet increases. Sahlu et al. (1992) found no differences in ruminal fluid parameter measurements (except for propionate) with various dietary concentrations of CP. Differences observed between the two studies might be attributed to differences in energy intake and in the time that ruminal fluid was sampled (4 h postprandially in the present study versus 2 h in others). However, in this study, all animals had free choice access to feed so that meals and eating times were not controlled.

Glucose, urea-N, and total protein concentrations in blood plasma are presented in Tables 5a and 5b. These metabolites were not altered significantly by either protein or energy content of the diet. Plasma glucose also was not affected by protein level in previous studies (Sahlu et al., 1993; Jia et al., 1995). De Jong (1981) reported that circulating glucose concentration of goats increased one hour after feeding.

Responses in cashmere production in g/d and percentage yield exhibited a protein x energy interaction ($P < .03$; $P < .02$) as depicted in Figures 2 and 3. Cashmere production was not influenced by the initial BW of the wethers, but cashmere percentage yield was higher for wethers with smaller initial BW. Fiber parameters are presented as effects of protein (Table 6a) or energy (Table 6b) because no significant protein x energy interactions were detected. Total fleece, guard hair, cashmere diameter and cashmere length did not differ with initial BW of wethers. The level of dietary protein did not significantly alter total fleece yield or guard hair production although fleece weight tended to be greater (5%) for those fed the 15% CP diet. Guard hair weight was 7% greater for the high protein diet. Cashmere diameter was greater ($P < .05$) for goats fed the 15% CP diet. Small increases in secondary fiber diameter can influence production. In general cashmere diameter ranges from 8 to 20 mm, however within age and gender, a much narrower range (4 to 6mm) has been reported when animals were kept under the same conditions. The range for fiber diameter in this study was very similar across all treatments. This consistency in fiber diameter is one of the positive attributes of cashmere. Market value of the fiber is greatest when diameter is consistent.

Energy intake affected total fleece growth (Table 6b); those fed the 2.0 ME diet had lower fleece weight than those fed the 2.35 and 2.7 ME diets. Numerically, goats fed the 2.35 ME diet produced more total fleece than goats fed the other two energy levels. Mean fleece production rates, at 2.3, 2.8, and 2.7 g/d can be contrasted with production rates of 1.1, 1.2, and 1.6 g/d reported for cashmere goats fed at energy intakes equal to .8, 1.0 and 1.5 times maintenance (McGregor 1988). Animals fed above maintenance generally produce more fleece than those consuming lower amounts of ME. A correlation between ME intake and cashmere yield was low ($r = .23$; $P > .15$). Goats fed at different energy levels (70, or 100% maintenance, and ad libitum) to lose, maintain or gain live weight, also produced different amounts .9, 1.2 and 1.3 g/d respectively of total fleece (Restall et al., 1994). In contrast, Ash and Norton (1984) found no difference in cashmere growth between goats fed ad libitum vs 75% of ad libitum intake. All goats in the study of

Ash and Norton (1984) gained weight during the trial which is unlike the studies of McGregor (1988) and Restall et al. (1994). Cashmere growth response was correlated positively with weight change (r = .33; $P < .05$). However, in this study only a small percentage of the variation could be explained by regression analysis ($R^2 = .11$; $P < .05$), with the Equation $Y = 72.35 + .28 X$ (Y = cashmere yield; X = weight gain). Weight gain was greatest for those fed the 2.70 ME diet, but that cannot account for all the differences in cashmere production. The present study was conducted between September and January, an optimum time for cashmere growth measurement; most secondary fiber are active during this period. One third of the total cashmere produced for the cashmere growing period was shorn at the end of adjustment period. Cashmere growth initiation begins in early summer (Henderson and Sabine 1992). Pre-treatment fiber yield represents growth for more than two months.

Nutritional influences on fiber diameter and production have been documented in sheep and Angora goats. Several studies with cashmere producing goat have failed to identified effects of dietary nutrients on cashmere diameter. (Norton and Ash, 1984; McGregor 1988 Jia et al., 1995;). Restall et al. (1994) reported that cashmere fiber diameter increased with increased feed intake (all nutrients) by high yielding cashmere goats. Animals in this trial had cashmere yields (1.08 g/d) comparable to those reported by Restall et al. (1994) of .75 g/d but considerably higher than .53 to .71 g/d reported by others (Ash and Norton, 1984; Johnson and Rowe, 1984; Jia et al., 1995). Cashmere diameter in this trial averaged 12% less than values reported for high yielding cashmere goats by Restall et al. (1994). However, diameters were increased by only 4% with increased dietary CP and were 8% greater than pre-treatment diameters when averaged across all treatments. Fiber diameter was 5% greater (16.5 vs 15.6 μm) than reported by Jia et al. (1995); this might be attributed to differences in gender (we used castrated) and fleece yield in our trial was 77% greater (2.62 vs .60 g/d).

Concentration of ME in the diet had no effect on fiber diameter (*P* = .27, Table 6b). McGregor (1988) also detected no difference in cashmere fiber diameter either between goats limit fed at 1.25 or 1.5 times maintenance or to animals with intake energy level above maintenance given free access to feed. However cashmere fiber diameter for meal fed goats at 0.8, 1.0 and 1.5 times maintenance energy increased from 16.7 to 17.7 μm (McGregor, 1988).

Guard hair weight, cashmere percentage yield and cashmere length were not affected by protein or energy content of the diet. However, cashmere percentage yield was 52% greater during the study than during the pre-treatment period. This is consistent with other studies (Kloren and Norton, 1993: McDonald and Hoey, 1987) and presumably reflects faster cashmere growth during this specific season. Cashmere length averaged 32.2 mm, much greater than the 19.8 mm reported by Jia et al. (1995) but less than growth of 56.4 mm expected for a complete growth season (McDonald et al., 1987).

Cashmere yields, as a percentage of total fleece, are presented in Figure 2. A significant interaction between protein and energy (*P* < .02) was detected. Cashmere yield as a percentage of total fleece tended to be greater for those fed the 10% CP - 2.0 ME diet and for those fed the 15% CP -2.3 ME diet. This implies that cashmere production was depressed by added protein with the lowest energy diet but enhanced by added protein with the intermediate energy diet.

Perhaps sulfur intake and the nitrogen to sulfur ratio (N:S) of the diets (Table 1) had some effect on cashmere yield. Sulfur levels were less than .18% and N:S ratio ranged from 15-25:1 of sulfur in the trial diets. These values are below the NRC (1981) recommended levels for fiber producing goats, of .16-.32% and N:S ratio of 10:1. For maximum daily gain, growing goats require .22% sulfur of dietary dry matter and a N:S ratio of 10:1 (Qi et al., 1993). The lowest cashmere yield was produced by animals receiving the lowest N:S of 25 to one. Fiber production was restricted by level of sulfur, and N:S ratio appears to influence cashmere yield.

Implications

Fleece production by young growing Spanish goats was increased by increasing the energy density of diets above 2.0 Mcal ME/kg. Higher amounts of dietary CP increased fiber diameter, probably because of improvements in the percentage dietary sulfur and the N:S ratio. Dry matter intake was influenced by the level of protein and the energy density of the ration. Average daily gain was correlated positively with cashmere production. The highest level of cashmere production occurred when rate of weight gain was maximum.

Table 1. Ingredient and nutrient composition (% of DM) of experimental diets[a]

	10% CP			15% CP		
Item	2.00 Mcal	2.35 Mcal	2.70 Mcal	2.00 Mcal	2.35 Mcal	2.70 Mcal
Ground corn	6.21	30.11	61.22	5.13	15.49	47.09
Cottonseed hulls	55.35	39.75	18.19	57.13	38.86	18.65
Rolled oats	24.31	17.68	9.99	5.02	18.19	7.37
Soybean meal	7.55	8.13	6.20	24.67	23.00	20.98
Alfalfa meal	3.64	1.96	2.00	5.02	2.02	3.68
Limestone	.58	.47	.47	.60	.48	.44
Dicalcium phosphate	1.16	.93	.95	1.19	.96	.88
Trace mineral salt[b]	.58	.47	.47	.60	.48	.44
Vitamin ADE premix[c]	.62	.50	.51	.64	.52	.47
Sulfur, %	.15	.15	.14	.17	.18	.18
Nutrient composition						
DM[d]	91.00	90.00	90.30	91.20	90.50	90.80
Crude protein	9.71	9.57	9.99	14.83	14.87	15.19
ADF	39.80	31.10	16.40	38.60	25.80	17.90
Ash	4.64	3.72	3.80	5.25	4.50	4.18
ME, Mcal/kg[e]	2.01	2.34	2.71	2.04	2.34	2.70
N:S ratio	19.46	16.96	15.27	25.03	20.18	18.16

[a] DM basis.

[b] Containing (percentage) NaCl, 95.5 - 98.5; Mn,> .24; Fe, > .24; Mg, > .05; Cu, > .032; Co, > .011; I, > .007; Zn, > .005.

[c] Contained 2,200 IU of vitamin A; 1,200 IU of vitamin D_3; 2.2 IU of vitamin E/g.

[d] DM expressed on an as-fed basis.

[e] ME and sulfur were calculated from feed composition tables (NRC, 1981).

Table 2. Pre-treatment values for cashmere-producing Spanish goats fed two levels of crude protein and three levels of energy[a].

	10% CP			15% CP			
Parameter	2.00 ME	2.35 ME	2.70 ME	2.00 ME	2.35 ME	2.70 ME	SE[b]
Initial age, d	213.17	210.00	204.17	211.33	210.40	210.80	2.03
Initial BW, kg	17.50	19.58	21.08	20.50	18.00	17.50	1.37
Fleece wt, g	167.50	165.83	158.17	166.00	171.17	163.33	11.45
Guard hair yield, %	70.96	75.67	73.29	76.37	67.42	73.93	6.48
Cashmere yield, %	29.04	24.33	26.71	23.63	32.58	26.07	4.58
Guard hair wt, g	118.59	126.02	115.58	126.53	116.62	117.67	10.49
Cashmere wt, g	48.91	39.82	42.59	39.47	54.55	45.67	8.35
Cashmere dia., µm	15.38	14.73	15.35	15.14	15.68	15.52	.43

[a] Values are least squares means.

There were no treatment differences *(P >.10)*.

[b] Standard error for treatment (n = 6)

Table 3a. Effect of two levels of protein on body weight and intake[a].

	Protein levels of Diets			Probability
Parameter	10% CP	15% CP	SE[b]	$P <$
DMI, g/d	654.65	736.06	27.74	.05
DMI, % BW	2.77	2.90	.06	.17
DMI, g/kg BW$^{.75}$	60.99	64.88	1.57	.09
UNDMI, g/d[c]	227.80	260.11	8.87	.02
MEI, Mcal/kg/d	5.95	6.23	.14	.18
ADG, g/d	53.39	78.82	7.09	.02
Final BW, kg[e]	23.50	25.66	.64	.03
Gain/MEI, g/Kcal	.15	.19	.01	.04
Gain/CPI, g/g	.92	.81	.06	.24
Gain/feed, g/kg	80.60	103.49	7.26	.04

[a] Results are least squares means for treatments.

No significant protein x energy interaction ($P > .11$).

[b] Standard error for protein (n = 18).

[c] UNDMI = indigestible DMI calculated from TDN of each diet.

[d] MEDMI = Metabolizable energy intake.

[e] Final BW adjusted with initial BW as covariate.

Table 3b. Effect of three levels of energy on body weight and intake[a].

	Energy Levels of Diets				Probability <	
Parameter	2.00 ME	2.35 ME	2.70 ME	SE[b]	Linear	Quad.
DMI, g/d	746.25	663.89	675.93	33.98	.49	.29
DMI, % BW	3.13	2.77	2.61	.08	.001	.94
DMI, g/kg $BW^{.75}$	69.02	61.16	58.63	1.92	.01	.64
UNDMI, g/d[c]	329.92	233.65	168.31	10.87	.0001	.14
MEI, Mcal/kg/d	6.32	6.49	7.08	.17	.01	.98
ADG, g/d	58.29	61.65	78.36	8.69	.10	.51
Final BW, kg[e]	23.93	24.22	25.60	.76	.22	.79
Gain/MEI, g/Kcal	.17	.17	.18	.02	.65	.33
Gain/CPI, g/g	.71	.93	.96	.08	.15	.75
Gain/feed, g/kg	76.51	90.71	109.36	8.90	.02	.23

[a] Results are least squares means for treatments.

No significant protein x energy interaction (*P* > .11).

[b] Standard error for energy (n = 12).

[c] UNDMI = indigestible DMI calculated from TDN of each diet.

[d] MEI = Metabolizable energy intake.

[e] Final BW adjusted with initial BW as covariate.

Table 4a. Effect of two levels of dietary crude protein on ruminal fermentation characteristics in cashmere-producing Spanish goats[a].

	Protein Levels of Diets			Probability
Parameter	10% CP	15% CP	SE[b]	$P <$
Total VFA (mM)	50.42	49.03	3.51	0.78
Rumen pH	6.01	6.14	0.06	0.11
NH_3-N (mg/dl)	22.74	30.97	2.20	0.01
Acetate (mol/100 mol)	64.37	63.53	0.92	0.52
Propionate (mol/100 mol)	21.87	20.46	0.93	0.29
Butyrate (mol/100 mol)	11.07	11.73	0.48	0.33
Valerate (mol/100 mol)	1.09	1.51	0.09	0.003
Isovalerate (mol/100 mol)	0.93	1.65	0.15	0.002
A:P ratio	3.09	3.25	0.17	0.52

[a] Results are least squares means for treatments.

No significant protein x energy interaction ($P > .10$).

[b] Standard error for energy (n = 18).

Table 4b. Effect of three levels of dietary energy on ruminal fermentation characteristics in cashmere-producing Spanish goats[a].

	Energy Levels of Diets				Probability <	
Parameter	2.00 ME	2.35 ME	2.70 ME	SE[b]	Linear	Quad.
Total VFA (mM)	52.52	43.92	52.73	4.38	.40	.82
Rumen pH	6.20	6.11	5.91	.07	.01	.07
NH_3-N (mg/dl)	29.18	22.01	29.37	2.75	.27	.12
Acetate (mol/100 mol)	65.46	64.19	62.20	1.15	.07	.17
Propionate (mol/100 mol)	18.76	21.48	23.26	1.16	.03	.18
Butyrate (mol/100 mol)	11.79	10.85	11.55	.60	.75	.31
Valerate (mol/100 mol)	1.44	1.24	1.21	.11	.34	.99
Isovalerate (mol/100 mol)	1.53	1.29	1.06	.19	.14	.07
A:P ratio	3.58	3.15	2.77	.22	.03	.25

[a] Results are least squares means for treatments.

No significant protein x energy interaction ($P > .10$).

[b] Standard error for energy (n = 12).

Table 5a. Plasma glucose, urea nitrogen and total protein levels cashmere-producing wethers, fed two levels of crude protein[a].

	Protein Levels of Diets			Probability
Parameter	10% CP	15% CP	SE[b]	*P* <
Plasma (mg/dl)				
Glucose	62.01	62.01	.88	.94
Urea-N	14.53	15.60	.66	.12
Total protein	61.77	59.57	.78	.07

[a] Results are least squares means for treatments.

No significant protein x energy interaction ($P > .72$).

[b] Standard error for protein (n = 18).

Table 5b. Plasma glucose, urea nitrogen and total protein levels cashmere-producing wethers, fed three levels of energy[a].

	Energy Levels of Diets				Probability <	
Parameter	2.00 ME	2.35 ME	2.70 ME	SE[b]	Linear	Quad.
Plasma (mg/dl)						
Glucose	61.83	62.36	61.85	1.09	.96	.83
Urea-N	15.07	15.59	14.54	.83	.36	.41
Total protein	59.65	59.90	62.47	.96	.06	.39

[a] Results are least squares means for treatments.

No significant protein x energy interaction (*P* >.72).

[b] Standard error for energy (n = 12).

Table 6a. Effect of two levels of dietary crude protein on fiber production and characteristics in wethers[a].

	Protein levels of Diets			Probability
Parameter	10% CP	15% CP	SE[b]	$P <$
Fleece weight, g	215.06	226.67	7.30	.27
Guard hair weight, g	125.28	134.33	7.33	.39
Cashmere diameter, µm	16.06	16.92	.29	.05
Cashmere length, mm	32.84	31.47	1.65	.56

[a] Results are least squares means for treatments.

No significant protein x energy interaction ($P > .10$).

[b] Standard error for protein (n = 18).

Table 6b. Effect of three levels of dietary energy on fiber production and characteristics in wethers[a].

	Energy Levels of Diets				Probability <	
Parameter	2.00 ME	2.35 ME	2.70 ME	SE[b]	Linear	Quad.
Fleece weight, g	196.75	238.50	227.33	8.94	.03	.68
Guard hair weight, g	119.05	139.88	130.48	8.98	.46	.15
Cashmere dia., µm	16.05	16.86	16.56	.36	.56	.71
Cashmere length, mm	30.80	33.90	31.80	2.02	.81	.56

[a] Results are least squares means for treatments.

No significant protein x energy interaction (*P* >.10).

[b] Standard error for energy (n = 12).

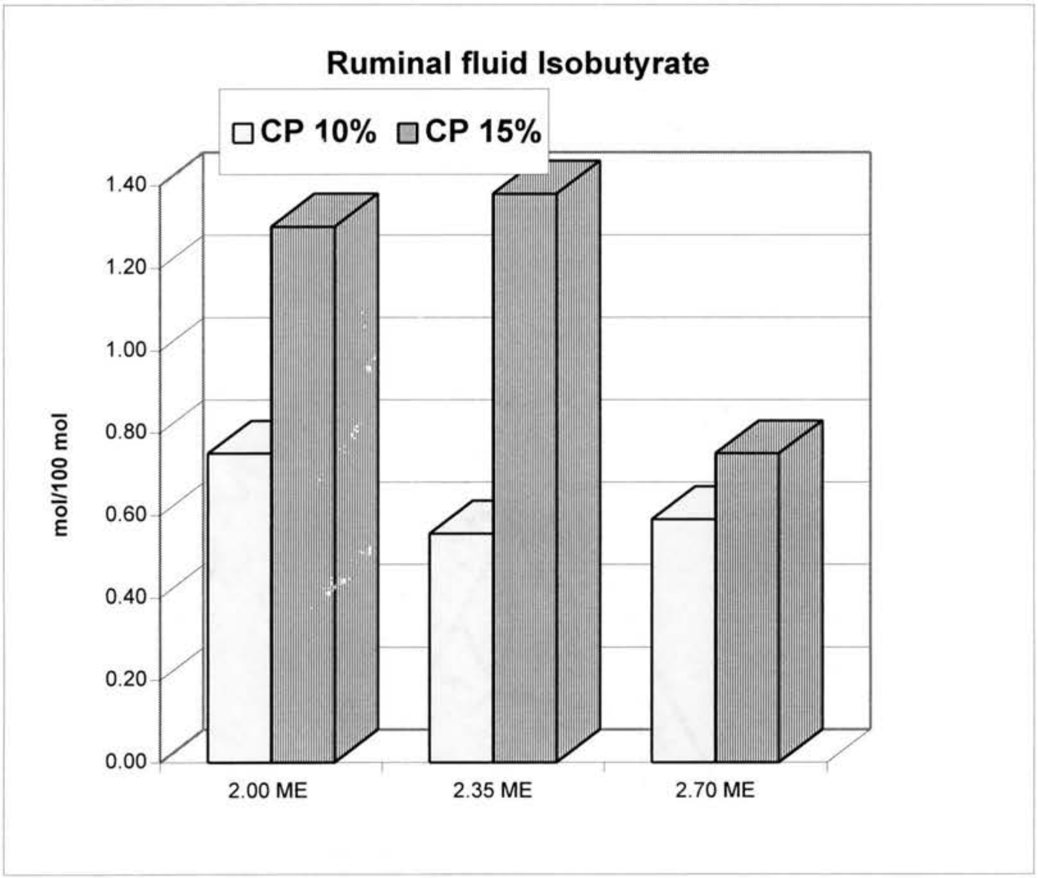

Figure 1. Ruminal fluid isobutyrate (mol /100 mol) of wethers fed two levels of protein and three levels of energy. Data are least squares means. Significant protein x energy interactions ($P < .05$) Standard error = .11 (n = 6).

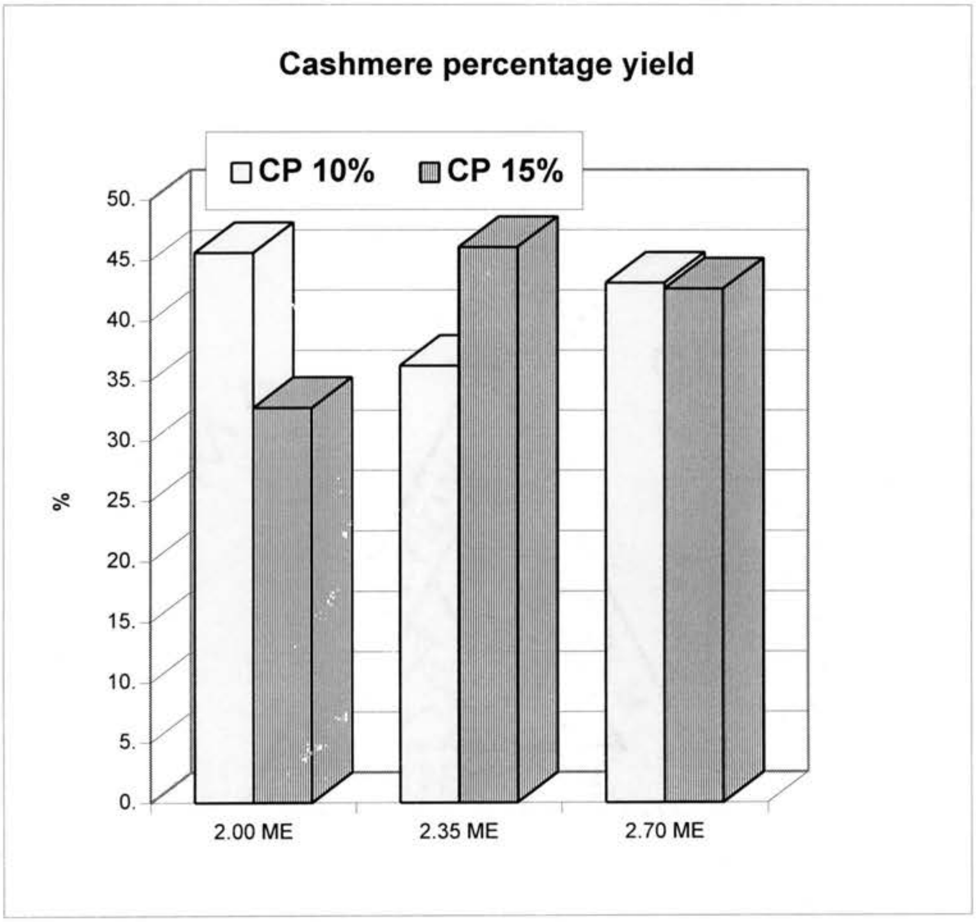

Figure 2. Cashmere percentage of wethers, fed two levels protein and three levels of energy. Data are least squares means. Significant protein x energy interactions ($P<.05$) Standard error = 3.67 (n = 6).

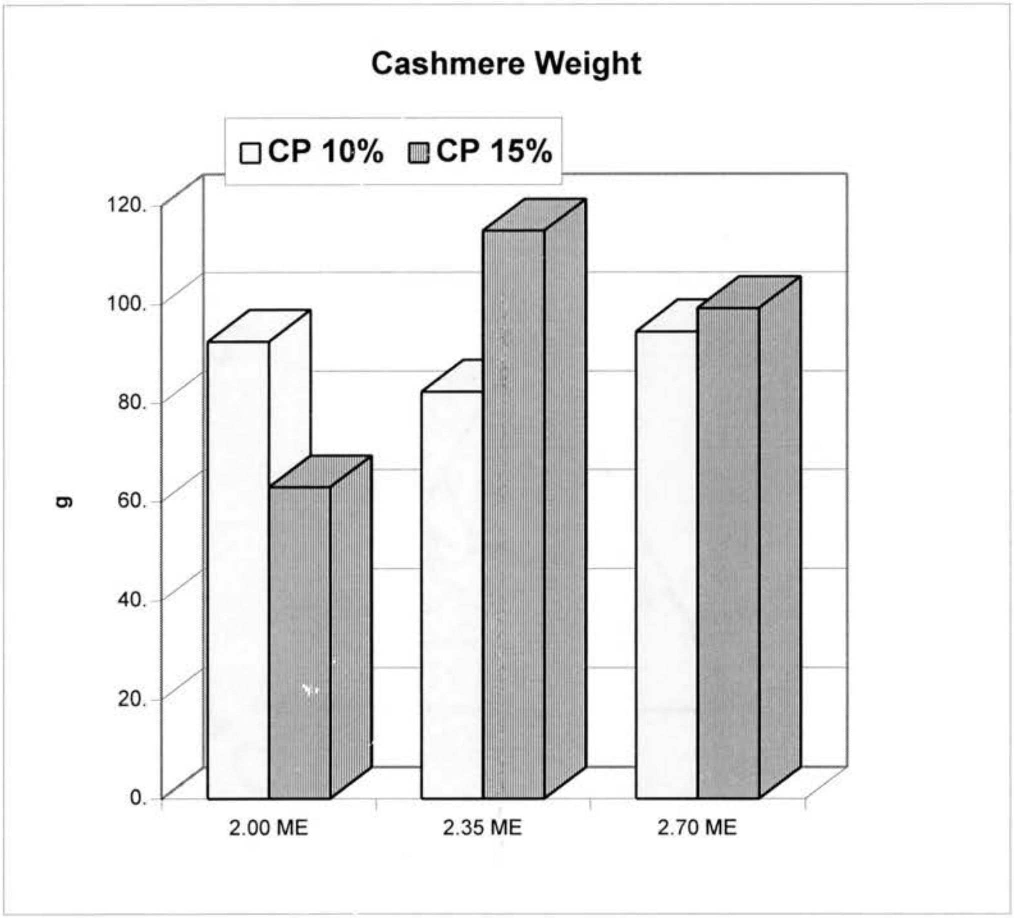

Figure 3. Cashmere weight for wethers, fed two levels protein and three levels of energy. Data are least squares means. Significant protein x energy interactions (*P* <.05). Standard error = 10.19 (n = 6).

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CHAPTER IV

INFLUENCE OF PROTEIN AND ENERGY SUPPLEMENTS ON PREGNANCY, LACTATION, PROGENY GROWTH, AND CASHMERE PRODUCTION BY SPANISH GOATS.

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Abstract

Forty-eight pregnant does and their progeny were used to examine the effects of supplement level and number of fetuses on cashmere production in does and on secondary (S) to primary (P) ratio of skin follicles in progeny. Does were assigned randomly to treatments in a 2 x 2 x 2 factorial arrangement. The factors included were single vs twin fetuses, two concentrations of crude protein (18.6% and 28.5%), and two concentrations of energy (2.2 and 2.8 Mcal of ME/kg). Animals received the supplement at 1% of BW daily and were given free choice access to Bermuda hay. Four of the does bearing twins and three of the does bearing single kids were used to measure milk production and composition. Kids were weaned at 50 d of age and fed a completely mixed grain diet for a additional 50 d. Does bearing twins gained more weight between d 90 and parturition than does bearing single kids (4.7 vs 3.3 kg; $P < .03$). Birth weight of kids born as twins was equal to that of kids born as singles. Gestation length tended to be shorter (147 vs 149 days, $P < .08$) for does fed the lower energy supplement. Does bearing twins had higher blood plasma concentrations of beta-hydroxy butyrate (BHBA; $P < .05$) and non-esterified fatty acids (NEFA; $P < .01$), plasma urea nitrogen was higher ($P < .01$) for does receiving the higher protein supplement. Fiber growth by does was not altered by the number of fetuses although guard hair yield tended to be higher ($P < .07$) for does bearing twins. Daily milk production, estimated from d 15 to d 45 of lactation was 56% greater for does bearing twins (1.313 vs 0.843 kg/d, $P. < .001$). Body weight gain by litters was 71% higher for twins than singles ($P < .001$). Dry matter intake and daily gain during the 50-d post-weaning feeding trial were 10 and 20% greater ($P < .03$; $P < .09$ resp.) for kids born as twins than for kids born as singles. The secondary:primary follicle ratio increased by nearly 60% between d 6 and d 49 but was not influenced by prepartum diet or fetal numbers.

Key words: Gestation; Cashmere goats, Follicle ratio, Supplement, Protein, Energy.

INTRODUCTION

The demand for nutrients by the dam increases as with development of the fetus(es) during gestation (Shelton and Menzies, 1968). Fiber production and strength were reduced when pregnant ewes were fed diets low in calories (Ray and Sidwell, 1964; Shelton and Menzies, 1968). Pregnant ewes produce 5 to 10% less wool than non-pregnant ewes. Rambouillet ewes carrying multiple fetuses produce 30% less wool than ewes bearing a single fetus (Snowder and Shelton, 1986); a similar reduction was reported for Merino sheep (Corbett, 1979). Information on the effect of pregnancy of quantity and quality of cashmere production by goats is not available. The annual amount of cashmere produced per animal averages 155 g. If fiber yield by does is reduced during pregnancy as it in ewes, pregnancy has a dramatic effect on economics of cashmere production.

The NRC (1981) lists nutrient requirement for goats based on BW and stage of gestation or lactation. In addition, nutrient status can affect the strength and diameter of fiber; differences in feed intake of sheep can change wool fiber diameter by up to 400% in sheep (Shelton and Menzies, 1968) and to a lesser extent in goats (Sahlu and Ferenandez, 1989).

The supply of nutrients to the gravid uterus can directly influence umbilical uptake and fetal growth (Bell 1984). A lamb's birth weight is influenced greatly by plane of nutrition, especially for ewes bearing twins; fetal growth retardation in undernourished ewes may have a placental component. Concentrate supplements are recommended for the last two months of gestation. At early stages of gestation, nutritional starvation can cause rejection of the fetus in both sheep and goats. Sheep that are severely undernourished during early and mid gestation have reduced fetal weight (Bell 1984); in late gestation, undernourishment can reduce birth-weight (Robinson et al., 1977). Feeding sufficient nutrients in late pregnancy may reverse this effect, depending on when re-feeding starts. Weight loss by the ewe often is greater than by the fetus indicating that the ewe maintains the fetus at the expense of maternal body reserves. The effect of low maternal protein intake on birth weight is amplified by low energy intake (Slykes and Field 1972). However, effects of specific nutrient limitations on fetal growth are not yet known.

Fiber growth is reduced more when dams bear multiple fetuses than when they bear a single. Decreases in feed intake during pregnancy generally are minor when compared with the reduction in wool growth; this suggests that pregnancy reduces the efficiency of converting nutrients into fiber. The timing and extent of intake reduction indicates that hormones may be involved (Corbett, 1979). Because production level is influenced by nutrient intake, those animals at higher rates of production are more responsive to changes in their nutrient supply. Uterine and mammary tissues generally can compete successfully with skin for nutrients that limit wool growth (Oddy and Annison 1979). Nevertheless, wool growth typically is slower for pregnant ewes during the last two months of gestation than for non-pregnant ewes fed a similar diet during the same time period and increasing feed intake had no effect on wool growth by ewes with multiple fetuses (Oddy 1985). By occupying abdominal space, the growing gravid uterus limits ruminal capacity and reduces forage intake. Mean retention time of particulate matter in the rumen of sheep decreases as gestation progresses (Faichney and White, 1988; Graham and Williams, 1962); this helps to compensate for decreased ruminal capacity and will permit a slight increase in voluntary feed intake. In the liver, pregnant ewes convert an increasing proportion of absorbed propionate to glucose (Steel and Leng, 1973). Through treatment with steroid hormones or other chemicals, the number of ova can be increased; combined with synchronized breeding, this can increase the number of multiple fetuses. Such practices further increase the need for supplementation in late gestation.

Both the activity of the hair-producing follicles and the total follicle population change seasonally; this matches the cyclical nature of fleece production in cashmere goats (Ryder, 1966). Cyclic patterns in hair follicle activity of cashmere goats were documented by Nixon et al. (1991b). Primary and secondary follicle density changes some time after birth (Parry et al. 1993), due primarily to changes in size and BW of the animal. Distinct seasonal differences in follicle maturity and density of Angora goats can explain the differences in composition between summer and winter coats (Ryder, 1970). Histological studies of skin indicate that follicle density is the major factor that controls the fineness and density of the fleece. Methods to prepare skin specimens for follicle examination have been devised; these are different between sheep and goats (Holst et al. 1982).

Fiber production takes precedence over fetal development, especially during periods of nutritional stress (Van Rensgurg 1971). Therefore, animals selected for high rates of fiber production have higher abortion rates. Huston (1980) showed that increasing caloric intake will increased fiber growth by angora kids. Because cashmere, like mohair, is produced from secondary follicles, one would expect a similar response from cashmere-producing goat kids. Norton (1991) examined secondary follicle development in Australian cashmere goats; nutritional status markedly affected follicle development and cashmere production.

Plasma glucose concentrations were consistently higher for non-pregnant than for pregnant sheep despite similar diets and feed intake levels (Oddy and Annison 1979). Glucose concentrations increased in pregnant ewes when higher amounts of energy were fed. Plasma glucose concentration in twin-bearing ewes declined in late pregnancy. If pregnant ewes were able to increase their energy intake to match the increased demands for nutrient imposed by their physiological state, plasma glucose should not decrease. Hence, these ewes apparently were unable to consume a sufficient energy to meet the nutrient requirements of the growing fetuses which occurs concurrently with physical crowding with the rumen for abdominal space. Lower glucose supply to skin and fiber follicles of ewes bearing multiple fetuses may be responsible for lower fiber production by such ewes. When multiple fetuses are present, the challenge of maintaining relatively a high plasma glucose level becomes more difficult.

Nutritional status of cashmere goats prior to the initiation of cashmere growth cycle also may influence fiber quality and quantity (Norton, 1991; Restall et al., 1993; McGregor, 1993). With cashmere goats, both primary and secondary follicles of the fetus develop prenatally. Follicle development can affect the animal's subsequent ability to produce fiber. So if an energy deficit reduces follicle growth by the fetus, it may reduce follicle numbers and hinder subsequent fiber production . Ewes bearing twin are more prone to be nutritionally stressed than ewes bearing single kids. Thereby, twins may differ from singles not only during development but also in their potential for fiber production. The number of follicles is determined during a critical stage of follicle maturation in utero in sheep (Black and Reis, 1979); this also may be true for cashmere goats. Because the effect of supply of various nutrients influencing follicle development by the fetus is unclear, it needs further research.

The objectives of this research were to determine the effect of energy and protein supplementation of pregnant cashmere-producing goats in late gestation on 1) fiber growth in pregnant does, 2) secondary follicle numbers in kids born to cashmere producing goats fed different levels of energy and protein, and 3) ability of the dam and progeny to compensate for changes in nutrient requirements.

Experimental Procedures

Forty-eight mature cashmere-producing Spanish goats (mean BW of 39.9 kg) from the running herd of the E (Kika) de la Garza Institute for Goat Research were used in this study. Does were bred to improved cashmere bucks; breeding dates were recorded. Pregnancy status and number of fetuses were determined by ultrasonography at 45 and 60 d after the last date of mating. At day 60 of gestation, does were assigned to one of eight treatment based on number of fetuses and dietary supplement of protein and energy. Each diet was fed to four does bearing a single fetus and to eight does bearing twin fetuses. Animals were penned by diet groups (4 pens), fed a supplement at 1% of BW, and given free choice access to Bermuda hay. Animals were kept in drylot with shelter, shade, and ad libitum access to water. Feed intake was adjusted every 14 d based on animal weight to maintain intake at 1% of BW. At d 90 of gestation, all does were moved inside a lighted barn to permit feed intake to be measured for individual does and to simplify sample collection. Each does was penned individually in a 1.2-m x 1.5-m pen. Ground Bermuda hay (length 70 mm) and fresh water was available continuously.

The study consisted of a completely randomized design with a factorial arrangement of treatments (2 x 2 x 2). The three factors were single or twin fetuses (the number of fetuses was determined prior to allocation to diets), two percentages of crude protein (18.6 and 28.5% of supplemental DM), and two concentrations of ME in the supplement (2.2 and 2.8 Mcal ME/kg supplement DM). Although the supplement normally was consumed completely within 30 minutes, orts sometimes remained or spillage occurred occasionally; these were measured, recorded, and discarded. Ingredient and nutrient composition of the diets are presented in Tables 1. All nutrient compositions except ME was measured; ME was calculated from mean values for ingredients listed by NRC (1984). Feeds (supplement and hay) were sampled every second week and composited for analysis. Body weights were measured before feeding at 14 d intervals during the trial and at the beginning and end of the study. Two does bearing single fetus aborted between 114 and 125 d of gestation; two other animals gave birth to triplets; data from these four animals were not included in data analyses.

Performance, Lactation and Growth

One week prior to and during the parturition period, does were observed for 14 hours each day. Eighty-five percent of the does had kidded within ten days. Ninety percent of all births (73 of 81) occurred during daylight hours. Immediately after parturition, each kid was tagged and weighed. Performance was evaluated in terms of litter weight, number of live kids born, dam's BW and gestation length. All does were switched to supplement HH (Table 1) on day 3 of lactation; thereafter, each doe was fed this supplement at 1.5% of its BW either in its individual pen or in a group pen of 8 does. Fifteen days after the start of kidding, does and their progeny were re-allocated to their prepartum dietary treatment; for lactation measurements, 16 of the 31 twin-bearing and 12 of the 13 single-bearing does were retained. Kids were separated from does and allowed to suckle for one hour periods at 0800 and 1530 each day, up to 28 d of age and once daily thereafter until weaning at seven weeks of age. All does were individually fed their prepartum supplement at 1.5% of BW once daily and given free access to ground Bermuda hay and fresh water. Milk intake of each kid was estimated from the difference in weight before vs after suckling on d 15 through 45 of lactation. Kids had free choice access to water and were provided access to grain starting at four weeks of age; grain consumption was negligible. On day 28 of lactation, milk samples were obtained from each doe prior to the morning suckling. Milk samples were analyzed for fat, protein (N x 6.38), lactose, and SNF contents by infrared spectrophotometer (Multispec 2, Multispec, Wheldrake, York, England) at the E (Kika) de la Garza Institute for Goat Research DHIA Laboratory.

Kids were weaned at 50 d of age and fed the completely mixed diet HL (Table 1) for 50 d. Each kids was kept in its individual pen and offered feed and water daily; orts were removed, weighed, and sampled twice each week. Kids were weighed every 14th day and at the end of the feeding period. Blood samples from kids were taken at 5, 21, 50 and 100 d of age using the procedures outlined for does. At the end of the trial, all kids were sheared completely and fleece weight and fiber characteristics were measured as described below.

Skin histology

Skin biopsies were taken from the left mid-side of each kid at 6 and 21 days of age. Samples were obtained by using an 8-mm trephine; samples were stored in 10% formalin. Similar skin biopsies were taken at 49 and 100 days of age for 44 of the 72 kids. Histological measurement techniques were used to determine the secondary:primary follicle ratio. Skin biopsies were wax embedded, sectioned at 5 or 8 microns, and stained with haematoxylin and eosin (modified from Auber, 1952 and Nixon, 1993) at the Oklahoma State University Disease and Diagnostic laboratory. Counts of the follicle population were made at 500 x on a projection microscope. Follicle identification and area counted followed standard methods (Holst et al., 1982; Parry et al., 1992).

Measurement and Analysis

Samples of feed, concentrate, and hay were dried at 65°C overnight, allowed to air equilibrate, and ground in a Wiley mill through 1 mm screen. Dry matter was determined by drying a 1 g sample overnight at 105^{O}C. Ground feed samples were analyzed for N (Technicon, Tarrytown, NY). Energy content (GE) was measured using a Parr adiabatic oxygen bomb calorimeter (Parr Instrument, Moline, IL). ADF and NDF were measured by the method of Goering and Van Soest (1970).

Blood was sampled prior to feeding on 100, 115, 130, 145 d of gestation and on the day of parturition. Blood was collected via jugular venipuncture into 10 mL vacuum tubes (Becton Dickenson Vacutainer Systems, Rutherford, NJ) containing either K_3EDTA or potassium oxalate with sodium fluoride (a glycolysis inhibitor). Blood sample tubes were immediately chilled in an ice bath, transported to the laboratory, and centrifuged at 1500 x g and 4 ^{O}C for 20 min. Aliquots of plasma were stored at -20 ^{O}C until analyzed. Beta-hydroxy butyrate in plasma was determined using the GDS Stat-site Meter with appropriate GDS Test Cards and controls (GDS Diagnostics Division of GDS Technology, Inc Elkhart, IN) . Concentrations of urea-N, glucose, and total protein in blood plasma were assayed colorimetrically using a Technicon Autoanalyzer II System (Technicon Instrument, Tarrytown, NY). Non-esterified fatty acid concentrations in plasma were analyzed using a commercially available kit (Wako Chemicals USA, Richmond, VA) as modified by McCutchcheon and Bauman (1986).

Ruminal samples were obtained via stomach tube 4 h postprandially on d 115 and 130 of gestation. This sample was collected using a tube equipped with a strainer which was inserted into the rumen; mild suction was applied using a 60 mL syringe. The first 20-30 mL of ruminal fluid was discarded to reduce contamination by saliva. Thereafter, 20 mL was collected for analysis. Ruminal fluid pH was determined using a pH meter (SA-

720, Orion Research, Boston, MA) immediately after sampling. To each 4 mL of ruminal fluid, 1 mL of 25% (wt/wt) metaphosphoric acid was added; this mixture was stored at -20 $^{\circ}$C until analyzed for VFA using a gas chromatograph (Hewlett Packard CO, Avondale, PA). Total ruminal ammonia N was analyzed using the method of Broderick and Kang (1980).

Goats were sheared on d 100 of gestation. Total fleece weight was recorded and a representative fleece sample was obtained. These samples were used to determine the cashmere, guard hair, and total ‘corrected‘ fleece yield after three passes through a Shirley Analyzer (ASTM 1990). For each animal, two samples (1.00 g) drawn randomly were separated manually into cashmere and guard hair. Both cashmere and guard hair length were measured to the nearest 0.5 mm. Diameters of 100 fibers from each cashmere sample were measured under projection microscope at a magnification of 500 x (ASTM 1988).

Statistical analyses

Statistical analyses were conducted according to GLM procedure of SAS (1985). Data were analyzed as a 2 x 2 x2 factorial arrangement of treatments in a completely randomized design; least squares means are reported to adjust for an unequal number of observations per cell. The model included effects of number of fetuses, protein, energy, number of fetuses x protein, number of fetuses x energy, protein x energy, number of fetuses x protein x energy, and the residual error. Main effects and interactions were tested using the residual error mean square. Each doe was considered to be an experimental unit. For measurements of growth of kids, each kid was considered to be an experimental unit. Exact probability values are presented in all tables. When interactions were detected at *P* < 0.05, individual means will be presented graphically. When interactions were not significant, main effects were tested and least squares treatment means are presented.

Results and Discussion

Does carrying twins fetuses consumed more feed during the study than does carrying single fetus (*P* < .03) simply because they gained more BW and feed intake was proportional to BW. Does bearing twins gained more weight (Figure 1) than does bearing single fetuses. The NRC (1981) did not differentiate energy requirements for pregnant does carrying single or twin kids. However, a 20% increase in energy intake during the last two months of gestation is recommended for sheep bearing multiple fetuses (McDonald et al., 1973). In our trial, the amount of supplement fed was only 10% greater for does bearing twins than for does bearing a single fetus.

Body weight at d 90 of gestation was not different (*P* > .10) for does bearing twins or altered by composition of the supplement (Tables 2a, 2b, and 2c). However at parturition BW was significantly greater (46.1 vs 41.7, *P* = .03) for does bearing twins than for does bearing single kids (Table 2a). Litter weight followed a similar pattern (*P* < .001), being virtually doubled for twins (5.5 vs 2.7 kg). This difference, 2.7 kg, was less than the difference in BW of does at parturition (4.5 kg); slightly more than half of the additional weight could be attributed directly to the weight of the extra kid.

For weight gain from day 90 of gestation until parturition, a significant interaction between number of fetuses and supplement composition was detected ($P < .06$) as shown in Figure 1. Although does bearing twins gained similar amounts of weight during this period, does bearing single fetuses tended to gain less when fed the lower ME supplement or the higher protein supplement. No explanation for this interaction is apparent.

Birth weights of individual kids were not affected by treatment (Table 2a); apparently, nutrient supply was adequate for full development of twins. Although gestation length was not changed significantly by twinning or supplement composition, it tended to be shorter (147 vs 149 d, $P < .08$) for does fed the lower ME supplement. Days on trial were not affected.

Ruminal measurements were not different between does bearing twins vs does bearing a single fetus. Compared with those fed the lower ME supplement, does fed the higher ME supplement had lower total VFA concentrations in the rumen ($P < .01$) and an increased molar proportion of butyrate ($P < .01$). The supplement with the higher protein content increased ($P < .01$) butyrate and valerate but decreased ($P < .01$) the acetate proportion of VFA in the rumen. For isobutyrate as a proportion of ruminal VFA, an interaction between protein and energy content of the supplement was detected ($P < .06$) as illustrated in Figure 2. The proportion tended to be increased by added protein, as might be expected because isobutyrate is derived from the amino acid valine, but at the lower protein level, the lower ME supplement resulted in a lower isobutryate proportion than the higher ME supplement did. The higher butyrate proportion with more supplemental protein and energy might be related to intake of hay; higher protein intake often stimulates greater forage intake. However, the decrease in the proportion of acetate and in the acetate:propionate ratio with added protein are opposite the directions expected from higher intake of forage.

Plasma metabolite values are presented in Tables 4a, 4b, and 4c. Both BHBA ($P < .04$) and NEFA ($P < .01$) were higher in plasma from does bearing twins than from does bearing single fetuses. In late pregnancy, ruminants often exhibit increased blood concentrations of ketone bodies; such an elevation presumably reflects an inadequate supply of absorbed energy or glucose (Pethick and Lindsay, 1982; Chandler et al., 1985). Both plasma BHBA and NEFA were lower ($P < .05$) with higher energy intake as might be expected. Indeed, sheep producers in Scotland routinely increase the amount of supplement they feed to ewes whenever BHBA concentrations are elevated. No significant differences in BHBA or NEFA were detected with the different levels of dietary protein supplementation. Sahlu et al. (1995) found no change in plasma BHBA and NEFA with levels of dietary crude protein or energy, but in their study plasma BHBA concentrations were much higher (.432 vs .310 mM) and NEFA were lower (285 vs 486 meq/L) than in this study. These differences in plasma concentrations may be attributed to breed; they used dairy goats.

Non-esterified fatty acids are released from body fat stores which are mobilized to meet a shortage of dietary energy; BHBA, one of the ketone bodies, is released from the liver when fatty acids from depot fat is mobilized faster than it can be oxidized by the liver, a condition often associated with a shortage of glucose. Both can be oxidized by skeletal muscle and the pregnant uterus (Pethick and Lindsay, 1982; Chandler et al., 1985). Circulating concentrations of NEFA often are elevated in late-pregnant versus non-pregnant ewes (Pethick et al., 1983; Bell, 1993). Therefore, a higher concentration of NEFA in does bearing twins in late gestation is not surprising.

Higher protein intake increased plasma urea nitrogen concentrations ($P < .01$) reflecting metabolism of the protein as a source of energy. Similar results were reported by Sahlu et al. (1995) with goats and by Preston et al. (1965) with lambs. No other plasma metabolites were altered by number of fetuses, or protein or energy intake. Plasma glucose was not affected by protein levels. The correlation between NEFA and BHBA concentrations were positive ($r = .57$;$P < .001$)

Does were sheared on d 100 of gestation; fiber production and characteristics were measured. Fiber growth was not changed with number of fetuses (Table 5a) although for guard hair, does bearing twins tended to have more ($P = .07$) guard hair. Does were sheared in February which is toward the end of the cashmere growing cycle; therefore differences due to nutrition would be expected to be minimal. No response in fiber production or fiber characteristics due to energy intake were detected (Table 5b). Although protein intake did not affect total fleece, guard hair, or cashmere diameter (Table 5c), cashmere length, percentage yield and total cashmere weight all tended to be lower ($P < 10$) with the higher protein supplement. Length was 10% less while yield and weight both were 15% lower with the higher protein supplement.

Tables 6a, 6b and 6c show milk production and composition. Milk production averaged across the 10 measurements from d 15 to d 45 of lactation was 56% higher for does bearing twins than for does bearing a single fetus (1.31 vs .84 kg/d, $P. < .001$). Except for solids-non-fat percentage, which was lower for does bearing twins, milk composition was not different between does bearing twins and does bearing a single fetus; this matches other results (Sahlu et al., 1995). The percentage of fat, only 1.34%, was considerably lower than in most reports. This may be due to the sampling method; only a strip sample was taken at the start of a suckling period and Lakshmanan et al. (1958) has shown that fat content of milk increases from the first to the last milk obtained within a single milking. This change during milking is not because fat is floating on top of milk within the mammary gland, but is due to later release of fat from the mammary cells. Milk protein, milk lactose, milk solid-non-fat and total milk solid were comparable to compositions reported by others. Significant energy x protein interactions were observed for percentage milk protein (Figure 3, $P < .05$), milk solids-non-fat (Figure 4, $P < .05$) and total solid (Figure 5, $P > .06$). All three exhibited similar patterns, being increased by adding protein with the lower ME diet but decreased by adding protein to the higher ME diet. Effects of prepartum diet on milk production have been reported for sheep (Treacher, 1970) and dairy goats (Sahlu et al., 1995). Generally, milk production has been increased by higher prepartum CP and energy concentrations. Ewes with twins produced more milk early in lactation has been higher for those fed high (15%) CP diets prepartum (Treacher, 1970). Does consuming higher concentrations of prepartum energy had higher peak milk production (Sahlu et al., 1995).

The higher milk production by does bearing twins than does bearing a single fetus was associated with greater postpartum weight loss from parturition to 21 d of lactation by the does bearing twins (8.38 vs 5.25 kg, $P < .05$). Does in all dietary treatment groups gained weight and presumably were fed above their maintenance requirement; even after parturition, BW remained greater ($P < .03$) for does bearing twins than does bearing a single fetus (46.11 vs 41.66 kg, Table 2a). The greater weight gain of ewes can be attributed to their increased weight which resulted in an increased amount of supplement being fed during both gestation and lactation. Glucose production rate increases with both stage of pregnancy and litter size (Wilson et al., 1983). Rate of whole-body glucose production is greater in pregnant than non-pregnant sheep and conversion of ruminal propionate to glucose in the liver is higher for pregnant ewes (Steel and Leng, 1973). However, the ability of the fetus to take advantage of surplus maternal nutrients may be limited by capacity for nutrient transport across the placenta in late gestation (Bell 1993).

Greater intake of supplement contributed to higher milk production and postpartum body condition of does bearing twins. For the first three weeks of lactation, milk production depends primarily on body reserves. The fact that both does bearing a single fetus and does bearing twins had similar BW before and after gestation reflect the ability of animals to adapt to a given level of production. Although milk production was estimated from weight change of suckling kids and might not reflect true milk production potential, results closely mirror results from range-rearing situations. Similar results were noted in a comparison of beef cows rearing single versus twin calves; milk production was 42% greater for cows nursing twins (Wyatt et al., 1975). Nutritional needs in late pregnancy can greatly affect performance of does and kids (Bajhau and Kennedy, 1990). They fed goats in late pregnancy and during lactation on pastures to lose from 13 to 21% of BW (low) or to maintain BW (high). Milk production by goats in the low group was comparable to those in the high group; this means that more energy reserves must have been mobilized by the group losing weight. The persistence of milk yield in spite of weight loss in sheep and goats has been attributed to a high efficiency for utilization of labile protein reserves to maintain milk production in early lactation (Gibb and Treacher, 1980; Cowan et al., 1980).

Body weights of the litter were greater for the twins than single kids at birth ($P <$ .001). Weight gain was 71% greater for twin than single litters between d 12 to d 50 (186 vs 109 g/d, $P < .001$). The ratio of milk intake to gain was not different between single than twin litters; therefore, the increased weight gain can be attributed primarily to greater rate of milk production discussed earlier (Table 6a). Concentrations of protein and energy in prepartum supplements fed to does did not alter either milk production or rate of weight gain by kids (Tables 7b and 7c).

Twinning and prepartum energy and protein intake might have residual effects on growth and production of kids. These were examined during a 50 d post-weaning growth study (50 to 100 d old). Kids were given ad libitum access to an 18.6% crude protein ration (Table 1, HL). Table 8a shows BW of kids during this period. On d 50, kids born as singles tended to be slightly (9%) heavier (8.31 vs 7.63; $P > .16$) than kids born as twins. However, subsequent daily gain tended to be greater (20%) for kids born as twins than as singles (125.6 vs 104.6; $P < .09$). Dry matter intake also tended to be greater

(10%; 333 vs 367 g/d) for kids born as twins than those born singles. Dry matter intake was greater as a % of BW ($P < .03$) for kids born as twins. These greater feed intake by kids born as twins may be inversely related to the milk consumption pre-weaning. Restricting access to milk has been shown to enhance solid feed consumption by goat kids (Lu et al., 1988). Increased DMI by twins perhaps is reflects of lower energy density or body energy reserves compared with single kids. Development and optimum function of the digestive system early post-weaning may have been influenced by the level of milk consumed by young ruminants (Hamada et al., 1976). Prepartum supplement compositions did not impact BW and DMI of the kids ($P > .10$, Table 8b and 8c). However, for BW at d 100 and feed efficiency, interactions between number of fetuses and level of prepartum energy was detected (Figures 7 and 8). Body weight and feed efficiency were better for single kids when their dams had been fed the lower energy diet. For twins, BW and feed efficiency were best when dams had been fed the higher energy diet. Prepartum protein intake did not influence BW or gain:feed ratio for the kids (Table 8c).

Blood metabolites of weaned kids at 50 and 100 d of age are presented in Tables 9a, 9b, and 9c. For plasma glucose of kids at weaning (50 d of age), an interaction ($P < .03$) between number of fetuses, prepartum energy and prepartum protein concentration was detected (Figure 9). Plasma glucose tended to be higher for twin kids when their dams had been fed the lower protein or higher energy prepartum diets; in contrast, response by single kids from does fed higher protein prepartum diet tended to be less than singles from does fed the lower protein diet. Kids from does fed the highest energy and highest protein prepartum diet had the lowest blood glucose concentration. This group also had the slowest gains and lighter weights for kids at the end of the 50 d growth study. Plasma glucose samples taken at 100 d were correlated positively ($r = .33$; $P < .03$) with cashmere fiber diameter but negatively correlated ($r = -31$; $P < .04$) with S:P ratio of kid fleece. In contrast to plasma glucose, plasma urea concentration at 50 d was correlated with the above two measurements in the opposite direction ($r = -40$; $P < .01$ and $r = .34$; $P < .03$) for fiber diameter and S:P ratio. Plasma urea concentration at 100 d was correlated positively ($r = .30$; $P < .05$) with weight gain. Among the other blood metabolites, plasma protein on d 50 differed ($P < .06$), being 11% higher for kids born as twins than kids born as singles (65.56 vs 58.88 g/L). Plasma glucose on day 100 tended to be lower ($P = .10$) for kids whose dams had been fed the lower protein (98.8 vs 93.6 mg/dl).

Fiber production, characteristics and follicle ratios are shown in Tables 10a, 10b and 10c. No differences were detected in the ratio of secondary:primary follicles at 6, 21 or 49 days of age and no differences were detected between kids born alone versus kids born as twins. Similar results have been reported for Australian cashmere-producing goats (Henderson and Sabine, 1991). The increases in the secondary:primary follicle ratio from 4.1 on day six to 6.1 on day 21 and 6.3 on day 49 day closely matches the 4.8 ratio reported at two weeks and 6.6 at 20 weeks of age for Australian cashmere-producing goats (Henderson and Sabine, 1991). The secondary:primary follicle ratio ranged from 4.7 to 6.6 for mature goats in a study by Nixon et al. (1991a) but did not change with maturation (24 vs 42 months of age). Parry et al. (1992) reported that the ratio increased from 8.3 at birth to 10.5 at six months in Angora goats. Also, gender (or weight) influenced the ratio (Parry et al., 1992). In this study, prepartum diet composition did not alter the follicle ratio (Tables 10b and 10c). However, for the ratio of fiber follicles measured on d 100, interactions of number of fetuses x energy x protein were detected (Figure 10); the ratio was unusually high for single birth kids whose dams had been fed low energy and low protein during gestation.

Fiber growth parameters did not differ between kids born as singles vs twins (Table 10a). Prepartum energy also had no effect on fiber growth (Table 10b). However, kids from dams fed higher protein during gestation had 14% smaller cashmere diameter ($P < .02$); they also tended to have a higher ($P < .08$) secondary:primary skin follicle ratio on d 21 of age. The finer diameter was not expected because samples were taken at a time of the year which is early in the cashmere growth cycle. This may be associated with the 14% lower total cashmere yield for this group of kids.

Implications

Pregnant cashmere does fed supplement at one percent of BW and given access to hay consumed sufficient energy and protein for developing single or twin fetuses. However, elevated blood free fatty acids and BHBA for does bearing twins indicated that those does were mobilizing their energy reserves more extensively. Does bearing twin fetuses gained more weight late in gestation than does bearing a single fetus; they also produced 56% more milk and lost 60% more weight during lactation. Birth weights of single and twin kids were virtually equal. Twin kids had greater feed intakes post-weaning than kids raised as singles. Cashmere production by does and kids was not altered by the levels of protein and energy in the prepartum supplement provided. The S:P ratio of fiber follicles was not different between kids born as singles versus twins and not altered by the concentrations of protein and energy in the dam's prepartum supplement.

Table 1. Composition of experimental diets[a]

	Diet[b]			
Item	HH	HL	LH	LL
Ingredient				
Ground corn	43.70	57.49	_	19.66
Rolled oats	_	11.37	_	_
Soybean meal	53.41	28.11	45.05	19.22
Alfalfa meal	_	_	51.48	57.66
Limestone	.99	1.04	1.19	1.19
Dicalcium phosphate	.35	.37	.42	.42
Trace mineral salt[c]	.75	.78	.90	.89
Vitamin ADE premix[d]	.80	.84	.96	.96
Nutrient composition[e]				
DM[f], %	89.43	89.50	91.50	90.95
CP, %	28.24	18.60	28.70	18.65
ADF, %	4.60	4.95	20.00	19.25
NDF, %	19.63	16.25	32.15	33.70
Ash, %	6.47	5.40	10.80	9.50
ME, Mcal/kg	2.82	2.81	2.29	2.20
GE, Mcal/kg	3.95	3.81	3.93	4.00

[a] DM basis.

[b] First letter in each diet name designates energy level; second letter designates protein level: H, high; L, low.

[c] Contained (percentage): NaCl, 95.5 - 98.5; Mn,> .24; Fe, > .24; Mg, > .05; Cu, > .032; Co, > .011; I, > .007; Zn, > .005.

[d] Contained 2,200 IU of vitamin A; 1,200 IU of vitamin D3 and 2.2 IU of vitamin E/g.

[e] ME was calculated from feed composition tables (NRC, 1981).

[f] DM expressed on an as-fed basis.

Table 2a. Effect of number of fetuses on gestation length, days on trial, supplement intake, and body weight of does.

	Number of Fetuses			Probability
Item	Single	Twin	SE	P <
Gestation length, d	147.98	147.56	.91	.70
Days on trial	63.81	63.71	1.57	.99
Intake of supplement, g/d	387.10	427.60	14.98	.03
Body Weight				
90 d of Gestation, kg	38.36	41.36	1.47	.10
Parturition, kg	41.66	46.11	1.63	.03
Litter weight, kg	2.75	5.47	.14	.0001
Kid birth weight, kg	2.75	2.74	.08	.74

Table 2b. Effect of energy content of supplement on gestation length, days on trial, supplement intake, and body weights of does

	Energy levels of Supplement			Probability
Item	High	Low	SE	P<
Gestation length, d	148.66	146.88	.78	.08
Days on trial	64.97	62.56	1.35	.45
Intake of supplement, g/d	410.32	404.38	12.95	.84
Body Weight				
90 d of Gestation, kg	40.31	39.42	1.26	.63
Parturition, kg	44.28	43.48	1.40	.63
Litter weight, kg	4.18	4.05	.12	.32
Kid birth weight, kg	2.80	2.69	.07	.23

Table 2c. Effect of protein content of supplement on gestation length, days on trial, supplement intake, and body weight of does.

	Protein levels of Supplement			Probability
Item	High	Low	SE	P <
Gestation length, d	148.17	147.36	.77	.69
Days on trial	65.19	62.33	1.33	.09
Intake of supplement g/d	410.40	404.30	12.73	.87
Body Weight				
90 d of Gestation, kg	40.35	39.37	1.25	.88
Parturition, kg	44.26	43.51	1.39	.94
Litter weight, kg	4.13	4.10	.12	.81
Kid birth weight, kg	2.75	2.74	.06	.85

Table 3a. Effect of number of fetuses on ruminal pH, VFA and A:P ratio, of does

	Number of Fetuses			Probability
Item	Single	Twin	SE	*P* <
Ruminal pH	5.71	5.75	.05	.49
VFA, mM	90.21	83.57	3.83	.22
Acetate, mol/100 mol	72.03	72.07	.73	.90
Propionate, mol/100 mol	18.17	18.61	.40	.30
Isobutyrate, mol/100 mol	.54	.53	.04	1.00
Butyrate, mol/100 mol	8.02	7.40	.35	.16
Isovalerate, mol/100 mol	.59	.55	.08	.91
Valerate, mol/100 mol	.66	.84	.12	.19
A:P ratio	4.07	3.93	.11	.21

Table 3b. Effect of energy content of supplement on ruminal pH, VFA and A:P ratio of does

	Energy levels of Supplement			Probability
Item	High	Low	SE	*P* <
Ruminal pH	5.76	5.70	.04	.58
VFA, mM	81.20	92.57	3.18	.01
Acetate, mol/100 mol	71.57	72.53	.63	.47
Propionate, mol/100 mol	18.08	18.70	.34	.12
Butyrate, mol/100 mol	8.35	7.07	.30	.01
Isovalerate, mol/100 mol	.68	.46	.07	.02
Valerate, mol/100 mol	.75	.76	.11	.63
A:P ratio	4.05	3.95	.10	.30

Table 3c. Effect of protein content of supplement on ruminal pH, VFA and A:P ratio of does

	Protein levels of Supplement			Probability
Item	High	Low	SE	*P* <
Ruminal pH	5.76	5.70	.04	.24
VFA, mM	88.68	85.09	3.26	.75
Acetate, mol/100 mol	70.80	73.29	.62	.002
Propionate, mol/100 mol	18.78	18.00	.34	.08
Butyrate, mol/100 mol	8.12	7.30	.29	.01
Isovalerate, mol/100 mol	.85	.28	.06	.0001
Valerate, mol/100 mol	.81	.69	.10	.74
A:P ratio	3.80	4.19	.10	.005

Table 4a. Effect of number of fetuses on blood metabolites of pregnant cashmere-producing does

	Number of Fetuses			Probability
Item	Single	Twin	SE	*P* <
Glucose, mg/dl	60.28	59.21	4.03	.93
βHBH, mM	.29	.33	.02	.04
NEFA, meq/L	433.78	537.86	28.07	.00
Total protein, g/L	92.90	99.04	7.87	.52
Urea-N, mg/dl	22.77	24.83	1.15	.23

Table 4b. Effect of energy content of supplement on blood metabolites of pregnant does

	Energy levels of Supplement			Probability
Item	High	Low	SE	*P* <
Glucose, mg/dl	63.42	56.07	3.43	.23
βHBH, mM	.29	.33	.02	.04
NEFA, meq/L	460.97	510.67	24.14	.04
Total protein, g/L	100.32	91.61	6.77	.43
Urea-N, mg/dl	24.34	23.26	.98	.20

Table 4c. Effect of protein content of supplement on blood metabolites of pregnant does

	Protein levels of Supplement			Probability
Item	High	Low	SE	*P* <
Glucose, mg/dl	62.83	56.66	3.42	.41
βHBH, mM	.31	.31	.02	.67
NEFA, meq/L	483.70	487.95	24.60	.99
Total protein, g/L	95.14	96.79	6.90	.70
Urea-N, mg/dl	25.84	21.75	.97	.01

Table 5a. Effect of number of fetuses on fiber production by pregnant does

	Number of Fetuses			Probability
Item	Single	Twin	SE	*P* <
Total fleece, g	377.05	397.10	21.29	.43
Guard hair, g	230.65	244.57	20.89	.07
Cashmere, g	146.40	152.53	16.11	.92
Cashmere yield, %	39.50	38.49	3.91	.65
Cashmere diameter, μm	18.22	17.96	.33	.45
Cashmere length, mm	58.89	62.96	3.47	.37

Table 5b. Effect of energy content of supplement on fiber production in pregnant does

	Energy levels of Supplement			Probability
Item	High	Low	SE	*P* <
Total fleece, g	401.98	372.17	18.41	.13
Guard hair, g	246.75	228.47	18.07	.32
Cashmere, g	155.23	143.70	13.93	.47
Cashmere yield, %	40.02	37.97	3.38	.73
Cashmere diameter, µm	18.15	18.03	.29	.80
Cashmere length, mm	60.77	61.08	2.97	.95

Table 5c. Effect of protein content of supplement on fiber production in pregnant does

	Protein levels of Supplement			Probability
Item	High	Low	SE	*P* <
Total fleece, g	386.31	387.84	18.10	.84
Guard hair, g	249.20	226.02	17.76	.26
Cashmere, g	137.11	161.82	13.69	.09
Cashmere yield, %	35.77	42.23	3.32	.07
Cashmere diameter, μm	17.91	18.27	.28	.18
Cashmere length, mm	57.86	63.99	2.95	.06

Table 6a. Effect of number of fetuses on milk production and composition for cashmere-producing does

	Number of Fetuses			Probability
Item	Single	Twin	SE	*P* <
Milk production				
Yield, kg/d	.84	1.31	.07	.0001
Fat, g/d	11.55	17.00	1.89	.04
Lactose, g/d	43.82	66.79	3.58	.0001
Protein, g/d	39.03	58.41	2.93	.0001
Composition, %				
Fat	1.38	1.30	.16	.66
Protein	4.63	4.48	.10	.24
Lactose	5.19	5.09	.05	.08
Solids-non-fat	10.28	10.04	.09	.03
Total solids	11.67	11.34	.18	.16

Table 6b. Effect of energy content of supplement on milk production and composition for cashmere-producing does

	Energy levels of Supplement			Probability
Item	High	Low	SE	*P* <
Milk production				
Yield, kg/d	1.08	1.07	.07	.70
Fat, g/d	15.96	12.59	1.78	.13
Lactose, g/d	55.47	55.14	3.38	.75
Protein, g/d	48.08	49.36	2.76	.90
Composition, %				
Fat	1.51	1.17	.15	.10
Lactose	5.13	5.15	.04	.74

Table 6c. Effect of protein content of supplement on milk production and composition for cashmere-producing does

	Protein levels of Supplement			Probability
Item	High	Low	SE	*P* <
Milk production				
Yield, kg/d	1.07	1.09	.07	.97
Fat, g/d	13.89	14.89	1.78	.96
Lactose, g/d	55.22	55.40	3.38	.85
Protein, g/d	48.40	49.04	2.76	.97
Composition, %				
Fat	1.28	1.40	.15	.71
Lactose	5.17	5.11	.04	.23

Table 7a. Effect of number of fetuses on growth of kids from does rearing single or twin kids

	Number of Fetuses			Probability
Item	Single	Twin	SE	*P* <
Birth wt. / kid, kg	2.75	2.74	.08	.74
Litter wt. at 12 days, kg	3.81	7.58	.44	.0001
Weaning wt /Litter (50 d), kg	7.61	14.10	.74	.0001
BW gain 12 to 50 d, g/d	108.78	186.28	11.84	.0001
Milk/Gain	7.95	7.18	.36	.15
BW 21 d post-partum, kg	36.41	37.73	1.33	.47
BW loss (lactation 21 d), kg	5.25	8.38	.93	.01

Table 7b. Effect of energy content of supplement on growth of kids from does rearing single or twin kids

	Energy levels of Supplement			Probability
Item	High	Low	SE	*P* <
Birth wt. / kid, kg	2.80	2.69	.07	.23
Litter wt. at 12 days, kg	5.75	5.64	.42	.76
Weaning wt/Litter (50 d), kg	11.03	10.69	.70	.54
BW gain 12 to 50 d, g/d	150.71	144.35	11.16	.44
Milk/Gain	7.53	7.59	.34	.64
BW 21 d post-partum, kg	37.94	36.19	1.14	.20
BW loss (lactation 21 d), kg	6.34	7.29	.80	.32

Table 7c. Effects of protein content of supplement on growth of kids from does, rearing single or twin kids

	Protein levels of Supplement			Probability
Item	High	Low	SE	*P* <
Birth wt. / kid, kg	2.75	2.74	.06	.85
Litter wt. at 12 days, kg	5.82	5.57	.42	.65
Weaning wt /Litter (50 d), kg	10.83	10.88	.70	.96
BW gain 12 to 50 d, g/d	143.21	151.85	11.16	.70
Milk/Gain	7.80	7.33	.34	.37
BW 21 d post-partum, kg	37.63	36.51	1.13	.85
BW loss (lactation 21 d), kg	6.63	7.00	.79	.89

Table 8a. Effect of number of fetuses on body weight and intake of kids

	Number of Fetuses			Probability
Item	Single	Twin	SE	$P <$
Initial BW (50d), kg	8.31	7.63	.41	.16
BW gain, kg	5.23	6.28	.51	.09
BW gain, g/d	104.58	125.59	10.26	.09
DMI, g/d	332.90	367.33	17.26	.11
DMI, % BW	2.46	2.65	.07	.03
DMI, g/kg $BW^{.75}$	47.12	50.94	1.17	.01

Table 8b. Effects of energy content of supplement on body weight and intake of kids

	Energy levels of Supplement			Probability
Item	High	Low	SE	$P <$
Initial BW (50d), kg	7.93	8.01	.34	.49
BW gain, kg	5.54	5.97	.43	.91
BW gain, g/d	110.76	119.41	8.51	.70
DMI, g/d	345.17	355.06	14.45	.71
DMI, % BW	2.55	2.56	.06	.43
DMI, g/kg $BW^{.75}$	48.74	49.31	.98	.62

Table 8c. Effect of protein content of supplement on body weight and intake of kids

	Protein levels of Supplement			Probability
Item	High	Low	SE	*P* <
Initial BW (50d), kg	7.84	8.10	.34	.89
Final BW (100d), kg	13.50	13.95	.66	.67
BW gain, kg	5.66	5.85	.43	.58
BW gain, g/d	113.17	116.99	8.51	.58
DMI, g/d	353.85	346.38	14.45	.69
DMI, % BW	2.62	2.50	.06	.18
DMI, g/kg $BW^{.75}$	49.98	48.08	.98	.19
Gain/feed, g/kg	321.05	334.65	11.36	.18

Table 9a. Effect of birth status on plasma glucose, urea and total protein of kids

	Number of Fetuses			Probability
Item	Single	Twin	SE	*P* <
50 days of age				
Total protein, g/L	58.88	65.56	2.86	.05
Urea-N, mg/dl	24.96	23.34	2.03	.53
100 days of age				
Glucose, mg/dl	94.89	97.49	5.29	.68
Total protein, g/L	63.69	66.98	2.43	.26
Urea-N, mg/dl	23.77	23.37	2.16	.87

Table 9b.Effect of energy content of supplement fed to does on plasma glucose, urea and total protein of kids

	Energy levels of Supplement			Probability
Item	High	Low	SE	*P* <
50 days of age				
Total protein, g/L	62.33	62.11	2.47	.80
Urea-N, mg/dl	23.48	24.83	1.74	.82
100 days of age				
Glucose, mg/dl	94.60	97.78	4.38	.54
Total protein, g/L	63.84	66.82	2.02	.53
Urea-N, mg/dl	24.03	23.11	1.79	.57

Table 9c. Effects of protein content of supplement fed to does on plasma glucose, urea and total protein of kids

	Protein levels of Supplement			Probability
Item	High	Low	SE	*P* <
50 days of age				
Total protein, g/L	61.19	63.25	2.45	.82
Urea-N, mg/dl	24.92	23.39	1.77	.63
100 days of age				
Glucose, mg/dl	93.62	98.76	4.38	.10
Total protein, g/L	67.15	63.52	2.02	.54
Urea-N, mg/dl	23.67	23.47	1.79	.75

Table 10a. Effect of number of fetuses on fiber production of kids

	Number of Fetuses			Probability
Item	Single	Twin	SE	*P* <
Total fleece, g	97.35	104.32	7.70	.38
Guard hair length, mm	41.67	44.80	2.70	.34
Cashmere diameter, mm	18.37	17.10	.93	.15
Cashmere length, mm	32.20	34.83	1.94	.32
S:P ratio	1.80	1.99	.32	.48
Skin follicle S/P ratio				
6, d	3.98	4.29	.27	.26
21, d	6.16	6.02	.25	.63
49, d	6.32	6.28	.30	.72

Table 10b. Effect of energy content of supplement fed to does on fiber production of kids

	Energy levels of Supplement			Probability
Item	High	Low	SE	*P* <
Total fleece, g	95.99	105.68	6.41	.73
Guard hair length, mm	43.18	43.29	2.25	.98
Cashmere diameter mm	18.59	16.87	.78	.17
Cashmere length, mm	34.90	32.13	1.62	.16
S:P ratio	1.82	1.97	.27	.89
Skin follicle S/P ratio				
6, d	4.13	4.14	.22	.55
21, d	5.96	6.22	.19	.35
49, d	6.28	6.32	.23	.55

Table 10c. Effect of protein content of supplement fed to does on fiber production of kids

	Protein levels of Supplement			Probability
Item	High	Low	SE	*P* <
Total fleece, g	97.12	104.55	6.41	.16
Guard hair length, mm	40.95	45.52	2.25	.25
Cashmere weight, g	39.78	46.27	5.19	.48
Cashmere diameter, mm	16.41	19.06	.79	.02
Cashmere length, mm	32.19	34.84	1.62	.40
S:P ratio	2.15	1.64	.27	.29
Skin follicle S/P ratio				
6, d	4.17	4.10	.22	.89
21, d	6.31	5.87	.21	.08
49, d	6.51	6.10	.25	.22

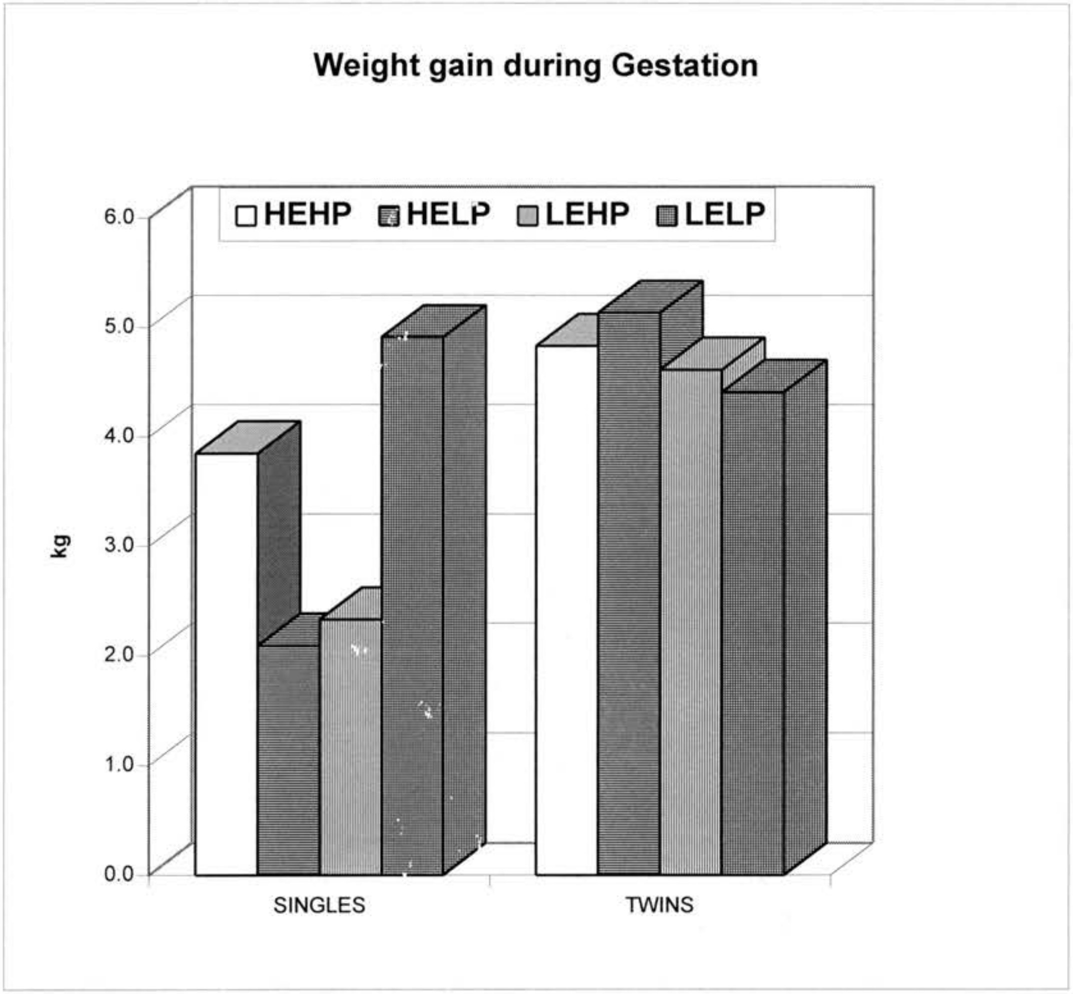

Figure 1. Weight gain (kg) from day 90 to parturition for does fed energy and protein supplement prepartum.

Data are least squares means.

Significant fetus number x energy x protein interactions (*P* = .05) standard error for singles = 1.05 (n = 3) and twins = 0.74 (n = 8)

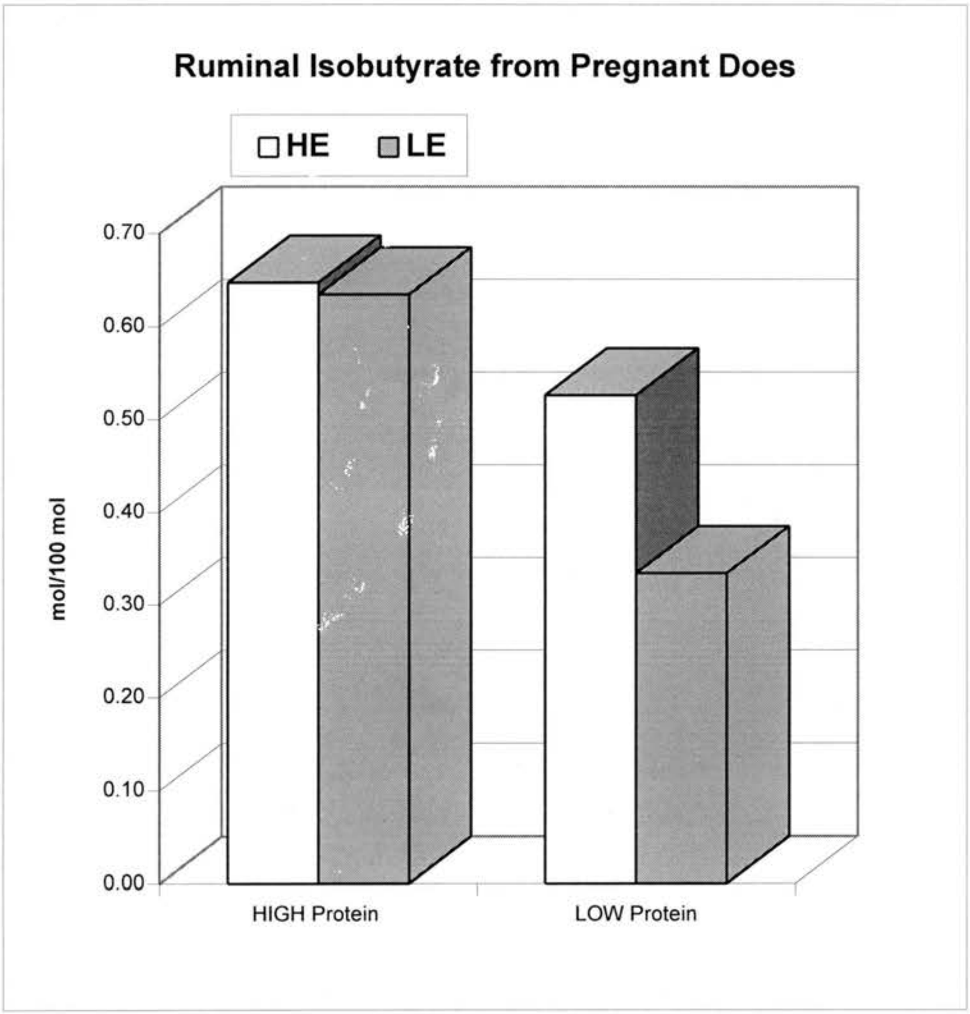

Figure 2. Ruminal isobutyrate (mol/100 mol) in pregnant does fed energy and protein supplement prepartum.

Data are least squares means. Significant energy x protein interaction (P = .02); Standard error = .054 (n = 11)

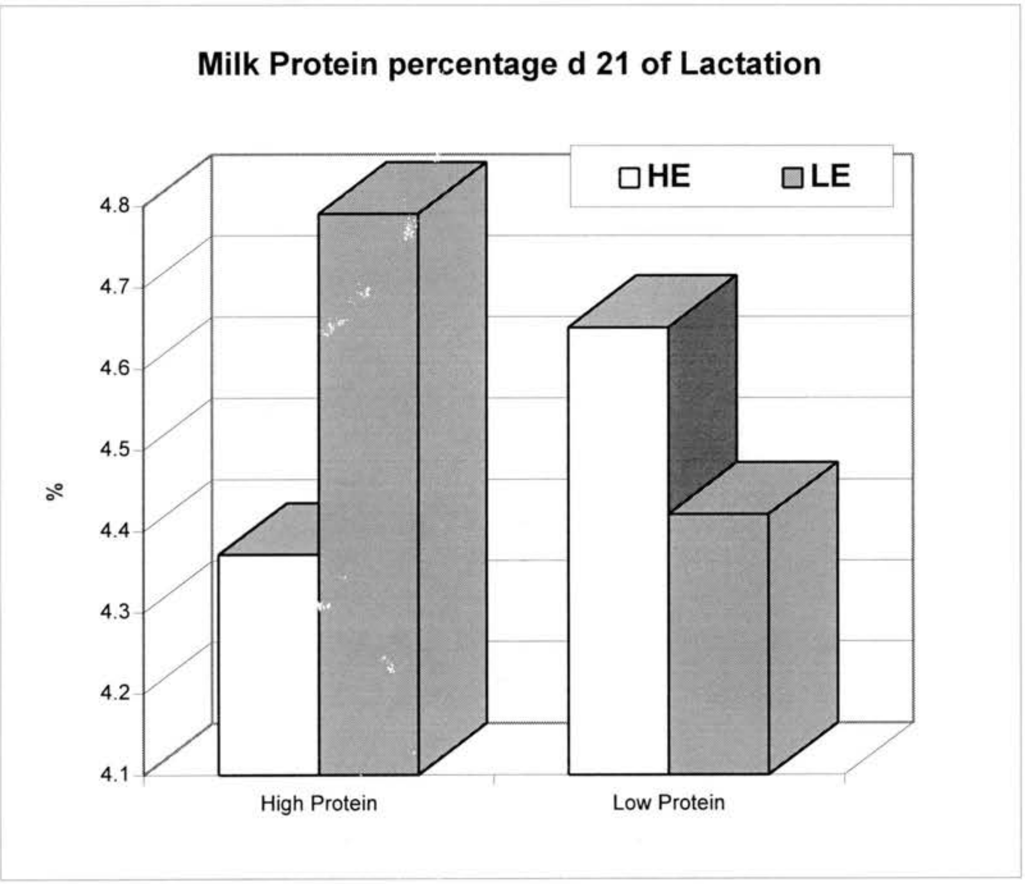

Figure 3. Milk protein percentage of sample taken on d 21of lactation

from does fed energy and protein supplement prepartum.

Data are least squares means.

Significant energy x protein interaction (P = .02).

Standard error = .14 (n = 11).

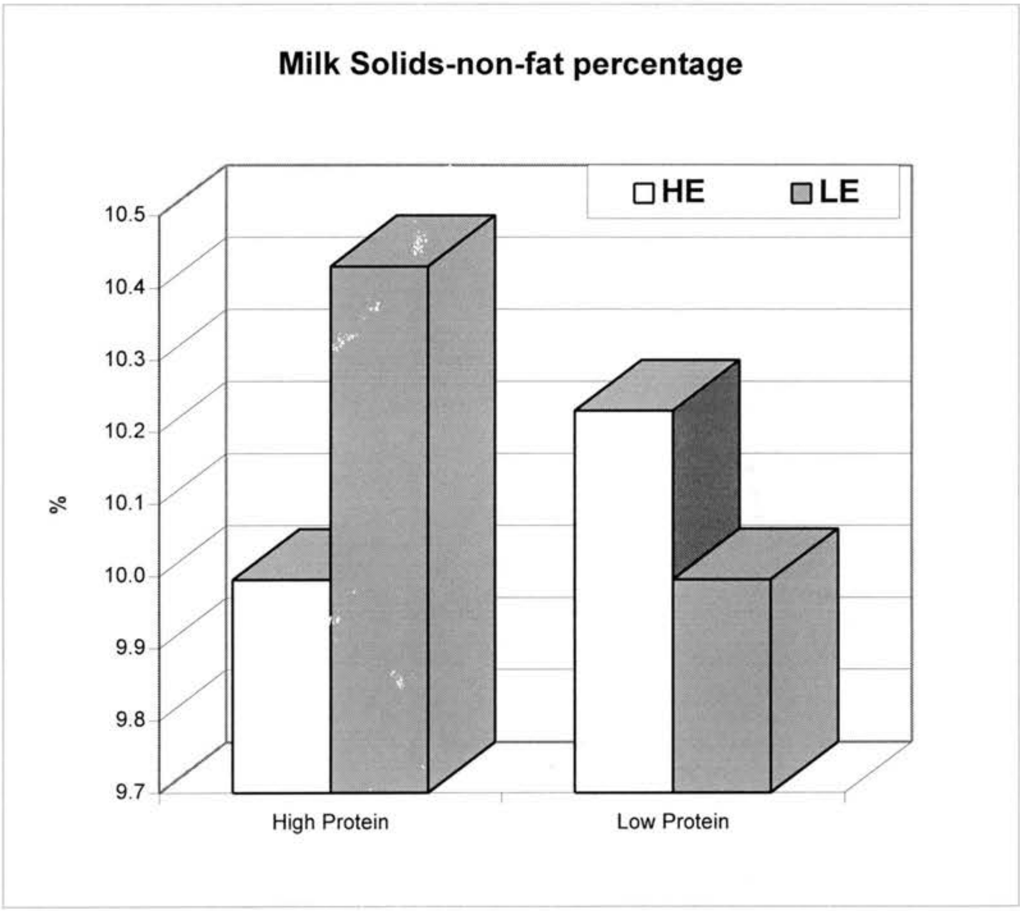

Figure 4. Milk solid-non-fat percentage sample taken d 21 of lactation Spanish goats fed energy and protein supplement prepartum. Data are least squares means.

The significant energy x protein interaction depicted (*P* = .01); Standard error = .12 (n = 11).

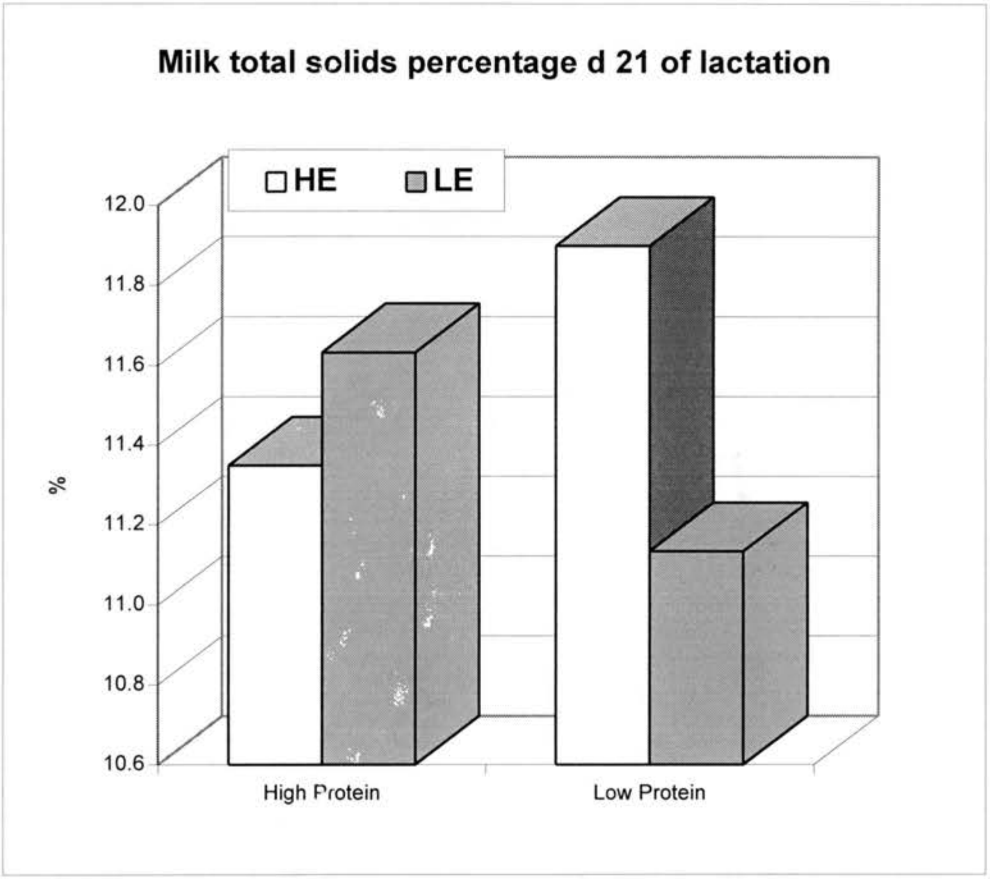

Figure 5. Milk total solid percent sample taken d 21 of lactation.

Spanish goats fed energy and protein supplement prepartum.

Data are least squares means.

The significant energy x protein interaction is depicted (*P* = .06)

Standard error = .25 (n = 11).

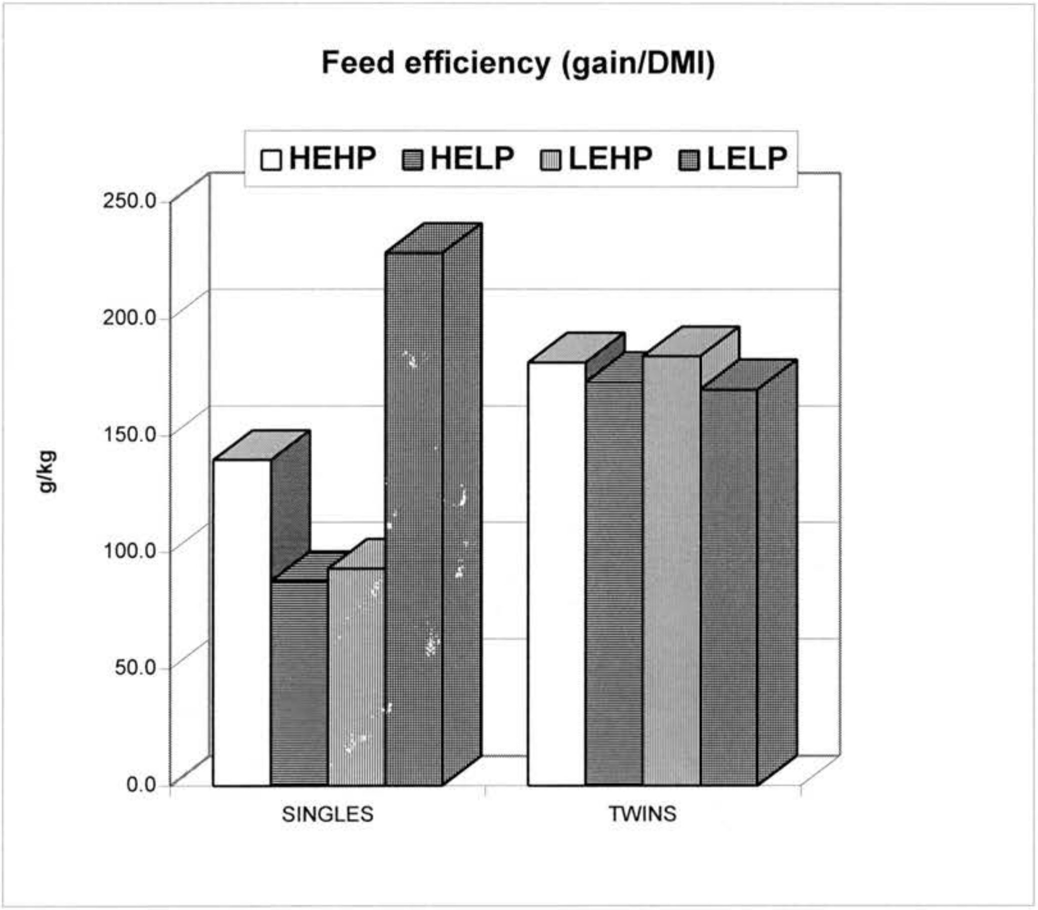

Figure 6. Feed efficiency (gain/DMI) for does fed energy and protein supplement prepartum. Data are least squares means. Significant fetus x energy x protein interactions (*P* = .05) Standard error for singles = .03 (n = 3) and for twins .04 (n = 8).

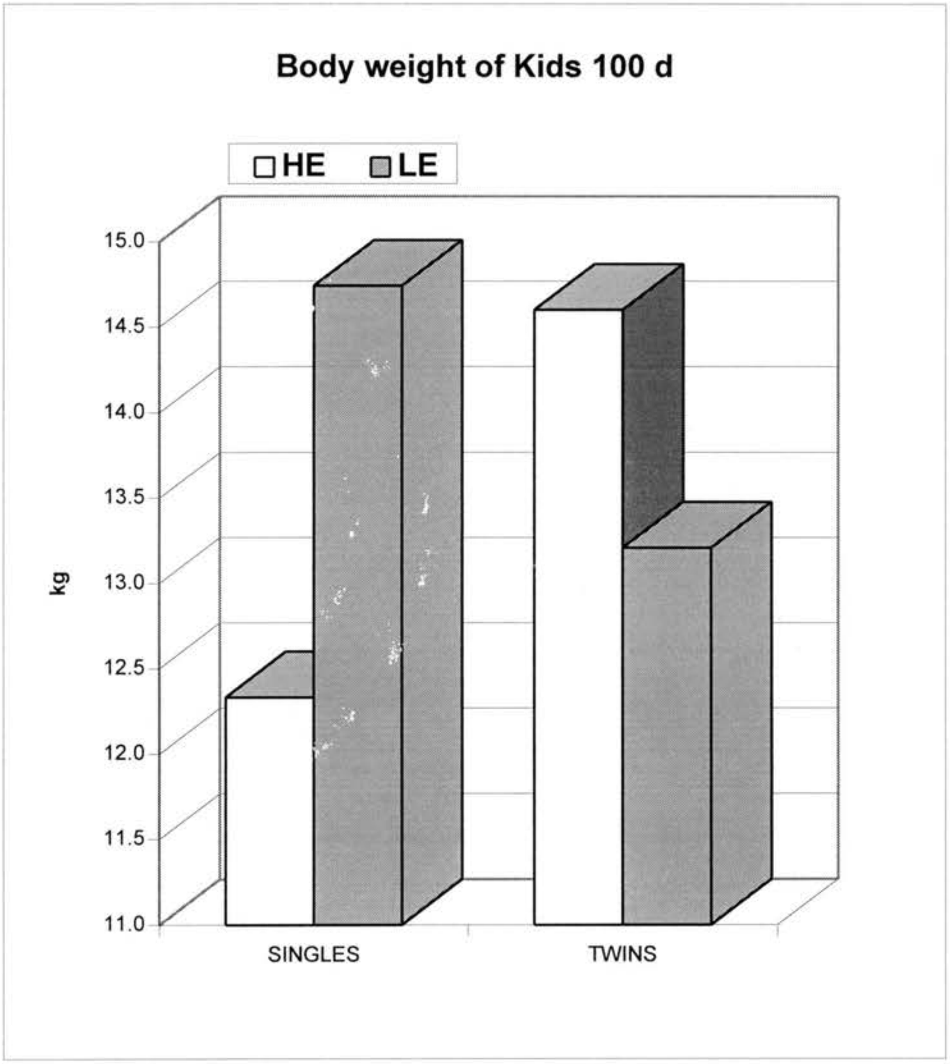

Figure 7. Body weight at 100 days old progeny of does, fed energy and protein supplement prepartum. Data are least squares means. Significant fetus x energy interactions (P = .05). Standard error for single = 1.12 (n = 3), twin = .68 (n = 8).

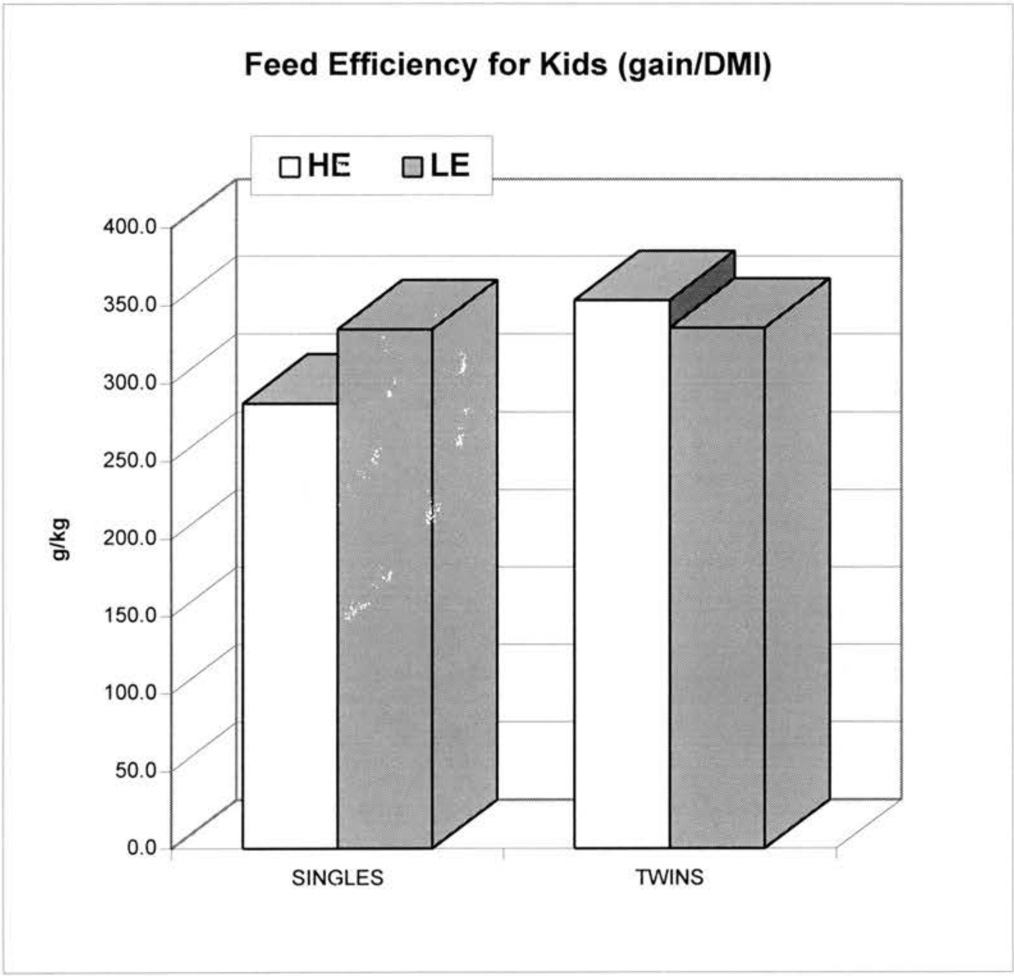

Figure 8. Feed efficiency of growing kids. Data are least squares means.

Significant fetus x energy interactions ($P < .05$).

Standard error for single = 19.19 (n = 3), twin = 12.17 (n = 8).

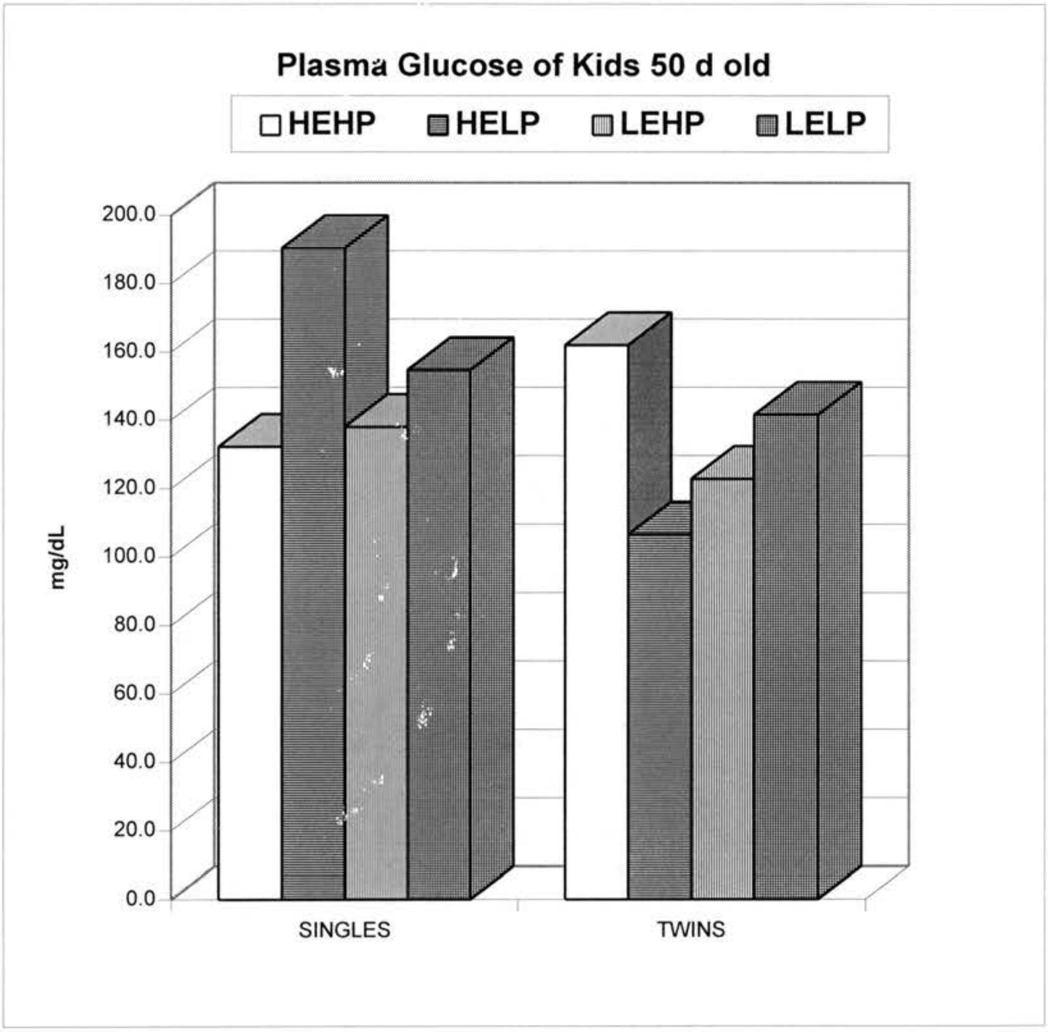

Figure 9. Plasma glucose of kids 50 d. Data are least squares means.

Significant fetus x energy x protein interactions (P = .02).

Standard error for singles = 23.98 (n = 3), twins = 13.85 (n = 8).

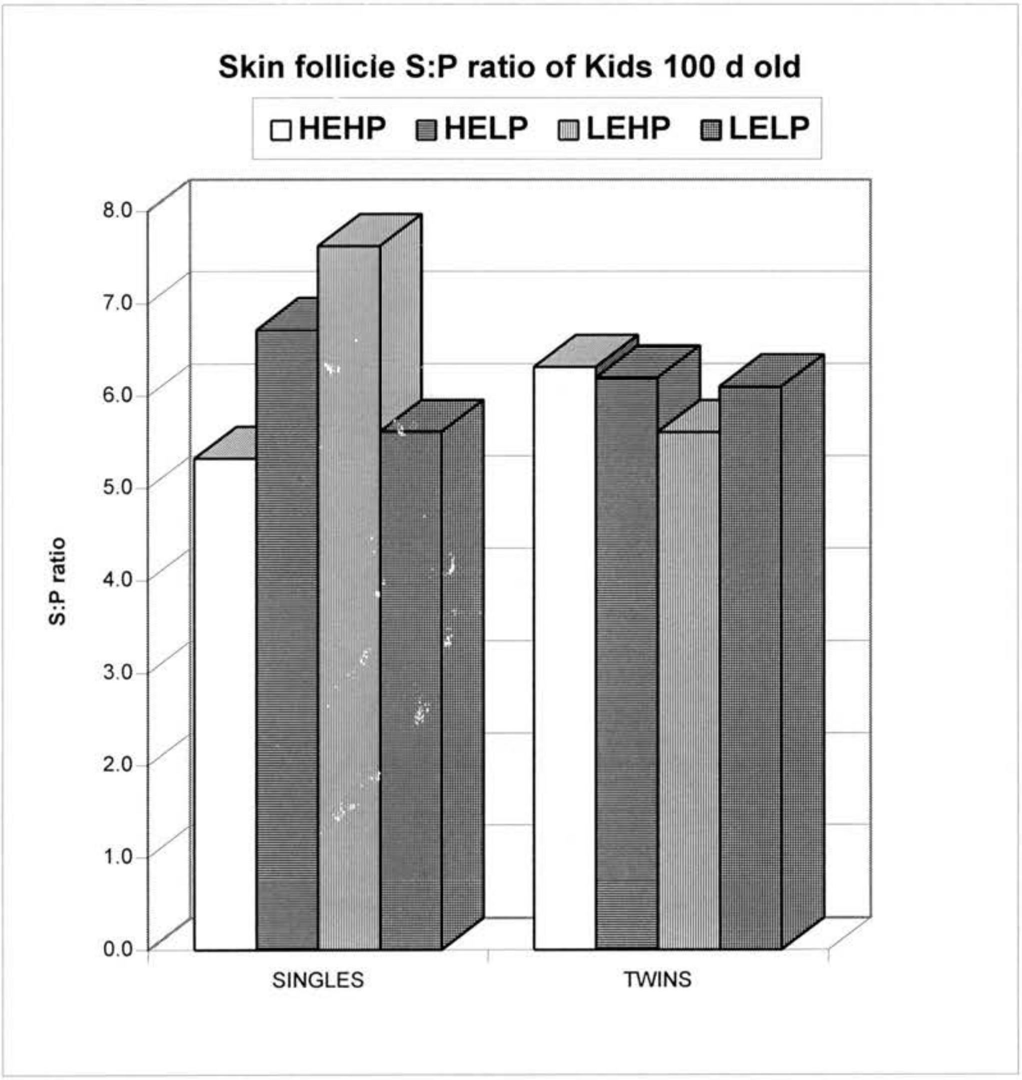

Figure 10. Skin follicle S:P ratio of kids 100 d old.

Data are least squares means.

Significant fetus x energy x protein interactions (P = .01).

Standard error singles = .6 (n = 3) twins = .25 (n = 8).

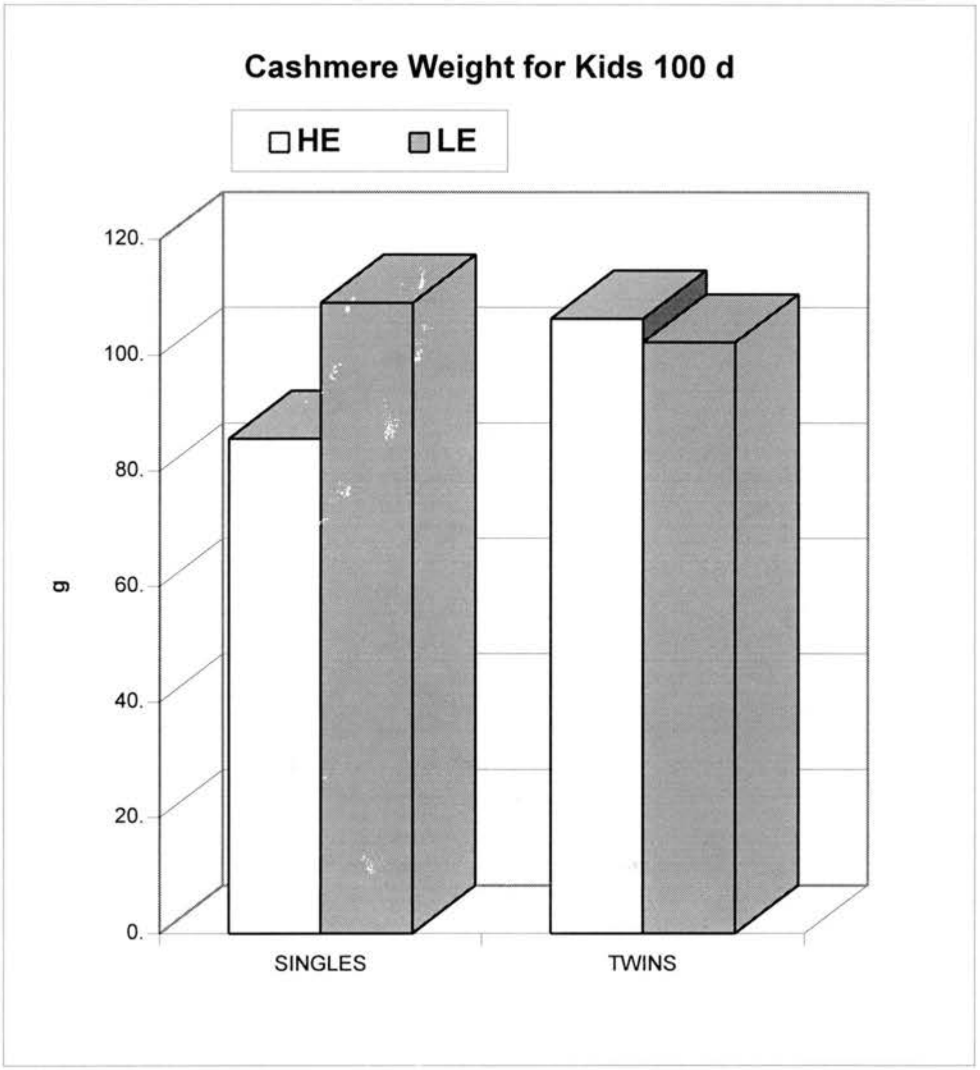

Figure 11. Effect of prepartum energy supplement on cashmere production of kids. Data are least squares means. Significant fetus x energy interactions (P = .03). Standard error for singles = 8.46 (n = 3), twins = 4.96 (n = 8).

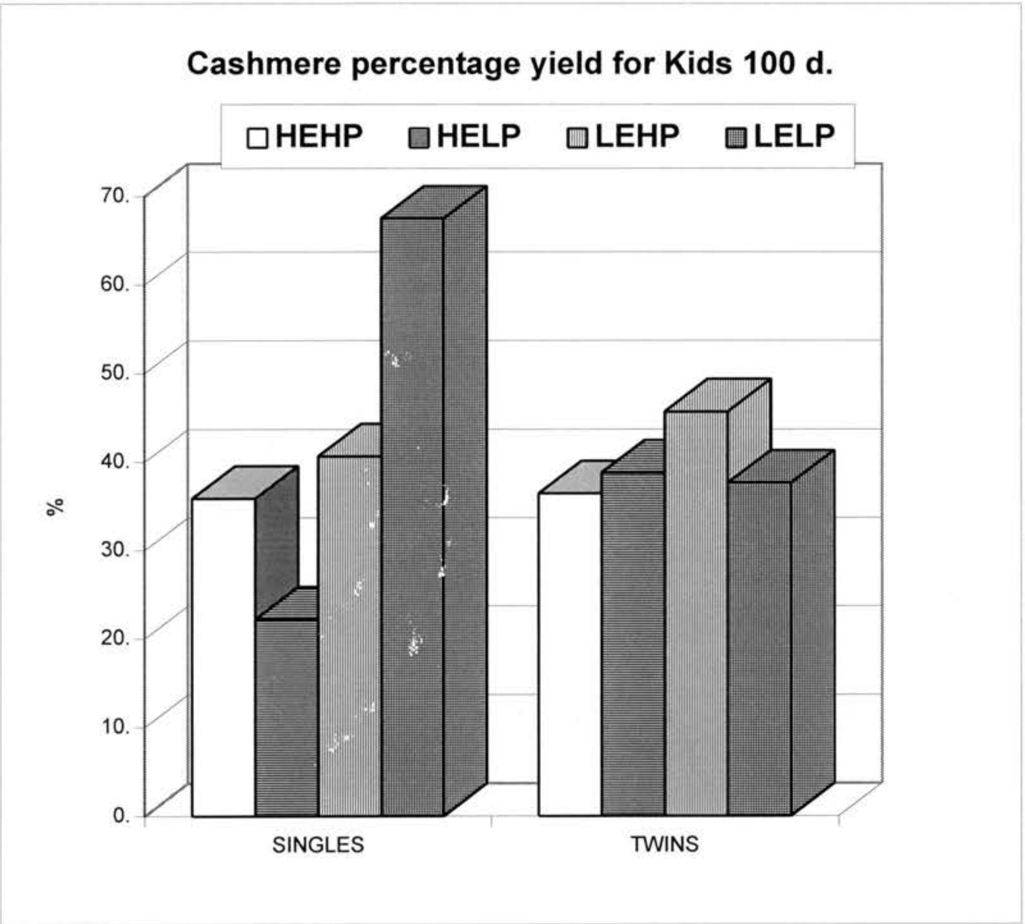

Figure 12. Cashmere percentage yield of progeny of does fed energy and protein supplement prepartum. Data are least squares means Significant fetus x energy x protein interactions (P = .01). Standard error singles = 8.95 (n = 3), twins = 4.90 (n = 8).

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CHAPTER V

SUMMARY

Scope of These Studies

A total of 154 cashmere-producing Spanish goats were used in the studies included in this dissertation. Diets that differed in concentrations of energy and protein were fed to growing, pregnant and lactating cashmere-producing Spanish goats. Responses measured included cashmere production and quality, body weight gain, feed efficiency and ratio of secondary to primary follicles in kids. In the first study, 36 wethers were given ad libitum access to diets containing two levels crude protein and three levels metabolizable energy. These diets were balance to provided nutrients above maintenance requirement for growing goats. Forty-four pregnant does with either single or twin fetuses were fed a supplement containing two levels of protein and two levels of energy from d 60 of gestation through to d 50 of lactation in the second trial. Does, fed supplement each day equal to 1% of BW (adjusted every 14 day), were given free choice access to Bermuda hay. Variables measured included weight change during gestation and lactation, fiber yield and quality, gestation length, and milk production and composition. For the kids, growth rate, ratio of S:P follicles in skin at 6, 21, 49 and 100 days old, fiber yield, fiber characteristics and DMI were measured. Rate and efficiency of growth of kids were measured during a 50 d nursing period and in a subsequent 50 d feeding study when kids were given ad libitum access to a high grain diet.

Findings and Conclusions

Dry matter intake was greater for wethers fed the 15% than for those fed the 10% CP diet but DMI was not altered by dietary energy concentration. In the first growth study, average daily gain was 48% greater for kids fed 15% than for kids fed 10% protein diets. Body weight at the end of the trial was heavier for those fed the higher protein diet. The higher protein diet produced greater gains for MEI and DMI. Feed efficiency (g/kg) was 28% greater for those fed the 15% CP than for those fed the 10% CP diet. Feed intake decreased linearly as metabolizable energy content of the diet was increased indicating that these kids were chemostatically regulating their energy intake. The gain to feed ratio was 43% greater with the 2.7 than the 2.0 Mcal/kg diet. Fleece weight was quadratically altered by diet energy content; goats fed either the intermediate or the highest energy diets produced more fleece than goat fed the lowest energy diet. Cashmere diameter was significantly greater for kids fed the higher crude protein diet, perhaps due to greater intake of sulfur. Results indicate that both quantity and quality of cashmere are influenced by dietary concentrations of energy and protein.

Dams carrying twin fetuses gained more weight than those carrying single fetuses in the gestation-lactation trial. Because they gained more weight, does bearing twin fetuses were fed more supplement during the last third of pregnancy. Birth weights of kids were not influenced by the lower energy or protein content of the prepartum supplement. Does bearing twins had higher blood concentrations of non-esterified fatty acids and beta-hydroxy butyrate both of which reflect greater mobilization of body fat reserves. Gestation length was not altered by prepartum diet or number of fetuses although it tended to be shorter for the group fed the lower energy supplement. Does fed the higher protein supplement had higher blood urea concentrations. Fiber growth by does was not altered by the number fetuses borne, but guard hair weight was slightly greater for does bearing twins. Cashmere length, percentage yield and total cashmere all were decreased by feeding the higher protein supplement.

Although milk composition was not altered, milk production was 56% higher for does bearing twins than for does producing singles. Litter weights were greater for twins than single kids between d 15 and d 35. Pre-weaning weight gain was 71% higher for offspring of does bearing twins (total litter weight) than does single kids. In the postweaning growth study, DMI and daily gain both were greater (10 and 20%) for kids born as twins than born as singles. Increased DMI for twin than single kids post-weaning could be a result of the level of milk consumed by the kids. Prepartum diet and twinning did not alter the ratio of S:P ratio of skin follicles of kids at 6, 21, or 49 d old. However, the ratio increased as kids grows.

Significance of the Studies

Cashmere production can be improved by increasing the nutrient supply for young growing Spanish goats. To maximize fiber yield, the increase in nutrient supply should coincide with the cashmere growing cycle. Higher levels of dietary crude protein increased diameter of hair fibers and reduced cashmere yield because coarser fibers are classified as guard hair. The level of sulfur in the diet should be greater than .18% and N:S ratio greater than 15:1 so that fiber growth will not be limited by sulfur supply.

Pregnant cashmere-producing does fed a supplement at one percent of body weight consumed sufficient dry matter so that birth weights of single or twin kids were not reduced. For maximum performance, the supplement for an 8% CP forage probably should contain more than 16% CP. Does bearing twin fetuses gained more weight during gestation and lost more weight during lactation than does bearing single fetuses. Kids from born as twins may gain less weight during their nursing period due to lack of milk supply. However, kids born as twins may consume more feed post-weaning if given free choice access to feed. The ratio of S:P fiber follicles in skin was not sensitive to nutritional changes for young growing goats.

Limitations and Future Outlook

We did not measure digestibility of the ration in either study. In the gestation study, hay intake and its digestibility were not measured. Milk production could have been underestimated because milk consumption by kids was measured only during short intervals of exposure to their dams. Milk composition presumably was not representative because it was obtained before kids nursed; therefore, it represents the first milk released, not an average of total milk produced during a suckling period. Gender of the kids was not included in the evaluation. Perhaps kid birth weight and growth responses differed with gender and adjustment for gender could alter values and interpretation of results. We did not differentiate fiber follicles with regard to their metabolic activity. And finally, at the time kids were sheared due to season, percentage of cashmere was quite low in some kids.

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VITA

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