2
Mohair

2.1 Introduction and brief history

2.1.1 General background

Mohair, the lustrous fleece of the Angora goat (Fig. 2.1), is one of the most important speciality animal fibres, detailed on the frontispiece. This is true although it represents less than 0.02 % of the total world fibre production.[1]

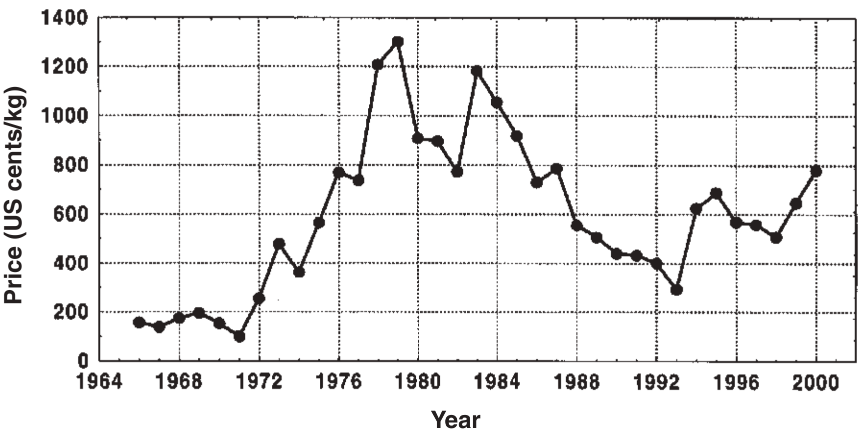
Mohair finds application in a wide range of textile end-uses, notably apparel and household textiles, but is very dependent upon fashion, as reflected in large fluctuations in price (see Fig. 2.2). Although a considerable amount of published information exists on mohair, much of the specialised knowledge required to convert the fibre into quality products remains unpublished and a closely guarded secret, even today.

A comprehensive review, containing more than 1000 references, on the properties, processing and applications of mohair published by Hunter in 1993[2] provides a more detailed source of reference and information.

For centuries, mohair has been regarded as one of the most luxurious and best quality fibres available to man. It is generally a long, straight (uncrimped but often wavy), smooth and naturally lustrous fibre which can be dyed to deep, brilliant and fast colours. The predominant natural colour of mohair is white, although there are also occasionally brown, black and pink or red varieties; such coloured fibres contain pigment (mainly melanin) in the cortex.[3] The Angora goat has a single coat with good quality mohair virtually free of medullation and kemp. On average, mohair fibre diameter ranges from below 24 μm for Superfine Kids to about 40 μm for Coarse Adults.

Today, mohair is largely produced in South Africa and the United States of America (Texas) but also in Turkey, Argentina, Lesotho, Australia and New Zealand. South Africa presently accounts for approximately 60 % of the world production of mohair. Table 2.1 gives the annual production of mohair worldwide since 1970.

2.1 Angora goats in the Pearston district of South Africa.



2.2 Fluctuations in the average price (US cents/kg) of South African mohair over time.

2.1.2 General characteristics of mohair

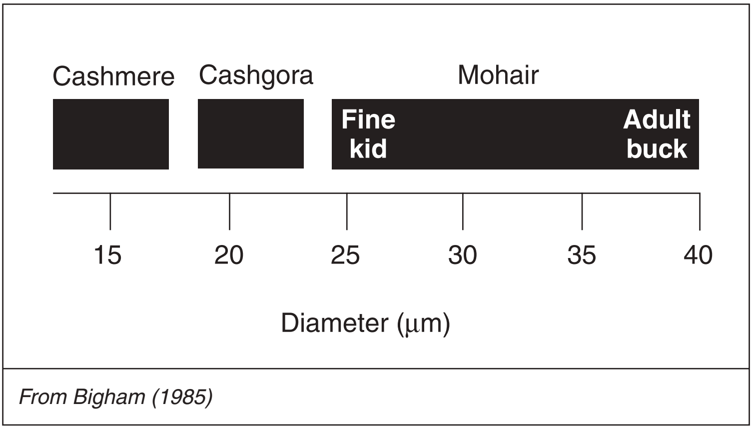
Mohair is characterised by excellent lustre, durability, elasticity, resilience, resistance to soiling, soil shedding, setting, strength, abrasion resistance, draping, moisture and perspiration absorption and release, insulation,

Table 2.1 World mohair production (million kg greasy)

Year	South Africa	USA	Turkey	Argentina	Lesotho	Australia	New Zealand	Misc. production	Total
1970	4.1	7.8	4.1	1.1	0.9	—	—	—	18.0
1971	4.3	6.8	4.5	1.0	0.9	—	—	—	17.5
1972	3.7	4.6	4.1	1.0	0.8	—	—	—	14.2
1973	3.4	4.5	4.1	1.0	0.6	—	—	—	13.6
1974	3.7	3.8	4.1	1.0	0.6	—	—	—	13.2
1975	3.8	3.9	3.9	1.0	0.6	—	—	—	13.2
1976	4.1	3.6	4.0	1.0	0.6	—	—	—	13.3
1977	4.6	3.6	4.1	1.0	0.4	—	—	—	13.7
1978	4.9	3.7	4.5	1.0	0.5	—	—	—	14.6
1979	5.4	4.2	4.5	1.0	0.5	—	—	—	15.6
1980	6.1	4.0	4.5	1.0	0.6	—	—	—	16.2
1981	6.9	4.5	4.5	1.0	0.6	—	—	—	17.5
1982	7.6	4.5	4.5	1.0	0.6	—	—	—	18.2
1983	7.2	4.8	3.8	1.1	0.7	—	—	—	17.6
1984	8.1	5.0	3.5	1.0	0.7	0.5	0.05	0.05	18.9
1985	9.2	6.0	3.5	1.0	0.8	0.5	0.07	0.06	21.1
1986	11.0	7.2	3.0	1.0	0.8	0.6	0.14	0.07	23.8
1987	11.5	7.3	3.0	1.0	0.8	1.0	0.25	0.08	24.9
1988	12.2	7.8	2.9	1.0	0.7	1.0	0.4	0.1	26.1
1989	11.7	7.8	2.0	1.0	0.6	1.2	0.6	0.2	25.1
1990	10.1	7.3	1.8	1.0	0.6	0.6	0.4	0.2	22.0
1991	7.6	7.4	1.2	0.9	0.5	0.5	0.3	—	18.4
1992	6.7	7.1	1.2	0.6	0.4	0.5	0.3	—	16.8
1993	6.0	6.5	0.8	0.6	0.4	0.4	0.3	—	15.0
1994	5.7	5.4	0.8	0.4	0.4	0.4	0.2	—	13.3
1995	5.4	4.8	0.6	0.5	0.5	0.4	0.2	—	12.4
1996	5.6	3.5	0.4	0.4	0.5	0.4	0.2	—	11.0
1997	5.2	2.5	0.4	0.4	0.4	0.3	0.2	—	9.4
1998	5.0	1.5	0.4	0.4	0.4	0.3	0.2	—	8.2
1999	4.5	1.2	0.4	0.3	0.4	0.2	0.2	—	7.2
2000	4.3	1.0	0.4	0.25	0.5	0.25	0.2	—	6.9

Source: Mohair South Africa.

comfort and pleasing handle, and by low flammability, felting and pilling. Its good insulation makes mohair fabrics light-weight and warm in winter and comfortably cool in summer, which is also a function of the fabric and garment construction. Although mohair has proved extremely popular in many applications it has some limitations in certain apparel applications, because of its coarseness relative to other types of apparel fibres such as, for example, cotton. Its outstanding properties, such as resilience and durability, also make it particularly suitable for household textiles, such as upholstery fabrics, curtains and carpets.



2.3 Diameter ranges of goat fibres.[4]

Mohair's lustre, smoothness, low friction, low felting and certain other properties are all related to its surface scale structure, the scales generally being thin (unpronounced or flat) and relatively long. Mohair shares many of the outstanding properties of other animal fibres, such as wool. Kettle and Wright[4] gave a figure that compares the diameter ranges of various goat fibres (see Fig 2.3).

Woodward[5] listed the main distinguishing characteristics of mohair.

Flammability

Mohair has low flammability, in common with other animal fibres such as wool. When exposed to a naked flame, it burns at a low temperature and tends to shrink. The flame produces a bead-like ash, but the fibre will stop burning almost as soon as it is taken away from the flame.

Durability

Because mohair's structure is pliable, it can be bent and twisted repeatedly without damage to the fibre, making it one of the world's most durable animal fibres.

Elasticity

Mohair is very elastic. A typical mohair fibre can be stretched to 130 % of its normal length and will still spring back into shape. Because of the fibre's resilience, mohair garments resist wrinkling, stretching, and bagging during wear.

Moisture absorption

Animal fibres, such as mohair, can absorb moisture from the atmosphere readily (up to 30 % without feeling wet). Because mohair dries slowly the danger of getting a chill is reduced.

Setting

Mohair may be set to retain extension or deformation more readily than most other animal fibres. The fibre's setting ability is capitalised on in the manufacture of curled-pile rugs and imitation Astrakhan rugs.

Lustre

Mohair's well-known lustre is caused by its closed (unpronounced) scale formation and can be preserved or even enhanced by careful processing and dyeing.

Dyeing

It is possible to dye mohair brilliant colours that resist time, the elements, and hard wear. From this property has come the name 'The Diamond Fibre'.

Soiling resistance

Because of its smoothness and other characteristics, mohair generally exhibits good soil resistance and desoiling.

Felting

Mohair has a very low tendency to felt.

Light weight

Mohair blends well with wool and can produce smooth yarns, enabling fabrics to be produced which are noted for coolness, such as lightweight summer fabrics. It is unsurpassed in tropical suitings, largely because it combines coolness with durability; the material is also effective when made into linings because of its good moisture absorption and drape characteristics.

Length

Prized as a textile fibre because of its length, mohair fibre averages about 300 mm for a full year's growth (i.e. 25 mm per month), and 150 mm when the animals are shorn biannually. For example, exceptionally long fibres (up to 300 mm) are used to make women's switches, doll's hair and theatrical wigs.

Various articles (quoted in Hunter[2]) provide general background information on mohair, its production, properties, marketing and related applications.

2.1.3 Historical background

Mohair, one of the oldest fibres known to humanity and referred to in biblical times, is the fibre (i.e. the coat) from the Angora goat. The word 'mohair' is derived from the Arabic word 'Mukhayar' (also spelt Makhayar[6] and Mukhaya[7]) stated to mean 'best of selected fleece',[8] 'select choice',[9] 'silky goat-skin cloth',[10] 'cloth of bright goat hair'[7] or 'hair cloth'.[11]

The Angora goat (*Capra hircus aegagrus*)[12] is of the same species, *Capra hircus*, as the European milch breeds and all other breeds of domesticated (common) goat, and also a near relative of the Cashmere goat of Asia[13] and certain types of Himalayan goats.[14] Richterich,[15] quoting Cronwright Schreiner, stated that the Angora goat descended from the genus *Capra falconeri*, that is thought to have had its origins in Tibet and Kashmir and is believed to be closely related to the Cashmere goat, whereas the domestic goat *Capra hircus* is descended from the genus *Capra aegagrus*, the wild goat of Persia. The Angora goat tends to thrive in areas of low rainfall and humidity.[14]

The Angora goat is regarded as being unique amongst goats, in that it grows fibres that do not differ widely in diameter from the primary and secondary follicles.[16] The Angora goat, unlike other goats, can therefore for all practical purposes be regarded as a single-coated animal,[16] and unlike cashmere goats, the Angora goat's fibres grow continuously throughout the year,[16] and the fibres are not shed annually, i.e. Angora goats do not moult.

The exact origins of the Angora goat are unknown, although it is believed to have originated in the Asian Himalayas (Asia Minor)[17] or Highlands of Tibet,[7,9] later migrating to Ankara (known in ancient times as Ancyra)[15] the province of Phrygia in Asia Minor,[15] in Turkey from where the name Angora was derived,[13] the Angora goat emerging in Turkey after the Middle Ages[6] (at least as late as the thirteenth or fourteenth century).[13] Records of the Angora goat dating back to the eleventh, twelfth and even fourteenth centuries BC have been uncovered.[7] In the Bible, 1500 BC, the book of Exodus relates that the sons of Israel left Egypt 'carrying with them goats of which the fleece [pure white goats' wool][17] was used to make fabric to dress the altar',[7] their fleeces being woven into altar cloths and curtains for the Tabernacle.[17,18,19]

In Ankara, the birth of the mohair industry took place, making Turkey the first country to supply mohair as a raw material.[17] This was after the animals had trekked thousands of kilometres from Turkestan, the journey beginning during the thirteenth century.[7] In 1550 a Dutchman found the Angora goat in Angora, Turkey and recognised the exceptional qualities of the fleece,[18] and a pair of goats was sent to the Holy Roman Emperor Charles V in 1554.[18,19] Ryder[20] stated that the first European record of the Angora was made by Belon, and Tournefort, a French botanist (1654) in his *Levant Voyage* wrote that the finest goats in the world were bred in Angora (Ankara).[20] Tournefort reported in 1653 that 'the Angora goats dazzled with their whiteness and had hair as fine as silk'.

The spinning of mohair in Ankara (or Ancyra, as it was then known) was undertaken by women for their families but later a closely guarded mohair industry developed in Turkey,[18] with the export of unprocessed mohair being forbidden by the Sultan.[18,21] In 1838, under pressure from England, the ban was lifted and to meet the demand, the Angora goat was crossed with the Kurdish goat which resulted in a decline in quality[18] and a few bales were shipped to Europe. Holland used an amount of 'Turex Gaaren' (Turkish yarn), combining a mohair weft with a silk warp.[18] In 1820 there occurred the first authentic record of the export of a few bales of mohair fibre from Asia Minor to Europe.[22] In 1853 mohair spinning began in England.

When mohair first reached Europe, wigmakers appreciated its qualities.[6] Mohair goods were first manufactured in England in the nineteenth century,[11] a cloth containing a mohair weft across a cotton warp being much in demand in 1883.[11]

The first Angora goats to leave Turkey went to South Africa in 1838.[18,22] During the journey, involving a cargo of 12 bucks and a doe, the latter gave birth to a male kid.[18] Not until 1865 did mohair exports from the Cape to the United Kingdom reach any magnitude.[23] Angora goats (seven does and two bucks)[9] arrived in the USA around 1849.[6] Angoras were introduced into Australia during the 1850s and 1860s[24] (although some state the date to be as early as 1832),[13] but received little interest; a new 'mohair industry' was established in about 1970.[24] Angora goats were introduced to Britain in 1881.[24]

2.2 Chemical and physical fibre properties

2.2.1 Single fibre tensile properties

Single fibre tensile properties are important from a textile point of view, fibre strength playing an important role in fibre breakage during mechanical processing, including spinning, yarn strength, fabric manufacturing and in the ultimate strength of the fabric. Generally, in the case of animal fibres, fibre strength increases almost linearly with the fibre cross-sectional area,

Table 2.2 Average values for some tensile properties of wool and mohair*[26]

Property	Mean	SD	CV%	Range	n
Wool**					
Fibre diameter (μm)	22.7	3.3	15	18.1–33.1	56
Linear density (dtex)	6.6	2.0	30	3.5–12.8	56
Staple crimp (cm^{-1})	4.2	1.2	27	1.9–6.5	56
Resistance to compression (mm)	17.5	2.8	16	13.6–24.7	56
Bulk/diameter ratio (mm/μm)	0.79	0.19	24	0.41–1.29	56
Tenacity (cN/tex)	12.7	0.9	7	10.9–15.0	56
Initial modulus (cN/tex)	290	27	9	230–392	56
Extension at break (%)	37.0	2.6	7	31.5–41.2	56
Mohair					
Fibre diameter (μm)	32.1	5.8	18	20.7–44.3	29
Linear density (dtex)	11.9	3.3	28	5.8–20.1	29
Tenacity (cN/tex)	16.7	0.7	4	14.6–18.1	29
Initial modulus (cN/tex)	407	13	3	384–430	29
Extension at break (%)	42.7	2.1	5	38.0–45.8	29

* 20 mm test length and rate of extension 20 mm/min.
** Low crimp wool excluded.

more particularly the cross-sectional area of the thinnest (i.e. weakest) place along the fibre. The fibre strength divided by the fibre cross-sectional area, preferably at the thinnest place, is therefore almost constant for a particular type of fibre.

Meredith[25] found that mohair and camel hair have a greater yield stress than the coarsest wool and about the same initial Young's modulus. Smuts et al.[26] found that mohair generally had a higher single fibre tenacity, initial modulus and extension at break than wool of the same diameter, and the mohair tensile characteristics were fairly constant over the whole range of diameters, probably because of the absence of crimp and variations in crimp and any associated fibre characteristics. Lustre wools (e.g. Lincoln and Buenos Aires) had tenacities and initial moduli close to those of mohair.[26] Table 2.2 (as given by Smuts et al.) shows average values for some tensile properties of wool and mohair.

Table 2.3 is reproduced from the report by Smuts and Hunter.[27]

2.2.2 Fibre bundle tenacity properties

Hunter and Smuts[28] found that both bundle and single fibre tenacity were independent of mohair fineness, although the initial modulus increased slightly with an increase in fibre diameter. They gave a table (Table 2.4) of typical tensile properties for mohair.

Table 2.3 Effect of gauge length on single fibre tensile values[27]

Gauge length (mm)	Extension at break (%)			Tenacity (cN/tex)		
	Mohair	Heterotype	Kemp	Mohair	Heterotype	Kemp
10	47.9	—	46.6	17.9	—	14.8
40 or 50	38.3	—	34.9	15.5	—	12.4
100	30.2	26.2	21.8	12.6	10.8	8.8

Table 2.4 Typical tensile properties of mohair[28]

Property	Bundle test*	Single fibre test
Tenacity (cN/tex)	14.0	16.7
Extension (%)	14.6**	43.0
Initial modulus (cN/tex)	—	407

* Leather linings were used and the tenacity values were multiplied by a correction factor of 1.16.
** The bundle test is not considered to give reliable extension values.

2.2.3 Fibre bending stiffness

King[29] found that the static bending and extension moduli of mohair fibres were similar and of the order of 308 cN/tex. They also found that the medullae of kemp fibres differed in optical density, indicating different cell densities; this affected the bending but not the extension moduli. Two types of kemp, one with a filled medulla and the other with a virtually empty medulla, were investigated. For the latter, the bending and extension moduli of the kemp were similar at about 77 cN/tex, whereas the filled medullae gave a bending modulus of about 365 cN/tex, which was higher than that found for mohair.[29] The extension moduli of the two types of kemp fibres were similar, indicating that any material in the medullae did not contribute to the tensile properties of the fibre, confirming the results of Hunter and Kruger.[30,31]

2.2.4 Fibre friction

As in the case of wool, mohair fibres have a lower friction when rubbed from the root to the tip (i.e. with the scales) than when rubbed in the oppo-

Table 2.5 Fibre frictional properties[35]

Fibre	μ_2	μ_1	$\mu_2 - \mu_1$	$\mu_2 + \mu_1$
Wool	0.40	0.22	0.18	0.66
Mohair	0.23	0.15	0.08	0.38
Human hair	0.19	0.09	0.10	0.28

(all measured in distilled water against felt)
μ_1 with-scale.
μ_2 against-scale.

site direction (i.e. from tip to root, termed *against-scale*). The low against-scale friction of mohair, relative to wool, which is one of its distinguishing features, can be largely attributed to its relatively smooth (unpronounced) scale structure. It is this characteristic which gives mohair its low felting propensity. Mohair has a very small directional friction effect (DFE), due to the extremely easy deformation of the thin distal edges in mohair and also to the absence of tilted outer surfaces and other high asperities. The against-scale (μ_2) to with-scale (μ_1) friction ratio of mohair is about 1.1 compared to about 1.8 for merino wool.[32] The 'scaliness' ($(\mu_2 - \mu_1) \times 100\,\%/\mu_1$) of mohair, measured dry, is about 5 compared to about 60 for a fine merino wool (Speakman and Stott[33] quoted by Onions[32]). When measured wet the respective values are about 16 for mohair and 120 for merino wool.

Frishman et al., quoted by Harris,[35] gave a comparative table (Table 2.5) for fibre friction.

2.2.5 Moisture related properties

Although mohair, as does wool, can absorb large quantities of moisture (up to about 30 %) without feeling wet or damp, its surface is naturally water repellent, largely due to the presence of a strongly bound thin surface layer of waxy or lipid material which requires strong chemical action to remove it.

The moisture-related properties of textile fibres are extremely important as they play a crucial role in the comfort of the fibre and in its behaviour during wet treatments and drying. Temperature and moisture also play an important role in the visco-elastic properties of wool and mohair.

Speakman[36] published a table (Table 2.6) illustrating the absorption and desorption of moisture by wool and mohair at different relative humidities. Watt presented a comparative table (Table 2.7) of equilibrium water content (regain) for seven keratins including mohair.

Table 2.6 The absorption and desorption of moisture by wool and mohair at different relative humidities[36]

Relative humidity %	Geelong 80s merino	Southdown	Oxford Down	Leicester	Wensley-dale	Mohair
	Percentage increase in weight of wool					
7.0	3.40	3.37	3.17	3.40	3.46	3.41
25.0	6.96	6.90	7.03	6.96	7.01	6.93
34.2	8.41	8.62	8.79	8.54	8.67	8.64
49.8	11.22	11.48	11.68	11.44	11.59	11.51
63.3	13.97	14.19	14.41	14.46	14.51	14.41
75.0	16.69	17.03	17.30	17.43	17.44	17.33
92.5	23.81	24.17	24.49	24.59	24.90	24.24
100.0	33.3	32.9	35.3	32.9	33.9	31.8
	Desorption					
92.5	24.70	25.70	26.33	25.98	26.13	25.82
75.0	18.69	18.79	19.05	19.02	19.16	18.91
63.3	16.12	16.16	16.43	16.28	16.46	16.26
48.7	13.36	13.38	13.47	13.39	13.46	13.46
34.2	10.57	10.55	10.64	10.58	10.63	10.68
7.0	4.77	4.73	4.83	4.79	4.76	4.87

Table 2.7 Equilibrium water contents for seven keratins at 35 °C (in percentages)

Relative humidity	Merino wool	Corriedale wool	Lincoln wool	Mohair	Monkey hair	Horse hair	Rhino horn
5	2.6	2.5	2.5	2.5	2.2	2.3	2.5
10	3.9	4.0	4.0	3.7	3.3	3.5	3.8
20	5.9	6.1	6.1	5.7	5.1	5.5	5.6
35	8.6	9.0	9.0	8.3	7.5	7.9	8.4
50	11.3	11.8	11.5	10.7	10.0	10.7	11.4
65	14.4	15.0	14.5	13.7	12.4	13.8	14.8
80	18.6	19.6	19.2	17.5	16.3	18.2	20.1
90	23.6	25.0	25.4	22.2	21.4	22.7	28.0
95	27.7	28.2	29.7	26.1	24.9	26.9	35.5
100	34.2	33.5	36.0	32.3	30.0	32.8	49.0

Source: Watt.

2.2.6 Scale pattern

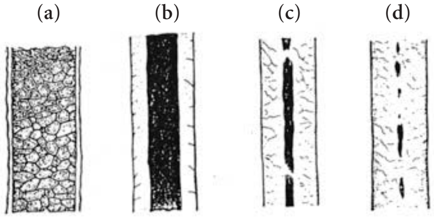
Mohair, wool and hair are covered by a layer of sheet-like hardened cuticle cells (epidermal scales) which overlap each other, with their exposed edges toward the tip of the fibre. The cuticle plays an important role for the whole fibre because it is, on the one hand, exposed to environmental influences and, on the other hand, responsible for the surface properties of the fibre. The cuticle or scale structure is largely responsible for the felting behaviour of wool and mohair and also for the lustre of mohair. Although, under a microscope, mohair is similar in appearance to wool, the epidermal scales (cuticle scales) of mohair are only faintly visible. The cuticle scales are quite thin and flat, generally being less than about 0.6 μm in thickness and hardly overlap.[37] They are anchored much more closely to the body of the fibre,[1,38,39,40] i.e. they lie near to the stem or are piled more tightly upon one another,[41] giving the fibre a very lustrous and smooth appearance.

In general, mohair has a relatively low scale frequency, with a wide distance between the cuticle scale margins. The number of scales per 100 μm is generally of the order of 5 compared with between 9 and 11 in fine wools, with the scale lengths ranging from 18 to 22 μm. In the case of kemp, the number of scales per 100 μm is 10 or more, which is twice that for mohair; and they are arranged in a coronal or ring pattern, with smooth margins.[1]

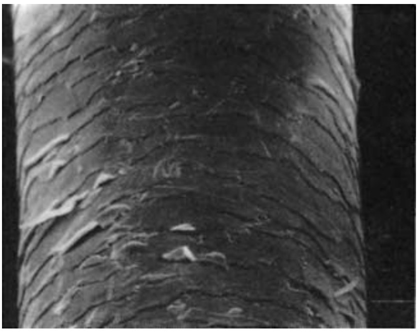
The scale structure described above is responsible for mohair's smooth handle, high lustre, low against-scale friction and very low felting propensity. The width to length ratio of mohair fibre scales is of the order 2.[20] Ryder and Gabra-Sanders[42] found that the width to length (W/L) ratios of scales from various goat fibres showed a clear sequence from the wild ancestor (*Capra aegagrus*) to mohair. They defined the scale width as equal to the fibre diameter. Indications were that the W/L ratio was independent of fibre diameter.

2.2.7 Medullation and kemp

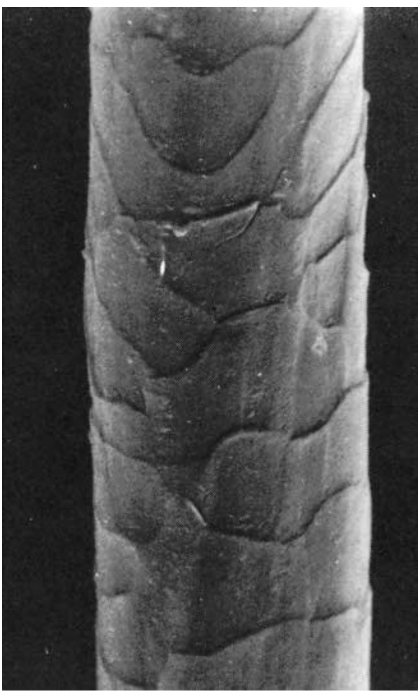
Medullated fibres in mohair can be a source of problems in many end-uses when they differ in appearance from the rest of the fibres which are not medullated. They are characterised by having a central canal (medulla) containing cell residues and air pockets, running in either a continuous or fragmented form along their length (Fig. 2.4). The term 'kemp' is probably more familiar, but this traditionally refers to the more problematic and extreme form of medullated fibre where the medulla is clearly visible to the naked eye. The main problems associated with the presence of kemp (perhaps more correctly termed 'objectionable' medullated fibres) are their chalky white appearance, their lighter appearance after dyeing and, to a lesser extent, their effect on handle, stiffness and prickliness.[2,50,253] The chalky



2.4 Classification of medullae[14]: (a) unbroken lattice (wide); (b) simple unbroken; (c) interrupted; (d) fragmented.



2.5 Kemp.[46]



2.6 Mohair.[46]

white appearance of kemp is largely caused by the decreased length of the light path through the dyed fibre material and light refraction at the fibre/medulla interface and within the hollow network of cells (aerian vesicles). This, and not poor dyeability, is considered to be the main cause of the different appearance of kemp fibres after dyeing.[43,44,45] Generally, the presence of even a small amount of kemp in a high quality mohair may have a pronounced adverse effect on its value. Higher grades of mohair are largely free from kemp and medullated fibres, the kemp content being well below 1 % in well-bred mohair.

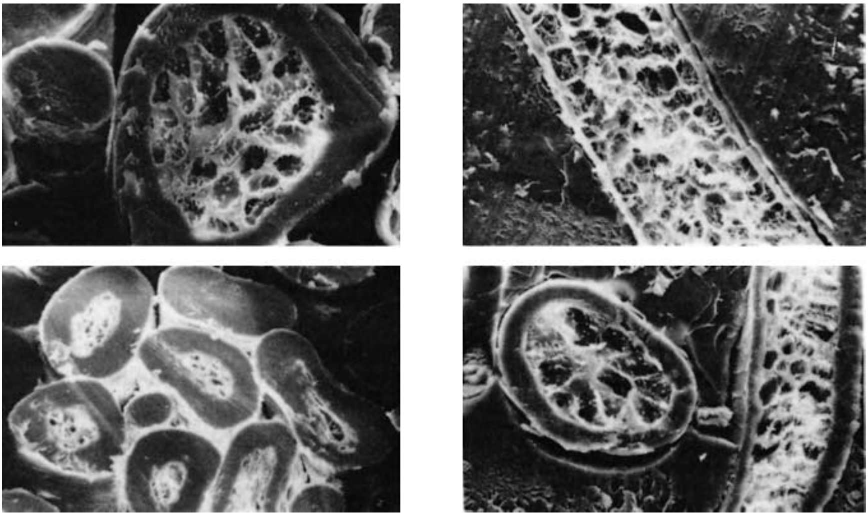
Those medullated fibres that contain a discontinuous (fragmented or broken) medulla are generally referred to as heterotype or 'gare' fibres.[47,48] Heterotype fibres are therefore medullated (or 'kemp-like') in certain sections and 'normal' (i.e. solid) in others.

Kemp is usually straight, and oval in cross-section. Of all the types of medullated fibres that occur in both wool and mohair, those collectively called kemp, tending to have a relatively large medulla and to be relatively coarse, are the most visible and unwanted in the final product. Kemp occurs as short kemp, long kemp and heterotype fibres. The 'short kemp' is generally the most common, being short, chalky white, medullated and pointed at each end when it has fallen out and has not been shorn off. Small portions of multiple medullae are also occasionally present in mohair fibres.[49] Kemp or 'objectionable medullated fibres' are generally much coarser than the parent population (on average 1.8 times coarser than the mean fibre diameter of the parent population).[50]

Hunter[46,51] gave an electron microscope photograph of kemp, illustrating its surface appearance (Fig 2.5) compared to that of mohair (Fig 2.6).

2.2.8 Chemical and physical nature of the medulla

The medulla consists of a hollow network of cell walls (Fig 2.7) (aerian vesicles), filled with air, which are cytoplasmic remnants of the basal layer cells (Clement et al., quoted in Powell).[45] The chemical composition of medullary cell residues appears to be different from that of the cortical cells,[53,54] the medullary cells containing little if any sulphur.[55] Swart[56] showed that the amino acid composition of kemp was different from that of adult mohair and that the medullated fibres contained more β-keratose but less γ-keratose than true mohair. It was reported (Mercer[57] quoted by Tucker et al.[58]) that the proteins of the medullary cells are of a non-keratin type and therefore exhibit different chemical behaviour to the keratins. They are easily broken down by proteolytic enzymes but have a high alkali stability (Kusch and Stephani,[59] quoted by Tucker et al.[58]). The levels of the amino acids citrulline, glutamic, lysine and leucine, in the medullary cells are higher than those present in the whole fibre whereas glycine, serine, proline,



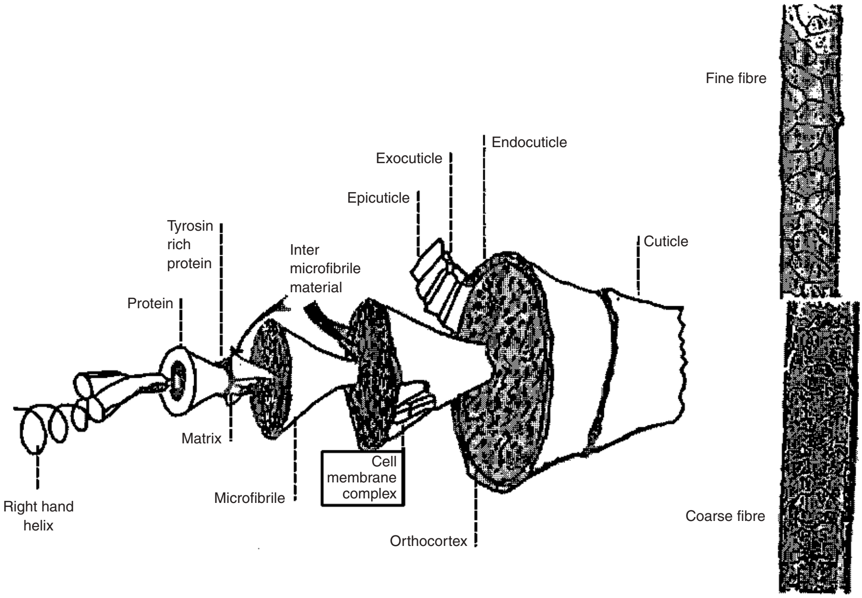
2.7 Cross-sections and longitudinal sections of medullated fibres illustrating the cellular nature of the medullae.

threonine and particularly cystine are lower (Bradbury and O'Shea,[60] Harding and Rogers[61] quoted by Tucker et al.[58]).

2.2.9 Fibre chemical, morphological and related structure and properties

The reader is referred to excellent and detailed reviews of this subject by Zahn,[40,63] Spei and Holzem[64] and Tucker et al.[58,65]. Zahn et al.[66] earlier reviewed the biological composite structure of wool, including mohair.

All animal fibres, except silk, contain the same chemical substance, a protein called keratin. Keratin can be regarded as a long fibrous composite, comprising crystalline, relatively water impenetrable microfibrils, lying parallel to the fibre axis and embedded in an amorphous, water penetrable matrix.[67] Thus wool and mohair fall into the class of protein materials known as keratins, characterised by their long filament-like molecules and insolubility in dilute acids and alkalis. They generally have a high sulphur content when compared with other proteins.[68] All mammalian keratin fibres contain three main protein fractions,[69] termed low-sulphur, high-sulphur and high-tyrosine proteins, with the low-sulphur proteins generally representing the largest proportion. All animal fibres contain approximately 3 to 4 % sulphur, largely as cystine. The mohair fibre generally consists of a cortex (cortical cells), the solid and main part or bulk of the fibre, which is predominantly ortho-cortex (cortical cells), and epidermis (cuticle cells) of



2.8 Structure of a mohair (Adult) fibre.[73]

numerous overlapping scales.[70] Sometimes there is also a continuous or discontinuous medulla present. The cuticle scales form a protective covering for the cortex and consist of three layers, epicuticle, exocuticle and endocuticle (see Fig 2.8). Each cuticle scale is enveloped by a thin semipermeable[71,72] membrane called the epicuticle, which comprises protein and lipid. Smith[73] depicted the structure of a mohair fibre as shown in Fig 2.8.[73]

(For further details and discussion of the physical and chemical composition of mohair see Appendix 3.)

2.2.10 Fibre identification and blend analysis

It is important, for such purposes as labelling and Mark Certification to distinguish between mohair and other animal fibres and to quantify the composition of a sample (be it raw fibre, top, yarn or fabric) which reportedly contains mohair in any proportion, particularly where the mohair is blended with another animal fibre, such as wool. It is hardly surprising, therefore, that considerable research effort has been directed over the years, but more particularly since the early 1980s, towards developing reliable methods for distinguishing between mohair and other animal fibres. Wilkinson,[99] in summarising the papers dealing with fibre identification, presented at the

Table 2.8 Fibre identification tools and targets

Tool	Target
1. Microscopy; light transmission and scanning electron, image analysis	fibre dimensions[1,2] ellipticity[1,2] surface features[1,2] pigment distribution[1] medullation[1] cortical segmentation[1]
2. Chromatography, electrophoresis	protein composition[1,2]
3. High pressure liquid chromatography, gas chromatography	external and internal[1,2] lipids
4. DNA hybridisation	cell nuclear remnants[1,2]

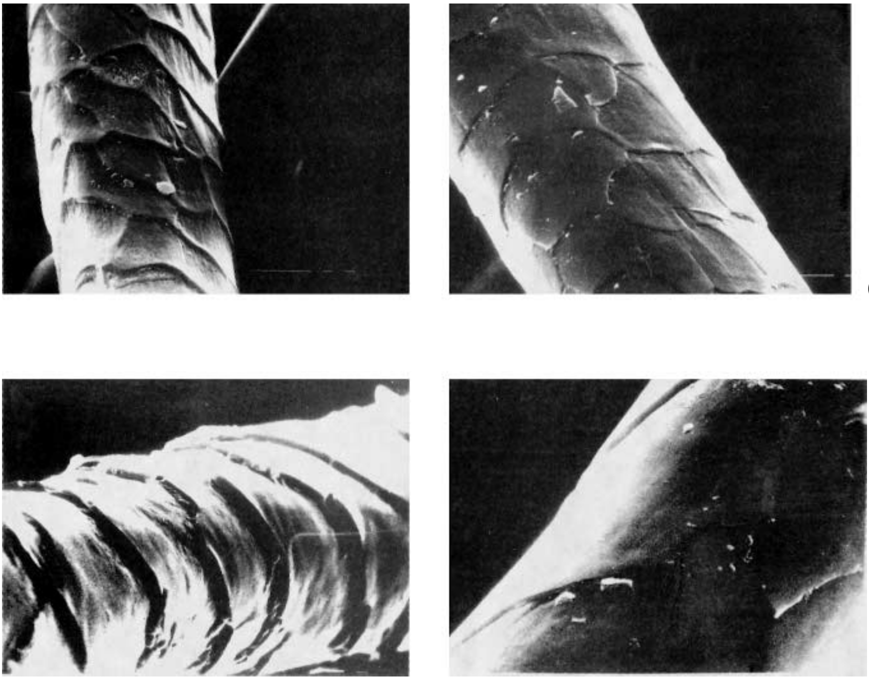
[1]First International Symposium on Speciality Animal Fibres.
[2]Second International Symposium on Speciality Animal Fibres (see ref. 99).

Second International Symposium on Speciality Animal Fibres in Aachen in 1990, pointed out that the list of possible techniques was quite long, but could be shortened if restricted to rapid, inexpensive and internationally accepted methods; shortened further if restricted to fibre mixtures of unknown origin in which suspect contaminants are in low proportion; shortened even further if the fibres or fabrics have been subject to pretreatments; and probably obliterated if all the restrictions are imposed. Some tools and targets are listed in Table 2.8.[99]

Figure 2.9 shows scanning electron micrographs of fibres showing scale structures of wool fibres (a and b) and of mohair fibres (c and d). (All magnification values here refer to original magnification.) Figure 2.10 shows the scale height (h) or thickness of a fibre. Laker and Wortmann[34] and Greaves[100] have reviewed the various methods of fibre identification and the quantitative analysis of fibre blends, while Hamlyn et al.[101] listed the methods (Table 2.9) that have been proposed for the qualitative and quantitative analysis of keratin fibres. A similar list has been given by McCarthy.[12]

The first methods relied upon the use of a light microscope to examine the surface scale appearance (prominence, pattern and frequency) of the fibre and then to classify the fibre as mohair or wool depending upon a subjective assessment of the nature, frequency and prominence of the scales and they required an experienced operator. Eventually, they led to modern scanning electron microscopic (SEM) methods, as well as image analysis.[102,103]

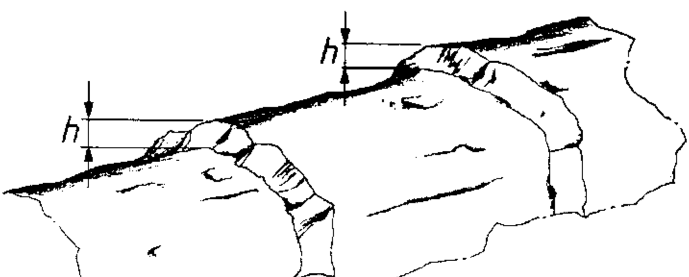
In recent years the scale height method, measured by SEM, has found the widest application. In one of the first studies (1985) relevant to the use of the scale height method for differentiating between mohair and wool,



(a) (c)

(b) (d)

2.9 Scanning electron micrographs of fibres showing wool and mohair fibres: (a) wool scale structures 1400×; (b) wool scale structures 3300×; (c) mohair scale structures 1400×; (d) mohair scale structures 3300×.[106–107]



2.10 Scale height (thickness), *h*, of a fibre.

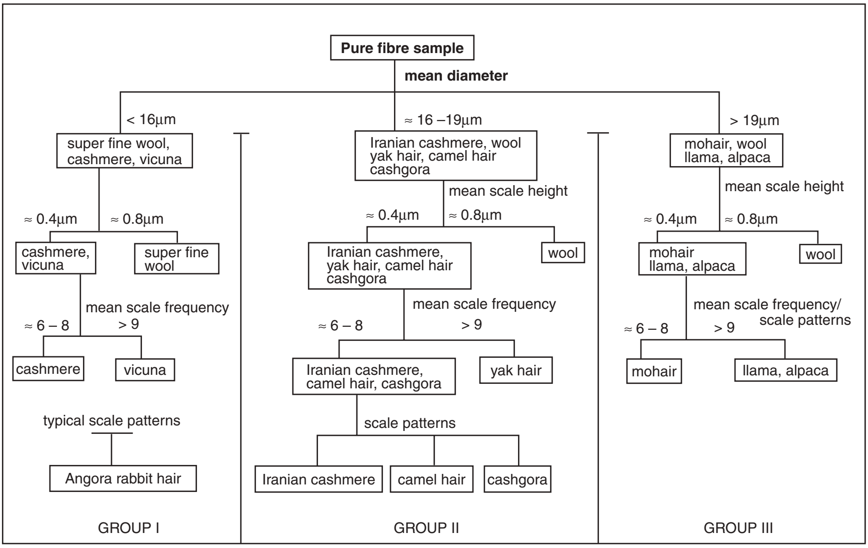
Table 2.9 Methods proposed for the analysis of keratin fibres[101]

Amino acid analysis
Scale-height measurement
Image analysis
PAGE Analysis of extracted proteins
Internal- and external-lipid analysis
DNA Fibre-profiling

Oster and Sikorski[108] showed that the scale thickness of merino wool is of the order of 1 μm and that of mohair of the order of 0.4 μm. Dobb et al.[109] were among the earliest to observe that differences in scale height (distal edge) measured by electron microscopy could be used to distinguish between wool and mohair. Nevertheless, it was not until 1980 that Kusch et al.[110] used the difference in cuticular scale height, as measured by SEM, to distinguish between wool and goat hair.

Kusch and co-workers were amongst the first to propose and use the SEM-measured scale heights to distinguish between wool and various animal fibres, for example mohair, and to quantify the blend composition of such fibres; their work is detailed by Hunter.[2] The scale thicknesses were measured at a magnification of 25 000 and the fibre diameter at a magnification of 1000, fibres with a scale height greater than 0.6 μm being classified as wool and those with a scale height smaller than 0.5 μm as mohair.[111,112] In essence, the SEM method (see International Wool Textile Organisation Draft Method – 1996 E) is based upon the fact that mohair scales are generally, but not always thinner than those of wool, having an average thickness (height) of around 0.4 to 0.5 μm (0.2 to 0.4 μm),[113] while those of wool, including lustre wools (such as Buenos Aires), have an average thickness (height) of around 0.8–1.0 μm (0.6–1.1 μm)[108,109,113,114,115,116,117] (see Fig. 2.11).

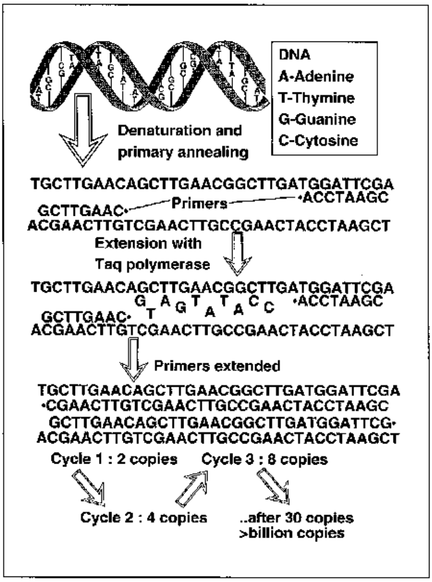
Wortmann and Arns[116,118,119] concluded that the scale heights of speciality animal fibres rarely exceed 0.5 μm (and are generally 0.2 to 0.4 μm)[116] while those of wool rarely fall below 0.5 μm (and are generally 0.6 to 1.1 μm,[116] rare occurrences are of little consequence in the application of the scale height method for analytical purposes). They found the scale height for the samples of wool they tested ranged from 0.4 to over 1.0 μm and that of the mohair samples they tested ranged from just over 0.1 to just over 0.5 μm. Phan et al. have also carried out SEM analyses.[120] Recent papers[121,122,123] discuss, and express opposing views on, the role of chemical treatments on the accuracy of the scale height method of blend analysis. A system of fibre classification (Fig 2.11) according to the SEM method was given by Phan et al.[117]. Schnabel et al.,[124] Wortmann et al.[125] and Hermann et al.[126] concluded that both the weighted discriminant analysis and the



2.11 Classifying and characterising of luxury fibres by means of scanning electron micrograph.[117]

cluster analysis may be applied as an approximate method for evaluating fibre blends, such as wool and mohair. Baxter[127] reported that a combination of Optical Fibre Diameter Analyser (OFDA) measured parameters enabled the composition of wool and mohair blends to be determined.

In more recent years the application of DNA techniques for distinguishing between different animal fibres has received considerable attention;[2,104,128,129] the DNA extracted from the fibre shafts, with about 20 mg of fibre sample, is adequate. A prerequisite for fibre profiling is the identification of short DNA sequences unique to each species.[130] Once located, complementary DNA sequences (oligonucleotides) can be constructed which, under carefully controlled conditions, hybridise to the target DNA molecule, giving a positive signal, confirming the presence of a particular fibre type.[130] Conventional DNA hybridisation analysis is carried out using a single dot-blot technique, but cannot be applied to wet processed fibre since the latter contains much less DNA. For such materials, *in vitro* DNA amplification[104] technology polymerase chain reaction (PCR) can be applied.[104,129,131] This cannot, however, be used as a quantification test, but only for showing the presence of a particular fibre, i.e. adulteration. A combination of the projection microscope technique and DNA investigation has been advocated.[130] The rapid and cost-effective application of the DNA



2.12 Amplification of target DNA using the polymerase chain reaction (PCR).[104]

technique for quantitative analysis of animal fibre blends remains a challenge, particularly in the case of wet processed yarns and fabrics.[104,129] The amplification of target DNA using the polymerase chain reaction is shown in Fig. 2.12.

2.3 Fibre production and early processing

2.3.1 Fibre growth and production

Mohair grows at about 25 mm each month, irrespective of age, and Angora goats are generally shorn twice a year in South Africa and the USA and once a year in Turkey and Lesotho, although high levels of nutrition could necessitate more frequent shearing.[3,8] Young and Adult goats produce about 2 to 2.5 kg of greasy mohair every 6 months, and rams generally produce considerably more,[132,133] and coarser hair than ewes.[3] In the case of Kids, the fleece barely weighs 1 kg at the first shearing and is generally less than 2 kg at the age of one year[134] (i.e. at the second shearing).

It appears that the Angora goat is very efficient in converting feed into fibre,[135] and is more effective than woolled sheep;[3,136] the latter are more effective in converting feed into body mass.

Greasy fleece mass has a hereditability of 0.4, i.e. 40 % is controlled genetically, although another study[137] suggested 0.22; the remainder is due

Table 2.10 Curvature and diameter values of several different wool fibres[140]

Fibre	Mean curvature (cm^{-1})		Mean diameter (μm)
	Wet	Dry	
White Alpaca	2.0	8.4	30.2
Fawn Alpaca	1.2	6.0	40.0
Lincoln	2.4	5.0	36.0
Mohair	1.2	1.4	43.6
Cashmere	6.8	12.7	13.8
Southdown	18.8	32.0	23.8
Corriedale	10.0	16.4	29.7

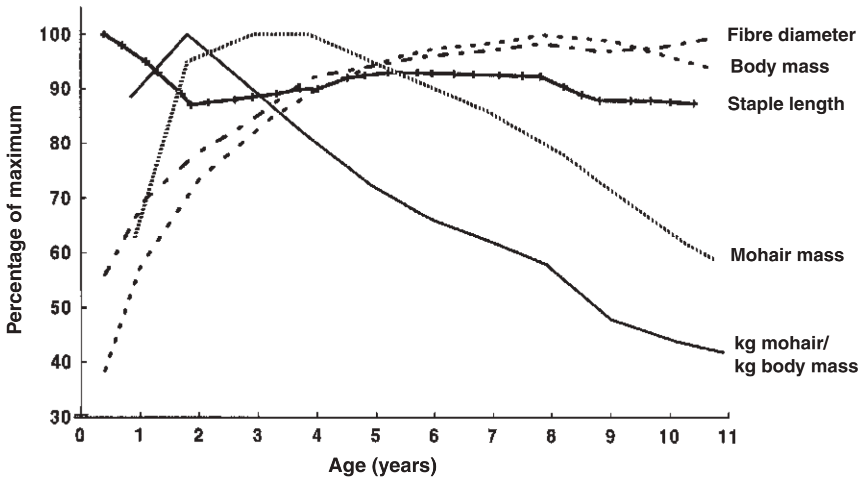
to (factors such as feed. Staple length has a hereditability factor of 0.8.[20,138] Fibre diameter has a hereditability of 0.2[138], (another study found 0.3)[139]; it is very sensitive to changes in nutrition and to the age of the animal.

Mohair does not have crimp in the true sense of the word but exhibits waviness or curl. Curvature values for mohair and other animal fibres are given in Table 2.10.[140,141]

2.3.2 Effect of Angora goat age on fibre production

According to Van Der Westhuysen et al.[3,142,143] the age of the goat is probably the most important factor determining the quantity and quality of mohair produced. Mohair production reaches an economic peak at approximately 18 to 24 months of age because at this stage the production of the finest and most valuable fibre is at its highest.[3] Kids have a birth coat of fibres that grow mainly from the primary follicles, those being the follicles which produce kemp and medullated fibres.[144] From about three to six months the goats shed their birth coat ('mother hair') as the fibres grow increasingly from the secondary follicles which produce the finer hairs.[144,145] Fibre production increases from birth, reaching a maximum fleece mass at an age of between approximately three and four years.[3,8,146,147] With age the fibre diameter increases, reaching a maximum at approximately five years.[3,146,147,148,149] Duerden and Spencer[150] and Venter[151] found the mohair fibres were finer towards the tips, due to the fact that the fibres become coarser as the goat ages.[3,146,148]

Kids nowadays produce mohair with an average diameter of about 26.5 μm at their first shearing, approximately 28 μm at the age of one year (second shearing), and 31 μm for Young Goats at 18 months of age (third



2.13 The effect of age on fleece and fibre characteristics in the Angora goat.[3]

shearing), while Adult Goats produce mohair varying in fibre diameter from about 34 to 40 μm. In general, mohair obtained from the first two shearings (i.e. at 6 and 12 months) is classified as from kids, that obtained from the third (and also sometimes from the fourth) shearing (i.e. at 18 months and sometimes at 24 months) is classified as from Young Goats and after that (i.e. from the fourth or fifth shearing or from the age of 24 or 30 months) the hair is classified as Adults. Generally mohair from Kids is finer than 30 μm, from Young Goats finer than 34 μm while from Adults coarser than 34 μm. Goats are classed as young goats up to the age of 3 years in Turkey but only up to 18 months in South Africa.[152]

Van Der Westhuysen et al.[3,143] gave Fig. 2.13 illustrating the effect of goat age on fleece and fibre characteristics.

2.3.3 Effect of nutrition, season and lactation on fibres and fibre production

Mohair growth shows a seasonal effect, probably mainly as a result of changes in the day length, even when the goats are kept on a constant diet,[166] fibre production tending to increase with increasing temperature and length of day;[136] lactation and low nutrition have the opposite effect. More fibre is grown in summer than in winter; nutrition affects the seasonal growth cycle but cannot eliminate it entirely. Angora goats can grow up to 1.7 times more mohair in summer than in winter.[20,153,154] Both in South

Africa and in Texas the winter mohair tends to be shorter, finer and less 'kempy'.[166] Reproduction generally suppresses the rate of mohair growth and the demands of lactation are more pronounced than are those of pregnancy.[3] Body mass, mohair production and fibre diameter generally decrease during lactation. Adult body mass is correlated with mohair production and fibre diameter.[3]

As happens to wool, the tips of the mohair fibres covering the back of the animal are damaged by sunlight or weathering, especially during the summer months.[1] This damage has an influence on the dyeing property of the affected fibre part.[1,38]

2.3.4 Secondary and primary follicles

The amount and type of hair produced by an Angora goat depends upon the number of follicles present in the skin, namely primary (P) and secondary (S),[145] and their ratio (S/P), the Angora having a skin follicle structure very similar to that of sheep, with an S/P ratio of between 7 and 12.[155]

It is generally thought that all primary follicles are producing fibre when the kid is born, the fibres that make up the birth coat being very coarse, although the primaries do subsequently produce finer fibres.[145] The secondary follicles show little sign of development in the first week of the kid's life, but during the next two weeks follicle maturity is very rapid. By the time a well fed kid is 6 to 8 weeks old, 75 to 80 % of its ultimate number of follicles may be producing fibres. Research results have emphasised the important relationship between nutrition and follicle numbers and hence the effect of nutrition on fibre production. Since there are many times more fine secondary follicles than primaries, it follows that the level of nutrition of the doe late in pregnancy (i.e. when the secondary follicles are developing in the foetus) and of the kid during its first ten months of life (i.e. when the secondary follicles are maturing and coming into production) are critical. If insufficient food is provided at these stages, the lifetime fibre production will be affected.[145] Table 2.11 shows some average values and ranges of various mohair properties.

2.3.5 Mohair grease and other fleece constituents

The fleece of the Angora goat, when shorn, contains natural and applied impurities; usually a total of 10 to 20 % of non-fibre is present. The sweat or suint, the water soluble component and grease (wax) combined are termed yolk. The grease (wax) is secreted by the sebaceous glands and the sweat (suint) by the sudoriferous glands. Other natural impurities contained in mohair include sand and dust (i.e. inorganic matter), vegetable matter (e.g. burr, grass, seed) and moisture. Applied impurities include branding

Table 2.11 Some average values and ranges of various mohair properties[157]

Property	Range	Average value
Diameter (μm)	23–45	33
CV (%)	20–33	25
Staple length (mm)	84–137	109
Medullation (%)	0.3–2.8	1.0
Curls per 10 cm	2.8–6.6	4.5
VM (%)	0.1–1.7	0.3
Grease (%)	2.9–8.0	4.6
Suint (%)	1.8–4.2	2.7
pH of suint	3.3–6.2	5.3
Scoured yield (%)	77–93	86
Compressibility (mm)	10–13	11

Table 2.12 The composition of raw whole fleeces[58]

Fibre	Moisture (%)	Grease (%)	Water solubles (%)
Wool	11.0–11.7	9.5–27.0	3.9–7.1
Mohair	12.0–14.4	1.2–8.0	1.8–4.2
Australian cashmere	10.7–13.9	0.7–2.5	1.2–3.5
Chinese cashmere	11.1–12.9	5.0–7.2	2.3–3.0
Cashgora	13.2	1.2–2.8	0.6
Llama	12.0	2.8	—
Alpaca	10.9–14.4	2.8–3.9	0.6–2.4
Camel	9.9	0.5–1.1	—
Yak	10.4	12.3	—

fluids and dipping compounds. Generally, mohair contains considerably less grease than wool (4 to 6% on average, compared with an average of about 15% for wool). Because the yolk content of mohair is lower than that of wool, shearers are said to have to change combs and cutters more often than with wool.

Tucker et al.[58] presented the data for various speciality fibres that is shown in Table 2.12. Mohair, by virtue of its open fleece structure on the goat, is more exposed to weathering than is wool and its wax is more oxidised than that of wool,[189] making it more difficult to remove during scouring.[143] Ilse[190] compared the composition of mohair, karakul and merino wool waxes as shown in Table 2.13 and concluded that the mohair and karakul waxes had the usual merino wax components in surprisingly similar proportions.

Table 2.13 Characteristics of the waxes[190]

	Merino wax	Mohair wax	Karakul wax
Wax content of the fleece (%)	14–16	5	3
Saponification value (mg KOH/g)	92–102	128	110
Acid value	4	14	9
Hydroxyl value	54	57	58
Iodine value	15–30	36	56
Acids (%)	49	55	50
Unsaponifiable material (%)	51	45	50

Table 2.14 Chemical constants for mohair grease[192]

Characteristics	Value	Literature
Saponification value	126–135	128
Acid value	14.6	14.0
Iodine value	14.8	36
Percentage acids	54	55
Percentage unsaponifiable fraction	46	45
Ester value	117	114

Mohair from Kids and Young Goats contains more grease than that from Adults, with the grease content higher in winter than in summer[191,192] and also higher towards the root (e.g. tip = 2.0 %, middle = 4.6 % and root = 6.0 %). Uys, quoted by Kriel,[192] found an average grease content of 4.5 % for summer hair and 5.8 % for the winter hair, with a melting point of 39 °C. He found the acid value to be 14.6 compared with a published value of 14. The unsaponifiable fraction was 46 %. Kriel[192] published values (given in Table 2.14) for the chemical constants for mohair grease.

2.3.6 Objective measurement

The textile processing performance, applications and general quality and therefore value and price of mohair are largely determined by the characteristics of the raw (greasy) mohair. It is therefore hardly surprising that considerable effort has been directed over the years towards the objective (i.e. instrumental) measurement of these characteristics, as opposed to the subjective techniques traditionally used. Today, characteristics such as fibre diameter and yield can be, and often are, measured objectively with high accuracy.

Properties that need ultimately to be measured to characterise greasy mohair completely include the following:

1 Fibre diameter and its distribution.
2 Yield.
3 Staple (or fibre) length and strength, and its variability.
4 Vegetable matter content and type.
5 Inorganic matter content.
6 Colour.
7 Lustre.
8 Medullation/kemp.
9 Style/character.

Douglas[193] discussed the advantages of objective measurement of mohair. He stated that the mohair top must achieve strict specifications to satisfy the spinning requirements that include requirements for:

- Quantity of top.
- Mean fibre diameter.
- Mean fibre length.
- Distribution (CV %) of fibre length.
- Maximum percentage of
  - short fibres (shorter than 30 mm).
  - dark fibre content.
  - vegetable matter speck contamination.
  - entanglement (Neps).
  - fatty matter content.
- Moisture regain.
- Maximum percentage of kemp content (specifically for mohair).

In addition, some spinners may have specifications which include:[193]

- Colour.
- Distribution (CV %) of fibre diameter.
- Bundle strength.

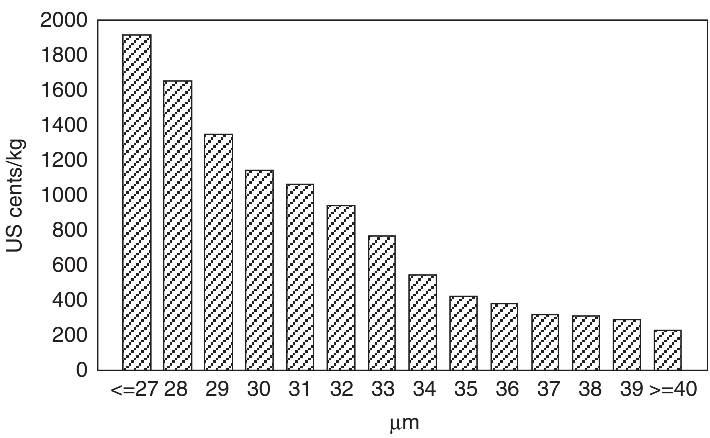
If specifications are incorrect, quality and productivity fail.[193] Douglas[193] emphasised that the variability of natural products, such as mohair, necessitated proper (representative) sampling and adequate testing in order to obtain an accurate and reliable result.

Mohair base (i.e. the amount of clean dry fibre, free from all impurities, expressed as a percentage of the greasy fibre mass) is converted into the International Wool Textile Organisation (IWTO) scoured yield basis.[193] This relates the tested yield to normal commercial yields for scoured greasy mohair. This yield is calculated from the mohair base to include all vegetable matter, standard residuals of grease and dirt, which would normally be retained in commercial scouring, and allows for moisture regain of 17 % which means that yields of over 100 % are possible.

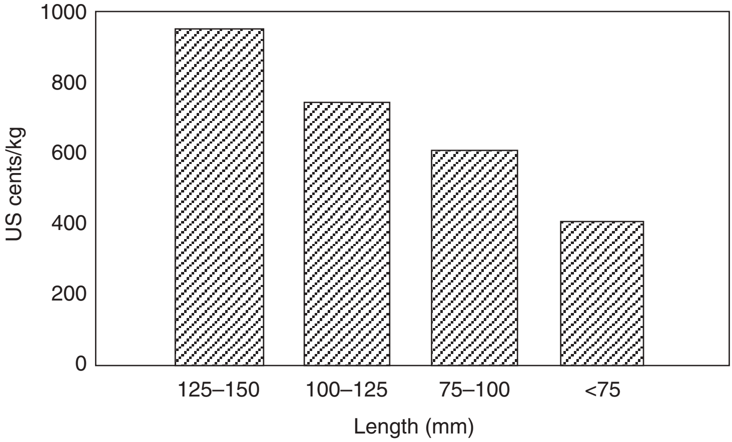
Qi et al.[194] applied image analysis to the objective measurement of mohair and other animal fibre properties, such as diameter and its variation, staple length, colour and coloured fibres. Various workers[121,195] have also reported on the application of Near Infrared Spectroscopy (NIRS) for measuring mohair characteristics, such as diameter, medullation and yield (Mohair Base), while other workers have successfully applied image analysis (e.g. OFDA) to the measurement of diameter, medullation and curvature.

2.3.7 Fineness

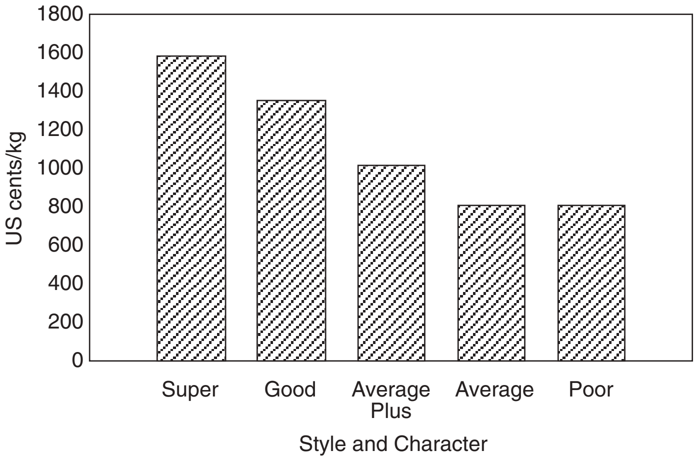
There can be little doubt that mohair fineness (diameter) is one of its most important characteristics from the point of view of price and textile application and performance, with a 1 μm change in diameter having a significant effect on price (Fig. 2.14). It is therefore not surprising that fibre diameter, that can be measured by airflow, projection microscope, FDA, OFDA or Laserscan, is generally the first objectively measured mohair characteristic. Mean fibre diameter is the parameter most generally measured and reported, although the distribution of fibre diameter, in terms of CV, also has textile significance. A major step forward in improving and standardising the interlaboratory measurement of mohair fibre fineness occurred upon the introduction of the Mohairlabs International Round Trials and associated issuing of Mohairlabs stamps (see 'Mohairlabs', Section 2.6.4).



2.14 Average 1999 prices per micron (fineness) for South African mohair.



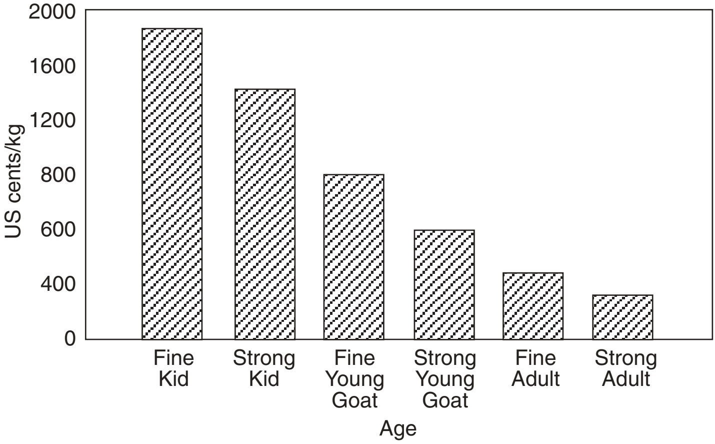
2.15 Average 1999 prices of the various length classes of South African mohair.



2.16 Average 1999 prices of various style and character classes of South African mohair.

The variation of price (in US cents/kg) against different characteristics is shown in Figs 2.14, 2.15, 2.16 and 2.17.

Hunter et al.[196] studied the diameter and variation in diameter, as measured by projection microscope, of some 852 samples of raw and scoured mohair and 380 mohair tops. They found that, although standard deviation tends to increase with increasing mean fibre diameter, the relationship was a tenuous one and the scatter large. There was a tendency for CV to decrease as mean fibre diameter increased up to a mean fibre diameter of somewhere around 35 μm, after which the reverse occurred. For most



2.17 Average 1999 prices of South African mohair of different age groups.

Table 2.15 Average values of coefficient of variation of fibre diameter corresponding to different mean fibre diameters[196]

Mean fibre diameter (µm)	CV of fibre diameter (%)
25	30
30	27
35	26
40	27
45	29

practical purposes, however, the CV of diameter could be regarded as independent of mean fibre diameter, with an average value of approximately 27 %. Some 95 % of the CV values were found to lie between approximately 23 and 32 %. The average standard deviation of fibre diameter for the samples was 8.7 µm, with more than 95 % of the values lying between 6 and 12 µm. The data are shown in Table 2.15, which gives average (typical) values for CV of fibre diameter.

Wang et al.[197] showed that there was a relationship between coefficient of variation (CV) of mohair fibre diameter and CV of single fibre strength as predicted theoretically. Turpie and co-workers[198,199,200,201] as well as others[202] reported on the calibration and application of the FDA200 for the rapid measurement of mohair fibre diameter and its distribution. It was concluded that, within the ranges covered, kemp level had little effect on the

Table 2.16 Fineness measurements of US commercial mohair tops[38]

Grades	Average (μm)	Deviation (μm)	CV (%)	Standard error (μm)	Average range (μm)	Dispersion range (μm)
Kid						
Super Kid	25.7	6.30	24.5	0.19	25.2–26.3	10–45
40s	27.0	5.29	19.1	0.17	26.5–27.5	10–45
36s	28.7	6.23	21.7	0.19	28.1–29.2	10–50
32s	30.0	6.89	22.9	0.22	29.4–30.7	10–50
First						
28s	32.2	7.81	20.5	0.24	31.5–32.9	10–55
26s	34.0	7.99	23.5	0.25	33.3–34.8	15–55
24s	35.7	9.25	25.7	0.29	34.8–36.5	15–60
Low-second	41.1	10.60	25.6	0.30	40.5–42.3	20–70

relationship between FDA, projection microscope and airflow diameter values. Turpie et al.[161] found that different calibrations are required for mohair and wool on both the FDA200 and the OFDA.

Various ASTM and USDA test methods and standards for the fineness of mohair (greasy and top) and the assignment of Grade have been published over the years.[203,204,205,206,207,208,209] The fineness measurement of some US commercial mohair tops is given in Table 2.16.[38]

2.3.8 Staple length and strength

Turpie and co-workers[157,210,211,212,213,214] reported results for the staple length, strength and profile of mohair as measured automatically by means of the SAWTRI Automatic Staple Length/Strength Tester. Using the staple cross-sectional profile (taper diagrams) and a technique of best-fit trapeziums, they showed that the staple profile and length distribution could be used to predict the fibre length distribution of the staple and the top. The mohair staple has a very pronounced taper, indicating a fairly wide variation in fibre length within the staple. There was a reasonably good correlation between mohair staple length measured manually and that measured by the automatic staple length/strength tester. An attempt was also made to relate staple profile to style and character, with some success.

2.3.9 Quality and related characteristics

The quality of mohair is described as a combination of style and character, freedom from kemp, lustre, handle, yolk and uniformity of length and fineness.[215] The presence of kemp is often the most undesirable quality characteristic of mohair. Handle is largely determined by fineness, although a soft natural yolk and oleaginous dips also improve softness of handle.

Mohair characteristics of economic importance (see Figs 2.14, 2.15, 2.16 and 2.17) are fineness (fibre diameter), length, style and character, contamination (kemp, coloured fibres and vegetable matter), and clean yield and uniformity in general, fibre diameter being the most important followed by kemp with length having a smaller, though still important, effect on price and processing as do style and character.

According to Van Der Westhuysen[216] mohair price (averaged over a ten year period) decreased by about 5% for each 1 μm increase in fibre diameter, stabilising at about 34 μm with a price of about 55% of the maximum value (paid for 26 μm mohair). Price was less affected by length, the maximum price being paid for about a 15 cm staple length, representing approximately 6 months' growth. Since there appears to be no benefit in production efficiency from shearing more than twice a year, there is no economic justification for shearing hair that is under 75 mm.[3]

Major burr and grass seed contaminants of mohair result in serious price penalties and so do kemp levels, vegetable fault mohair fetching about half the average price of other mohair types.[217] Any undesirable contaminant, that will either affect the quality of the final product or will have to be removed, reduces the economic value of the mohair. Coloured (e.g. black or red) fibres, if present, could affect the finished cloth, particularly if light shades are dyed, and thereby the value of the mohair. Burrs or excessive vegetable matter in the fleece also have to be removed.[3] Urine and certain types of soil and vegetable matter contain substances which stain mohair permanently.[3] These affect the dyeing and value of the mohair and the quality of the final product. Precautions must be taken to limit such stains, particularly urine stains.[3] Clean yield (i.e. the percentage of actual fibre plus commercially allowed moisture content in raw mohair) generally varies between about 80 and 90% in most fleece classes, but may be as low as 60% in some outsorts, such as lox (locks), the remaining portion being made up of grease, dirt, dust and sweat.

Style and character are judged subjectively, high quality style being described as solid-twisted ringlets (staples or locks), while character is described as the waviness or crimp shown in the staple.[3,143] Style without character or vice versa is undesirable, and a good balance between these two characteristics is considered to be of paramount importance.[3,143]

The simplest description of good classing has been given as uniformity within each class of length, fineness, style and character and degree of contamination (kemp, vegetable matter and stain).[143] An important objective of classing is therefore to achieve uniformity of quality, particularly fine-

Table 2.17 Some approximate quality types[2]

Spinning count		English grades	Fineness /quality Bradford count	Age group	Crimp* per 10 cm	Maximum mean diameter (μm)	Mean fibre diameter (μm)	Description	Age (years)
Tex	Worsted								
14.5–15.5	58–60s	—	8	Kids	6.5–8.0	25	<26	SSK	$^1/_2$
16	56s	Kid	7	Kids	5.5–6.5	28	26–28	SWK	1
16.7–17.5	50–54s	30	6	Kids	5.5	30	29–30	WSK	—
—	—	—	6/5	—	—	32	—	—	—
18.5–19.5	46–48s	32	5	Young Goat	5.0–5.5	34	31–34	SYG	$1^1/_2$
20	44s	34	4	Adult	4.0–5.0	36	35–36	SWH	2
22–24.5	36–40s	36	3	Adult	3.0–4.0	39	37–39	SSF	$2^1/_2$
24.5–27.5	32–36s	38	2	Adult	2.5–3.0	—	>40	SFO	2
31.5	28s	40	1	—	1.5–2.5	—	—	WHO	2
								ARH	—
								CBH	—

* Preliminary.
SSK – Super Summer Kids
WSK – Winter/Summer Kids
SWH – Super Winter Hair
SFO – Summer First and Older
ARH – Adult (Ram's Hair)
SWK – Super Winter Kids
SYG – Summer Young Goats
SSF – Super Summer Ferals
WHO – Winter Hair and Older
CBH – Cross-bred Hair (Adult)

ness (diameter), and classing standards and regulations are laid down and continuously updated in most of the important mohair-producing countries. Classing, therefore, must separate the different parts of the fleece which differ noticeably in one or more important characteristics.

2.3.10 Grades

Much of the information in this section is merely of historical interest, since the trend is to categorise (grade) mohair on the basis of objectively measured characteristics, notably diameter (fineness). The grades of mohair vary in different countries. In general the best grades of mohair are from kids under six months old (i.e. first shearing). Table 2.17 is an attempt to consolidate and rationalise some of the different systems of quality, fineness and grades encountered in the literature.

Table 2.18 Spinning limits and quality of mohair compared[219]

Spinning limit		Mohair quality
Worsted	Tex	
16's	55	1's
24's	37	2's
28's	32	3's
32's	27	4's
40's	22	5's
44's	20	6's
50's	18	7's

2.3.11 Spinning limits and quality

Mohair is often considered to be very difficult to spin because of its smoothness and lack of cohesion. Nevertheless, provided the correct processing additives and conditions and raw materials are used, very high quality mohair yarn can be spun with acceptable efficiencies. The finest yarn which can be spun largely depends upon the mohair fibre diameter or fineness, traditionally expressed in terms of 'quality or quality counts', and these are related to the minimum number of fibres in the yarn cross-section. Today, mohair fineness is almost solely expressed in terms of the objectively measured mean fibre diameter.

According to Wood,[218] the finest mohair yarns were originally spun on the flyer method, using the Bradford worsted system.

Villers[219] described the traditional processing of mohair, and detailed comparisons of the spinning limits of mohair with its quality as given in Table 2.18. He stated that mohair was rarely spun finer than a 40's worsted count (i.e. 22 tex).

2.3.12 Scouring

Scouring is a critical process in mohair production and often it is at this stage that the ultimate state of the finished article is decided. As previously mentioned, mohair generally contains far fewer impurities than does wool[220,221] (e.g. 4 to 6 % of grease compared to about 15 % for merino wool)[222] and scouring generally causes a loss in mass of between 15 and 20 %.[10] Mohair is generally regarded as more sensitive to alkali than wool. Therefore less, or even no, soda-ash should be used during scouring[220,221] and non-ionic detergents are preferred today.

Before scouring, individual mohair bales are often sorted on screens for style and quality, frequently up to eight different kinds being obtained from a single bale,[223] efficient sorting and blending playing an important role in the eventual quality of the yarn. The fibre can then be willeyed (opening/cleaning) before it is scoured, and this is advisable. Scouring conditions for mohair are generally gentler than they are for wool and it has been suggested that the first bowl temperature is strictly controlled to no higher than 50 °C, dropping to about 40 ° or 45 °C in the last bowl.[11,223] Alkali need not be used and the scouring rate is generally much lower than the capacity of the scouring train.[223] The pH must also be strictly controlled and in a 3-bowl scouring set the pH of the first bowl could be 10.5, that of the second bowl 9.5 and that of the third bowl 8.5, and 4 or 5 bowls are preferable. Excess alkali in the fibre can lead to discolouration in dyeing.[11] Where a non-ionic detergent is used without any alkali, it is possible to have first bowl temperatures as high as 60 °C, whereas if an alkali is used, the first bowl temperature should not exceed 55 °C.

Care must also be taken during scouring not to impair the lustre of mohair, hence soda-ash is often only used in the first bowl[224] or even omitted altogether. Spencer[11] suggested that mohair should be scoured to a residual grease level of 0.6 % and that 1 to 1.2 % of combing oil should be added to give a total fatty matter content of 1.6 to 1.8 %, which was considered ideal, for the Bradford system. A series of pilot-scale experiments on the scouring of mohair was carried out at SAWTRI in the 1960s.[220,221,224] Kriel,[189,220] quoting unpublished work by Veldsman, stated that a higher consumption of detergent was required to remove 1 g of grease from mohair than from wool, the generally lower level of grease (4 to 6 %) in mohair as well as its more oxidised nature, because of greater weathering than in the case of wool, being relevant factors. A second bowl temperature of 50 °C was judged better than one of 45 °C, the third bowl temperature being kept constant at 45 °C and that of the fourth bowl at 40 °C. Increasing the first bowl temperature from 45 to 55 °C increased the grease removal, the residual grease decreasing linearly from 0.9 to 0.2 %.[189,221] Grové and Albertyn[224] concluded that it was unwise to exceed 55 °C in either the first or second bowls when scouring mohair, particularly when using soda-ash. Soda-ash, if used in the first bowl, should also be restricted to 2 % (mass on mass of raw mohair).[224] It has also been stated that the scouring liquor should preferably not exceed 45 °C and the drying temperature not be above 55 °C[10], and that a pH of 9 is considered suitable for mohair scouring.

For the Continental worsted system (French or rectilinear comb) of processing, which is very popular today, scouring to a residual grease content of 0.2 to 0.3 % is advisable, with a total fatty matter level of between 0.7 and 0.9 % (up to 1.2 % for flexible card clothing) prior to carding. After scouring (which normally takes place at between 45 and 55 °C),[143] the fibre can be dried to a moisture regain of about 20 % for the longer lengths and about 25 % for the shorter types, the higher regain helping to control fly during carding.[223] Drying temperatures should be as low as possible, e.g. 80 °C.

Turpie and Musmeci,[222] investigating the centrifugal treatment of mohair scouring liquors, found that the grease recovery potential from such liquors was rather poor, with the choice of non-ionic detergents having a noticeable effect on the results obtained. Mozes and Turpie[225] reported on the treatment of mohair scouring liquors (using hollow fibre pilot-scale ultrafiltration membrane separation) as well as on the particle size distribution of suspended solid dirt in a range of industrial raw wool, mohair and karakul aqueous scouring wastes.[226] Mozes[227] reviewed literature published on the treatment and purification of wool and mohair scouring wastes, much of the information on wool also being applicable to mohair. Turpie et al.[228,229,230] reported on the membrane treatment of wool and mohair scouring effluents from an industrial operation.

2.3.13 Carbonising

Very little mohair (±2 %) is normally classified as carbonising, although in high rainfall areas and seasons it can rise to as high as 15 %; mohair with vegetable matter exceeding 3 % is normally carbonised.

According to Pfeiffer et al.[231] vegetable matter (defect), such as burrs, seeds, twigs and other plant parts that become entrapped in the goat fleeces can pose serious problems in the manufacture of textiles. Some vegetable matter is inevitable but excess amounts increase waste in the carding and combing processes. Some types of vegetable matter cannot be physically removed by carding and combing and may require carbonising, a method using acid, normally sulphuric, followed by baking, crushing and de-dusting to remove cellulosic contaminants completely. This process, which follows scouring, is expensive and results in decreased fibre lustre and strength. Hence, mohair buyers are prepared to pay more for mohair free of vegetable matter contamination. It has been stated[232] that the sulphuric acid content of mohair prior to baking should be less than 6 % and that carbonising is normally resorted to when the vegetable matter exceeds 3 %.[143]

Most carbonised mohair is sold for processing on the woollen system. Nevertheless, Turpie[233,234] showed that a mild carbonising treatment (±2.5 % acid as opposed to 6 or 7 % and baking at 115 °C for 60 s) can be advantageous for further processing on the worsted system. Generally, only about 2 % of the Cape mohair clip is classified as carbonising.[235] Seasons of high rainfall, however, can result in abundant growth of grass and other vegetation and the presence of undesirable seeds in excessive quantity and therefore of considerably higher (up to 12 %) of mohair classified as carbonising types.

2.4 Yarn and fabric manufacture

2.4.1 General

In converting mohair into yarn, similar machinery is used as in the case of wool. Nevertheless, mohair is not an easy fibre to process, particularly in drawing and spinning. Considerable secrecy exists even today concerning the precise processing conditions used; firms which have built up this specialised knowledge do not share it because it provides them with a competitive edge. It is generally easier to disentangle mohair than wool during carding, with less fibre breakage in this process, although problems with fly generation often necessitate lower carding speeds.

Mohair's low cohesion often necessitates that the fibres (slivers) be supported, for example by aprons, during processing. The efficient mechanical processing of mohair into quality yarn is widely accepted to be a highly specialised field, requiring considerable skill, experience and practical knowledge. Mohair can present problems during processing due to its lack of cohesion (smoothness) and the generation of static electricity. Mohair blends well with wool, however, and wool facilitates its processing. The application of the correct types and levels of processing lubricants and additives (such as antistatics) and the selection of the most appropriate processing machinery and conditions (including atmospheric) are all crucial in the efficient processing of mohair into a quality product.

Today, the bulk of mohair is processed on the Continental or dry-combed (French/rectilinear combing) as opposed to the oil-combed system. Nevertheless, most of the shorter mohair and also a significant amount of longer hair as well as mohair waste, such as carbonised noils, are processed on the woollen system. For the woollen system, a minimum amount of vegetable matter is essential (see the section on carbonising (2.3.13)). The final web is normally taken off the card by a Tape Condenser, with special attention to splitting the web and rubbing it, as well as to the choice of rubbing leathers. For woollen carding, an oil and antistatic are applied to the level of about 5 %, a 1-part Scribbler with Breast, a 1-part Intermediate and a 1-part Carder generally being adequate, flexible clothing being used. The handling of the web normally requires special attention, Broad Band feeds being ideal, a Scotch feed being possible for blends with wool.

Traditionally, mohair was processed on the Bradford worsted (oil-combed) system (drafting against twist) followed by flyer spinning.[236] In earlier times, some mohair qualities used to be double Noble-combed, some Noble- and then Lister-combed and some single-combed, the Noble comb being advantageous for kemp removal. Today, mohair is mainly processed on the French (continental or dry-combed) system of drafting and spinning[237] involving French (rectilinear) combing. It is possible to use either flyer (twisted) roving or rubbed (twistless) roving for subsequent yarn spinning.

In woollen spinning, mohair shorter than 75 mm is generally used while on the Bradford (worsted) system the length is generally 90 mm and longer, with a staple length of some 120 mm often required for worsted processing.[166] In order to qualify for a spinners type, which is the top end of the market, a minimum staple length of 125 mm is reportedly required.[238]

2.4.2 Worsted processing

Mohair is most commonly carded on single swift cards, the forepart equipped with burr beaters and morel roller to deal with vegetable contaminants. Lower swift speeds than those used for wool are applied so as to minimise fly and other problems. Card losses usually lie between 3 and 7 % but could exceed 10 % for types of mohair that have an exceptional number of seeds. It is important to apply a suitable lubricant (having good cohesion and antistatic properties) to the mohair prior to carding. Three gilling operations generally follow carding, with lubricant/antistatic being added, by spraying, prior to combing to increase the dichloromethane (DCM) extractable matter level to 1 to 1.2 % for dry-combing and 3 to 3.5 % for Noble oil-combing.

It is normal practice to gill combed mohair twice, using autoleveller intersecting gill boxes, to produce commercial tops, because it is important to use cans with springs to support the hair, and ensure delivery in the form of a bump rather than a ball.

Spinning can take place on mohair oil-combed tops using the flyer system or Bradford system of drawing and spinning, employing the draft-against-twist principle, the twist in the roving providing cohesion and controlling the drafting action. More commonly today, the continental system of drawing and spinning is applied, using dry-combed tops, drawing involving two stages of intersecting gill boxes followed by a passage through a double-apron high-draft draw box. In preparation for spinning, either twisted roving can be produced on a Flyer (Speed frame) or rubbed (false twist) roving on a rubbing frame or false twist rover.

It is believed[239,240,241] that mohair top and roving should be rested or stored for prolonged periods of weeks between the various stages of its mechanical processing from top to yarn. It used to be customary to rest mohair tops for extended periods (e.g. six weeks) after combing (or top-making)[239,240,241] and also after the drawing operation in roving form[243] so as to improve spinning and reduce waste. The subsequent improvements in spinning performance and reduction in fly waste were ascribed to the dissipation of static electricity.[239]

Parkin and Blackburn[241,244] found that, in the case of Cap spinning, storage reduced static electricity on the rovings and end breakage as well as waste during spinning. The rovings were found to reach equilibrium regain after approximately one week of storage. Yarn evenness, strength and elongation generally improved with increasing periods of roving storage, with yarn twist liveliness increasing with roving storage until it reached a maximum after about 18 weeks storage. Yarn hairiness first increased and then decreased with longer roving storage time. Parkin and Blackburn concluded,[245] however, that although roving storage resulted in improved yarn properties, particularly in the finer count, the improvements were generally too small for storage to be of commercial benefit. They also concluded that measuring the cohesive properties of mohair rovings should provide a measure of spinning performance and yarn properties.

2.4.3 Yarn hairiness

It has been found that mohair yarn hairiness was reduced by roving storage, decreasing fibre diameter, plying and increasing fibre length (Barella and co-workers and Turpie and Hunter quoted by Hunter[2]).

2.4.4 Fancy (novelty) yarns

Mohair is used to particular advantage in fancy or novelty yarns, such as loop, knop, brushed, bouclé, flame, snarl, slub and gimp, where its properties provide outstanding aesthetic appeal and comfort. Such yarns are used in blankets, stoles, shawls, scarves, knitwear (sweaters, cardigans, jerseys), travel rugs, curtaining, table coverings, upholstery, furnishings, pram covers, women's dresswear, suitings and coatings. Traditionally, mohair yarns, particularly loop yarns, were raised after knitting by passing the fabric through a teazle machine. Although loop yarns are often brushed prior to fabric manufacture, they can also be converted into fabric and then brushed to give the desired light and fleecy appearance. Adult hair is often used to form the loops of bouclé yarn properly.[259]

Curl yarn is produced by twisting a number of yarns together, setting the yarn (e.g. boiling at pH 6.7) and then untwisting and separating the individual yarns again. Metchette[260] has discussed the spinning and dyeing of fancy yarns.

2.4.5 Fabric production and machinery

Generally, mohair yarn is converted into knitted and woven fabrics using similar equipment as for wool, though sometimes in a modified or adapted form and under special conditions.

2.4.6 Weaving and woven fabric properties

Mohair finds significant application in woven suiting and coating type fabrics, particularly in men's light-weight summer (tropical) suitings where it provides the wearer with considerable comfort and good wrinkle resistance.

2.4.7 Wrinkle recovery

Mohair is widely recognised as having very good wrinkle resistance and recovery, which, together with its stiffness, make it an ideal fibre for use in comfortable light-weight tropical type fabrics. Nevertheless, laboratory tests for wrinkling are often at variance with perceived and actual performance in wear, with different laboratory tests also often providing contradictory results. For example, according to the Thermobench wrinkle recovery test mohair was superior to wool, whereas according to the AKU test there was little difference between the two fibres, at the same mean fibre diameter. Ageing has a considerable effect on laboratory test results.

According to laboratory tests, wrinkle recovery actually deteriorates with an increase in fibre diameter, which is contrary to widely held beliefs.[280] The reader is referred to Hunter[2] for more detailed information on this subject.

The fibre and fabric properties of mohair and their relationship to other variables are discussed in Appendix 5.

2.4.8 Knitting and knitted fabric properties

Mohair, often in blends with other natural fibres, notably wool, is used to great advantage in knitwear, mostly in brushed, loop or some other fancy form, particularly to impart a soft, lustrous and brushed appearance. Knitwear traditionally represented some 80 % of mohair's outlets, but this sector is fairly sensitive to cyclical fashion changes. Historically, large quantities have been used in women's sweaters, the brushed appearance being typical, producing a highly lustrous fabric.

The medium grades of mohair (24s, 28s, 32s and 36s) are mainly used in knitted outerwear. For machine knitting, 36 to 37 μm mohair has proved fairly popular,[281] with 37 to 39 μm being used for hand knitting. Kid and Young Goat mohair is used in machine knitting and Young Goat and even Adult hair in hand knitting. With the trend towards softness and lightness, more and more Kid mohair (and Young Goat mohair) has found its way into the knitting trade, even for the brushed look.[281]

2.4.9 Dyeing and finishing

2.4.9.1 General

It is generally the case that firms which dye and finish mohair also dye and finish wool and hence similar machinery is used for the two fibres, although often under different conditions. Furthermore, it is nowadays very rare to find pure mohair in yarns and fabrics; it is mostly present in blends with wool, which means that the dyeing and finishing machinery and conditions used must be suited to both fibres.

In general, weak acid-dyeing dyestuffs are used for light/bright shades and acid milling, super milling and reactive dyestuffs for medium and dark shades. It is common practice to dye at temperatures below the boil, preferably below 90 °C and to limit the time of dyeing at high temperatures, so as to curtail any adverse effects on lustre and other desirable properties. It is also possible to limit damage to the fibre by using fibre protective agents. The pH of the dyebath should ideally lie between 4.5 and 5.5 and should never exceed 6.5.

Dyeing and finishing represent crucial stages in the manufacture of mohair products of the outstanding quality and appearance associated with items bearing the label 'mohair'. Although the dyeing and finishing of mohair, including the machinery used, are similar to those used for wool, certain differences and special precautions are often necessary for mohair, particularly so as to preserve its lustre, brilliant colours and other desirable properties. Although a vast literature exists on the dyeing and finishing of wool, much of which is applicable to mohair, there is far less literature available on the specialised knowledge of conditions and procedures required for the dyeing and finishing of mohair products because most of such knowledge is a well-kept secret. In general, milder conditions are used for the dyeing and finishing of mohair than for wool, partly because of the need to conserve the lustre of mohair and partly because mohair is more sensitive to wet treatments than is wool.

Veldsman stated[284] that the finishing procedure of light-weight wool/mohair fabrics is a highly secretive affair, and it appears that reputed firms have constructed special machines or techniques to achieve a highly lustrous, resilient cloth.

The following sequence of finishing operations was found to give a commercially acceptable fabric.[284]

- Crabbing at the boil.
- Piece scouring (open width, if at all possible).
- Steaming and brushing.
- Shearing (the last two operations can be repeated, if deemed necessary).
- Blowing (decatising).
- Hydraulic pressing.
- Autoclave setting (KD process).

Further details concerning dyeing and finishing are set out in Appendix 6.

2.4.9.2 Flammability

Keratin fibres, such as mohair, have traditionally been regarded as being safe from the point of view of flammability. Mohair may be ignited if subjected to a sufficiently powerful heat source, but will normally not support combustion and will smoulder for only a short period after the heat source has been removed. This can be ascribed to the high ignition temperature, low heat of combustion and low flame temperature of the fibre. The natural flame resistance of mohair is connected with its chemical and morphological structure. Mohair was one of the few fibres which met most of the earlier requirements for flame retardancy for contract markets (e.g. office furniture, hotels and theatres). Nevertheless, although, like wool, mohair does not burn easily, it cannot be regarded as completely flame resistant, and flame proofing is necessary for it to conform to modern specifications for flame resistance. Traditional high-density mohair and wool carpets were acceptable without treatment but fashionable long-pile low-density structures were classed as hazardous unless specially treated. The Limiting Oxygen Index (LOI) of mohair is about 24, with 27 generally regarded as the minimum required to pass the vertical flame test.

By blending mohair with certain synthetic fibres or with cotton, the problem of flammability could become more serious because these latter fibres often burn easily in the untreated state.

2.4.9.3 'Easy care' finishes

An area which is now receiving attention is the development of easy-care wool and mohair knitwear garments, which can be washed in a washing machine without any adverse effect on the garment dimensions or appearance.[290]

2.5 Mohair production in various countries

2.5.1 South Africa

The first Angora goats to leave Turkey reached South Africa in 1838 and were imported by Henderson. South Africa presently accounts for over 60 % of the world mohair production; its mohair is generally known as Cape mohair and is widely regarded as one of the most superior, finest, best prepared and highest yielding in the world. The excellent quality of Cape mohair makes it ideally suited to high quality application, e.g. high quality men's wear and women's wear, fineness and length being important in both cases. Van Der Westhuysen et al.[143] published a book on the Angora goats and mohair in South Africa, covering the production of mohair and its classification. Uys[156] described the history of mohair in South Africa from 1838 to 1988, mentioning that the first mohair tops were produced in 1963 at Gubb & Inggs. Today, some 95 % of South African mohair is exported, the distribution being carried out in a free market system.

The South African Mohair Growers' Association was re-established on 16 August 1941, having previously existed from 1896 to 1904. The South African Mohair Growers' Association is funded by Mohair South Africa from income generated by the Mohair Trust, the assets of which were built up over many years by the mohair growers of South Africa, and for whom there are neither subsidies nor incentive schemes. Mohair South Africa was formed in 1998 to take over some of the responsibilities and duties of the Mohair Board that was formed in 1965 and disbanded in 1997. Mohair South Africa is a beneficiary of the Mohair Trust. The Angora Goat Stud Breeders' Society has been in existence for over 100 years.

There are presently (year 2000) approximately 2000 mohair farmers in South Africa, farming with just under 1.2 million goats and producing about 4.5 mkg of mohair; average annual greasy mohair production per goat is 4 kg at an average clean yield of about 85 %. Mohair is mainly produced in the Cape Province, more specifically the Eastern Cape area, within 300 km distance from Port Elizabeth. In 2000 the annual value of the South African mohair clip was about 225 million rand (≈32.5 million US dollars) with the value of the fabric being about 2500 million rand.

2.5.2 United States of America

Angora goats were first introduced into the USA in 1849, from Asiatic Turkey. In the United States of America, as in South Africa, there are two mohair clips each year, the one termed Spring (shearing in February/March) and the other Fall (shearing in August/September),[158] most of the mohair being produced in the south-western United States. In the USA, Angoras are largely concentrated in Texas, with smaller numbers in New Mexico, Oklahoma, Michigan and other states.[15] Texas produces about 96 % of the total US mohair production, with the most important area being the Edwards Plateau in south-western Texas which accounts for about 90 % of production. Here the mild dry climate and hilly, bushy terrain are particularly suited to the well-being of the goats. Mohair in Texas is mainly grown in the area circumscribed by Uvalde, San Antonio, Austin, Fort Worth and San Angelo. In Texas, mohair is sold through various warehouses in a free market system in which producers have the final say over the sale of their product. The Mohair Council of America was established in 1966 as the promotional organisation for mohair produced in the United States and is involved in marketing, development and research; the executive offices are located in San Angelo. It is primarily funded through a check-off programme in Texas, involving a 0.04$/lb (0.088$/kg) levy (assessment) on all mohair sold in Texas, collected through the Mohair Producers' Board. There are no federal government incentives or check-off programmes for mohair producers.

The USA market has established various grades of product, based on staple or lock characteristics, from the ringlets of the finest fleece to flat locks in which the curl is less pronounced and takes on the form of a wave.[160] Classing is mainly associated with grading for fineness, and length is also a criterion;[160] there are only 9 basic grades for mohair.[161] The hair is generally not skirted but is normally separated into Kid, Young Goat and Adult. About 98 % of the US mohair production is exported.[159]

Performance testing of Angora goats is undertaken at the Texas A & M Centre.[162] Lupton et al.[163] discussed the performance testing of Angora goats in Texas and reported that during the 8-year period under consideration, average clean mohair production of yearling buck increased from 4.6 to 5.5 kg (180-day basis), while clean yield, fibre diameter and staple length remained constant, at about 69 %, 40 μm and 150 mm respectively. Kemp (≈0.4 %) also remained approximately constant, but medullation increased from about 1.3 to 3.3 % (average about 2 %). Kemp content was not correlated with any of the measured characteristics except medullation, where the correlation was 0.33. The average annual mohair yield per goat is about 4 kg. At the beginning of 1999 there were some 631 000 Angora goats in the USA.

2.5.3 Turkey

There can be little doubt that the world mohair industry, as we know it today, had its origins in Turkey. In Turkey there is normally only a spring clip each year,[164] the goats being shorn once a year during May.[165] An official grading standard exists, with the hair normally sorted, by exporters, into First Kid, Best Average (Young Goat), Good Average (Fine Adult), Fair Average (Low Adult) and Mountain Konia (mountain hair about 31/32 μm). The clean scoured yield is about 70 to 75 %.

Mohair-growing in Turkey is concentrated in the central provinces of the Anatolian peninsula (within a radius of approximately 160 km from Ankara) where the summers are hot and dry and the winters cold with frequent snowfalls. The mohair clip is sold in its unclassed state, although exporters grade before exporting hair. Mohair for export is divided into two categories, namely Principal Mohair and Secondary Mohair, with the former divided into nine classes and the latter into eight. The grease content is usually less than 4 %. The best grades are clear white.

In Turkey, a reddish brown mohair, containing a colour pigment, and known as Gingerline, is produced.

2.5.4 Australia

Angora goats were first imported into Australia as early as 1856,[15] but the Australian mohair industry only really started to expand in about 1970.[166] In Australia, the Angora goats are mostly shorn twice a year[165] (in the past, they were sometimes shorn at 9 months) and graded into standard qualities (various grades of Kids, Young Goats and Adults), depending upon quality and kemp content. Classers grade mohair into Super, Good and Average Style and Character categories. Cotting is classed into soft and hard cott.[155] Pigmentation is severely penalised. Stains must be skirted from the fleece which increases with increasing coverage and fleece weight.[155] The scoured yields are approximately 88 to 90 % and the colour good.[165] Australian mohair is considered to be relatively fine and kempy,[167,168,169] kemp being present in varying degrees, from FNF (free/nearly free) to very kempy cross-bred.[165] There is now a single classing standard for Australian mohair.[169]

Harmsworth[170] gave some details of Australian mohair as seen through the eyes of some Bradford merchants, while aspects of mohair production in Australia have been discussed by Stapleton[155] and others.[171,172,173] According to Stapleton[174,175] and Gifford et al.[176] as quoted by Stapleton,[155] Australian mohair has a yield of about 90 %, a mean fibre diameter ranging from 24 μm at the first shearing, 26 μm at the second, 30 μm at the third and fourth shearing and about 33 μm at later shearings, and the kemp levels at about 2 %. Fleece mass increases rapidly to the third shearing, reaches a peak at the fifth or sixth shearing and then gradually declines showing some seasonal effect.[155] In Australia, the maximum greasy fleece weights range from about 1.4 to 1.9 kg, at 6 months.

Recent infusions of new bloodlines from South Africa and Texas are stated to be one of the most potentially beneficial events in the history of Australian Angoras.[177] The MOPLAN performance recording system in Australia has been referred to in an anonymous paper.[178]

2.5.5 New Zealand

In about 1860, Angora goats were brought to New Zealand from Australia,[182] and approximately 20 000 Angora goats were imported into New Zealand from Australia during the early 1980s. Woodward[179] discussed the increasing production of mohair in New Zealand, explaining the breeding strategies of goat farmers. In 1992 the New Zealand clip was marketed through two separate companies.[180] At the turn of this century (2000), New Zealand produced about 3 % of the world mohair.[181] Shearing takes place every six to nine months. Mohair production in New Zealand and Australia has been discussed in various articles,[167,182,183,184] the mohair tending to be relatively fine, high yielding[182] and kempy. The scoured yield is mostly around 88 to 90 %, and the colour good. Kemp is present to varying degrees, from nearly free to very kempy cross-bred.[165] Bigham et al.[185] stated that the levels of kemp and medullation in New Zealand mohair were high relative to those in Texas and Cape mohair, but steps to rectify this, such as the use of imported low-kemp breeding stock and a dekemping process, were in progress.[5]

2.5.6 United Kingdom

Ryder[186,187,188] reported on the very small production of mohair in the United Kingdom and on the development of the Angora goat industry there.

2.5.7 Argentina

In Argentina there are generally two clips each year, namely in March (short) and November (long).[165] Sorting is mostly done by the exporters, the scoured yields are approximately 75 to 80 % with the colour good but the hair relatively kempy.[165] In 1985 guidelines for the classing and types of mohair were approved by the Department of Agriculture for application in the entire country.

2.6 Marketing and cost considerations

The textile application of mohair goes back many thousands of years, the fibre finding application in almost every conceivable textile end-use. Today, up to 80 to 90 % of mohair consumption, especially of the Adult hair, can be affected by fashion.

2.6.1 The end-uses of mohair

Table 2.19 lists some of the end-uses of mohair, and a detailed list of mohair applications is given in Appendix 7 (after Hunter[2]). The presence of mohair in a material is considered to lend elegance and quality to it, mohair being sought after for its comfort, resilience and durability. For example, in lean worsted-type light-weight tropical suitings, mohair is regarded as a cool fibre, whereas in brushed articles, such as shawls, stoles, rugs, sweaters and blankets, mohair provides warmth without weight. Velours, also embossed, have always been one of the most popular outlets for mohair. Mohair's characteristics of hard-wearing durability, resilience or springiness, moisture absorption, comfort, lustre and smoothness make it ideally suited to many applications in apparel and interior textiles. Because of its general smooth-

Table 2.19 Mohair consumption by end-uses[291]

End-uses	Share (%)
Hand-knitting yarns	65
Men's suiting fabrics	15
Women's woven accessories and rugs	12
Woven furnishings and velours	8

ness and low static propensity, except under dry conditions, mohair does not collect dust or soil very easily and is also easily cleaned.

Traditional mainstays of mohair have been blankets, stoles, scarves, travel rugs and hand-knitting yarns, fluffy look women's wear in fancy yarns, women's couture clothes and mohair velours for furniture. Mohair comes into its own and is probably unequalled in brushed fabrics (also called 'candy floss' mohair in certain cases) and plush and velour fabrics. As early as the 1870s, imitation furs, using mohair pile fabrics, were manufactured,[22] and mohair plush for upholstery was already popular by the 1890s. Mohair was used as automobile upholstery and rugs, and as upholstery in railway carriages more than 60 years ago,[23] and in 1924 America had all its automobile upholstery made from mohair.[17] Mohair pile furnishing fabrics were already very popular over 70 years ago.[17] Before the Second World War, 'uncrushable' mohair velvet was already being made.

Mohair has traditionally found outlets in plush and pile fabrics (e.g. velours in furnishings and upholstery), hand-knitting, men's suitings, blankets, rugs and garment linings. Its lustre, resilience, smoothness, hard wearing and crease-resistant properties make mohair valuable for upholstery and any pile fabric (e.g. plush, velvet and moquettes) and it is virtually unsurpassed for general durability, recovering very quickly after being crushed. The smooth fibres do not allow dirt to collect readily, and stains are generally fairly easily removed. Mohair blends very well with other fibres and is usually used in this form.

2.6.2 The International Mohair Association

The International Mohair Association (IMA) was formed on 21 November 1974 for the purpose of promoting the use of mohair, protecting its members against unfair competition and trade malpractice and to ensure the maintenance of the highest quality standards associated with this luxury fibre.[292] It is funded by its members who come from agriculture, commerce and industry, the IMA consisting of various product groups. It is split into National Committees depending on geographical area.

Originally the most important functions of the IMA were reported to be the promotion of mohair internationally, the collection and dissemination of market information and the running and support of the Mohair Laboratories (Mohairlabs) and Mark schemes and labelling, the IMA owning the International Mohair Mark. All parties with interests in mohair were brought together into a single organisation with the main purpose of promoting the image of mohair and its uses as a speciality textile fibre. The membership of the IMA is divided into two sections, namely growers and users. The IMA created a forum for all parties to discuss their mutual interests and problems and to exchange ideas, from which a very sound understanding resulted to the benefit of everybody concerned. Much confidence and stability were engendered through the advent of the IMA. This was apparent throughout the trade.[293]

2.6.3 The Mohair Mark

The International Mohair Association (IMA) Mohair Mark was introduced in 1976, and in 1999 registered in 35 countries. It is shown in Fig. 2.18.

A Diamond Mark, for woven fabric containing a 100 % mohair weft, was introduced in 1988 but was subsequently dropped. Furnishing velours with 100 % mohair pile, irrespective of the backing, are promoted under the Gold Label system, the Silver Mark being allocated to goods with a minimum pile content of 70 % mohair. Finished woollen goods, such as stoles, blankets, scarves with a minimum mohair content of 70 %, have a Silver rating, while women's piece goods, for apparel manufacture, must contain a minimum of 40 % mohair to qualify for promotion.[294] A minimum of 70 % mohair is required for the IMA Gold Mark in hand-knitting yarns,[295] with at least 40 % for a Silver Mark.[295]

The rules for the use of the mohair trade mark are set out in Appendix 8.

2.18 The Mohair Mark.

2.6.4 Mohairlabs

In order to achieve better and more consistent fibre diameter and length test results worldwide, the IMA Mohairlabs Association was formed in 1984. It now runs annually international interlaboratory round trials on the basis of which the right to use a Mohairlabs stamp is awarded to those laboratories that achieve the prescribed accuracy.[292]

Mohairlabs was formed with the following purpose, aims and membership.

Purpose

The purpose of the Association is not to conflict with already established Textile Testing Associations (such as Interwoollabs) but recognizes the need for specialist knowledge and expertise necessary for accurate testing of mohair, due to certain fundamental differences between wool and mohair. The most significant of which is the much greater variation in fibre diameter inherent to mohair.

Aims

The aims of the Association are:

1 To develop co-operation between member laboratories with the view to standardisation of test methods, in order to achieve correct and uniform test results on mohair.
2 To promote the confidence of all processors and users of mohair, in the accuracy and integrity of member laboratories' test results.
3 To assist all interested parties in resolving disputes arising from differences in test results.
4 To undertake to investigate and establish standard rules for any aspect of mohair testing which may from time to time become necessary.
5 The method of application of the aims is defined in the Rules of the Association.

Membership

1 The Association shall be open to all suitably equipped Textile Testing Houses, which have applied to, and complied with, the entrance requirements and who agree to abide by the Rules of the Association as administered by the Technical Committee.
2 Membership of the Association does not imply full membership of the International Mohair Association.

2.6.5 Environmental, health and safety issues

Angora goats feed on, and control, vegetation such as shrubs and thorn bushes, often in areas not very suited either to other domestic animals or to the cultivation of food or other crops. Therefore, in this respect, they play a positive role from an environmental point of view. They do, however, require some chemical controls in the form of pesticides, for example dips for lice. Such pesticides can represent an environmental hazard, for example polluting scouring effluent. To combat this, countries such as South Africa have banned the use of the very harmful classes of pesticides, notably the organo-chlorides (OCs) and arsenic compounds. Presently the organophosphates, used as dips, are also increasingly coming under the spotlight and more environmentally acceptable alternatives are being developed and introduced. To combat the problem further, certain countries have also introduced monitoring programmes.

In addition to the possible hazards posed by the pesticide residues in effluent, mohair scouring and carbonising plants also produce polluting effluents but today these are generally very effectively treated as in the case of wool. Beyond this, mohair can be regarded as an eco-friendly fibre, provided appropriate dyestuffs and other chemicals are used during processing, including mothproofing.

From the point of view of health and safety, mohair, in common with other animal fibres is generally very comfortable and it is rare that any allergic reaction to it occurs, although there are very occasionally problems with prickliness or scratchiness when the fibre comes into direct contact with the skin. These can be minimised by increasing the length of the fibres protruding from the fabric surface, by using the finest mohair possible and by applying a softening treatment to the fibre. The softening process is receiving increasing attention because it could extend greatly versatility and consumer acceptance provided other desirable characteristics, such as lustre, comfort and durability, are not deleteriously affected.

The low flammability of mohair renders it useful in several applications that have been detailed in Section 2.4.9.2.

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