Goat nutrition for fibre production

2 authors:

Adriana Di Trana
Università degli Studi della Basilicata

Lucia Sepe
Council for Agricultural Research and Economics

11 Goat Nutrition for Fibre Production

A. Di Trana[1] and L. Sepe[2]

[1]Università degli Studi della Basilicata, Dipartimento di Scienze delle Produzioni Animali, Viale dell'Ateneo Lucano 10, Campus di Macchia Romana, 85100 Potenza, Italy; [2]CRA – Unità di Ricerca per la Zootecnia Estensiva, Via Appia-Bella Scalo, Muro Lucano (PZ), 85054 Potenza, Italy

Introduction

The primary products of most goat breeds are milk and meat. Nevertheless, goat breeds capable of producing a highly insulating and valuable fleece have evolved in low-temperature environments. In such environments, goats are an important resource for local animal production, since they produce milk, excellent fibre and also meat from kids.

Even though goats for fibre represent about 20% of the world's goat production, consumers do not associate cashmere or mohair with goats as immediately as they relate wool to sheep.

Goats for fibre are subdivided into two large groups: (i) Cashmere goats, to which different breeds and populations belong; and (ii) Angora goats, from which mohair is obtained. Cashmere goats can have a double or triple aptitude, without showing the strong competition between fibre and milk for nutrients found in Angora goats and sheep.

After providing a description of goats for fibre, focusing on the specific nature of their fibres, information on their nutrition is given in this chapter.

Cashmere Goats

Almost all goat breeds can produce two types of fibre. The so-called secondary fibre or down is extremely fine, generally shorter than the main fleece (called primary fibre or guard hair), and is visible especially in young goats. Figure 11.1 shows the presence of smaller fibres produced by secondary follicles (SFs) in dairy goats, in comparison to fibre goats.

In Cashmere goats these fibres are far more developed, and therefore provide efficient thermal insulation. Goats are classified as Cashmere when their

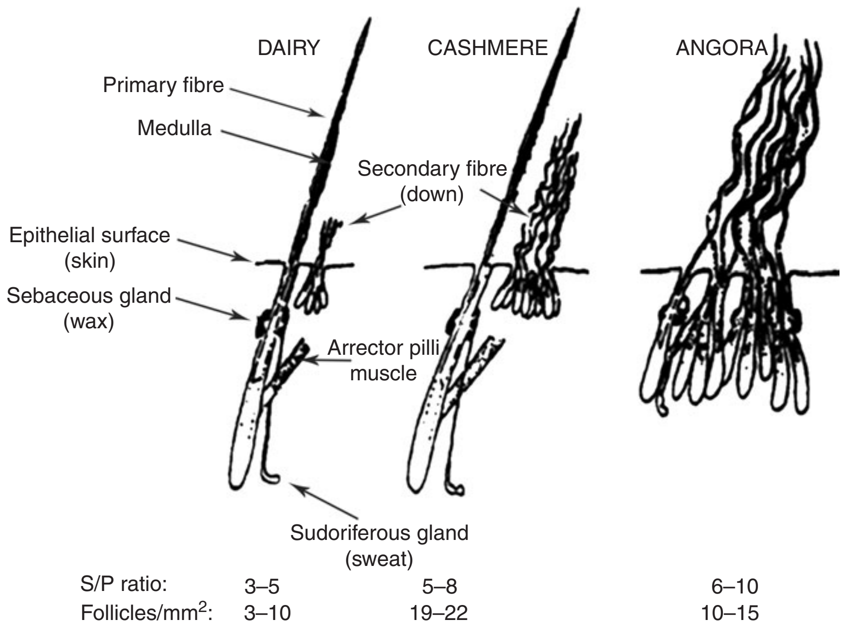

Fig. 11.1. Comparison of the organization of the secondary follicles (S) and primary follicles (P) in dairy and fibre goats. (Adapted from Millar, 1986.)

down fibre, or cashmere, is composed of fibres which have a precise diameter and length, with features of elasticity and lightness.

This fibre owes its name to Kashmir, an area situated to the west of the Himalayas. This fibre is also known as *cachemire* in French or as pashmina, the Indian–Pakistan equivalent (which, however, has not been recognized by the official nomenclature).

Several indigenous fibre goats are reared in Spain. Recently, a fibre aptitude has been observed in certain Italian goat populations (Rubino *et al*., 2000), such as the Nicastrese goat (Di Trana *et al*., 2004). Moreover, the presence of a modest quantity of fibre has been found in the Bionda dell'Adamello, an autochthonous goat breed from the Lombardy Alps.

Cashmere Fibre

Cashmere is a fibre without medulla, produced by secondary piliferous follicles, characterized by the features described in Table 11.1.

Since diameter is the main characteristic for distinguishing cashmere from other animal fibres, different industrial textile institutions have established accepted upper limits for cashmere diameter (Table 11.2) (Phan and Wortmann, 2000).

The growth of cashmere is seasonal, as opposed to wool, which has a continuous growth. The development cycle of cashmere fibre is greatly influenced

Table 11.1. Cashmere fibre characteristics.

Parameter	Range	Merchandise considerations
Average diameter (μm)	13–19	The smaller the diameter, the smoother is the product to the touch
Length (mm)	5–90	When shorter than 20 mm, product quality decreases
Colour	white, cream, grey, brown	White is more appreciated because of minor coloration costs
Yield (%)	30–85	Combed cashmere has a higher price than sheared cashmere, due to its higher yield and length
Crimps	from tight to loose	They give elasticity and softness. When closing an amount of cashmere in the hand, the mass returns to its original volume when the hand is opened

Table 11.2. Upper limits for the diameter accepted by the main international textile institutions. (Adapted from Phan and Wortmann, 2000.)

	International institutions			
	Chinese International Standard (China)	CCMI (Europe, Japan, USA)	AATCC (USA)	ASTM (USA)
Upper limit of cashmere diameter (μm)	16.0 ± 0.5	18.5 ± 0.5	18.5	19.0

CCMI, Cashmere and Camel Hair Institute; AATCC, American Association of Textile Chemists and Colourists; ASTM, American Society for Testing and Materials.

by the photoperiod, and, as a consequence, by the concentration of the melatonin and prolactin hormones in plasma. The growth phase (anagen) starts between the spring equinox and the summer solstice and finishes between the autumn equinox and the winter solstice. This is followed by a regressive phase of the piliferous follicle (catagen) and a final phase of rest (telogen), which is associated with a natural loss of hair or moulting (Lynch, 1990). The latter phenomenon occurs between the winter solstice and the spring equinox. Since photoperiod is related to latitude, at lower latitudes the telogen comes about earlier (in the middle of January) compared with higher latitudes (in February), and mostly coincides with the kidding period (McGregor, 1996a). According to the Chinese point of view, the highest-quality cashmere is that produced on the 40th parallel in Inner Mongolia (Petrie, 1995).

Fibre harvesting is carried out by two techniques: (i) combing; and (ii) total shearing. Combing is done using combs which have long, closely set teeth. In this way, a mass with a high yield (78–83%) is obtained, and is therefore much appreciated by textile industries because of the reduced guard hair percentage. Combing is carried out when the animal is 'ready', i.e. when a tuft of down fibre comes away very easily.

In areas where drastic changes in temperature are unlikely (e.g. Australia and Texas), total shearing is done. Sheared fleece has a lower price on the market, because of the lower yield of dehairing (the elimination of the guard hair from the mass), and the shorter cashmere produced.

Due to its high thermal insulation properties (three times higher than wool of the same weight) and its extreme lightness, as well as its limited production and high processing costs (due to the laborious dehairing process), cashmere is considered a luxury textile fibre and is utilized mostly in the clothing sector. Based on diameter, cashmere is classified into two typologies: (i) hosiery (< 16 μm), utilized for knitwear and luxury items of clothing such as stockings and ties; and (ii) weaving (16–18.5 μm), for clothing and furnishings.

Since the demand from industry is fairly constant, prices vary depending on the availability of the Chinese fibre on the market, which has been run by private companies since 1991. Naturally, this has influenced the supply and price of raw cashmere for the European industries (i.e. Italy and Scotland).

The diameter and length of cashmere are features which have very high hereditability ($h^2 = 0.47$ and 0.70 for down diameter and down length, respectively), yet at the same time they are influenced by many different factors, such as sex, age, nutritional status, health and environment. For example, female goats produce better-quality cashmere, with a mean fibre diameter 1–2 μm lower than that of male goats (Ryder, 1989; Li *et al.*, 1996). Peak production is reached at 2 years of age and drops, progressively, up to the sixth to seventh year (Zhang and Shi, 1996). The nutritional, environmental and physiological factors which influence fibre production are analysed as follows.

Nutritional Requirements of Cashmere Goats

The protein and energy requirements for the production of cashmere fibre are estimated according to the chemical composition and energy content of the fleece (Table 11.3) (Russel, 1990). Protein and energy are also required for maintenance, milk production, pregnancy, grazing and thermoregulation (see Cannas *et al.*, Chapter 6, this volume).

Like other animal fibres, cashmere fibre and guard hair are composed of proteins belonging to the α-keratin family. These proteins are rich in sulphurated amino acids such as cystine and cysteine, as a result of the trans-sulphuration of methionine. Apart from the two already-mentioned types of hair, the fleece contains small quantities of sebum and sweat, produced by the sebaceous glands

Table 11.3. Chemical composition and net energy content of cashmere fibre, guard hair and their associated secretions, and nutrient and energy retention in cashmere and guard hair production, considering a growth period of 6 months. (Adapted from Russel, 1990.)

	N	S	Ca	P	Mg	K	Na	Energy
	Chemical composition (g/kg)							Content (MJ/kg)
Fibre	165	33	1	0.1	0.1	0.05	0.3	23.5
Sebum	1.5	–	0.3	0.8	0.1	6.8	0.3	40.8
Sweat	27	4	7	1.2	2	200	10	–
	Nutrient retention (mg/day)							Retention (kJ/day)
Fibre growth of 3.4 g/day	573	114	5	1	1	56	4	84

and sweat glands, respectively. These glands are associated with the primary follicles (PFs).

The retention of nutrients in the fleece, such as cashmere, guard hair and secretions, is evaluated on the basis of an annual production of 250 g of cashmere per head, which represents 30–40% of the fleece, and a growth period of 6 months (Table 11.3) (Russel, 1990).

The energy and protein requirements for the production of fleece in Cashmere goats are determined by the protein and energy retained in the fleece during the growth period. Over the period during which the fibre is growing, the proportion of the energy consumed that is stored in the fibre, or used to produce sebum and sweat, is about 0.006 (0.6% of total energy consumed), or, on an annual basis, about 0.003 (0.3% of total energy consumed) (Russel, 1990). The proportion of protein ingested retained is about 0.02 (2% of protein ingested) over 6 months or 0.01 (1% of protein ingested) over the whole year (Russel, 1990).

Fleece weight of Scottish Cashmere goats varies from 300 to 700 g per head, of which about 30–40% is cashmere (Table 11.4). The efficiency of utilization of metabolizable energy (ME) to fibre energy is not known precisely, but it is estimated to be 0.18 (McDonald *et al.*, 1992). Therefore, a goat which produces a fleece of 700 g with 280 g of cashmere and which retains 96.06 kJ of net energy per day (Table 11.4) would require 534 kJ (i.e. 96.06/0.18) of ME per day (for 6 months) for fleece growth only. This energy requirement for fibre production could be met by supplying daily 63 g of medium-quality hay or 42 g of barley grain.

Protein requirements are related to the quantity of energy supplied. On average, 9 g of rumen-degradable protein per megajoule of ME should be supplied (Russel, 1990). For most foodstuffs fed at normal levels, the degradability of the protein fraction could be assumed to be approximately 0.75 and thus the requirement for crude protein (CP) would be about 12 g CP/MJ ME (Russel, 1990). Therefore, for the production of 700 g of fleece with 280 g of cashmere, 6.4 g CP/day (for 6 months) are required, which could be supplied with 56 g of barley grains or 24 g of broad beans.

Table 11.4. Energy and protein retained in the fleece of Cashmere goats at different productive levels, considering an average period of fleece growth of 6 months.

	Cashmere weight (g/year)			
Fleece weight (g/year)	30% yield	40% yield	Energy retained in the fleece (kJ/day)	Protein retained in the fleece (g/day)
300	90	120	41.17	1.76
350	105	140	48.03	2.05
400	120	160	54.89	2.34
450	135	180	61.75	2.63
500	150	200	68.61	2.93
550	165	220	75.47	3.22
600	180	240	82.33	3.51
650	195	260	89.19	3.80
700	210	280	96.06	4.10

Nutrition of Cashmere Goats

Proper nutrition of Cashmere goats is needed to produce good-quality fibre, one or two kids and sufficient milk, as well as to ensure high reproductive efficiency and a marketable carcass.

Feed intake

The intake level of a Cashmere dry goat with a body weight (BW) of 40 kg, fed natural pasture hay, was 40.9 g dry matter (DM)/kg $BW^{0.75}$ per day (Table 11.5) (Sepe *et al*., 1996). This value is within the wide range of values (40–140 g DM/kg $BW^{0.75}$) indicated for dairy goats and for French meat goats (Sauvant *et al*., 1991). Moreover, an intake of 40.9 g DM/kg $BW^{0.75}$ per day is lower than the intake level of dry dairy goats reared in southern Italy (Fedele *et al*., 2002).

Feed quality has a major impact on DM intake. For example, as organic matter digestibility of hay increased from 0.47 to 0.63, an increase in intake from 42.8 to 77.7 g DM/kg $BW^{0.75}$ occurred in Scottish Cashmere castrated male goats (Hadjigeorgiou *et al*., 2001).

The herbage intake of Cashmere dry goats grazing natural Mediterranean pastures, characterized by high botanical variability and seasonal changes in quality, averaged 47 g DM/kg $BW^{0.75}$ on a season basis. A supplement of commercial concentrate with 16% CP, at a level of 12 g/kg $BW^{0.75}$, reduced herbage intake by 9 g DM/kg $BW^{0.75}$, for a total DM intake only slightly higher than that of the unsupplemented goats (Table 11.5) (Sepe *et al*., 1996). Intake levels varied between 57 and 140 g DM/kg $BW^{0.75}$ in Cashmere goats reared in northern European pastures (Merchant and Riach, 1994).

Table 11.5. Level of dry matter intake of Cashmere goats fed indoors (natural pasture hay plus commercial concentrate 200 g/day) or grazing on hill pasture (360 m above sea level) in late spring. (Adapted from Sepe *et al.*, 1996.)

	DM intake (g/kg BW$^{0.75}$)	
	Mean	SD
Housed goats		
Dry	40.88[b]	16.93
Lactation	68.89[a]	21.22
Grazing goats		
With supplement	49.92[a]	19.45
Without supplement	46.87[a]	18.95

DM, dry matter; BW, body weight; SD, standard deviation.
[a,b]Mean values in a column with different superscript letters were significantly different ($P < 0.05$).

Proteins

In contrast to sheep and Angora goats, an increase in the amount of dietary protein did not have any positive effect on down length and production of Cashmere goats (Russel, 1995). It should be noted, however, that such an increase led to a greater BW, guard hair growth and thickening of cashmere.

Once production (maintenance and fleece) requirements are satisfied, no additional improvements in quality and quantity of the produced cashmere are determined by a further increase in dietary protein, by supplementation with feeds rich in sulphurated amino acids (casein, cotton, sunflower, lupin and lucerne), or with rumen-protected protein. This was observed in goats fed either in housed conditions or on pasture, as well as for different genetic types, with various production levels of cashmere (McGregor, 1998).

However, when animals fed on a diet lacking in protein were given a protein supplement, both cashmere growth and diameter thickening of the fibre increased (McGregor, 1998).

In contrast to cashmere, the guard hair, originating from the PF adjacent to the SF, is sensitive to increasing N content in the diet, even if these two types of fibre have similar chemical composition. This suggests that SFs producing cashmere have a reduced activity of the enzymes involved in the process of trans-sulphuration of the methionine in cysteine (Russel, 1990). Follicles which produce cashmere have fewer cells able to synthesize fibre proteins, and less intrinsic capacity for protein synthesis, as far as single cells are concerned, than mohair follicles (Lee *et al.*, 1994). Such a hypothesis might be extended to guard hair, based on the similar responses of both guard hair and mohair to protein supplements.

Table 11.6 reports the productive responses of Scottish Cashmere goats reared in mountain environments (1180 m above sea level (asl)) in southern Italy with a feeding regimen consisting of natural pasture (40% grasses, 30% legumes and 30% forbs), or of natural pasture (CP content of 15 and 12% of DM in spring and summer, respectively) plus supplements of 13 or 18% CP (Di Trana and Sepe, 2007). The use of a supplement increased the length of guard hair and the diameter of the down. The latter, however, was not advantageous for production, since it reduced cashmere quality. The highest dietary protein concentration increased guard hair yield and reduced cashmere yield (percentage of down fibre on the total fleece). This may also be related to the shorter growth period of cashmere fleece, caused by an earlier start of moult of cashmere in comparison to the other two diets (Di Trana and Sepe, 2007).

On the basis of these considerations, the most advantageous diet for a better cashmere output seems to be the one with a CP level of 13%, even if a thicker down was obtained compared with goats which have utilized pasture only. Feeding regimen based only on pasture reduced fibre length, without worsening significantly the cashmere yield with respect to the groups fed a supplement. Actually, the use of pasture alone improved the quality of cashmere, which became 2 and 4% thinner than that of goats fed 18% CP and 13% CP, respectively. Moreover, the availability of natural pasture caused a delay in moulting of about 1 month

Table 11.6. Effect of feeding regimen on fibre production traits of Scottish Cashmere goats grazing on natural pastures (CP content of 15 and 12% of DM in spring and summer, respectively) with or without supplements. (Adapted from Di Trana and Sepe, 2007.)

	Feeding regimen		
		Grazing plus supplement	
Parameter	Grazing natural pasture	CP 13%	CP 18%
Cashmere length (mm)	49	55	54
Maximum guard hair length (mm)	59	63	75
Cashmere growth rate (mm/day)	0.28	0.30	0.36
Growth period of cashmere (days)	182[a]	180[a]	148[b]
Cashmere diameter (μm)	16.8[b]	17.5[a]	17.2[ab]
Cashmere production (g/kg BW)	5.20	5.92	5.10
Cashmere yield (%)	33.5	34.1	32.0
Guard hair yield (%)	66.5	65.9	68.0
Start of moult (days)	393[a]	361[b]	350[b]

CP, crude protein; DM, dry matter; BW, body weight.
[a,b]Within rows, values with different superscript letters were significantly different ($P < 0.05$).

compared with the feeding regimen at 13% CP, and a 6-week delay compared with the feeding regimen of 18% CP (Table 11.6) (Di Trana and Sepe, 2007).

Ivey *et al*. (2000) studied the effects of diets differing in concentrations of CP (10 and 15%) and ME (2.00, 2.35 and 2.70 Mcal/kg; DM basis), fed *ad libitum*, on growth and cashmere fibre production of cashmere-producing Spanish wether goats, in an 84-day trial during autumn. Guard hair weight and cashmere length were not affected by dietary treatments. Cashmere fibre diameter was not altered by dietary ME level but was greater for 15% CP than for 10% CP (16.92 versus 16.06 μm; $P < 0.05$). Cashmere weight was influenced by an interaction between CP and ME levels; cashmere fibre weight with 10% CP was 92, 82 and 95 g, and with 15% CP was 63, 115 and 99 g for diets with 2.00, 2.35 and 2.70 Mcal ME/kg, respectively.

No cashmere growth responses have been observed by supplying protected protein to low-production goats or to high-production goats when the basal diet appeared to contain sufficient protein. When high-protein legume grains were fed to cashmere goats consuming a basal diet deficient in protein, large increases in both cashmere growth and mean fibre diameter were obtained (McGregor, 1998).

Amino acids

In Australia, cashmere growth of fully grown male Cashmere goats was not influenced by integration with methionine (Ash and Norton, 1987). However, other studies on Scottish Cashmere yearling goats showed that the inclusion of methionine (2.5 g/day), in addition to a basal diet containing 9.9 MJ ME and 107 g CP (per kg DM), increased cashmere yield and diameter, while the guard hair was not influenced (Souri *et al*., 1998; Galbraith, 2000). These opposing results could be attributed to a different genetic potential for cashmere production of the animals utilized, and to an inadequate supply of the amino acids required in the non-supplemented group.

Considering that the annual production of cashmere is seldom higher than 300 g per head, the requirement for amino acids (< 1 g protein/day) for cashmere growth can be easily satisfied by the circulating amino acid pool, without being limited by the availability of protein in the diet (Galbraith, 2000).

Energy

Fibre production is less affected by energy supply than by protein supply (Reis, 1989). For the Cashmere goat, neither the timing nor increasing levels of feeding above maintenance increased the growth of down fibre, although these same feeding regimes promoted significant increases in both guard hair growth and BW gain in the same goats (Galbraith *et al*., 2000).

In grazing goats, neither decreased stocking rate (Norton *et al*., 1990) nor supplementary grain feeding (McGregor, 1996b) increased cashmere production. On the other hand, undernourishment, i.e. when maintenance requirements are not satisfied, reduced animal weight and cashmere growth in goats. This phenomenon was more evident when undernourishment occurred during the anagen phase of fibre growth (McGregor, 1998).

In castrated goats reared in Australia, undernourishment (at 0.73 of maintenance level), between the summer solstice and winter solstice, caused a 16% BW loss, a 24% reduction in cashmere production and a 2% reduction in fibre diameter, as compared with control goats fed at maintenance levels (McGregor, 1988). Similarly, when Australian cashmere does of two genotypes (a Random line, made of goats selected from a population mated in a random manner, under no selection pressure; and a Cashmere Plus line, selected for down production) were fed at $0.7 \times$ maintenance, weight loss and reduction in cashmere production occurred (Restall *et al*., 1994).

It should be pointed out that the response to undernourishment varies according to the origin of Cashmere goats. In fact, in selected breeds of Australian origin, probably having Angora blood, weight loss and reduction in the growth and diameter of cashmere were observed, while in non-selected types the responses to an inadequate dietary supply were not clear (Restall *et al*., 1994).

Therefore, in goats of Australian origin, the most convenient feeding treatment, which increased cashmere production without decreasing its quality, led to an increase of 1–2 kg in BW during the period of maximum growth of the down fibre (i.e. between summer and autumn) (McGregor, 1998). Feeding goats to gain 4 kg in BW (Fig. 11.2a) (McGregor, 1998) over summer and autumn gave maximum cashmere growth. Maximum production was achieved at energy intakes of about $1.4 \times$ maintenance. On average, cashmere production is greatest in heavier goats, which increase BW, and lowest in goats of inferior size, which lose weight (Fig. 11.2b) (McGregor, 1998).

In conclusion, the convenience of feed integration depends on several factors: (i) the cost of integration; (ii) seasonal conditions, such as dry or wet years, and duration of feed supplementation; (iii) goat productivity; (iv) the level of response to better nutrition; and (v) the quality of the cashmere produced.

Effects of Energy Supply on Cashmere Moulting

Nutrient supply has indirect effects on fibre moulting because of its relationship with the concentration of hormones which regulate nutrient distribution and competition between tissues. The mechanisms that regulate fibre shedding are still not well understood, but a large body of evidence indicates that this event is related to seasonal changes in hormonal concentration of prolactin (Dicks, 1994). Growth hormone indirectly stimulates wool growth in sheep (Wynn *et al*., 1988), while no evident influence of this hormone on the cashmere growth cycle was found (Klören *et al*., 1993). In a more recent study, insulin-like growth factor-I (IGF-I) receptors have been identified in hair follicles (Dicks *et al*., 1996), suggesting a direct role of IGF-I in the control of hair follicle activity. Thyroid hormones also seemed to be involved in the regulation of seasonal pelage exchange in goats (Rhind and McMillen, 1995).

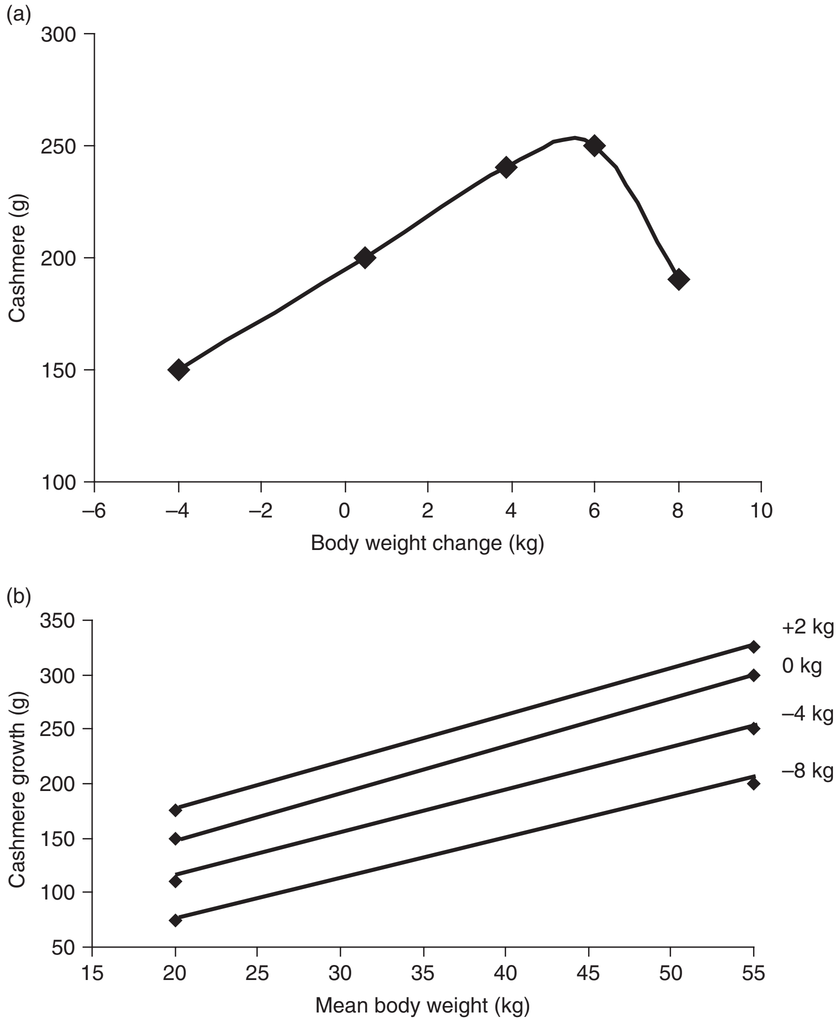

Fig. 11.2. (a) Relationship between the annual production of cashmere and the body weight change in Australian Cashmere goats; (b) relationship between cashmere growth and mean body weight for goats with different body weight changes during the cashmere growing season. (Adapted from McGregor, 1998.)

Energy restrictions at levels lower than maintenance (0.8 × maintenance), during the 6 months following the winter solstice, caused weight loss and delay in moulting of about 1 month. Energy levels higher than maintenance (1.2 and 2 × maintenance) anticipated moulting (Merchant and Riach, 2002). These authors have proposed that undernutrition also delayed the onset of regrowth of the new coat. At latitudes of 40–41°N, where Cashmere goats were reared either in mountain environments (1200 m asl) or on hills (360 m asl), the moulting peak was reached earlier in the mountains. In fact, during February, 79% of the cashmere is harvested in the mountain environment and 67% in the hilly areas. These results are also related to the different dietary regimens of the two environments. From autumn until the beginning of winter, goats reared on the hills grazed pastures for a longer period of time, during which the amount and quality of the available biomass may not have satisfied nutrient requirements. By contrast, in mountain environments, due to the bad weather conditions of that period, goats were fed indoors, thus assuring a more constant supply of nutrients (Di Trana *et al*., 1998).

At latitudes of 40–41°N, for Cashmere kids at first moult, maximal fibre shedding occurred a month earlier in males than in females. This was due to the higher prolactin and growth hormone concentration in males (Celi *et al*., 2003).

Environmental and Physiological Factors

Cashmere goats reared in different altitudes and weather conditions show different productive capacities. At higher altitudes (1180 m asl) and low temperature humidity index (THI), the percentage of active SFs, fibre length, cashmere yield and growth period increased in comparison to animals at lower altitudes (50 m asl) and a higher THI, while diameter remained the same (Celi *et al*., 2000, 2001; Di Trana *et al*., 2001, 2003).

The effects of latitude on down production are similar for high- and low-producing Cashmere goats. The down produced by Cashmere and Spanish goats, reared at a latitude above the 40th parallel, was higher and finer by 59 and 83%, respectively, compared with that of the same breeds reared at a latitude near the 30th parallel (Lupton *et al*., 2000).

In the Cashmere goat where the anagen phase is shorter and more concentrated in certain months of the year, the overlap between lactation and the production cycle of cashmere fibre reduces the activity of the SF. This was limited to the first 4 months of lactation (between June and September), with negligible effects on yield, the total annual production and diameter of cashmere (Celi *et al*., 2002).

At Italian latitudes (40–41°N), the overlap between the period of pregnancy and the beginning of lactation with that of the activity of SFs (May–December) decreased production, length and yield of cashmere, without influencing its diameter (Celi *et al*., 2005). Similar behaviour was observed in Cashmere goats of Australian origin (Klören and Norton, 1993).

Milk Production and Quality in Cashmere Goats

Information regarding milk quantity and quality produced by Cashmere goats is scarce. Table 11.7 reports the milk production and fat and protein content, at the 4th week after the colostrum phase, of Scottish feral Cashmere goats that had previously been reared in extensive systems until 14 or 9 weeks before delivery. Following housing the does were fed according to BW and were turned out to graze following kidding (Galbraith *et al*., 1992).

In extensive systems, individual milk production increases according to the availability of the fodder biomass.

Table 11.7. The production and quality of milk produced by Scottish feral Cashmere goats reared in extensive systems, housed before delivery and turned out to graze following kidding. (Adapted from Galbraith *et al.*, 1992.)

	Housed before delivery for		
Values at 4 weeks postpartum	14 weeks	9 weeks	SED
Milk production (g/day)	200–230	225–379	66.9
Fat (%)	2.5–3.0	4.1–6.4	1.0
Protein (%)	4.0–4.1	3.8–3.9	0.3

SED, standard error of the difference.

Table 11.8. Milk production and chemical composition of Cashmere goat's milk. (Adapted from Di Trana and Sepe, 2000.)

	Days after delivery						
Item	45	60	75	90	105	120	SEM
Milk (g/day)	1079[a]	1028[a]	943[a]	725[b]	558[c]	534[c]	59.2
Fat (%)	3.5[ab]	3.6[ab]	3.2[a]	3.5[ab]	3.7[b]	4.3[c]	0.2
Protein (%)	3.9	3.9	3.7	3.8	3.8	3.8	0.1
Lactose (%)	4.8	4.8	4.9	4.6	4.5	4.3	0.1
Casein N (mg/dl)	497	457	445	462	464	465	22
Whey N (mg/dl)	100	97	105	95	94	94	8
Non-protein N (mg/dl)	44	45	42	46	47	44	2

SEM, standard error of the mean.
[a,b,c]Mean values in rows with different superscript letters were significantly different ($P < 0.05$).

From Cashmere goats of Scottish origin, introduced into a Mediterranean environment and reared in an extensive system, a fair amount of milk is obtained together with the production of fibre of excellent quality. During the 75 days of lactation after the sale of kids, pluriparous goats kidding at the beginning of March produced 60.9 kg of milk per head. Contents of milk fat, protein and its nitrogenous fraction (Table 11.8) (Di Trana and Sepe, 2000) were similar to those of autochthonous goat breeds in southern Italy (De Maria Ghionna *et al.*, 1984). This suggests that milk and its products could be a further source of profit for the fibre goat sector.

The Dahlem Cashmere breed, created in the 1980s by cross-breeding the Angora breed with milk breeds, has a high level of milk production with a total protein content of 3.6%, which is similar to that observed in the Scottish Cashmere goats. Since Scottish Cashmere goats showed lower milk production, their milk casein content was higher (2.9 g/100 g) (Di Trana and Sepe, 2000) than that of the Dahlem Cashmere breed (2.7 g/100 g) (Dimassi *et al.*, 2004).

The Angora Goat

Unlike Cashmere goats, the Angora goat experiences strong competition for nutrients between milk and fibre, similar to that found in sheep. The main difference between the Angora and the Cashmere goat is in the physiology of their fibre growth as well as the structure of the epidermic scales of the fibrous filament and the ratio between SFs and PFs (Fig. 11.1).

The Angora goat has been reared as a pure breed in Turkey and was first exported to South Africa in 1838; subsequently it reached Russia and Australia, where cross-breeding was carried out with local Cashmere breeds (Millar, 1986). This created a breed named Cashgora, with fibre which had intermediary features between cashmere and mohair.

Mohair Fibre

Mohair fibre is produced exclusively by Angora goats from the SF, and is characterized by the features described in Table 11.9 (Shelton, 1981; Epplestone and Moore, 1990; Antonini *et al*., 1994b).

The fineness of the fibre is the main element which distinguishes mohair from other fibres. In Italy, this fibre is classified by diameter and length according to the South African method (Table 11.10) (Gallico, 1992).

In Angora goats a marked aptitude for fibre production is demonstrated by a predominant number of SFs compared with PFs (Fig. 11.1), attaining the SF/PF ratio of 8–10 (Shelton, 1981).

In contrast to cashmere, mohair has a continuous anagen all year long, even if it is faster in the summer. This kind of growth has a stronger influence on the

Table 11.9. Characteristics of mohair fibre. (Adapted from Shelton, 1981; Epplestone and Moore, 1990; Antonini *et al*., 1994b.)

Item	Range	Merchandise considerations
Average diameter (μm)	25–39	The thinner the softer
Length (mm)	75–150	Turkish mohair is longer and, owing to this, more requested
Yield (%)	70–90	
Colour	white, grey, brown, black	Normally white; occasional black hairs depreciate the mass
Sheen	–	Main characteristic which makes mohair especially valuable
Kemp (fibres with medulla, short and dead) (%)	1–2	As kemp increases, flock quality decreases

Table 11.10. Classification of mohair used in Italy according to diameter and length; quality increases from adult to super kid and from E to A. (Adapted from Gallico, 1992.)

Type	Diameter (μm)	Class	Length (mm)
Super kid	24.0–26.5	A	150 and above
Kid	26.5–29.5	B	125–150
Young goat	29.5–34	C	100–125
Fine adult	34–36	D	75–100
Adult	36–39	E	< 75

nutritional requirements during the various physiological stages of Angora goats compared with that of fibre growth on Cashmere goats.

A well-reared and well-fed adult Angora goat has an average monthly growth of mohair of 2–5 cm (Shelton, 1981). Thanks to its particular structure, mohair has a characteristic silken sheen and a mean tenacity about 30% higher than that of wool.

The harvesting of the fleece takes place by shearing. The first shearing, carried out on 6-month-old kids, supplies the very best quality fibre. In general, two shearings are carried out annually, the first in April, when the fibre is 120 mm long, and the second in September. Turkish mohair is obtained from one single shearing per year, and is therefore longer. In this case, the annual production per head is reduced to 2.5 kg compared with the 3 kg of double shearing in Australia and the 4–5 kg from the South African goat population.

Mohair is considered a luxury fibre for both its quality and its limited availability, even if it is evaluated at a lower price than cashmere. This depends on the lower costs for transformation into yarn. There is a traditional use of mohair for rugs and curtains by Arab nomads. The use of this fibre for men's and women's clothing is widespread. Other than for luxury upholstery, the demand for mohair varies according to the requirements of the textile industry and the designers. Age is the determining factor for both the quality and quantity of mohair in a rearing system which satisfies the nutritional requirements of the Angora goat. The number of SFs increases from the moment of birth up to 2 years of age, bringing the SF/PF ratio from the initial 2–3 to 8–10. As kids grew, mohair diameter increased from 24 μm in a 6-month-old kid to 49 μm in an adult goat, so the mohair production and yield also increased (Shelton, 1981).

Female goats had a higher number of follicles per square millimetre, and lower diameter and percentage of medullated fibres than the males (Antonini *et al*., 1994b). As confirmed by this information, the best-quality mohair comes from females, and this has led to the use of castration in male kids (Willingham *et al*., 1988).

The production of kemp increases with age and has a high degree of hereditability ($h^2 = 0.43$); therefore, there is potential for genetic improvement of this trait.

Nutritional Requirements of Angora Goats

The amount of fibre produced by the Angora goat on a daily basis varies between 5 g/day (1.8 kg/year) and 16.7 g/day (6.0 kg/year), being higher than the amount produced by sheep.

Recently, a system for goats, with specific predictions for Angora goats, has been developed by the E(Kika) de la Garza Institute for Goat Research at Langston University (USA) to estimate the nutritional requirements for maintenance, fibre and milk production and also weight gain under different grazing and climatic conditions (Luo *et al*., 2004a,b). A summary of these requirements is reported in Table 11.11.

Mineral and vitamin requirements

Fibre-producing goats do not have any particular requirements for minerals and vitamins. A mineral deficiency, as with other goat breeds, causes a decrease in production and threatens animal health. In areas where the soil–plant system does not guarantee the right amount of microelements (e.g. Se, Cu, Co, I and Zn), diet integration with these is necessary. Anyway, mineral and vitamin integration for Cashmere and Angora goats must be taken into consideration whenever the feeds utilized in their diet are deficient.

Specific nutritional requirements for Angora goats have been established for S, an essential microelement for the synthesis of sulphurated amino acids, microbial protein in the rumen and fibre proteins. An intake of S equal to 0.267% of DM and a ratio of 7.2:1 between N and S are considered optimal (Qi *et al*., 1992).

Table 11.11. Daily total nutritional requirements and intake of the Angora goat at different fibre production levels grazing on hill pastures (body condition score was equal to 2, and average air temperature was 12°C). (Adapted from Luo *et al*., 2004a,b.)

BW (kg)	Clean mohair production (g/day)	ME (MJ/day)	MP (g/day)	CP (g/day)	DM intake (% of BW)
30	5	6.85	51	76	2.70
	10	7.64	59	88	2.77
	15	8.42	68	101	2.84
40	5	8.22	61	92	2.45
	10	9.00	70	104	2.51
	15	9.79	78	116	2.56
50	5	9.50	71	106	2.28
	10	10.29	79	118	2.33
	15	11.07	88	131	2.37

BW, body weight; ME, metabolizable energy; MP, metabolizable protein; CP, crude protein; DM, dry matter.

By increasing the S in the diet, the production of mohair and the length and resistance of the flock increase, without any reduction in fibre quality.

A deficit in P and vitamin A reduced the keratinization of the skin and the activity of piliferous follicles (Morand-Fehr and Galbraith, 1992). Therefore, it is better to integrate these nutrients in the diet, especially when fresh forage availability is limited.

In Inner Mongolian White Cashmere goats, the optimum Cu level is 27.46 mg/kg of diet during the cashmere growing period (Zhang *et al*., 2004).

Among the vitamins, biotin has an important influence on the growth of tegumental tissues and piliferous follicles. In fact, deficiency of this vitamin in kids led to a reduction of weight gain, an *in vivo* mohair loss and a reduction of *in vitro* vitality of the mohair follicles (Galbraith *et al*., 2000).

Nutrition of Angora Goats

Feed intake

As for all ruminants, the intake of Angora goats differs according to the type of hay utilized. In fact, the daily intake was 716, 546 and 724 g of DM per head for hays of lucerne, poliphita lowland pasture and meadow (73.7% *Trifolium repens* and 26.3% *Lolium perenne*), respectively. Daily intake was 576 and 864 g of DM per head for sorghum and oat hays, respectively (Antonini *et al*., 1994a).

As NDF concentration in the hay increased from 38.2 to 73.6% and up to 75.8%, organic matter intake was, respectively, 67.6, 45.5 and 34.6 g/kg $BW^{0.75}$ (Morand-Fehr, 1993). During lactation, increases in the CP level of the diet from 9 to 18% of DM caused a non-significant increase of DM intake from 1.54 to 1.56 kg/day ($P > 0.05$) (Sahlu *et al.,* 1992a).

Pasture intake is greater in periods of time when forage availability is high. As for other breeds (see Avondo *et al*., Chapter 7, this volume), intake of Angora goats is influenced by animal factors, especially selective behaviour, as well as by the type of herbage utilized. Pasture intake is also related to stocking rate and individual production. Both the productivity and the economic efficiency of fibre-producing farms are influenced by stocking rates. The effects of high stocking rates (higher than 7.5 head/ha) on mohair features of grazing Angora goats are often negative and commercially relevant (Table 11.12) (McGregor, 1998).

On pastures in temperate areas, it is advisable to use a stocking rate of 7.5 head/ha (season average) for Angora goats. Such a stocking rate minimizes both gastrointestinal parasite infections and post-shearing weather stress. At high rates of stocking the mortality rate (primarily gastrointestinal parasitism and post-shearing weather stress) was twice that at lower rates of stocking (McGregor, 1998). Under such conditions, the goats increase in weight fairly quickly and produce more and longer mohair, which, however, is not as fine as that of goats reared at high stocking rates.

Table 11.12. The main effects of high stocking rates (> 7.5 head/ha) of Angora goats grazing annual pastures in temperate areas on mohair production and quality parameters. (Adapted from McGregor, 1998.)

Item	Effect of high stocking rate
Weight of mohair	20% reduction in fibre production per head
Fibre diameter	Thinner coat – diameter decrease by ≥ 5 μm
Kemp	Increase in the incidence of kemp
Clean mohair yield	Decrease by ≥ 5%
Mohair length	Reduction of fibre length

Energy

In Mediterranean environments, energy deficit usually occurs in summer. This is determined by scarce pasture resources and leads to a decrease in body condition score and BW of the animals. During this time, weight loss can be minimized by utilizing cereal grains (e.g. barley, oats and wheat), which are relatively low-cost energy sources that do not dirty the fleece remaining on the flocks. The use of energy supplements influences BW and mohair diameter. Goats losing weight produced less mohair (from 15 to 40%) and their fibre was thinner by 2–3 μm than goats at constant weight. On the other hand, goats fed for BW gain produced much more mohair (up to 100% increase) and fibre which was 2–3 μm thicker than animals with a constant weight (McGregor, 1998). When integration was supplied, an increase of 0.26 and 0.40 μm in diameter for each kilogram of weight gain was recorded, respectively, for animals on pasture and those housed (McGregor, 1998).

Determination of the economic convenience of using energy integration should take diameter increase into consideration, since a 5% depreciation of the price occurs for each micrometre increase (up to diameters of 32 μm) (van der Westhuysen, 1982). In young animals, a dietary supplement which increased weight reduced the incidence of medullated fibres when compared with goats which had an unvaried BW during the growth cycle of the fibre. In 6-month-old Angora kids, during a period of scarce herbage availability, supplementation actually doubled fibre production. The percentage of medullated fibre (7.6 and 0.9% in New Zealand and South African genotype, respectively) and kemp (4 and 0.5% in New Zealand and South African genotype, respectively) (Newman and Paterson, 1999) was not strongly influenced by the utilization of dietary supplement, but rather by genetic factors and age (Galbraith *et al*., 2000).

Energy supplementation in pregnant or lactating goats is advisable when goat welfare is at risk (e.g. scarce pasture availability or pregnancy) or when animal reproductive and productive performance is to be improved. An increase in fleece value at the kid's first shearing is added to these benefits.

In extreme situations, such as bad weather conditions after shearing, or a lack of hay or pasture availability, a quick and high intake of cereal grains could induce rumen acidosis. In this case, it is advisable to supply rumen buffers together with cereal grains to limit the increase in rumen acidity or to supply feed as dried beet pulps, citrus pulp and soybean hulls.

Proteins

Protein supplements with high rumen escape and rich in sulphurated amino acids increase weight and diameter of mohair. The beneficial effects of this kind of integration depend on the quantity and the balance of nutrients in the basal diet (Galbraith *et al*., 2000).

During the period of the year in which the lengthening of the mohair is more rapid, a substantial increase in fibre growth can be obtained with diets containing large amounts of sulphurated amino acids reaching the intestine.

The effects of two protein (108 and 180 g CP/kg DM) and energy (10.0 and 11.9 MJ ME/kg DM) levels on the production and the quality of the mohair were evaluated in castrated Angora goats. The results confirmed the fact that mohair growth can be significantly limited by an inadequate amount of dietary protein, and also that protein supplement stimulates yield (Shahjalal *et al*., 1992; Galbraith, 2000). However, such supplement also increases fibre diameter, which is a commercially undesirable consequence. As an example, an increase in dietary protein from 12 to 18% increased the yield of the clean fleece by about 23% and the average fibre diameter by 5.2% (Galbraith *et al*., 2000).

It is difficult to optimize protein supplements in the diet of goats to improve at the same time the quality and the quantity of the fibre. The highest production of mohair was reached by supplying 165 g CP/kg DM per day, while the lowest fibre diameter was achieved by a lower CP supply (102 g/kg DM) (Shahjalal *et al*., 1991).

In 18-month-old Angora female goats, high mohair yield was reached with CP levels up to 190 g/kg DM with an isoenergetic diet (Sahlu *et al*., 1992a,b). A dietary supplementation with horsebeans (*Vicia faba* var. *minor*) in 90- and 150-day-old kids increased fibre growth rate, follicle activity and fibre length, and decreased mohair diameter, as opposed to what happens with adult animals (Trabalza Marinucci *et al*., 2003).

Protein sources with a high biological value or a high content of rumen-protected protein, such as cysteine treated with formaldehyde and heat-treated soybean, increased the growth of mohair fibre (Morand-Fehr and Galbraith, 1992; Galbraith *et al*., 2000).

Methionine, cystine and cysteine are amino acids involved in the synthesis of the proteins deposited in mohair. A great amount of cystine and cysteine can be recuperated through the trans-sulphuration of methionine. This amino acid has a specific role in the stimulation of mohair growth. In fact, with 1-year-old Angora goats the inclusion of protected methionine (2.5 g/head per day), in a diet of 9.9 MJ ME/kg DM and 107 g CP/kg DM, increased both the yield and the diameter of the mohair produced in 2 months (Souri *et al*., 1998; Galbraith, 2000). Protected methionine improved mohair production by 0.8 g/head per day for each gram of methionine supplied (Morand-Fehr and Galbraith, 1992).

In conclusion, Angora goats respond to a dietary supplementation of good-quality protein, or protected methionine, with an increase in mohair yield and a decrease in its quality.

Photoperiod

The seasonal photoperiod has an influence on mohair growth. In the winter, the lengthening of mohair is at a minimum whereas it reaches its maximum value in the summer. Castrated Angora goats kept at a constant BW had 55% higher fibre growth in the summer than in the winter. Medullated fibre and kemp showed a similar trend. In the winter, the percentage of inactive piliferous follicles was greater and increased as the animals aged (McGregor, 1998). The practical implications of these observations are: (i) an increase in the presence of kemp in the fleece collected in the autumn; and (ii) an indication for the most appropriate slaughtering age based on the reduction in the percentage of active follicles as the animal ages.

Conclusions

The Cashmere goat is recognized to have a large productive potential due to: (i) its limited nutritional requirements for fibre production; (ii) the reduced influence of protein or energy supplementation on the yield; (iii) its easy adaptation to various rearing environments; and (iv) its production, in addition to fibre, of kids and milk.

For these particular reasons, the rearing of Cashmere goats could give a real boost to farm activities or even to farm holidays utilizing market niches, so as to guarantee an added income for that type of enterprise. Another advantage would be that this goat could utilize and protect native pasture systems.

On the other hand, the Angora goat, having undergone a selective process, is characterized by nutritional requirements closely associated to its fleece production.

The productive response of the Angora goat is sensitive to both protein and energy supplementation, with an increase in mohair yield and a decrease in quality. Therefore, since the value of the product decreases as fibre diameter increases, an economic analysis of feed supplementation is necessary.

Because of its functional features and the strong competition for nutrients between milk and fibre, the Angora goat expresses a productive potential which is limited to luxury fibres.

References

Antonini, M., Abbadessa, V., Trabalza Marinucci, M. and Misiti, S. (1994a) Prime osservazioni sul comportamento alimentare di capre Angora importate in Italia: ingestione, selezione e digeribilità apparente di alcuni foraggi tipici. In: *Proceedings* *of the XI National Congress of Società Italiana di Patologia e di Allevamento degli Ovini e dei Caprini*. Università degli Studi di Perugia, Perugia, Italy, pp. 389–392.

Antonini, M., Carnevali, F., Castrignano, F., Misiti, S. and Pieramati, C. (1994b) Angora goat production in Italy. In: Laker, J.P. and Bishop, S.C. (eds) *Proceedings of the European Fine Fibre Network, Occasional Publication 1*. Macaulay Land Use Research Institute, Peebles, UK, pp. 65–75.

Ash, A.J. and Norton, B.W. (1987) Effect of D,L-methionine supplementation on fleece growth by Australian cashmere goats. *Journal Agricultural Science (Cambridge)* 109, 197–199.

Celi, R., Di Trana, A., Colonna, M.A., Toteda, F., Facciolongo, A.M. and Rubino, R. (2000) Influence of altitude on Cashmere production in goats reared in Southern Italy. In: Gruner, L. and Chabert, Y. (eds) *Proceedings of the 7th International Conference on Goats*. Institut de l'Elevage and Institut National de la Recherche Agronomique, Paris, pp. 652–654.

Celi, R., Labate, M., Di Trana, A., Desantis, S., Rubino, R. and Cirillo, F. (2001) Percentage of active primary and secondary follicles and fibre length in cashmere goats reared at different altitudes. In: Antongiovanni, M., Bozzi, R., Franci, O., Giorgetti, A., Gualtieri, M., Acciaioli, A., Parisi, G., Martini, A. and Biagioli, O. (eds) *Proceedings of the ASPA XIV Congress, Recent Progress in Animal Production Science*, Vol. 2. Dipartimento di Scienze Zootecniche, Università di Firenze, Firenze, Italy, pp. 523–525.

Celi, R., Di Trana, A. and Celi, P. (2002) The influence of lactation on the quantity and quality of cashmere production. *Italian Journal of Animal Science* 1, 79–86.

Celi, P., Seren, E., Celi, R., Parmeggiani, A. and Di Trana, A. (2003) Relationships between blood hormonal concentrations and secondary fibre shedding in young cashmere-bearing goats at their first moult. *Animal Science* 77, 371–381.

Celi, R., Di Trana, A., Celi, P., Marsico, G. and Forcelli, M. (2005) The influence of pregnancy and the beginning of lactation on pelage traits in cashmere goats. *Italian Journal of Animal Science* 4, 85–96.

De Maria Ghionna, C., Catillo, G., Angelucci, M., Zarriello, G. and Rubino, R. (1984) Indagine conoscitiva sulla produzione e qualità del latte di un gruppo di capre locali, allevate nelle aree interne della Lucania. *Annali Istituto Sperimentale per la Zootecnia* 17, 155–166.

Dicks, P. (1994) The role of prolactin and melatonin in regulating the timing of the spring moult in the cashmere goat. In: Laker, J.P. and Allain, D. (eds) *Proceedings of the European Fine Fibre Network, Occasional Publication 2*. Macaulay Land Use Research Institute, Aberdeen, UK, pp. 109–128.

Dicks, P., Morgan, C.J., Morgan, P.J., Kelly, D. and Williams, L.M. (1996) The localisation and characterisation of insulin-like growth factor-I receptors and the investigation of melatonin receptors on the hair follicles of seasonal and non-seasonal fibre-producing goats. *Journal of Endocrinology* 151, 55–63.

Dimassi, O., Herold, P. and Zárate Valle, A. (2004) Yield, composition and cheese making potential of Dahlem Cashmere goat milk. *South African Journal of Animal Science* 34(Suppl. 1), 159–161.

Di Trana, A. and Sepe, L. (2000) Milk production traits of Cashmere goats in Southern Italy. In: Gruner, L. and Chabert, Y. (eds) *Proceedings of the 7th International Conference on Goats*. Institut de l'Elevage and Institut National de la Recherche Agronomique, Paris, p. 612.

Di Trana, A. and Sepe, L. (2007) The effect of protein supplement on the quantity, quality and moult of cashmere fibre in Cashmere goats kept at pasture in Southern Italy. In: Rubino, R. and Sepe, L. (eds) *Proceedings of the International Symposium*

'The quality of goat products: models and tools for evaluation and promotion', Bella (Potenza), Italy. Consiglio per la Ricerca e sperimentazione in Agricoltura, Bella (Potenza) Italy, pp. 121–124.

Di Trana, A., Sepe, L. and Rubino, R. (1998) Influenza dell'ambiente di allevamento e della frequenza di raccolta sulla muta della fibra cashmere. In: *Proceedings of the XIII National Congress of Società Italiana di Patologia e di Allevamento degli Ovini e dei Caprini*. Università degli Studi di Palermo, Palermo, Italy, pp. 454–458.

Di Trana, A., Celi, R., Desantis, S., Celi, P. and Labate, G.M. (2001) Influence of environmental temperature and humidity on cashmere traits in goats reared in southern Italy. In: Antongiovanni, M., Bozzi, R., Franci, O., Giorgetti, A., Gualtieri, M., Acciaioli, A., Parisi, G., Martini, A. and Biagioli, O. (eds) *Proceedings of the ASPA XIV Congress, Recent Progress in Animal Production Science*, Vol. 2. Dipartimento di Scienze Zootecniche, Università di Firenze, Firenze, Italy, pp. 526–528.

Di Trana, A., Celi, P. and Celi, R. (2003) The effect of environmental temperature and humidity on cashmere yield, secondary active follicles and thyroid hormones in cashmere goats. In: Lacetera, N., Bernabucci, U., Khalifa, H.H., Ronchi, B. and Nardone, A. (eds) *Proceedings of 'Interaction between climate and animal production'*. European Association for Animal Production, Technical Series No. 7. Wageningen Academic Publishers, Wageningen, The Netherlands, p. 96.

Di Trana, A., Celi, P., Sepe, L., Desantis, S. and Rubino, R. (2004) Fleece and skin traits of goats of different genetic types reared in Southern Italy. *South African Journal of Animal Science* 34(Suppl. 1), 156–158.

Epplestone, J. and Moore, N.W. (1990) Fleece and skin characteristics of selected Australian Angora goats. *Small Ruminant Research* 3, 397–402.

Fedele, V., Claps, S., Rubino, R., Calandrelli, M. and Pilla, A.M. (2002) Effect of free-choice and traditional feeding systems on goat feeding behaviour and intake. *Livestock Production Science* 74, 19–31.

Galbraith, H. (2000) Protein and sulphur amino acid nutrition of hair fibre-producing Angora and Cashmere goats. *Livestock Production Science* 64, 81–93.

Galbraith, H., Bell, J., Scaife, J.R., Acamovic, T., MacDonald, D.C. and Roger, L.C. (1992) Milk production, vitamin and immunological status of cashmere does and kids differing in pre-partum housing date and buck genotype. In: *CIV Proceedings of the British Society of Animal Production*. BSAS, Edinburgh, pp. 472–473.

Galbraith, H., Norton, B.W. and Sahlu, T. (2000) Recent advances in the nutritional biology of Angora and Cashmere goats. In: Gruner, L. and Chabert, Y. (eds) *Proceedings of the 7th International Conference on Goats*. Institut de l'Elevage and Institut National de la Recherche Agronomique, Paris, pp. 59–65.

Gallico, L. (1992) La fibra tessile mohair. *Notiziario dell'ENEA e di RENAGRI* 22, 44–49.

Hadjigeorgiou, I.E., Gordon, I.J. and Milne, J.A. (2001) The intake and digestion of a range of temperate forages by sheep and fibre-producing goats. *Small Ruminant Research* 39, 167–179.

Ivey, D.S., Owens, F.N., Sahlu, T., Teh, T.H., Claypool, P.L. and Goetsch, A.L. (2000) Growth and cashmere production by Spanish goats consuming *ad libitum* diets differing in protein and energy levels. *Small Ruminant Research* 35, 133–139.

Klören, W.R.L. and Norton, B.W. (1993) Fleece growth in Australia cashmere goats. II. The effect of pregnancy and lactation. *Australian Journal of Agricultural Research* 44, 1023–1034.

Klören, W.R.L., Norton, B.W. and Waters, M. J. (1993) Fleece growth in Australian cashmere goats. III. The seasonal patterns of cashmere and hair growth, and the underlying seasonal patterns of growth hormone, prolactin and thyroxine concentration. *Australian Journal of Agricultural Research* 44, 1035–1050.

Lee, D.R., Galbraith, H. and Scaife, J.R. (1994) *In vitro* fibre production and protein synthesis in secondary hair follicles of the Cashmere and Angora goat. *Animal Production* 58, 483.

Li, Y., Ma, N., Song, Y., Luan, W. and Lou, Y. (1996) Effects of non-genetic factors on main economic traits in Liaoning cashmere goat. In: Holst, P.J., Rubino, R., Galal, E., Soedjana, T., Haenlein, G.F., Gatenby, R., Morand-Fehr, P., Lebbie, S.H. and Restall, B. (eds) *Proceedings of the VI International Conference on Goats*. International Academic Publishers, Beijing, pp. 202–204.

Luo, J., Goestch, A.L., Nsahlai, I.V., Sahlu, T., Ferrel, C.L., Owens, F.N., Galyeans, M.L., Moore, J.E. and Johnson, Z.B. (2004a) Prediction of metabolizable energy and protein requirements for maintenance, gain and fibre growth of Angora goats. *Small Ruminant Research* 53, 339–356.

Luo, J., Goestch, A.L., Nsahlai, I.V., Moore, J.E., Galyeans, M.L., Johnson, Z.B., Sahlu, T., Ferrel, C.L. and Owens, F.N. (2004b) Voluntary feed intake by lactating, Angora, growing and mature goats. *Small Ruminant Research* 53, 357–377.

Lupton, C.J., Dooling, A.R., Lankford, K., Huston, J.E. and Pfeiffer, F.A. (2000) Effect of location on fiber production by Cashmere goats. In: Gruner, L. and Chabert, Y. (eds) *Proceedings of the 7th International Conference on Goats*. Institut de l'Elevage and Institut National de la Recherche Agronomique, Paris, p. 655.

Lynch, P. (1990) Cashmere growth: its control and possible manipulation. In: Russel, A.J.F. (ed.) *Scottish Cashmere – The Viable Alternative*. D. & J. Croal Ltd, Haddington, UK, pp. 5–12.

McDonald, P., Edwards, R.A. and Greenhalgh, J.F.D. (1992) *Animal Nutrition*, 4th edn. Longman Group UK Limited, Harlow, UK.

McGregor, B.A. (1988) Effect of different nutritional regimens on the productivity of Australian cashmere goats and portioning of nutrients between cashmere and hair growth. *Australian Journal of Experimental Agriculture* 28, 459–467.

McGregor, B.A. (1996a) Environmental, nutritional and management influences on quality and production of mohair and cashmere. In: Holst, P.J., Rubino, R., Galal, E., Soedjana, T., Haenlein, G.F., Gatenby, R., Morand-Fehr, P., Lebbie, S.H. and Restall, B. (eds) *Proceedings of the VI International Conference on Goats*. International Academic Publishers, Beijing, pp. 285–296.

McGregor, B.A. (1996b) Lupin grain but not barley straw supplements allow cashmere buck kids to grow rapidly during winter. *Proceedings of the Australian Society of Animal Production* 21, 294–297.

McGregor, B.A. (1998) Nutrition, management and other environmental influences on the quality and production of mohair and cashmere with particular reference to Mediterranean and annual temperate climatic zones: a review. *Small Ruminant Research* 28, 199–215.

Merchant, M. and Riach, D.J. (1994) The intake and performance of cashmere goats grazing sown swards. *Grass and Forage Science* 49, 429–437.

Merchant, M. and Riach, D.J. (2002) The effect of plane of nutrition and shearing on the pattern of the moult in Scottish cashmere goats. *Animal Science* 74, 177–188.

Millar, P. (1986) The performance of cashmere goats. *Animal Breeding Abstracts* 54, 181–199.

Morand-Fehr, P. (1993) Nutritional characteristics and feeding strategies for Angora goats. In: Güney, O., Biçer, O. and Ranieri, M.S. (eds) *Production of Hides, Skins, Wool and Hair*. Pudoc Scientific Publishers, Wageningen, The Netherlands, pp. 97–107.

Morand-Fehr, P. and Galbraith, H. (1992) Nutritional characteristics and feeding strategies for fibre producing goats. In: Galbraith, H. (ed.) *New Developments in Goat*

Husbandry for Quality Fibre Production. Aberdeen University Studies Committee, Aberdeen, UK, pp. 40–66.

Newman, S.A.N. and Paterson, D.J. (1999) Variation in fibre and fleece characteristics between and within South African, New Zealand, and South African × New Zealand Angora goat genotypes. *New Zealand Journal of Agricultural Research* 42, 77–82.

Norton, B.J., Wile, C.A. and Hales, J.W. (1990) Grazing management studies with Australian cashmere goats: 1. Effect of stocking rate on the growth and fleece production of weaner goats grazing tropical pastures. *Australian Journal of Experimental Agriculture* 30, 769–775.

Petrie, O.J. (1995) *Harvesting of Textile Animal Fibres*. FAO Agricultural Services Bulletin No. 122. Food and Agriculture Organization of the United Nations, Rome.

Phan, K.H. and Wortmann, F.J. (2000) Quality assessment of goat hair for textile use. In: Gruner, L. and Chabert, Y. (eds) *Proceedings of the 7th International Conference on Goats*. Institut de l'Elevage and Institut National de la Recherche Agronomique, Paris, pp. 638–640.

Qi, K., Lu, C.D., Owens, F.S. and Lupton, C.J. (1992) Sulphate supplementation of Angora goats: metabolic and mohair responses. *Journal of Animal Science* 70, 2828–2837.

Reis, P.J. (1989) The influence of absorbed nutrients on wool growth. In: Rogers, G.E., Reis, P.J., Ward, K.A. and Marshall, R.C. (eds) *The Biology of Wool and Hair*. Chapman and Hall, London, pp. 185–204.

Restall, A.J.F., Restall, H., Restall, M. and Parry, A. (1994) Seasonal production of cashmere and environmental modification in Australian cashmere goats. In: Laker, J.P. and Allain, D. (eds) *Proceedings of the European Fine Fibre Network, Occasional Publication 2*. Macaulay Land Use Research Institute, Aberdeen, UK, pp. 63–74.

Rhind, S.M. and McMillen, S.R. (1995) Seasonal changes in systemic hormone profiles and their relationship to patterns of fibre growth and moulting in goat of contrasting genotypes. *Australian Journal of Agricultural Research* 46, 1273–1283.

Rubino, R., Di Trana, A. and Sepe, L. (2000) First appearance of Cashmere in a local goat breed in Italy. In: Gruner, L. and Chabert, Y. (eds) *Proceedings of the 7th International Conference on Goats*. Institut de l'Elevage and Institut National de la Recherche Agronomique, Paris, p. 656.

Russel, A.J.F. (1990) Nutrition of cashmere goats. In: Russel, A.J.F. (ed.) *Scottish Cashmere – The Viable Alternative*. D. & J. Croal Ltd, Haddington, UK, pp. 32–46.

Russel, A.J.F. (1995) Current knowledge on the effects of nutrition on fibre production. In: Laker, J.P. and Russel, A.J.F. (eds) *Proceedings of the European Fine Fibre Network, Occasional Publication 3*. Macaulay Land Use Research Institute, Aberdeen, UK, pp. 3–22.

Ryder, M. (1989) *Cashmere, Mohair and Other Luxury Fibres*, 1st edn. Itchen Printers Ltd, Southampton, UK.

Sahlu, T., Fernandez, M.J., Carneiro, H. and El Saher, H.M. (1992a) Partitioning of nutrient between milk and mohair in Angora goats. In: Lokeshwar, R.R. (ed.) *Proceedings of Recent Advances in Goats Production*. Nutan Printers, New Delhi, p. 1634.

Sahlu, T., Fernandez, M.J., Lu, C.D. and Manning, R. (1992b) Dietary protein level and rumen degradability for mohair production in Angora goats. *Journal of Animal Science* 70, 1526–1533.

Sauvant, D., Morand-Fehr, P. and Giger-Reverdin, S. (1991) Dry matter intake of adult goats. In: Morand-Fehr, P. (ed.) *Goat Nutrition*. EAAP Publication No. 46. Pudoc, Wageningen, The Netherlands, pp. 25–36.

Sepe, L., Fedele, V., Rubino, R. and Claps, S. (1996) Preliminary results on the adaptation of cashmere goats to the environment in Southern Italy. In: Holst, P.J., Rubino, R., Galal, E., Soedjana, T., Haenlein, G.F., Gatenby, R., Morand-Fehr, P., Lebbie, S.H. and Restall, B. (eds) *Proceedings of the VI International Conference on Goats*. International Academic Publishers, Beijing, pp. 329–332.

Shahjalal, M., Galbraith, H., Topps, J.H. and Copper, J.M. (1991) Effect of level of protein supplementation on growth, body composition and fibre characteristics of British Angora goats. *Animal Production* 52, 608.

Shahjalal, M., Galbraith, H. and Topps, J.H. (1992) The effect of changes in dietary protein and energy on growth, body composition and mohair fibre characteristics of British Angora goats. *Animal Production* 54, 405–412.

Shelton, M. (1981) Fiber production. In: Gall, C. (ed.) *Goat Production*. Academic Press Inc. Ltd, London, pp. 379–409.

Souri, M., Galbraith, H. and Scaife, J.R. (1998) Comparison of the effect of genotype and protected methionine supplementation on growth, digestive characteristics and fibre yield in Cashmere and Angora goats. *Animal Science* 66, 217–223.

Trabalza Marinucci, M., Acuti, G., Antonini, M. and Olivieri, O. (2003) Fibre characteristics and follicle activity in Angora kids as affected by diet. *Italian Journal of Animal Science* 2(Suppl. 1), 545–547.

van der Westhuysen, J.M. (1982) Mohair as a textile fibre. In: Ayers, J.L. and Foote, W.C. (eds) *Proceedings of the III International Conference on Goat Production and Disease*, Tucson, Arizona. Dairy Goat Journal Publishing Co., Scottsdale, Arizona, pp. 264–267.

Willingham, T.D., Thompson, P.V. and Shelton, J.M. (1988) Chemical castration in Angora goats. *Research Reproduction Sheep and Goat, Wool and Mohair*. PR-4577. San Angelo Agricultural Research and Extension Center, San Angelo, Texas, pp. 28–30.

Wynn, P.C., Wallace, A.L.C., Kirby, A.C. and Annison, E.F. (1988) Effects of growth hormone administration on wool growth in Merino sheep. *Australian Journal of Biological Science* 41, 177–187.

Zhang, F. and Shi, B. (1996) Effects of age on the cashmere production of goats. In: Holst, P.J., Rubino, R., Galal, E., Soedjana, T., Haenlein, G.F., Gatenby, R., Morand-Fehr, P., Lebbie, S.H. and Restall, B. (eds) *Proceedings of the VI International Conference on Goats*. International Academic Publishers, Beijing, pp. 102–103.

Zhang, W., Zhu, X.P., Lu, D.X., Hou, W.J. and Jia, Z.H. (2004) Study on dietary copper proper level of Inner Mongolian White Cashmere Goats during the cashmere growing period. *Journal of China Agricultural University* 9, 36–40.