BREEDING FOR YEAR-ROUND CASHMERE PRODUCTION AND INCREASED HOLDING CAPACITY ON SPANISH GOATS

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Format of Dissertation

This dissertation is presented in the Journal of Animal Science style and format, as outlined by the Oklahoma State University graduate college style manual. The use of this format allows for independent chapters to be prepared suitable for submission to scientific journals.

CHAPTER I

INTRODUCTION

Cashmere, the undercoat from cashmere and related goats, is one of the finest natural fibers and is used in the manufacture of luxury goods. Its products are soft and beautiful. On an equal weight basis, it has three times the insulating capacity of wool.

The United States has become the major importer, processor, and user of cashmere. Americans consume 37% of the world's production and will require approximately 11.6 million goats with an average yield of 100 g or 2.5 million goats with an average cashmere production of 450 g to produce sufficient quantities for domestic use. Traditional world suppliers of cashmere are China, the Mongolian Peoples Republic, Iran, and Afghanistan and other areas with more limited quantities. Due to political and economic differences between the suppliers and importers, it is difficult for processors to secure adequate supplies of the raw product; and unstable supply has resulted in wide price variation from year to year. The fate of the cashmere industry in the United States will likely be determined by other countries. As a result, we must develop alternative sources of supply.

Spanish goats in Texas produce limited quantities of fiber with cashmere qualities. Spanish goats have average cashmere down length of 1.5 inches (0.9 - 2.0 inches), cashmere yields of over 25.4% (9.4 - 56.5%), down weight of 0.21 lb (0.09 - 0.50 lb), and a mean diameter of µm 16.1 µm (14.3 - 18.5 µm). Approximately 300,000 Spanish goats grow cashmere and provide good meat performance, complementary grazing ability with sheep and cattle, and the ability to control weeds in improved hill pastures. Because of their economic value and fiber characteristics, these goats can be the basis of the cashmere industry in America. These developments have resulted in a demand for information on breeding for increased down production in Spanish goats.

Breeding for improved production implies that clearly defined breeding goals exist, and these breeding plans are based on a knowledge of the production parameters of goats. Unfortunately, we lack any systematic study of the genetics of down production in these goats and, indeed, have only fragmentary data on fleece characteristics and their variation in the Spanish goat population. The biological capacity for cashmere production depends on the proportion of undercoat down to the amount of guard hair, down bearing surface area, diameter of fiber, fiber length, and density of the down fiber per unit area. These goats, due to long-term natural selection and no artificial selection for cashmere production, have low cashmere production capability, short growth period, poor fiber retention ability, and low down weight. To improve cashmere production and meat performance, we intend to do systematic and long-term intensive genetic selection.

Producers in Australia, New Zealand, and Scotland started as long as 15 years ago to select for cashmere among the feral goat populations of those countries. Apparently, progress has been realized (Kloren et al., 1993[b]). Presumably, the same could be accomplished with Spanish goats. The objectives of this experiment will be to evaluate animals for year-round cashmere production and increased fiber retention ability (later time of shedding), to select those animals exhibiting desired levels for those two traits using classical animal breeding methods, and to propagate those selected animals. Understanding the relative importance of their biological components, their variability, heritability, and the genotypic and phenotypic correlations among them is also our research goal.

CHAPTER II

REVIEW OF LITERATURE

Biology of Fiber Growth

The coat of cashmere goats consists of a thick heavy outercoat of long, straight, coarse medullated fibers (also known as "guard hairs"), and an undercoat of short, nonmedullated "down" with fineness less than 18.5 μm and intermediate fibers with interrupted medulla (Epstein, 1969). The physical characteristics of textile fibers influence their suitability for different uses and hence their commercial value. Returns to goat farmers from fiber sales are influenced by those values and the level of fleece production from individual animals. These the biology of fiber growth in goats and the options available to farmers to manipulate the quality and quantity of the fiber production will be reviewed.

Follicle Population

Goats have two distinct types of fiber-producing follicles within the skin, distinguished by their associated accessory structures (Sumner and Bigham, 1993). Primary (P) follicles are characterized by an associated sudoriferous or "sweat" gland, an often bilobed sebaceous gland, and an errector pili muscle; whereas secondary (S) follicles are only associated with a monolobed sebaceous gland. The follicles in adult animals are arranged within groups consisting typically of three P follicles and a variable number of S follicles. Groups with one, two, four, and five P follicles were also found. (Parry et al., 1992). In double-coat cashmere goats, the depth of S follicles extends only to the depth of the sebaceous glands of P follicles, and the depth of Ps is more than double that of the S. This accounts for a fundamental difference from Angora goat, in which the depth of all follicles is similar (Millar, 1986). In double-coat cashmere goats the long coarse outer-coat is produced by P follicles and the finer under-coat by S follicles.

Follicle density in the skin of cashmere goats varied with age, sex, birth type, body weight, and breed. The density of P follicles decreased with age until maturity when the density remained nearly constant. Parry et al. (1992) reported the density for Australian feral goats was 14.37 folls/mm^2 at birth, 6.97 folls /mm^2 at 57 days of age, then 4.10 folls/mm^2 at 107 days of age. However, the P follic number index (the density of the P times the skin area of the body) did not change. Density decreased due to increasing in body size. The density of the S increased with age. For example, the density of S in Australian feral goats was 12.84 folls /mm^2 at birth, and 28.75 folls /mm^2 at 57 days. Because of the small sample size, generally 1 cm^2, and large experimental variation, the data were not consistent. Lambert et al. (1984) reported the P density in Australian goats increased markedly between birth and one month of age, but most researchers reported the P density decreased at young age (Holst et al., 1982; Kloren et al., 1993[b]; Parry et al., 1992; Restall and Pattie, 1989).

Birth type influenced the total number of S follicles, single birth had more S follicles than twin kids, but the P and S densities are not influenced (Parry et al., 1992). Male cashmere goats have more P and S follicles (Parry et al., 1992). Restall et al. (1984) reported that there existed correlations between live weight and S follicle density over time (-0.53) and within the sampling time (-0.23). The density of P follicles per unit area of skin among adult goats was similar (Sumner and Bigham, 1993), but the S follicles density exhibited large differences among breeds, e.g., Australian feral goats 22.9 /mm^2 for 10-month old kids (Holst et al., 1982), but 46.0 /mm^2 for Black Kirgiz bucks (Millar, 1986). In a crossbreeding experiment using Don and Angora x Don does and bucks with different undercoat fiber diameter, the greatest follicle density (44.8 /mm^2) and the finest undercoat (18.0 μm) was obtained from the offspring of crossbred bucks with an average fiber diameter of 30.4 μm mated with Don does with an average diameter of 19.2 μm; the lowest follicle density and the coarsest fibers (34.4/mm^2 and 21.8 μm) were obtained from the offspring of crossbred parents (Millar, 1986).

Because the density of P and S varied with age, sex, birth type, body condition, and breed, the relative proportion of P and S follicles, expressed as an S/P ratio, varied. The S/P ratio increased with increasing age (Parry et al., 1992; Lambert et al., 1984). Single kids showed higher S/P ratio than twin kids (Lambert et al., 1984; Parry et al., 1992). Lambert et al. (1984) reported that male kids had higher S/P ratio than females kids at birth, but the difference tend to disappear at 1 month of age. Parry et al. (1992) found no significant difference in S/P ratio between male and females at any age. However Henderson and Sabine (1992) found females have higher S/P ratio at 2 weeks age. The

S/P ratio differs among breeds; generally, the greater the ratio, the more cashmere is produced. S/P ratio of cashmere goats is generally smaller than that of sheep and Angora goats. The S/P ratio increase in crossbreds with Angora inheritance towards values found in Angora goats, but this advantage may be outweighed by disadvantages occurring with changes in the nature of the cashmere coat, such as the emergence of a high percentage of fibers of immediate thickness (Ryder, 1984). A comparison of S/P ratio among several goat breeds, compiled from several sources, is summerized in Table 1.

Follicle Development

A follicle is formed by down growth of the epidermis into the dermis and has an associated papilla at its base or bulb. The dermal papilla is continuous with the connective tissue sheath which forms the outer-most layer of the follicles (Millar, 1986). Internal to this layer are the outer and inner root sheaths and the hair. The outer root sheath is the progression of the epidermal down growth and extends from the epidermis to the dermal papilla. The inner root sheath and the hair are formed from the division and differentiation of cells in the follicle bulb (Millar, 1986). Studies of follicle development in the sheep fetus have determined that P follicles are formed first, S follicles being formed later (Carter and Clarks, 1957; Hardy and Syne, 1956). Schinckel (1955) pointed out that the follicles development should be considered in two stages, i.e., initiation (physical development of the follicle) and maturation (production of fiber from the follicle). In the Merino, all P follicles are mature at birth (Hardy and

Lyne, 1956), and all or almost all S follicles are initiated before birth (Short, 1955), although many do not mature until after birth. Wildman (1954), however, showed that this was not necessarily so in other breeds such as the British Romney. Hardy and Syne (1956) suggested that most immature follicles seen at birth and in early postnatal samples of the Merino are derived S, which arise from branching. The age at which all secondary follicle development is completed also appears to vary among breeds of sheep, but all continue to undergo S follicle maturation after birth (Burns et al., 1962; Fraser and Short, 1960; Schinckel, 1955).

Follicles development in goats parallels sheep with the development phase. Parry et al. (1992) found that Australian cashmere goats had extensive branching of S follicles through the examination of pre-natal skin. They also found all P, but few S, follicles, Australian cashmere goats were mature at birth and no P follicles and few S follicles were initiated after birth. Post-natal follicle development in the skin involves the maturation of S follicles only, the total follicle population has been completed by 3 to 4 months of age. Dreyer and Marinocowitz (1967) found the S follicles of Angora goats did not mature until 6 months of age, but exhibited the greatest increase in S/P ratio within the first 3 months after birth. Lambert et al. (1984), however, considered that in Australian feral goats, post-natal development involves not only maturation, but also initiation. They also found some P follicles not mature at birth. Henderson and Sabine (1991) confirmed that the S follicles of Australian cashmere goats matured at 4 months of age.

Parry et al. (1992) found that the follicle number index (density times the surface area of the skin) of the S follicles of twins was smaller than that of single births, but that there was no different in follicle densities and S/P ratio. This may indicate that maturation of S follicles, in Australian cashmere goats, is retarded in twins compared to single kids (up to 301 days after birth) or that there are fewer S follicles in twins.

Dreyer and Marinocowitz (1967) compared the follicle populations of growing Angora goats and detected a significant difference in S/P ratio between females and castrated males at 3 months of age, but it did not persist. They also found that females attained a mature ratio earlier than castrated males, but by 6 months of age this discrepancy disappeared. Henderson and Sabine (1991) found no differences between Australian cashmere female versus male goats. Parry et al. (1992) found that males had 12% more P follicle number index (PFNI) than females at 107 days and 301 days of age, the male had 19% and 16% more S follicle number index (SFNI) than females at 107 and 301 days of age, respectively. Because males were significantly heavier than females at all ages, the difference in S follicle population may be associated with body weight.

In sheep, nutrition influences on the development and/or maturation of the S follicles. Although reports vary as to the precise "critical time" of this influence, there appeared to be no doubt that poor nutrition in early life lead to decreasing of mature fiber production (Turner, 1961; Fraser and Short, 1960; Schinckel, 1955; Short, 1955). For goats, Lambert et al. (1984) found that nutritional supplementation during the last month of pregnancy and the first month after birth had little effect on adult follicle population. However, supplementation during early pregnancy was associated with a significant increase in the density of S follicles at 1 month of age.

The S/P ratio is commonly used an index of S follicle development in the skin, assuming that the number of P follicles remains constant. Parry et al. (1992) found that the P follicle number estimated from body weight and density is not a constant, it decreased at 2 months of age to 4 months of age, but the S follicles increased during this period. Follicle number index was a more useful measure of follicle development than either follicle density or S/P ratio. Follicle density changes with changing body surface area, and considerable variation in body surface area occurs between growing animals. The rapid maturation of the follicle population from birth to weaning coupled with rapid changes in skin surface area over this time suggested that follicle number index would be a more reliable indicator of follicles development than woud be follicle density.

Fiber Growth

Many mammalian species exhibit seasonal changes in their pelage, the usual pattern being the production of a dense, fine coat which traps warm air for winter warmth, and a less dense coat in the spring and summer allowing air circulation and evaporative cooling (Henderson Sabine, 1992; Sumner and Bigham, 1993). Some animals have a visible moult once a year, with a shedding of the heavy winter coat in spring and gradual growth of the new winter coat throughout the summer (Ryder, 1966, 1974). The pattern of growth of individual follicles can be divided into three main phases, anagen (active fiber growth), catagen (follicle regression), and telogen (a resting phase with previously grown fiber anchored in the follicle by a club or brush end) (Chase, 1954; Henderson and Sabine, 1992). Shedding of the previously grown fiber tends to occur about the time of onset of anagen, having been observed before and after growth of the new fiber with shedding in cashmere-producing goats (Nixon et al., 1991). Breeds of sheep and goats differ in their pattern of fiber growth. For sheep, it is widely accepted that seasonal variation in wool growth in many domestic breeds is a modified vestige of this primitive rhythm of moulting and replacement of fibers (Ryder and Stephenson, 1968). Even when sheep are kept on a constant diet, a residual seasonal pattern still exists that is independent of nutrition (Ferguson, 1975). Some sheep breeds, however, show less seasonal variation than do others (Ryder, 1966, 1974). A decrease in the tendency to shed is associated with the increase in selection for wool production. Soay and Shetland sheep have a visible moult in the spring with a lesser moult in the autumn; the Merino sheep apparently has continuous wool growth during the whole year (Ryder and Stephenson, 1968). The same trend is also true for goats. In the cashmere-bearing goat, the whole down undercoat (produced from S follicles) is shed each year in late winter/early spring (Burns et al., 1962); whereas, the Angora goat has lost its tendency to shed. Even in cashmere goats, some differences exist among breeds, the high fiber yield breed moulted late and initiated early (Rhind and McMillen, 1995). The pattern of P and S fiber growth in moulting breeds is different. Primary fibers are replaced as they are shed maintaining a covering over the animal. Replacement of S fibers, however, may not occur for 1 to 3 months after shedding (McDonald et al., 1987). The seasonal pattern of down production in cashmere-producing goats commences around the summer solstice and ceases near winter solstice (Betteridge et al., 1988). The S/P ratio in these animals is low in early summer and high in winter (McDonald et al., 1987).

The seasonal cycle in down cashmere growth is associated with concomitant changes in fiber length growth rate, mean fiber diameter, and mean fiber volume (Henderson and Sabine, 1992; Rhind and McMillen, 1995). Significant increases in average cashmere length growth rate occurred as daylength decreased and a maximum cashmere fiber was reached in mid-summer and was maintained until late winter (Henderson and Sabine, 1992). Fiber diameter reached a maximum in autumn, but then decreased again in winter. In sheep, Woods and Orwin (1988) found, using autoradiographs, length growth rate cycle and fiber diameter cycle is independent and differ among animals and among fibers within an animal. An animal has a very similar fiber development pattern in consecutive years (Henderson and Sabine, 1992). These trends highlight the complexity of physiological mechanisms regulating fiber length and diameter growth changes at the follicular level (Orwin, 1989).

The physiological control mechanisms which regulate fiber growth are presently unknown, but are associated with photoperiod. Fiber growth cycles appear to result from intrinsic rhythms within the follicle modified by systemic inputs that entrain the cycle. The systemic input is possibly mediated via the nervous system. Evidence for an intrinsic rhythm is provided by skin transplant studies where follicles retained their original rhythm and fiber characteristics following either graft rotation (Ebling and Johnson, 1959) or delayed grafting (Ryder and Priestly, 1977). Seasonally moulting goats held in constant photoperiodic conditions also maintain a shedding cycle, although this trend with time becomes disengaged from the normal seasonal pattern (McDonald and Hoy, 1987; Maxwell et al., 1988). Goats located in different latitudes are different with respect to time of moulting (Henderson and Sabine, 1992). Association with the central nervous system is evidenced by pinealectomy (Rougeot et al., 1984) and cervical sympathectomy (Lincoln et al., 1980) as both procedures inhibit moulting. The timing of moulting in cashmere-producing goats (Betteridge et al., 1988; Lynch and Russel, 1989) can also be influenced through the use of exogenous melatonin to mimic the effect of short days.

Fiber Structure

The goat fiber consists of three components, i.e., cuticle, cortex and ,in the case of coarse fibers, a medulla. The cashmere fiber consists of cuticle and cortex, and lacks crimp (Millar, 1986).

The cuticle is a single layer of chemically resistant, overlapping cells (Bradbury, 1973). As the growing fiber moves up the follicle towards the skin surface, a scale pattern in which the scale edges point to the tip of the fiber, is imprinted on the hardening fiber by the inner root sheath cuticle cells (Woods and Orwin, 1982). Variations in the scale pattern, which differ between species and breeds, are associated with felting, luster, and handle properties of the fiber (Orwin and Woods, 1983) and may be affected by fiber growth rate (Rougeot, 1965). Cashmere fiber shows cylindrical scales with a width-to-length ratio of about 2:3. The main part of the cashmere fiber shaft is encircled by two scales, rolled impressions of which reveal a form of waved mosaic. Margins of scales are distinct and smooth with practically no crenations. Coronal type scales appear only at the tip, and ripples and crenations become more numerous towards the tip.

The cortex, which is the major output of the follicle, consists of elongated cells of two principal types, ortho- and paracortex, and an intermediate type, mesocortex (Orwin et al., 1984). Cortical cells form a complex matrix of filamentous macrofibrils which contain bundles of microfibrils consisting of filaments of fibrous protein and a non-fibrous proteinaceous cementing matrix (Rogers, 1959). The microfibril matrix structure differs between ortho- and paracortex with the paracortex being more cystine (Bradbury, 1973). Orthocortical cells also tend to be larger than paracortical cells (Orwin et al., 1984) with the two cell types following distinct forms of differentiation in the follicles (Chapman and Gemmell, 1971). The proportion and location of cortical cell types affect fiber crimp and dye-accessibility, both of which are related to processing and end-product performance. Highly crimped wools or hairs/cashmeres, which tend to be associated with follicles with deflected bulbs relative to the skin surface, contain a bilaterally segmented cortex. Paracortical cells which take up dye less readily occur on the inside of the crimp curve; whereas, orthocortical cells which are dye-accessible occur on the outside of the crimp curve (Horio and Kondo, 1953). Lightly crimped wools or hairs/cashmeres are predominantly orthocortex with a cellar or locate arrangement of the paracortical cells (Orwin et al., 1984).

The medulla consists of a central core of vacuolated cells which may be continuous, discontinuous, or non-existent within an individual fiber (Wildman, 1954). The extent of differentiation of medulla cells, which differs between breeds, is positively associated with the size of the dermal papilla relative to the follicle bulb (Rudall, 1956). Heavily medullated goat fibers are harsh handling with a chalky appearance and poor dyeability making this type of fiber less suitable for many end-uses relative to nonmedullated fiber. This is of particular importance in cashmere production where the outercoat or guard hair is separated from the down as an initial processing step.

Genetic Factors Influencing Fiber Growth and Other Characteristics

Inheritance of Coat Color

The coat colors of cashmere-producing goats range almost across the whole scale of possible colors (white, black, gray and blue, dark-wild type, brown-wild type, reversed wild pattern, red) of domestic goats. The most common natural colors of cashmere are gray, brown and black; white is more rare. White fibers command the highest prices because of their rarity and suitability for dying without bleaching. Because of the commercial importance of color, its inheritance has been investigated by many researchers (Lauvergne, 1982; Millar, 1986; Wang, 1980). The loci and alleles at each locus are listed in Table 2.

The goat is a domesticated species with only a few breeds having an established color. Much greater genetic variation of color than any other domesticated species. The demand for white fibers and the primium price paid for them will result in a much more intensive selection for white color.

Heritability Estimates

Most variations in fiber production and fleece characteristics are due to the interacting effects of genes at many loci. The basic parameters needed for constructing breeding plans are the heritability of each character and genetic correlections among the characteristics. In recent years estimates of genetic parameters influencing responses to selection for production and fleece characteristics of cashmere have been published. The range of heritability estimates for liveweight, fleece weight and fleece characteristics for cashmere-producing goats are given in table 3.

Due to the difference of the animals, environments, models and estimation methods, the heritabilities are different. But from these results we can find that down weight and two of its components (diameter and length) and yield have high heritabilities, but the density of secondary follicles and primary follicle, and kidding have considerably lower heritabilities. Liveweight, total fleece weight and S/P ratio have moderate heritabilities while the multi-birth has high heritability. The high heritabilities for down weight and length indicate that down weight can be improved by selection. The heritability for weight of guard hair is lower than that for down weight and this may reflect the genetic difference between the Primary and Secondary follicle populations as cashmere is produced entirely by Secondary follicles. Heritabilities for the skin-follicle characters were lower than those for down weight, length and diameter. This indicates that genetic variation in down weight may be caused mainly by variation in length and diameter. Alternatively, it may be that sampling and measurement errors involved in sectioning the small samples of skin have inflated environmental variance thus reducing heritability (Pattie and Restall, 1989). Because of lower heritability and requirement for trained technical staff and laboratory back-up, direct selection on S/P ratio will be difficulty to implement and will have poor genetic gain. As down and guard hair weight are calculated through estimation of down yield, estimates for these traits will be automatically subject to a spurious positive correlation. Nevertheless, the results indicate that there will be more genetic variation present for down weight than for hair weight in cashmere producing goats assuming similar phenotypic variation.

Body weight is an important trait because of its positive effect on body surface area and goat meat, and many Spanish goats in American are small in size. Increasing the body weight by selection will also increase the profit of producer and cashmere production (Teh, 1990).

The heritability of kidding rate is relatively low. It is mainly influenced by environment. In contrast, the heritability of multiple birth is high. So selection must be carefully studied because bias against twins or triples will result in permanently lose in breeding program. Because reproduction rate has an important effect on the profitability of a breeding through its direct influence on the number of surplus stock that can be sold. It also has indirect influence through the rate of genetic improvement because increased fertility will increase intensity of selection and allow generations to be turned over more rapidly.

Bigham et al. (1993) found that the heritabilities were generally higher for traits in yearlings than for traits in the same animals as kids. So the age may influence the value of estimates. But the present breeding goal want to improve lifetime production of cashmere so the application of estimates must be carefully studied.

Bigham et al. (1993) compared the heritabilities estimated using univariate method and that using multivariates methods, the later had higher value than the former. Also the age of dam, year, date of birth, year of the birth, birth and rearing rank and management influence the production level, adjustment of production record for environmental factor will increase the effectiveness of breeding plans.

Phenotypic and Genotypic Correlations

The range of genetic and phenotypic correlations estimated for live weight, fleece characteristics for cashmere producing goats are listed in table 4. The most important traits for maximizing financial returns from cashmere goats are down weight, fiber diameter and liveweight (Millar, 1986). Liveweight is generally negative correlated with various fleece and skin characteristics and these kinds of relationships are unfavorable for simultaneous improvement of liveweight and down weight. However, positive phenotypic relationships between liveweight and some of these characters indicate the presence of environmental correlations which mask the negative genetic relationships. Also Pattie and Restall (1989) found there were many progenies which had high liveweight and down production so it would be possible to improve both with suitable selection index.

There is a high correlation between fleece weight and down weight, but fleece weight can not accurately be used to assess down production because down weight is calculated from total fleece weight and yield, there are automatic 'spurious' positive correlations between these traits and also if fleece weight is used as a predictor of down weight, hair weight will also increased.

There are very strong relations between down weight and its components (down length and diameter). Selection for down weight will result in increase down diameter which will decrease down quality or disqualify the characters of cashmere. Generally keeping the diameter in the range of requirements improving down weight is the selection goal of cashmere production. Strong relationship between down weight and down length give the light in cashmere selection, down length can be used as a predictor of down weight. Down length is easy to measure on the animal prior to shearing and can therefore greatly reduce the costs of estimating down yield.

Secondary follicle density and S/P ratio had moderate positive genetic correlations with down weight, indicating that they would be increased following the selection for high down weight. However , lack of strong relationships and low heritabilities show that specific attention to the skin parameters would result in little increase in down production and would not be warranted in a selection program.

There are favorable genetic correlations between liveweight and both components of reproduction so that objectives related to improving the meat producing ability of these goats are compatible. However the situation with down production is not so promising. There is a negative and sufficient magnitude correlation between down production and multiple birth to raise concerned in the design cashmere selection programs.

Management Factors Influencing Fiber Production

Nutrition

There is a positive relationship between fiber growth and feed intake in sheep and Angora goats. Increasing the level of energy and protein will result in increased fiber production. But cashmere production appears relatively insensitive to nutrition under grazing conditions although guard hair production may be responsive (Norton, 1984). For Australian goats, cashmere growth does not respond to increased food intake above maintainence (Ash et al., 1987; Mcgregor 1988), protein supplementation (Ash et al., 1987; Johnson et al., 1986; McGregor, 1988; Jia, 1991) or to the provision of Methionine (Ash et al. 1987) with hair weight increased by supplementation in all above studies. But when goats were fed less than their maintenance requirement the cashmere growth rate decreased (McGregor, 1988).

Klorean et al. (1993) found that feeding level did not influence cumulative or additive cashmere length, cashmere growth rate, maximum length grown, initiation and cessation dates, the period of cashmere growth, cashmere diameter, cashmere or hair volume growth rates, the calculated number of cashmere, cashmere hair weight.

Ma et al. (unpublished data) found that supplementation of rare earth elements increased down yield, down production.

Age

Fiber production and fleece characteristics are influenced by age. Fiber growth rate increases from birth to maximum at 3 to 4 years of age after that it declines (Gifford et al., 1990). Kloren et al. (1993) found that 16 month old goats had longer cumulative cashmere length, longer additive cashmere lengths (cashmere length from the addition of lengths grown on repeated shorn areas of skin) in May and June, greater cashmere diameter, greater cashmere volume ($3.142*LD^2/(4*10^9*days)$, L and D are the average length (mm) and diameter (μm)) growth rate, more active growing cashmere fibers, more cashmere in Australian cashmere producing goats.

McGregor (1991) found that the adult bucks had higher yielding fleeces with coarser cashmere and higher estimated S/P follicles ratio than other classes of Liaoning goats. Ma et al. (1992) found that adult ZiWuling goats and its crossbreeds had greater cashmere production: adult does were 1 to 1.5 μm coarser than yearling does, adult bucks were 2 to 3.5 μm coarser than yearlings. Restall and Pattie (1989) found that there was a significant non-linear components showing rapid increases in down weight, diameter, length and liveweight between the first and second fleece with reduced increases thereafter. The down production and fiber dimensions were continuously increased, the diameter difference between fourth fleece and first fleece was 2.2 μm.

Sex

Pattie and Restall (1989) and Gifford et al. (1990) reported males were heavier and grew more down at each age than females but the diameter and length were not different in Australian cashmere goats. In contrast to this, Bigham et al. (1993) found that male goats had heavier total fleece weight, female had higher yield, male and female had no difference in down weight. Ma et al (1992) reported that yearling ZiWuling and its crossbreeds female goat produced more cashmere, were coarser than yearling males, but adult males had greater cashmere diameter.

Mcgregor et al. (1991) reported adult Liaoning cashmere bucks had higher cashmere yield and adjusted cashmere yield (cut the hair to the same length with down), greater cashmere diameter, longer cashmere length and hair length, higher S/P ratio, greater cashmere length/hair length ratio and cashmere diameter/length ratio than females.

Reproductive Status

Due to the changes in partitioning of nutrients and physiological status during the pregnancy and lactation, the fleece production is affected. Restall and Pattie (1989) reported that pregnancy and lactation severely restricted fleece growth and appeared to act multiplicatively. Pregnancy reduced down production by 30% and lactation by 48%; together they resulted in a reduction of 65%. Kloren and Norton (1993) reported that pregnancy or lactation did not influence the rate of cashmere or hair growth, instead they affected the initiation and cessation times and period of activity. Kidding one month before summer solstice (normal initiation time of activity) will delayed initiation. Kidding before the winter solstice (normal cessation times of activity) resulted in early cessation of growth cycle. Kidding during the growth period of cashmere will resulted part of follicle growth totally inhibited. Kidding one or two month after the winter solstice had the least effect on cashmere growth, while kidding at other time resulted in reduction of the cashmere growth period and a reduction of heavestable length of cashmere. So if shearing is practiced in February (in United States), kidding from April onward is unlikely to reduced harvestable cashmere. Similarly, with initiation of cashmere growth occurring in July, kidding up to June is unlikely to delay initiation of cashmere growth. Kidding outside these times would require does to be shorn around 2 months prior kidding when cashmere growth has ceased. Kidding during the active cashmere growth cycle is likely to result in significant reductions, and may result in complete inhibition of cashmere growth.

Birth Type

Single-born animals had weight advantage and grew more down (Restall and Pattie, 1989; Bigham et al., 1993), with longer and coarser down in Australian feral goats (Restall and Pattie, 1989), but with similar diameter and longer down in NewZealand Cashmere goats (Bigham et al., 1993). These differences were greatest at first shearing but small differences still remained at fourth shearing. So selection for down production must be adjusted for birth type in the yearling animal selection.

Harvesting Method

There are two methods to harvest the cashmere: traditionally combed from the moulting goats (China, Mongolian, Russian, Iran and Indian), and shorn from the goats

(New Zealand, Australian, England and United States)(McGregor et al., 1991). As the inner-coat sheds in the spring before the outer-coat, it is possible to separate the fiber types as required for cashmere production by choice of combing time. The methods used are related to the economic development level and labor value, and are also related to the geography, ecological condition and management. The shearing method can avoid broken fibers due to combing and increase the average length of cashmere, but the animal remain virtually naked for some time until growth recommences.

To meet most processing requirements, cashmere should be shorn once yearly. Recently Australian researchers try to shear twice yearly to increase cashmere production. Norton (1984) reported that twice a year can increase cashmere production. Johnson (1986) reported that shearing feral goats twice a year at April and July can increase the cashmere weight by 76%. McDonald et al. (1987) found changing the photoperiod regime of the goats resulted the change of fleece growth cycle, so shearing times should be changed. The frequency of harvesting depends on the harvesting method and cashmere length, climate.

Timing of harvesting is very important for moulting goats to maximum the amount and length of harvested fiber. Too early will result in short length and cold stress to animal; too late loss of cashmere. Mitchell et al. (1988) found that shearing in early of May resulted in 25% shorter, in August resulted in loss of cashmere in New Zealand goats, so the best time for New Zealand goats is June when the cashmere is longest and less cashmere is lost. McDonland et al. (1987) reported that because the growth season was January to July in Australian goats, the best time for shearing is June to July.

The extent of the difference between fleece shorn at different times is also related to the level of feeding and the physiological status of the animal. These factors all impact the suitability of the fiber for a particular processing route and end-use. Shearing cost, the sale value of market, cash flow requirements and interest charges also impact on the decision as to the optimum time to shear (Parker and Gary, 1989).

Breeding Objectives and Selection Indexes

In the traditional cashmere producing countries, the cashmere producing goats are raised extensively, and recording performance and pedigrees becomes very difficult. There are limited published data on selection for finer traits and undercoat production. Recently along with the increase of concern and importance of cashmere, more researches have been conducted in Russia, Scotland, Australian and New Zealand (Russel and Bishop, 1990; Pattie et al., 1989; Ponzoni et al., 1990; Baker et al., 1991; Restall et al., 1989; Gifford et alm, 1991; Couchman, 1983).

Breeding Objectives

Factors that affect income from cashmere goats that could be considered in a breeding objective include qualitative characters, such as color, and a range of quantitative traits for body, fleece and reproductive characteristics, such as undercoat weight, fiber diameter, fiber length, body weight and body size, S/P ratio (Millar, 1986; Pattie et al., 1989). In Australian, white down from goats with white guard hair is preferred by processors and attracts a price premium over gray and brown down; white down from colored goats receives the price for gray down (Pattie et al., 1989). The inheritance of down color is not fully determined, but it is likely different from guard hair because white down can be grown by goats with colored hair. Breeding objectives usually aim to produce white animals and this character is treated independently to other measured characters.

Increasing lifetime down weight, reducing down diameter, increasing fiber length and body weight are also the goals of farmers. But due to unfavorable correlations between fiber diameter and other down characteristics, increasing down weight and length will result in an increase of fiber diameter. With the prices applicable at the time, a breeding objective to maximum financial returns would result in increasing for fiber diameter and reducing in body weight. Such an objective would not be sustainable in the long term and would have to be changed before diameter increased to a level where down could not be sold as cashmere. Restricting the diameter and body weight, increasing down weight and length will be suitable objectives for cashmere production.

Ryder (1984) suggested that selection on undercoat weight would result in increase in undercoat density. But due to low heritability and special equipment and trainer required, direct selection based on skin characteristics are avoided (Millar, 1986). Pattie and Restall (1989) also reported that including S/P ratio, Secondary follicle density and Primary density in selection index did not increase genetic gain.

In the future, it is possible that pricing schedules may include penalties for low yield, because of processing costs, and wide diameter distribution because of the reduction in dehair efficiency and product quality caused by excessive numbers of coarse fibers. At the present there is insufficient information available to derive satisfactory economic values and include these characters in a breeding objective.

Selection Criteria and Economic Weight Value Estimates

In the United States, all cashmere producing goats are goats with emphasis on meat, milk, or fur. The interests of the cashmere industry will be served by a specialized breed used almost exclusively in purebred production. The future large-scale cashmere goats industry is likely to have a hierarchical structure in which breeding herds (breeding their own male and female replacements) and commercial herds (purchasing replacement males from breeding herds) can be distinguished. With this breeding objective and breeding structure, the traits that influences the future cashmere industry would be cashmere down weight, down diameter, live weight and kidding rate and multiple births.

In Australian and New Zealand, the testing and classification systems are well developed. The purchasing price of cashmere are basically determined by characteristics of cashmere. Ponzoni and Gifford (1990) derived the economic value for each trait from the profit equation using discount gene flow.

The development of efficient selection systems for improving down production is restricted by measurement problems. Full measurement of yield, and hence down weight and diameter is very expensive, so independent culling methods and two-stage methods are used in cashmere selection programs (Pattie and Restall, 1985, 1987, 1989). In independent culling selection programs, the easily measured traits are selected first, and the expensive measurements left till last when they are needed on fewer animals. A major problem with independent culling levels is that it is extremely difficult to calculate the correct levels where more than two characters are to be included. Furthermore, a set of culling levels must be applied in a specific order at all times and this can be inconvenient. Pattie et al. (1986, 1989) developed a multi-stage selection index. In the first stage, the traits included were body weight and down length. Besides these traits, down diameter and down weight or diameter are included in the second stage selection index. However, selection down weight will be followed by increased diameter and reduced liveweight and fecundity. Restricted selection indexes to set the diameter and liveweight change to zero resulted in halving of the potential rate of increase in cashmere production (Pattie and Restall, 1986, 1989).

The characteristic of greatest general economic importance to goat farmers is the amount of saleable fiber produced by each animal. In biological terms fleece weight is determined by the number of follicles producing fiber, average fiber dimensions and fiber gravity and can be expressed by the relationship:

$$W=S \times N \times A \times L \times D \qquad \text{(Turner, 1958)}$$

Where W=clean fleece weight; S=skin surface area; N=average density of active fiber-producing follicles; A=average fiber cross-sectional area; L=average fiber length; D=average specific gravity of fibers. Some research has been done on how to increase down weight and quality, especially in Australian and New Zeland. But in the United States more information is needed to improve the down production of Spanish Goats to find alternative resources for cashmere industry.

TABLE 1 SECONDARY/PRIMARY FOLLICLE (S/P) RATIO FOR SEVERAL BREEDS OF GOATS

Breed	S/P Ratio	Source
Milk	3.70	Clarke, 1977
Saanenurg	3.00--5.00	Ryder, 1966
Red Sokoto	2.50--3.90	Ryder, 1966
Australian	4.00--5.00	Burns, 1965
Toggenburg feral	5.80--7.00	Clarke, 1977
	6.68	Henderson et and Sabine, 1991
	6.87	Lambert et al., 1984
	5.84--7.09	Restall and Pattie, 1989
	5.74--7.27	Restall et al., 1984
	6.06--6.51	Parry et al., 1992
Siberian	9.86	Rhind and McMillen, 1995
Icelandic x Scottish	6.35	Rhind and McMillen, 1995
Saanen x Toggenburg	6.00	Ryder, 1966
	6.40--9.10	Clarke, 1977
Angora	6.56	Pant and Kapri, 1966
	7.17--7.40	Koratkar and Patil, 1983
	9.20	Dreyer and Marinocowitz, 196

TABLE 2. ALLELIC COAT COLOR SERIES IN GOATS

Agouti locus		**Brown locus**	
A^r	red	B^+ *or* B	wild, black eumelanine
A^b	badger-face	B^d	dark brown
A^+ or A	wild	B^l	light brown
A^t	black and tan		
A^{tb}	black and tan, black belly		
A^{rc}	red check	**Extension locus**	
A^m	mantled	E^d	dominant black
A^{mr}	mantled reversed	E^+ or E	wild
a	non-agouti		

Spotting locus		**Roan locus**	
S^p	pitbald	Rn^d	dominant roan, homozygous Rn^d is white)
S^+ or S	wild	Rn^+ or Rn	wild

Source: Millar, 1986.

TABLE 3 RANGE OF HERITABILITY ESTIMATES FOR LIVE WEIGHT, FLEECE CHARACTERISTICS, AND REPRODUCTION TRAITS IN CASHMERE-PRODUCING GOATS

Characteristic	Heritability
Liveweight	
Birth weight	0.21
Weaning weight	0.14--0.20
Yearling weight	0.22--0.39
Adult weight	0.29--0.68
Growth rate	0.56
Fleece Traites:	
Fleece weight	0.25--0.45
Hair	0.35--0.55
Yield	0.23--0.92
Down weight	0.36--0.76
Down diameter	0.47--0.99
Down length	0.58--0.93
Primary follicle density	0.16
Secondary follicle density	0.17
S/P ratio	0.17--0.29
Reproduction Traits:	
Kidding	0.21
Multiple birth	0.51

source: Baker et al. 1991; Bigham et al., 1993; Pattie and Restall, 1990; Restall et al., 1984; Sumner et al, 1993.

TABLE 4. RANGE OF GENOTYPIC AND PHENOTYPIC CORRELATION ESTIMATES FOR LIVE WEIGHT, FLEECE CHARACTERISTICS, AND REPRODUCTION TRAITS IN CASHMERE PRODUCING GOATS

Correlation	Genotypic	Phenotypic
Birth Weight and		
Fleece weight	-0.25	0.15
Hair weight	-0.15	0.10
Yield	-0.15	0.02
Down weight	-0.18	0.11
Down diameter	-0.03	0.04
Down length	0.09	0.03
Weaning Weight and		
Fleece weight	0.30	0.17
Hair weight	0.18	0.22
Yield	-0.01	-0.14
Down weight	0.10	-0.02
Down diameter	0.00	0.06
Down length	0.18	0.02
Yearling Weight and		
Fleece weight	0.27	0.33
Hair weight	0.46	0.35
Yield	-0.22	-0.10
Down weight	-0.34	0.09
Down diameter	-0.25	0.13
Down length	-0.32	0.00
Adult Weight and:		
Fleece weight	0.09 to 0.17	0.11 to 0.21
Yield	-0.20 to -0.24	-0.07 to -0.15
Down weight	-0.13 to -0.18	-0.04 to 0.12
Down diameter	-0.06 to -0.14	0.04 to 0.23
Down length	0.00 to -0.31	-0.05 to -0.32
Primary (P) follicle density	-0.38	-0.30
Secondary (S) follicledensity	-0.11	-0.22
S/P ratio	-0.19 to 0.19	0.06
Kidding ratio	0.38 to 0.58	---
Multiple birth	0.39 to 0.52	---

TABLE 4. RANGE OF GENOTYPIC AND PHENOTYPIC CORRELATION ESTIMATES FOR LIVE WEIGHT, FLEECE CHARACTERISTICS, AND REPRODUCTION TRAITS IN CASHMERE PRODUCING GOATS (CONTINUED)

Correlation	Genotypic	Phenotypic
Fleece Weight and		
Hair weight	0.62	0.78
Yield	-0.39 to 0.43	-0.30 to 0.10
Down weight	0.34 to 0.83	0.41 to 0.80
Down diameter	0.12 to 0.69	0.18 to 0.45
Down length	0.05 to 0.56	0.24 to 0.56
Primary density	-0.15	-0.14
Secondary density	-0.01	-0.09
S/P ratio	0.049	0.041
Hair Weight and		
Yield	-0.44	-0.52
Down weight	-0.10	-0.04
Down diameter	0.07	0.07
Down length	-0.12	-0.01
Yield and		
Down weight	0.74 to 0.94	0.70 to 0.90
Down diameter	0.30 to 0.70	0.25 to 0.45
Down length	0.41 to 0.89	0.41 to 0.89
Primary (P) follicle density	0.22	0.02
Secondary (S) follicle density	0.53	0.17
S/P ratio	0.35	0.21
Down Weight and		
Down diameter	0.04 to 0.81	0.42 to 0.56
Down length	0.45 to 0.92	0.45 to 0.92
Primary density	0.19	-0.06
Secondary density	0.48	0.11
S/P ratio	0.32	0.21
Kidding	0.04 to 0.10	---
Multiple birth	-0.23 to 0.39	---

TABLE 4. RANGE OF GENOTYPIC AND PHENOTYPIC CORRELATION ESTIMATES FOR LIVE WEIGHT, FLEECE CHARACTERISTICS, AND REPRODUCTION TRAITS IN CASHMERE PRODUCING GOATS (CONTINUED)

Correlation	Genotypic	Phenotypic
Down Diameter and		
Down length	0.28 to 0.75	0.28 to 0.75
Primary (P) follicle density	-0.28	-0.13
Secondary (S) follicle density	0.08	-0.13
S/P ratio	0.32	0.21
Kidding ratio	-0.10 to 0.14	
Multiple birth	-0.21 to -0.34	
Down Length and		
Primary (P) follicle density	0.48	-0.00
Secondary (S) follicle density	0.55	-0.07
S/P ratio	0.11	0.09
Kidding ratio	-0.08 to 0.11	---
Multiple birth	-0.29 to -0.48	---
Primary (P) Follicle Density and		
Secondary (S) follicle density	0.37	0.65
S/P ratio	-0.49	-0.27
Secondary (S) Follicle Density and		
S/P ratio	0.63	0.51

source: Baker et al., 1991; Bigham et al., 1993; Pattie and Restall, 1989; Restall et al., 1984; Sumner and Bigham, 1993.

CHAPTER III

Seasonal Variation for the Cashmere Growth and Holding Capacity on Spanish Goats

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Abstract

Seven adult bucks and 134 does were used as the base population to study the season variation of the diameter and yield retention over three years. The fleece from the right side was shorn completely in August and February of each year to determine total fleece weight of each animal. From February through August, strip fleeces were shorn from the left side of the animals every six weeks to measure cashmere retention. Diameter and yield were significant different ($p<0.01$) among different age/sex and year groups. As the age increased the diameter increased, two years old female in June has highest diameter (19.98) in 1993. The diameter decreased from 1993 to 1995, from February to June the diameter increased and from June to August the diameter decreased. When the goats became older, the cashmere retention ability increased. High cashmere producing

goats had better cashmere retention ability. The goats with good retention ability had higher yield, down weight and longer length. Within the animal, the coarser cashmere has better retention ability. The strong relation between the cashmere production and cashmere retention ability indicates selection for cashmere weight will increase the cashmere retention ability.

Introduction

Many mammalian species exhibit seasonal changes in their pelage, the usual pattern being the production of a dense, fine coat which traps warm air for winter warmth, and a less dense coat in the spring and summer allowing air circulation and evaporative cooling. Some animals have a visible molt once a year, with a shedding of the heavy winter coat in spring and gradual growth of the new winter coat throughout the summer (Ryder, 1966, 1974). The pattern of growth of individual follicles can be divided into three main phases, anagen (active fiber growth), catagen (follicle regression) and telogen (resting phase with previously growth fiber anchored in the follicle by a club or brush end) (Chase, 1954; Hendeson and Sabine, 1992). Shedding of the previously grown fiber tends to occur about the time of onset of anagen, having been observed to occur both before and after growth of the new fiber with shedding in cashmere-producing goats (Nixon et al., 1991). Breeds of sheep and goats differ in their pattern of fiber growth. For sheep, it is now widely accepted that seasonal variation in wool growth in many domestic breeds is a modified vestige of this primitive rhythm of molting and replacement of fibers (Ryder and Stephenson, 1968), even when the sheep is kept on a constant diet there is still a residual seasonal pattern that is independent of nutrition (Ferguson et al., 1975). Some sheep breeds, however, show less seasonal variation than others (Ryder, 1966, 1974), and a decrease in the tendency to shed appears to be associated with increase in the degree of selection for wool production. Soay and Shetland Sheep have visible molt in the spring with lesser molt in the autumn; the merino sheep apparently has continuous wool growth during the whole year (Ryder and Stephenson, 1968). The same trend is also true for the goats. In the cashmere-bearing goat, the whole of the down undercoat produced from secondary follicles is shed each year in late winter/early spring (Burns, et al., 1962), whereas the Angora goat has lost its tendency to shed. Even in cashmere goats there also exists some difference between breeds, the high fiber yield breed molt late and initiated early (Rhind and McMillen, 1995). The coat of cashmere goats consists of a thick heavy outercoat of long, straight, coarse medullated fibers, and undercoat of short, nonmedullated "down" cashmere fibers. The former is produced by primary follicles and the later is produced by secondary follicles. The Pattern of primary and secondary fiber growth in molting breeds is different. Primary fibers are replaced as they are shed maintaining a covering over the animal. Replacement of Secondary fibers however may not occur for 1 to 3 months after shedding (McDonald et al., 1987). The season pattern of down production in cashmere-producing goats commences around the summer solstice and ceases near winter solstice (Betteridge et al., 1988). The S/P fiber ratio in these animals is low in early summer and high in winter (McDonland et al., 1987).

The season cycle in down cashmere growth is associated with concomitant changes in fiber length growth rate, mean fiber diameter and mean fiber volume (Henderson and Sabine, 1992; McDonald et al. 1987; Rhind and McMillen, 1995). Significant increases in average cashmere length growth rate occurred as the daylength decreases and a maximum cashmere fiber growth rate is reached in mid-summer and this is maintained until late winter (Henderson and Sabine, 1992). Fiber diameter reached maximum in Autumn but then decreased in winter. In sheep, Woods and Orwin (1988) found, using Autoradiographic, length growth rate cycle and fiber diameter cycle are independent and differ between animals and between fibers within animals. Individual animals have very similar fiber development pattern in consecutive years (Henderson and Sabine, 1992). These trends highlight the complexity of physiological mechanisms regulating fiber length and diameter growth changes at the follicular level (Orwin, 1989).

The physiological control mechanisms which regulate fiber growth are presently unknown but are associated with photoperiod. Fiber growth cycles appear to result from intrinsic rhythms within the follicle modified by systemic inputs that entrain the cycle. The systemic input is probably mediated via the nervous system (Sumner et al, 1993). Evidence for an intrinsic rhythm is provided by skin transplant studies where follicles retain their original rhythm and fiber characteristics following either graft rotation (Ebling and Johnson, 1959) or delayed grafting (Ryder and Priestley, 1977). Seasonally molting goats held in constant photoperiodic conditions also maintain a shedding cycle, although this trends with time become disengaged from the normal seasonal pattern (McDonald et al., 1987; Maxwell et al., 1988). Goats located in different latitudes is different with respect to time of molting (Henderson and Sabine, 1992). Associated with the center nervous system is evidenced by pinealectomy (Rougeot et al., 1984) and cervical sympathectomy (Lincoln et al., 1980) as both procedures inhibit molting. The timing of molting in cashmere-producing goats (Betteridge et al., 1987; Lynch and Russel, 1989) can also be influenced through the use of exogenous melatonin to mimic the effect of short days.

The characteristics of greatest general economic importance to cashmere goat farmers is the amount of saleable fiber produced by each animal and new kids. Due to the seasonal cashmere growth and associated characteristics change, the choice of appropriate harvesting time to maximum the economic income always concerns the farmer. In China, the combing method is used to collect cashmere, due to the difference of shedding time between the animals, it is very hard to choose the suitable time to collect all the cashmere. Some animals sheded early and lost the cashmere, but late shedding animal's cashmere is hard to collect due to not loose from the skin. In United States and Western Countries the shearing method can avoid this problem, but the early shearing will result in stress to the animal due to cold weather in late winter and early spring. Selecting for holding capacity is very important to increase farmer income.

The cashmere weight difference between the animals are largely due to the combined differences in fiber length growth, fiber cross-section area, total follicle number and wool-bearing surface areas. In sheep the difference between the high fleece weight and low fleece weight group (Wuliji et al., 1995) is mainly due to the growth rate difference in winter; the high fleece weight group has high growth rate in winter.

Increasing the length of the cashmere will increase the cashmere production. Selection based on animal difference in seasonal growth pattern could be exploited for better cashmere production. Accordingly, the present work was designed to measure in detail the change in cashmere components during the season. The aim of this research to determine the holding capacity of each animal, the seasonal change of the cashmere and the relation with cashmere weight.

Materials and Methods

In the fall 1991, seven adult bucks and 134 adult does were purchased from several farms in Texas as the foundation animals for this experiment. Twenty cashmere goats were also donated to this project from a cashmere breeder in New York. Cashmere production and ability of the goats were evaluated objectively for yield, length, diameter and holding capacity. In the first year only 43% of the animals purchased showed ability to hold cashmere. Bucks were evaluated using the same procedures and only two bucks were used for (Pattie and Restall, 1989) subsequent breeding experiment. Goats that did not produce the commercial quantity and quality or holding capacity of cashmere were culled. The Australian Stage II index was also used to cull non-productive animals.

This experiment began in fall of 1992. Bucks were separated from the does until the breeding season. Does were supplemented with one pound of concentrate (16% CP and 70% TDN) per day one month before the breeding season (September 15th) and also during the lactating periods. Throughout the kidding period (March to April), birth weights and litter size of kids were recorded. Kids were immediately eartagged and earnotched.

In August and February of each year, the right side fleece of bucks, does and kids were completely shorn for determining total fleece production. A grid sample was also taken for determination of yield, diameter and length. Fleece samples were analyzed for cashmere yield (Shirley Analyzer, SDL 102A-Wool Model, England), diameter (FDA) and length (February samples only, manually with ruler graded in mm). Body weight were also measured in February and August. Strip fleece samples (40 cm long) were taken in February, March, April, May, June and August in 1993 and in February, April, June and August in 1994 and 1995 on the left side of the animal to monitor shedding pattern of cashmere fiber. These fleeces were also analyzed for length, yield and diameter as described above.

Results of strip fleeces, from February through August, were used to calculate holding capacity index, an objective measurement on individual's ability for shedding and holding of cashmere over time. The holding capacity was calculated as follows.

1. Yield was calculated for each strip sample.

2. Using general linear models procedure to do multivariable analysis to estimate the variance and covariance of age, sex and period using all period data.

3. Using repeated measures analysis of variance method to estimate the nth degree polynomial contrast for periods to find linear, quadratic, cubic (for 1994 and 1995 data), 4th or 5th degree influence.

4. The result from step 3 were used for regression analysis for each animal get regression curve line.

5. The equation for the curve was used to calculate the area between the line and X axis to calculate the area which is the holding capacity index for each animal.

Statistics analysis: Using SAS GLM procedure to do variance analysis for the yield and diameter. Due to small numbers of animal for some age and sex groups, the two were combined to perform the analysis. The model included age/sex, animal within each age/sex group, periods, and age/sex & period interaction. The contrast for the periods were adjusted for the age/sex and the animal effects. The correlations were also adjusted for the age/sex and animal effects.

Results and Discussions

Diameter Variation

The analysis of variance for the diameter is presented in Table 1. Age/sex, animals within age/sex, periods, interaction between age/sex and period significantly influence the cashmere diameter of the Spanish goats. The diameter variation with period in each age/sex group is shown in figure 1 and figure 2. In 1993 two years old female had largest diameter, in females from one year to two years old the diameter significantly increased, then from two to three years it decreased a little and three year old male and female had similar diameter. In each age/sex group, from February to June, the diameter gradually increased, but the cashmere in August had the smallest diameter, which indicates the new fiber are grown. This will be verified from the yield variation with period. In 1995, two years old females had largest diameter, the male and female were similar in one year old, and diameter in August is smallest. The least squares means for diameter also revealed that the two and three years old female's products in June were not good enough to be used as the cashmere.

In 1993, the diameter changes with periods were quadratic, cubic, and quartistic (Table 2). These changes may be confounded with seasonal change within each fiber(from February to June the diameter increased). The cashmere population changed within animal(finer cashmere lost from the body), the animal population changes (the goats with finer cashmere molted early). The correlation coefficients of the diameter between different periods in 1993 (Table 3) were large. This indicates a strong relationship between periods within the animal, from February to June the individual fiber diameter increased with period; the diameter in August was lower than that in April and June also indicated the new fiber, which had smallest diameter, compose some part for the August cashmere population. In each growth cycle, the fiber diameter, from beginning to the end, increased.

Yield Variation

The Analysis of Variance for the yield is shown in Table 5. Age/sex, year, animal within age/sex, period, interaction between period and age/sex were all significant factors influence of the yield. Yield did not change much among age/sex groups (Figure 3), but 3 years old males had the highest yield which may be due to sex or to genetic differences.

From February to August, the yield decreased, but in different age/sex groups the degree of the change was different. Two years and three years old females decreased more slowly then one year old females and three years old males had the slowest change during periods. Yield in August was greater than that in June (Figures 4 and 5), which is because some new fibers were grown. The yield variation during the periods for the one years old male and female is smaller than that for the two years old female. The yield variation in 1995 was smaller than that in 1994.

For the individual animal, the yield changes with period have liner, quadratic and cubic regression (Table 2). The correlation coefficients of the yield among the periods were significantly larger than zero (Tables 6, 7, and 8). Higher yield animals had high yield later, so the higher yield animal had good holding capacity.

These results indicated the characteristics of cashmere had seasonal variation. This seasonal change was confounded with the change of the cashmere population within the animal and animal population. In order to test the animal population difference, Animal were divided into two groups (zero and non-zero) according the yield in each period. If the animal had cashmere it was assigned into non-zero group, otherwise the zero group, and tested their performance difference in February. The good holding capacity animal has higher yield and heaver downweight and longer down length. In 1993, the yield of the animal which held cashmere in May and June was significantly higher than that of the animal which did not hold cashmere. In the other periods, the animal which held cashmere are also higher, but there was no statisticly significant difference. Also the downweigh was significant heavier for the animals which had good holding capacity than that for the animal which could not hold cashmere in May and June. But the animals which had good holding capacity also had larger diameter. So the animal population change contributed to the diameter change during our experiment. The fleece weight for the good holding capacity animal was not different from the animal with poor holding capacity. The higher cashmere producing animal had good holding capacity. In 1994, there were no statisticly significant difference in yield, downweight, length and fleece between the animals with good holding capacity with animals with poor holding capacity, but there existed some difference in value (Table 10). In 1995, the animals which held cashmere in April, June and August had higher yield in February than the animals without holding cashmere. The goats holding cashmere in April had heavier downweight than the goats without holding cashmere. The down length of the goats holding cashmere in April was longer than that of the goats without holding cashmere (Table 11). These results indicate the good holding capacity goats had higher performance than the animal with poor capacity. Selection for cashmere weight will increase the cashmere holding capacity. Cashmere goats with good holding capacity may have a longer producing period.

Since the value of cashmere fleece is determined by diameter, color and weight of the cashmere fiber, circannual change in diameter and other fleece components to weight will influence the financial return from goats. It can be concluded from this work that cashmere production may be maximized by exploiting the basic circannual rhythm of growth. It is possible to determine the harvest time to maximum production profit. Also the goats with strong holding capacity had high performance and a longer growth season. Selection for holding capacity should increase the cashmere production performance.

Conclusions

The environmental factor (grass condition and management) influenced the cashmere production. The physiology condition (age and sex) also influenced the diameter and yield change. The older animal has coarser cashmere and better cashmere retention. During the cashmere growth cycle the cashmere diameter also changed during season. Higher performance animal had better cashmere retention ability and coarse cashmere producing goats also had better cashmere retention ability. But producing finer and heavier cashmere and good retention ability should be reached through genetic selection.

Table 1. Analysis of Variance for Diameter

Year	93			95		
Source	df	SS	Pr	df	SS	Pr
AgeSex	3	101.0088	0.0001	2	46.1255	0.0001
Animal(AgeSex)	143	878.3263	0.0001	166	281.1292	0.0001
Period	5	50.9679	0.0001	2	7.7703	0.0001
AgeSex*Period	15	35.3668	0.0001	4	9.6547	0.0001
Error	362	101.1199		189	74.3896	

Table 2. Yield and Diameter Variation With Periods

		Period						Contrast				
Year	**Trait**	**February**	**March**	**April**	**May**	**June**	**August**	**Linear**	**Quadratic**	**Cubic**	**4th**	**5th**
93	**Yield**	38.63	36.35	20.64	12.45	5.44	3.89	0.01	0.45	0.01	0.08	0.21
	Diameter	17.20	17.55	17.61	17.37	18.08	16.11	0.05	0.01	0.01	0.01	0.05
94	**Yield**	33.59		20.18		0.45	1.84	0.01	0.01	0.01		
95	**Yield**	36.77		28.58		8.69	15.51	0.01	0.01	0.10		
	Diameter	17.19		16.95			16.56					

1. The Yield and Diameter are significant different among the different period.

Table 3. Correlation Coefficients of Diameter Among Different Periods in 1993

	February	March	April	May	June	August
February	1.00	0.94	0.96	0.91	0.89	0.79
March	0.94	1.00	0.88	0.90	0.83	0.66
April	0.96	0.88	1.00	0.92	0.80	0.73
May	0.91	0.90	0.92	1.00	0.86	0.63
June	0.89	0.83	0.80	0.86	1.00	0.89
August	0.79	0.66	0.73	0.63	0.89	1.00

Table 4. Correlation Coefficients of Diameter Among Different Periods in 1995

	February	April	August
February	1.00	0.72	0.35
April	0.72	1.00	0.35
August	0.35	0.35	1.00

Table 5. Analyses of Variance for Yield

Year	93			94 and 95		
Source	df	SS	Pr	df	SS	Pr
AgeSex	3	8210.0201	0.0001	5	14134.8970	0.0004
Year				1	28607.0467	0.0001
Animal(AgeSex)	151	63480.7468	0.0001	433	113034.5525	0.0001
Period	5	91859.5722	0.0001	3	4.676.3967	0.0001
AgeSex*Period	15	8630.0543	0.0001	15	2810.1199	0.0001
Error	559	50068.0670		985	97280.4665	

Table 6. Correlation Coefficients of Yield Among Different Periods in 1993

	February	March	April	May	June	August
February	1.00	0.86	0.60	0.50	0.33	0.33
March	0.86	1.00	0.72	0.61	0.37	0.26
April	0.60	0.72	1.00	0.61	0.18	0.17
May	0.50	0.61	0.61	1.00	0.41	0.26
June	0.33	0.37	0.18	0.41	1.00	0.52
August	0.33	0.26	0.17	0.26	0.52	1.00

Table 7. Correlation Coefficients of Yield Among Different Periods in 1994

	February	April	June	August
February	1.00	0.64	0.18	0.32
April	0.64	1.00	0.22	0.26
June	0.18	0.22	1.00	0.61
August	0.32	0.26	0.61	1.00

Table 8. Correlation Coefficients of Yield Among Different Periods in 1995

	February	April	June	August
February	1.00	0.69	0.26	0.45
April	0.69	1.00	0.29	0.36
June	0.26	0.29	1.00	0.68
August	0.45	0.36	0.68	1.00

Table 9. Performance Difference in February in 1993 Between Holding and Nonholding Groups

Trait	Group	March	April	May	June	August
Yield	Zero		41.23	36.53[a]	37.15[a]	39.70
	Nonzero		45.69	43.13[b]	42.81[b]	44.39
Down weight	Zero		112.18	105.61[a]	111.53[a]	115.28
	Nonzero		130.22	126.79[b]	133.93[b]	121.30
Length	Zero		4.53	5.45[a]	5.43	5.61
	Nonzero		6.05	5.82[b]	5.94	5.42
Fleece	Zero		291.05	271.04	276.71	273.01
	Nonzero		268.38	278.03	289.48	254.36
Diameter	Zero	17.11	16.75[a]	17.38	17.08	17.44
	Nonzero	17.49	17.77[b]	17.42	16.71	17.28

The follow pairs are significant different: yield in May and June; downweight in May and June; length in May; diameter in April.

Table 10. Performance Difference in February in 1994 Between Holding and Nonholding Groups

Trait	Group	April	June	August
Yield	Zero	29.77	31.90	33.32
	Nonzero	32.42	32.15	36.65
Down weight	Zero	107.70	125.20	120.31
	Nonzero	130.10	123.50	127.60
Length	Zero	3.02	4.01	5.56
	Nonzero	4.14	5.00	5.05
Fleece	Zero	361.30	389.90	360.82
	Nonzero	400.90	392.40	346.38

Table 11. Performance Difference in February Between Holding and Nonholding Groups in 1995

Trait	Group	April	June	August	August in 94
Yield	Zero	25.31[a]	39.93[a]	28.89[a]	40.33
	Nonzero	44.00[b]	46.38[b]	37.06[b]	43.49
Down weight	Zero	61.66[a]	107.56	88.72	116.98
	Nonzero	123.70[b]	122.34	97.24	130.27
Length	Zero	3.50[a]	4.54	4.35	4.89
	Nonzero	4.82[b]	4.79	4.53	4.87
Fleece	Zero	230.23	273.17	295.18	298.17
	Nonzero	288.01	269.49	267.57	297.64

The follow pairs are significant different: yield in April, June and August; Down weight in April; Length in April.

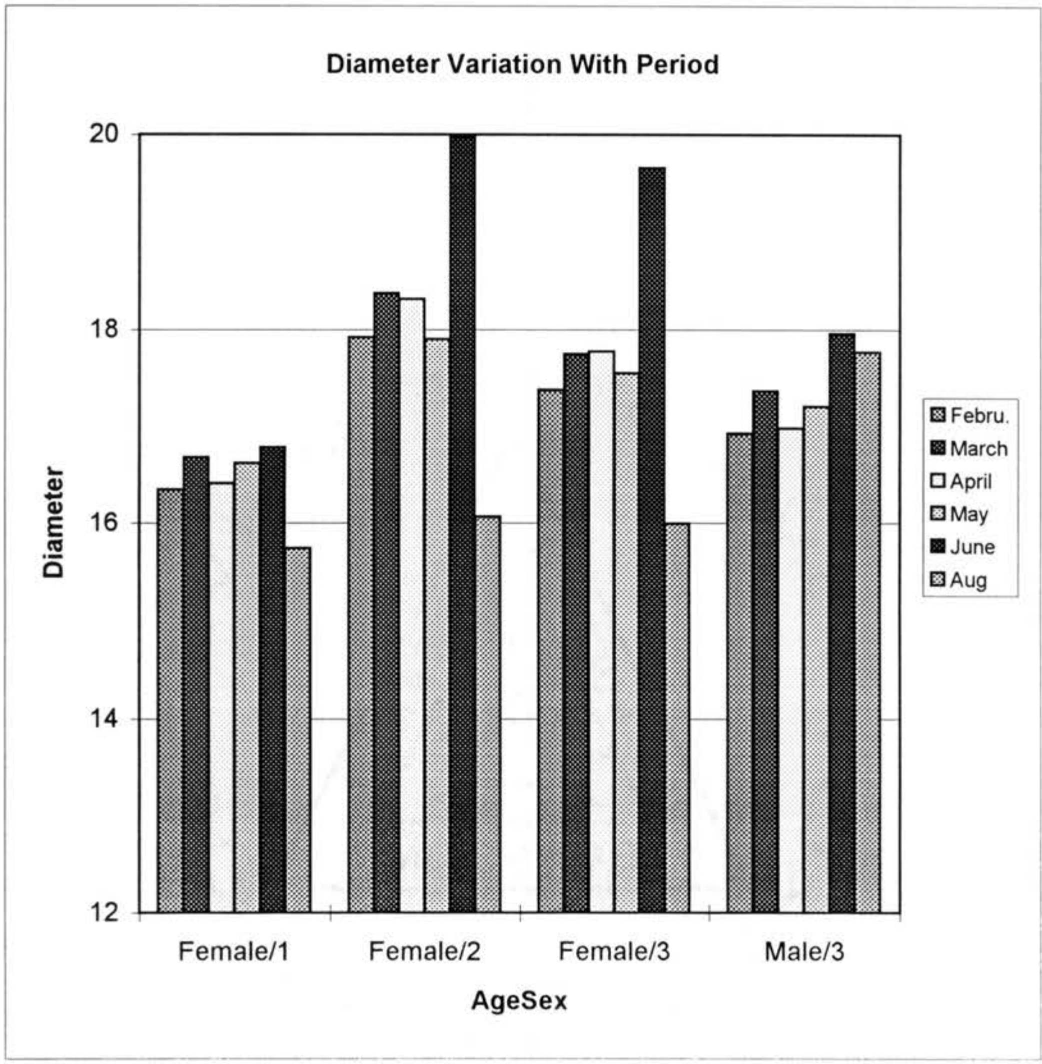

Figure 1. Diameter Variation with Period in Each Age/Sex Group in 1993

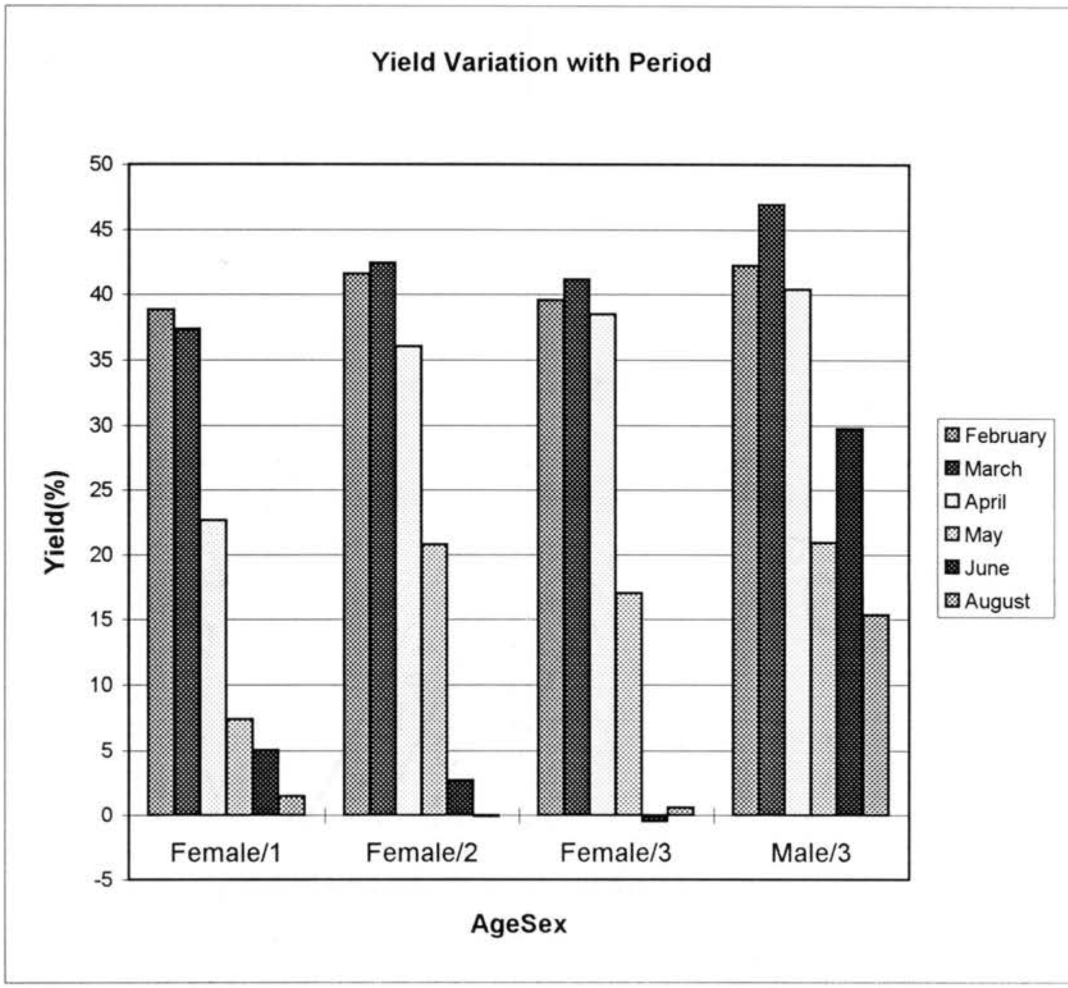

Figure 3. Yield Variation with Periods in Each Age/Sex Group in 1993

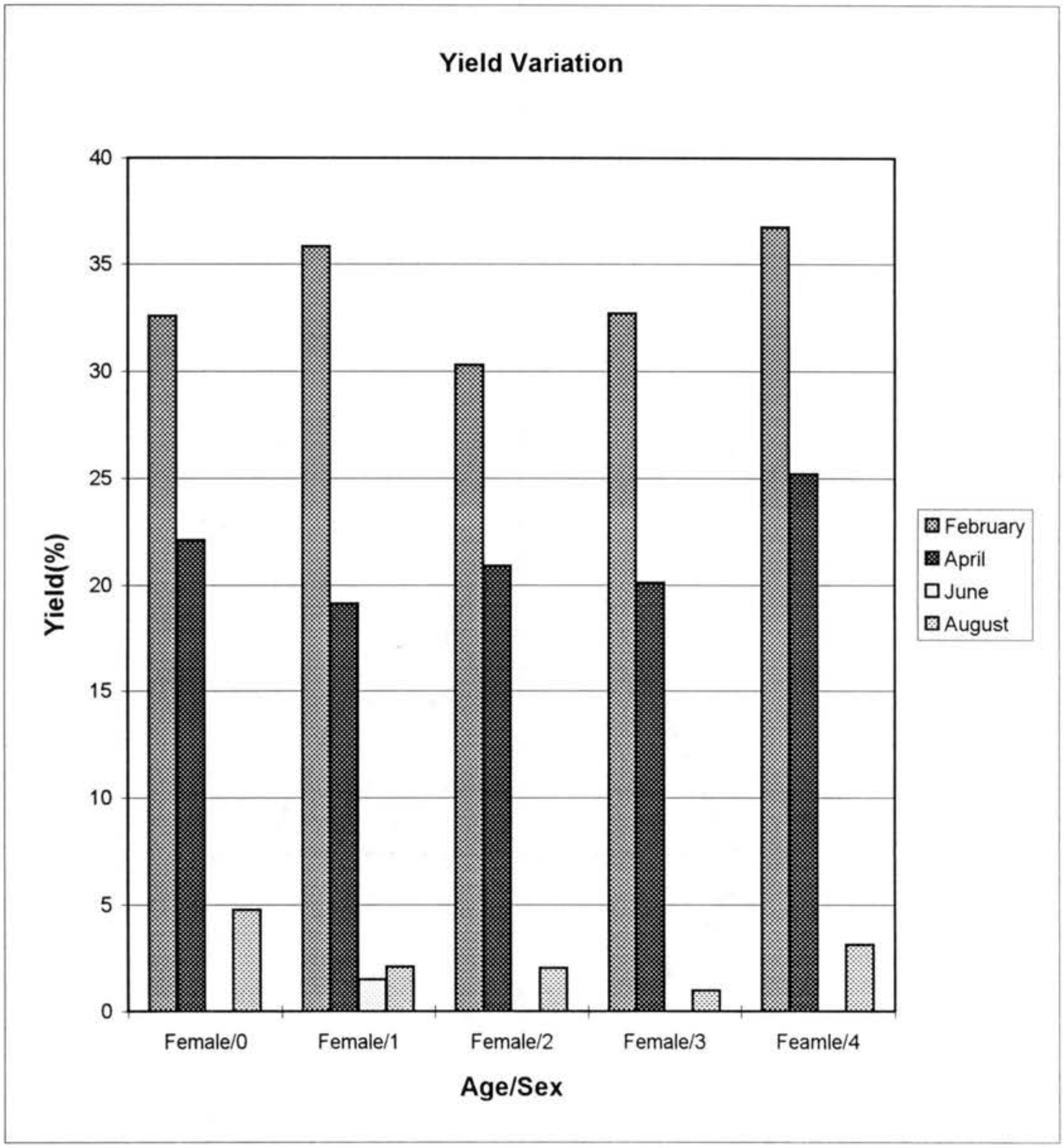

Figure 4. Yield Variation with Periods in each Age/Sex Group in 1994

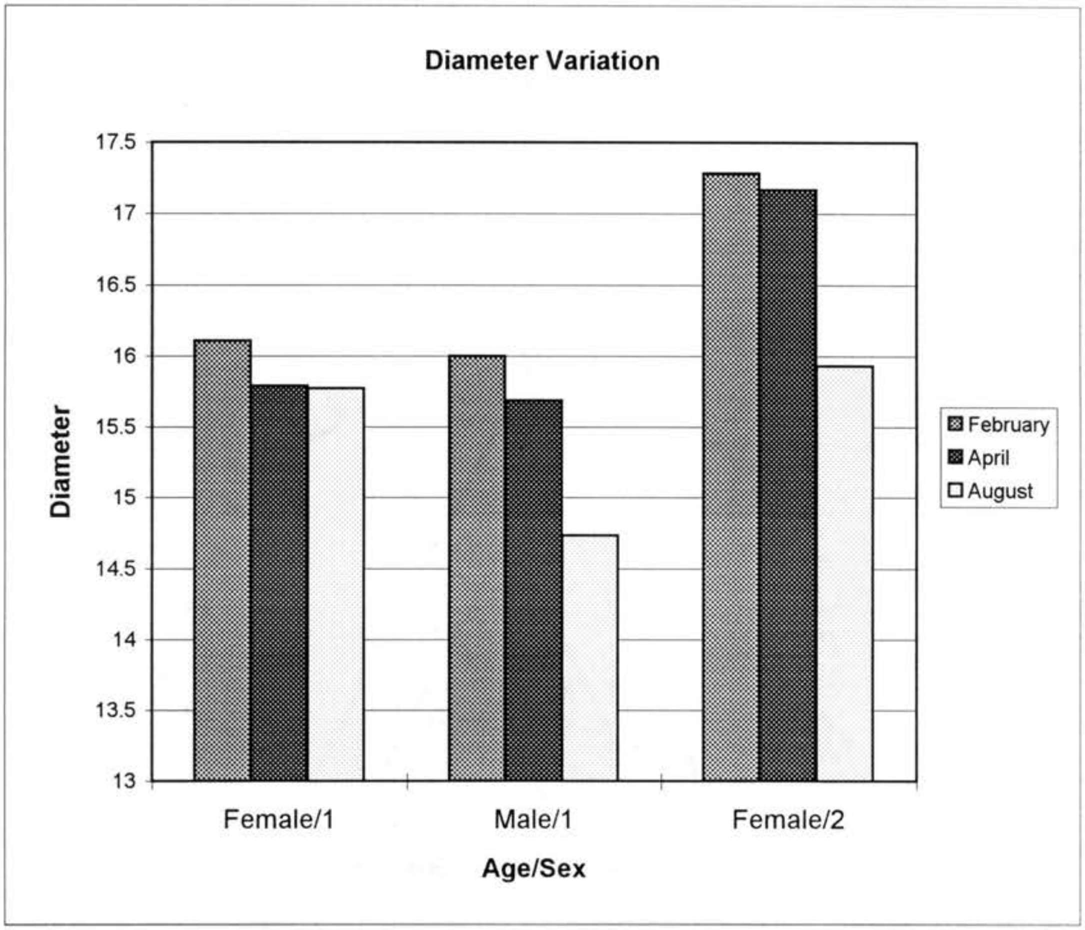

Figure 2. Diameter Variation with Periods in Each Age/Sex Group in 1995

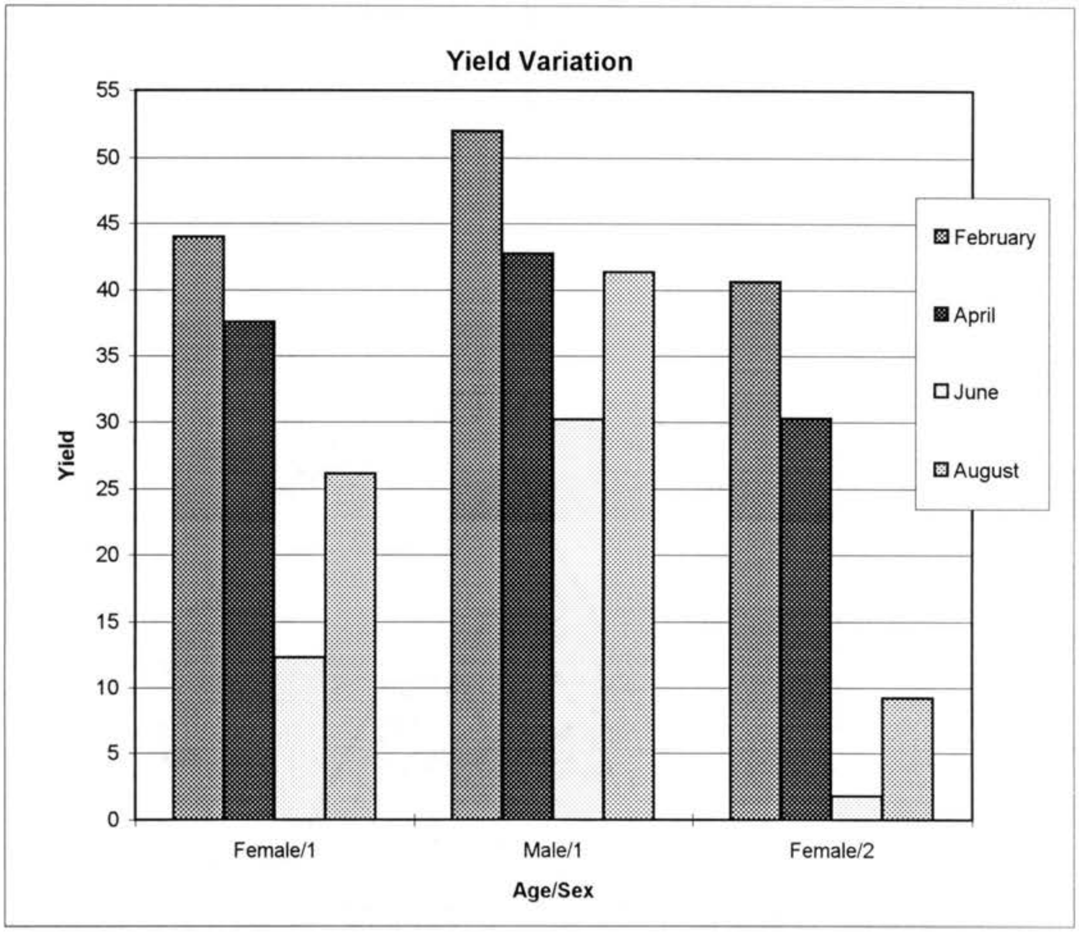

Figure 5.Yield Variation with Periods in Each Age/Sex Group in 1995

CHAPTER IV

Genetic and Environmental Effects on Cashmere Characteristics of Spanish Goats

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Abstract

Seven adult bucks and 134 does and their descendants were used to study environmental effects and genetic parameters for fleece weight and its characteristics and body weight over three years. Least squares procedures were used to estimated the effects of year, age and sex to fleece weight and its characteristic and body weight. Age of the goat was an important ($p<0.01$) source of variation for diameter, length and body weight. Fleece weight was influenced by the sex of the goats ($p<0.05$). Environmental factors due to variation of climate and management and sampling method and other factors were different, so fleece weight, fleece characteristics and body weight were different ($p<0.01$) between years.

The Multi Trait Derivative-Free Restricted Maximum Likelihood procedure was used to estimate the variances and covariances for multiple traits individual animal model.

The fixed effects of year, age and sex were included in the model to represent the contemporary environment groups. A total of 850 records were used to estimate the variances and covariances for fleece weight and its characteristics and body weight. The heritabilities were 0.64, 0.59, 0.63, 0.68, 0.41, 0.64 and 0.45 for fleece weight, down weight, yield, down diameter, down length, body weight and holding capacity, respectively. The genetic correlation coefficients of fleece weight with down weight, yield, down diameter, down length, body weight and holding capacity were 0.68, 0.04, 0.52, 0.81, 0.42 and -0.02 respectively. The genetic correlations of down weight with yield, down diameter, down length, body weight and holding capacity were 0.82, 0.56, 0.96, 0.03 and 0.69 respectively. The genetic correlation coefficients of yield with down diameter, down length, body weight and holding capacity were 0.41, 0.41, -0.39 and 0.93 respectively. The genetic correlation coefficients between down diameter with down length, body weight and holding capacity, between length with body weight and holding capacity, between holding capacity with body weight were 0.79, 0.64, 0.84, 0.41, 0.80 and -0.49 respectively. Selection for cashmere weight will result in considerble genetic improvement and genetic antagonisms between cashmere weight and diameter must be considered in selection system.

Introduction

In traditional cashmere producing countries, the cashmere producing goats are raised extensively and recording performance data and pedigree information is very difficult. There were very limited reports of estimates of genetic parameters for finer traits and undercoat production. Recently along with the increase of concern and importance of cashmere, more research has been conducted in Russia, Scotland, Australian and New Zealand (Couchman and Wilkinson, 1988; Gifford et al., 1988; Restall et al., 1989; Russel and Bishop, 1990; Pattie et al., 1990; Ponzoni et al., 1990; Baker et al., 1990). But due to the difference of environment, animal population, and estimating method , the heritabilities were different. In order to improve the genetic potential of the goats and increase cashmere production as rapidly as possible, we have to estimate the phenotypic and genetic parameter accurately and support the information to design the breeding objective and selection methods.

The most important traits for maximizing financial returns from cashmere goats are down weight, fiber diameter and liveweight. The objective of this study was to estimate phenotypic and genetic parameters for fleece traits and live weight on Spanish goats.

Materials and Methods

In fall of 1991, seven adult bucks and 134 adult does were purchased from several farms in Texas as the foundation animals for this experiment. Twenty cashmere goats were also donated to this project from a cashmere breeder in New York. Cashmere production and ability of the goats were evaluated objectively for yield, length, diameter and holding capacity. In the first year only 43% of the animals purchased showed ability to hold cashmere. Bucks were evaluated using the same procedures and only two bucks were used for subsequent breeding experiment. Goats that did not produce the commercial quantity and quality or holding capacity of cashmere were culled. The Australian Stage II index was also used to cull non-productive animals.

Animal management, sampling method and holding capacity's calculation were described in the previous paper.

Data Analysis: Estimates of variance of components for traits in this study were obtained using the derivative-free restricted maximum-likelihood (DFREML) procedure developed by Meyer (1988, 1989) modified for use with a sparse matrix solver package (SPARSPAK) (Boldman et al., 1991). The DFREML program was described by Smith and Graser (1986) and Mayer (1989). The SPARSPAK package (George et al., 1980) was used to reorder the mixed-model equations once and then to interactively update equations repeatedly solved by Cholesky factorization to calculate the likelihood.

The procedure uses an animal model fitting an additive genetic effect not only for animals with records but also for parents included in the analysis by pedigree information. Multivariate analyses were used to estimate correlation between traits. A convergence criterion, which was the minimum variance of the function value (-2log likelihood) after each round of interaction, was required to be 1×10^{-9} for each analysis. The animal model include the fixed effect of age , year, and sex.

Results and Discussion

Environment effects: Results from least squares analysis of variance for cashmere characteristics and body weight on Spanish goats are presented in Table 1. Least squares means and standard errors for cashmere characteristics and body weight are shown in Table 2 and Table 3. Age of the goat was important ($p<0.01$) source of variation for diameter, length and body weight. Similar results were reported on the effects of the age to the fiber production and fleece characteristics (Gifford et al.,1989; Kloren et al., 1993; McGregor, 1991; Ma et al., 1992). Diameter are increased from one years old to four years old. Selection based on one years old animal must consider this effect.

Restall and Pattie (1989) found there were significant non-linear rapid increase in down weight and fleece weight in first and second fleece with reduced increase thereafter. But in our experiment the fleece and downweight were not significantly influenced by age.

Fleece weight was influenced by the sex of the goats. Similar results were reported by Bigham et al. (1993). The down weight, yield, holding capacity, diameter, length and body weight between male and female were not significantly different. Pattie and Restall (1989) found male had heavier down weight in Australian cashmere goats and Bigham et al. (1993) found female had higher yield. McGregor et al. (1991) reported adult Liaoning cashmere male goats had higher cashmere yield and adjusted yield (cut the hair to the same length with down), greater cashmere diameter, longer cashmere length. The lack of significant differences in our research may due to the small number of males in our research. This was also evident from the standard errors for fleece weight, down weight , yield, diameter, length, body weight and holding capacity which were large. The differences among animals within each sex were large.

The fleece weight, yield, down diameter, down length, body weight and holding capacity were significantly different ($p<0.01$) between years because of different management, nutrition, measurement, sampling schedule, and other ecological and man-made errors.

The heritabilities and genetic correlations of fleece weight and fiber characteristics and body weight are given in Table 4. The heritability for fleece weight was 0.64, which was higher than those reported by Baker et al. (1991), Bighma et al. (1993), Pattie et al. (1990), Restall et al. (1984) and Sumner et al. (1993). Here the heritabilities were estimated using multivariate MTDFML which used all the information of the animals and included year, age and sex as the fixed factors. According to Baker et al. (1991), the heritabilities in all cases from multivariate REML analysis were slightly higher than those estimated from univariate analyses. The heritability for down weight was 0.59, which was similar with that reported by Pattie et al. (1989), a little higher than that reported by Baker et al. (1991) and a little lower than that reported by Bighma et al. (1993). The down diameter had 0.68 in heritability, which was a little higher than that reported by Pattie et al. (1989), a little lower than that reported by Baker et al. (1991), Bighma et al. (1993) and Sumner et al. (1993). The heritability for down length was 0.41, which was a little lower than that reported by Baker et al. (1991), Bighma et al. (1993), Pattie et al. (1990) and Restall et al. (1984). The heritability for yield was 0.64, similar with that reported by Pattie et al. (1989) and a little lower than that reported by Bighma et al. (1993) and a little higher than that reported by Baker et al. (1991). The heritability for body weight was 0.64 which was a little higher than that reported by Pattie et al. (1989), Baker et al (1991) and Nicoll et al. (1989). The heritability for holding capacity was 0.41. All these traits had high heritabilities and selection for these traits should be beneficial to cashmere production.

The genetic correlation coefficients for fleece weight , fiber characteristics and body weight are given in table 19. Fleece weight had a strong positive genetic correlation with down weight, fiber diameter, length and body weight, low correlation with yield and holding capacity. These results were similar with those reported by Baker et al (1991), Pattie et al. (1989) and Bighma et al. (1993). The correlation with body weight was a little higher than those reported by above sources. The other genetic correlation coefficients located in the middle of those reported. The downweight had strong genetic correlation with yield, down diameter and down length and holding capacity, low correlation with body weight. These results were similar with those reported by Baker et al. (1991), Pattie et al. (1989) and Bighma et al. (1993), except the relation with body weight which was higher than that reported by above sources (-0.18 to -0.34). Yield had strong positive genetic correlation with diameter and length and holding capacity, moderate negative correlation with body weight. These results were similar with those reported by Baker et al. (1991), Pattie et al. (1989) and Bighma et al. (1993), except the genetic correlation with fiber length whic was lower than 0.89 and 0.781 reported by Bighma et al. (1993) and Pattie et al. (1989) respectively. Diameter had strong correlation with down length and holding capacity, which was similar with those reported by other authors, but also strong relation with body weight which is contrast to -0.06 reported by Pattie et al. (1989), and -0.25, reported by Bighma et al. (1993). Down length had high positive genetic correlation with holding capacity , but also higher positive correlation with body weight which is contrast to -0.32 (Bighma et al., 1993) and -0.37 (Pattie et al., 1989). Holding capacity has strong negative genetic correlation with body weight.

The most important traits for maximizing financial returns from cashmere goats are down weight, fiber diameter and live weight. Although the live weight has negative correlation with yield, but nearly no correlation with down weight, it is possible to increased body weight and down weight simultaneously using suitable selection index. Diameter has strong relation with down weight and other fiber characteristic traits, these relation are unfavorable to cashmere production Selection for down weight and length will result in increasing in down diameter which will decrease down quality and disqualify the characteristics of cashmere. There exists very strong correlation (0.96) between down weight and down length, then down length can be used as a predictor of down weight. Down length is very easy to measure on the animal prior to shearing and can therefore greatly reduce the costs of estimating down yield. And we also can measure all the goats and increase the selection intensity to speed up the genetic gain of the population. Pattie and Restall (1989) have shown that good breeding value estimates for down weight can be obtained indirectly from down length and live weight or down length alone, with little reduction in accuracy compared with direct selection for down weight.

A complete breeding program would also need to include some measure of reproductive performance such as number of kids weaned per doe mated and number of kid weaned. There are favorable genetic correlations between live weight and both components of reproduction. Also the reproduction performance of Spanish goats in United States is considered at present at a satisfactory level. This may, however, change in the future and there is a need to establish relationships between reproductive performance, liveweight and fleece traits.

Conclusion

Environmental changes due to climate were probably the main sources of variation of fleece weight, fleece characteristics and body weight between years. Management and nutrition may also contribute the difference between years. The age and sex also influence the fleece weight, down weigh, fleece characteristics and body weight. The higher heritability estimates for down weight and down length, fleece weight and yield confirm those previously published results for Australian cashmere and New Zealand Cashmere goats and indicate there is considerable potential for genetic improvement.

Genetic antagonisms are present such that selection for increased down weight will lead to an increase in down diameter, a undesirable responses. Restricted selection indexes could be utilized to prevent such undesired responses, or selecteion for decreased down diameter since diameter is high now in this population. But restricting or decreased the down diameter will reduce the potential rate of genetic gain. The data present no alternatives for indirect measurement of fiber diameter, this implies that fiber diameter should measured accurately so that efficient selection indexes can be constructed to limit its increase.

Table 1 Analyses of Variance for Cashmere Characteristics and Body Weight of Spanish Goats

Factor	Year			Age			Sex		
Trait	df	SS	P-Value	df	SS	P-Value	df	SS	P-Value
Fleece Wt	2	378649.99	0.001	3	43851.42	0.055	1	22305.75	0.049
Down Wt	2	7172.47	0.229	3	1807.86	0.863	1	3045.25	0.263
Yield	2	2676.02	0.001	3	213.64	0.662	1	17.61	0.718
Diameter	2	4416.93	0.001	3	17322.14	0.001	1	2.47	0.899
Length	2	57053.85	0.001	3	3372.50	0.001	1	455.21	0.090
Body Wt	2	48114.47	0.001	3	22401.05	0.001	1	2.34	0.843
Holding	2	175576.28	0.001	3	926.93	0.939	1	4620.05	0.156

Table 2 Least Square Means and Standard Errors for Cashmere Traits and Body Weight Among Age Groups of Spanish Goats

Age	1		2		3		4	
Trait	No. Goat	LSM±SE	No. Goat	LSM±SE	No. Goat	LSM±SE	No. Goat	LSM±SE
Fleece WT(g)	174	324.55±15.27	80	351.10±16.88	41	345.37±19.17	23	332.53±17.90
Down Wt(g)	174	128.56±9.95	80	130.51±11.00	41	134.57±12.49	23	122.59±11.66
Yield(%)	174	40.31±2.34	80	38.61±2.59	41	40.04±2.94	23	37.91±2.75
Diameter(μ)	174	16.36±0.25	80	17.83±0.28	41	17.71±0.31	23	18.22±0.29
Length(cm)	174	3.89±0.25	80	3.39±0.28	41	4.58±0.32	23	3.78±0.30
Body Wt (LB)	174	34.32±1.55	80	51.94±1.72	41	48.99±1.95	23	53.20±1.82
Holding	174	104.15±9.65	80	101.08±10.67	41	106.83±12.12	23	105.55±11.31

Table 3 Least Square Means and Standard Errors for Cashmere Traits and Body Weight Among Years and Sexes of Spanish Goats

Year/Sex	Year						Sex			
	93		94		95		Female		Male	
Trait	No.	LSM±SE	No.	LSM±SE	No.	LSM±SE	No.	LSM±SE	No.	LSM±SE
Fleece Wt(g)	109	299.01±15.04	109	389.05±14.56	100	327.09±15.09	309	309.79±6.18	9	366.98±27.18
Down Wt(g)	109	121.79±9.80	109	133.87±9.49	100	131.51±9.83	309	118.49±4.02	9	139.62±17.71
Yield (%)	109	41.53±2.31	109	34.77±2.23	100	41.35±2.31	309	38.41±0.95	9	40.02±4.17
Diameter(μ)	109	17.44±0.25	109	18.06±0.24	100	17.08±0.25	309	17.56±0.10	9	17.50±0.44
Length(cm)	109	5.09±0.25	109	6.21±0.24	100	4.78±0.25	309	4.32±0.10	9	3.50±0.45
Body Wt(LB)	109	36.16±1.53	109	39.20±1.48	100	65.97±1.53	309	46.82±0.63	9	47.40±2.77
Holding	109	130.69±9.50	109	69.70±9.20	100	112.82±9.54	309	117.42±3.90	9	91.39±17.18

Table 4 Heritabilities (on the diagonal), and Genotypic Correlations (below) and Phenotypic Correlations (above) for Cashmere Characteristics, and Body weight in Spanish Goats

Trait	Fleece Wt	Down Wt	Yield	Diameter	Length	Body Wt	Holding
Fleece Wt	**0.64**	0.70	0.00	0.39	0.46	0.39	0.13
Down Wt	0.68	**0.59**	0.70	0.49	0.68	0.14	0.64
Yield	0.04	0.82	**0.63**	0.48	0.69	-0.28	0.81
Diameter	0.52	0.56	0.41	**0.68**	0.77	0.71	0.76
Length	0.81	0.96	0.41	0.79	**0.41**	0.39	0.81
Body Wt	0.42	0.03	-0.39	0.64	0.41	**0.64**	-0.30
Holding	-0.02	0.69	0.93	0.84	0.80	-0.49	**0.45**

CHAPTER V

Selection for Year-Round Cashmere Production and Related Characteristics on Spanish Goats

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Abstract

Seven adult bucks and 134 does and their descendants over three years were used to estimate the genetic parameters, using MTDFREML, which were used to estimate the phenotypic and genetic variance and covariance of the base population of selection. The selection index, accuracy and predicted genetic gain for different selection objectives with different selection methods were estimated. Reducing or controlling diameter will reduce the maximum potential genetic gain for cashmere weight. Keeping the genetic gain for diameter to zero, the potential genetic gain for down weight decreased 25%, 37.87 to 47.35 g each generation, but this compromise is necessary to guarantee the quality of cashmere. In our research, we find selection for body weight and down length can achieve

good selection accuracy and genetic gain for down weight when controlling diameter and body weight, this will reduce the selection cost.

Introduction

Factors that affect income from cashmere goats are down weight, down diameter, down color, and body weight and reproductive characteristics. Down weight is determined by down length and density (S/P ratio) and diameter and size of the body. In Australian, white down from goats with white guard hair is preferred by processors and attracts a price premium over gray and brown down (Pattie et al., 1990). But the inheritance of down color was not fully determined and generally this character was treated independently to other measured characteristics.

Due to the strong positive genetic correlations between diameter with down weight and down length, selection for down weight and down length will result in increasing of down diameter. Such a selection direction would not be sustainable in long term and would have to be changed before diameter increased to a level where down could not be sold as cashmere. Controlling the diameter to selecte for down weight will be suitable objective for cashmere production in USA.

Secondary follicles density and S/P ratio influence the down weight. But these traits has low heritability and special equipment and train required to measure these traits, direct selection based on skin characteristics are avoided (Millar, 1986). Ryder(1984) found that selection on undercoat weight resulted in increasing in undercoat density.

Pattie and Restall (1989) also reported that including S/P ratio, Secondary and Primary follicle density in selection index do not increase genetic gain. Reproductive characteristics had low heritability and also body weight had positive correlation with multiple birth, so these traits are not considered in our selection index.

In Australian and New Zealand, the testing and classification systems developed well. The purchasing price of cashmere were basically determined by characteristics of cashmere. Ponzoni and Gifford (1990) derived the economic value for down weight, live weight and diameter from the profit equation using discount gene flow method. But in United States, most consumers are not very sophisticated with regard to the fiber content of the garments they purchase. They are more apt to look at the price tag than the content label (Fort, 1990). So the price was not strictly determined by the quality of the cashmere.

The development of efficient selection systems for improving down production is also restricted by measurement problems. Full measurement of yield, down weight and diameter is very expensive. The objective of this research to compare different selection methods and their predicted genetic gain with different selection objective.

Materials and Methods

In fall 1991, seven adult bucks and 134 adult does were purchased from several farms in Texas as the foundation animals for this experiment. Twenty cashmere goats were also donated to this project from a cashmere breeder in new York. Cashmere production and ability of the goats were evaluated objectively for yield, length, diameter and holding capacity. In the first year only 43% of the animal s purchased showed ability to hold cashmere. Bucks were evaluated using the same procedures and only two bucks were used for subsequent breeding experiment. Goats that did not produce the commercial quantity and quality or holding capacity of cashmere were culled. The Australian Stage II index was also used to cull non-productive animals.

Animal management, samoling method and calculation of holding capacity were described in previous parper.

Data Analysis: Estimates of variance components for traits in this study were obtained using the derivative-free restricted maximum-likelihood (DFREML) procedure developed by Meyer (1988, 1989) modified for use with a sparse matrix solver package (SPARSPAK) (Boldman et al., 1991). The DFREML program was described by Smith and Graser (1986) and Mayer (1989). The SPARSPAK package (George et al., 1980) was used to reorder the mixed-model equations once and then to interactively update equations repeatedly solved by Cholesky factorization to calculate the likelihood.

The procedure uses an animal model fitting an additive genetic effect not only for animals with records but also for parents included in the analysis by pedigree information. Multivariate analyses were used to estimate correlation between traits. A convergence criterion, which was the minimum variance of the function value (-2log likelihood) after each round of interaction, was required to be 1×10^{-9} for each analysis. The animal model include the fixed effect of age , year, and sex.

Selection Objective: The objective of selection is to increase down weight, live weight and decrease or control diameter. The economic weight values come from report of R.W.

Ponzoni and D.R. Giffore (1990) who derived economic value by numerical evaluation of profit equation for Australian Cashmere goats, expressing it as a function of biological traits.

Selection Indexes were developed as:

$b=P^{-1}Ga$, Where:

P: the phenotypic variance and covariance matrix. $P=SR_pS$: S is the diagonal matrix of standard error for each trait adjusted age and sex in 1995. R_p is the phenotypic correlation.

G: Genetic Variance and Covariance matrix. $G=S_gR_gS_g$. S_g is the diagonal matrix of genetic standard error for each trait adjusted for age and sex in 1995. R_g is the genetic correlation.

a: vector of economic value.

b: vector of selection index.

Accuracy=COV(H, I)/V(I).

COV(H, I): Covariance of Selection Objective and Selection Index.

V(I). The Variance of Selection Index.

$\Delta G=COV(G, I)/\sigma_i*D$.

ΔG: The predicted genetic gain for each trait.

COV(G, I): The genetic covariance between trait and selection index.

σ_I The standard deviation of selection index.

D: selection intensity factor. 5% for male and 30% for female.

Results and Discussion

The selection accuracy and predicted genetic gains from different selection methods with selection objective H=55.31*Down Weight + 47.61*Body Weight - 3088.82*Down Diameter were listed in Table 1. When only down length was selected the down weight, fleece weight, down length will gain the most, also holding capacity will also show considerable increase. But this also results in increase of down diameter by 0.59 μm each generation which will decrease qualityof the cashmere. When body weight and length are included in the selection index, then the selection accuracy will increased a lot. This method also can control the diameter, but the down weight gain will decrease and body weight will decrease considerably. Here the selection coefficient for body weight is negative, this is due to the strong genetic correlation between diameter and body weight. When the diameter is included in the selection index, this method can decrease the diameter more than any other method, 0.7 μm each generation. But genetic gain for down weight will be 6.14 g each generation, lowest for all methods. When the down weight was also included in the selection index, then the accuracy is highest, down weight will gain more than the method 3 and method 5. From table 1, we can find the accuracy will increase when more traits are included in the selection index. When only down length and body weight were included in the selection index, the selection result will be good, the genetic gain for down weight 24 g in each generation and down diameter -0.27 μm. Also the holding capacity should not be included in the selection index, because this method will not increase selection accuracy, but increase the cost of selection.

The accuracy and predicted genetic gains from different selection methods with selection objective H=104.55*Down Weight +641.66*Body weight - 1310.37*Diameter were listed in Table 2. From this table we can easily find this objective is not suitable for cashmere selection. When more traits are included in selection index, the selection accuracy increase a small amount. All the methods will increase down diameter genetic gain by 0.59 to 0.73 μm each generation. In this selection objective when only down length was selected, the down weight genetic gain is highest, 35.94 g, and diameter genetic gain is lowest, 0.59 μm.

Using restricted selection index, the accuracy and predicted genetic gains are listed in Table 3. When more traits were included in selection index, the accuracy, down weight genetic gain, down length genetic gain increased. The genetic gain for down weight was large for all methods, 31.47 to 34.91 g each generation. The body weight was decreased slightly.

If the down weight was the only objective of selection, the genetic gain for down weight, yield, length and holding (Table 4) are very large, but the cashmere quality decreased, 0.41 to 0.60 μm, each generation. The body weight will be stable, -1.03 to 3.47 kg, each generation. Including holding capacity in selection index will decrease the selection accuracy and genetic gains for down weight and holding capacity. When the down weight was included in selection index, the accuracy increased a lot. From this result we also find only including body weight and down length in selection index will get good selection result.

When down weight and body weight were the selection objectives, the genetic gain for down weight, yield, down length, and body weight were (Table 5) good, but the cashmere quality also decreased. When more traits were included in the selection index, the genetic gain for down weight, yield, down length increased, but the diameter also increased. When down weight was included in the selection index, this significantly increased the selection accuracy and genetic gain.

From these tables we can find that controlling or decreasing down diameter will sacrifice the down weight gain. When the down diameter selected for -0.70 μm, the down weight genetic gain will be 6.14 g. If keeping the diameter genetic gain to be 0.00 μm, the genetic gain for down weight will be 37.87 g, loosing the controlling of diameter, the down weight gain will be 47.35 g each generation. In the current situation, the down diameter of Spanish goats is less than 17.0 μm, so keeping the zero control is good strategy for cashmere selection.

The development of efficient selection systems to improve down production is restricted by measurement problems. Full measurement of yield, and hence down weight, and diameter is very expensive, so designing suitable selection indexes without adding too much cost is very important to efficiently execute selection program. From our research results, we can find selection for body weight and down length can achieve good selection accuracy and genetic gain for down weight when controlling diameter and body weight. In Australia, two stage selection index (Pattie, and Restall, 1989) were applied, the first stage I selection for length and body weight, stage II select for body weight, down diameter, down length and down weight. This method can also be applied in North America.

Conclusion

Selection systems are available to meet a variety of breeding objectives and to reduce measurement cost to minimum. They have been designed to reconcile the conflicting requirements of increasing cashmere production while not allowing diameter to increase or body weight to decrease. Typically these systems will reduce by 25% the maximum possible rate of increase in down weight, but that is a necessary compromise.

Table 1. Accuracy and Predicted Genetic Gain from Different Selection Methods with Objective I[a]

Selection Method	Accuracy	Fleece Gain	DownWt Gain	Yield Gain	Diameter Gain	Length Gain	Body Wt Gain	Holding Gain
1[b]	0.12	55.75	35.94	4.31	0.59	0.56	3.47	24.16
2[c]	0.55	-3.45	24.00	8.13	-0.27	0.05	-9.05	34.74
3[d]	0.78	3.52	6.14	-2.98	-0.70	-0.13	-6.07	-18.98
4[e]	0.84	13.68	14.66	0.05	-0.60	0.01	-6.01	-17.27
5[f]	0.83	9.06	11.09	-1.63	-0.65	-0.02	-6.15	-29.77

[a]Selection Objective: H=55.31*DownWt+47.61*BodyWt-3088.82*Diameter
[b]Selection Trait: Down length
[c]Selection Index: I=712.82*DownLength-99.53*BodyWt
[d]Selection Index: I=-2459.03*Diameter+2202.554*DownLength+2.36*BodyWt
[e]Selection Index: I=15.58*DownWt-2566.67*Diameter+1624.68*DownLength+17.42*BodyWt
[f]Selection Index: I=16.22*DownWt-3211.24*Diameter+1637.31*DownLength+63.79*BodyWt+6.22*Holding

Table 2. Accuracy and Predicted Genetic Gain from Different Selection Methods with Objective II[a]

Selection Method	Accuracy	Fleece Gain	DownWt Gain	Yield Gain	Diameter Gain	Length Gain	Body Wt Gain	Holding Gain
1[b]	0.56	55.75	35.94	4.31	0.59	0.56	3.47	24.16
2[c]	0.73	52.48	18.36	-1.54	0.71	0.47	9.15	-1.40
3[d]	0.73	52.38	18.49	-1.40	0.72	0.47	9.15	-0.71
4[e]	0.76	58.03	24.21	0.66	0.73	0.55	8.61	-0.37
5[f]	0.73	52.93	19.32	-1.91	0.70	0.54	8.90	-19.16

[a]Selection Objective: H=104.55*DownWt+641.66*BodyWt-1310.37*Diameter
[b]Selection Trait: Down length
[c]Selection Index: I=2438.29*DownLength+293.81*BodyWt
[d]Selection Index: I=121.71*Diameter+2364.56*DownLength+288.77*BodyWt
[e]Selection Index: I=32.94*DownWt-105.85*Diameter+1142.86*DownLength+320.60*BodyWt
[f]Selection Index: I=16.22*DownWt-3211.24*Diameter+1637.31*DownLength+63.79*BodyWt+6.22*Holding

Table 3. Accuracy and Predicted Genetic Gain from Different Selection Methods with Objective III[a]

Selection Method	Accuracy	Fleece Gain	DownWt Gain	Yield Gain	Diameter Gain	Length Gain	Body Wt Gain	Holding Gain
2[c]	0.43	18.28	31.47	8.53	0.00	0.25	-6.35	38.64
3[d]	0.48	36.25	31.51	3.73	0.00	0.31	-2.93	16.92
4[e]	0.58	43.31	37.87	6.76	0.00	0.41	-3.43	10.92
5[f]	0.54	39.30	34.91	4.32	0.00	0.45	-3.30	-12.44

[a]Selection Objective: H=55.31*DownWt+47.61*BodyWt with Controlling Diameter Gain to zero
[c]Selection Index: I=963.23*DownLength-78.34*BodyWt
[d]Selection Index: I=-768.32*Diameter+1648.18*DownLength-27.93BodyWt
[e]Selection Index: I=19.46*DownWt-1082.88*Diameter+985.55*DownLength-5.90*BodyWt
[f]Selection Index: I=21.08*DownWt-2047.65*Diameter+929.09*DownLength+73.81*BodyWt+11.08*Holding

Table 4. Accuracy and Predicted Genetic Gain from Different Selection Methods with Objective IV[a]

Selection Method	Accuracy	Fleece Gain	DownWt Gain	Yield Gain	Diameter Gain	Length Gain	Body Wt Gain	Holding Gain
1[b]	0.61	55.75	35.94	4.31	0.59	0.56	3.47	24.16
2[c]	0.66	46.54	38.46	6.65	0.41	0.49	-0.32	33.37
3[d]	0.69	42.04	40.25	9.91	0.60	0.54	-0.41	49.64
4[e]	0.81	51.2	47.35	12.60	0.60	0.65	-0.84	42.85
5[f]	0.73	44.20	42.75	9.69	0.55	0.66	-1.03	16.54

[a]Selection Objective: DownWt
[b]Selection Trait: Down length
[c]Selection Index: I=30.69*DownLength-0.90*BodyWt
[d]Selection Index: I=18.29*Diameter+19.61*DownLength-1.66*BodyWt
[e]Selection Index: I=0.46*DownWt+15.14*Diameter+2.68*DownLength-1.22*BodyWt
[f]Selection Index: I=0.49*DownWt-14.72*Diameter+3.27*DownLength+0.93*BodyWt+0.29*Holding

Table 5. Accuracy and Genetic Gain from different Selection Methods with Selection Objective V[a]

Selection Method	Accuracy	Fleece Gain	DownWt Gain	Yield Gain	Diameter Gain	Length Gain	Body Wt Gain	Holding Gain
1[b]	0.65	55.75	35.94	4.31	0.59	0.56	3.47	24.16
2[c]	0.66	53.26	37.41	5.22	0.53	0.54	2.15	27.88
3[d]	0.68	48.75	39.24	8.42	0.72	0.59	1.96	43.77
4[e]	0.79	56.74	46.47	11.28	0.70	0.69	1.21	38.34
5[f]	0.72	50.53	41.77	8.21	0.66	0.70	1.24	11.38

[a]Selection Objective: DownWt and BodyWt
[b]Selection Trait: Down length
[c]Selection Index: I=1670.74*DownLength-18.47*BodyWt
[d]Selection Index: I=987.59*Diameter+1072.44*DownLength-59.40*BodyWt
[e]Selection Index: I=24.43*DownWt+818.83*Diameter+166.41*DownLength-35.79*BodyWt
[f]Selection Index: I=26.08*DownWt-848.27*Diameter+199.09*DownLength+84.13*BodyWt+16.08*Holding

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