MORPHOLOGY AND THERMAL BEHAVIOUR OF TEXTILE FIBRES FROM THE HAIR OF DOMESTIC AND WILD GOAT SPECIES

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Abstract:

The performances and properties of the fine hairs from the coats of several domestic and wild mammals, namely the "speciality animal fibres" used for manufacturing high quality, luxury textiles, are influenced by the domestication process, heritability, hybridisation, nutrition, and life environment.
In this work, the fibre morphology and cell structures of fibres from wild, domestic and crossbred goats were studied, with the aim of investigating the relationships with the thermal behaviour of the crystalline fraction of the fibres. Scanning Electron Microscopy investigation confirmed that exposure to thermal excursions and nutritional stresses lead to finer hair, associated with lower rate of growth, yielding strong orientation and elongation of the cuticle cells in the direction of the fibre axis. Transmitted Light Microscopy and Differential Scanning Calorimetry revealed specie-specific differences in the internal structure of the fibre cortex, probably related also to moisture during the process of hair keratinisation.

Keywords:

Down hairs, capra hircus, capra ibex, keratin

Introduction

The fine, soft and warm fibres from several domestic mammals of the specie *Capra hircus* are used by the fashion industry for manufacturing high-quality, luxury textiles. Among these so-called “speciality animal fibres” Mohair, the lustrous fleece of the Angora goat (*Capra hircus aegagrus*), is one of the oldest fibres known [4] and is still regarded as one of the most luxurious and best quality fibres available to man. It is generally a long, straight, smooth and lustrous fibre which can be dyed to brilliant and fast colours. Good quality Mohair fibres are free from medullation and kemps, and the predominant natural colour is white, although they also occasionally come in brown and black. Mohair is predominantly produced in South Africa and Texas (USA), but also can come from Turkey, Argentina, Australia and New Zealand. According to the mean fibre fineness, fibre lots are generally classed into Kid Mohair (Fine Kid, Good/Average Kid), Young, and Adult Mohair. Mohair’s average fibre diameter ranges from below 24 µm for Superfine Kids to about 40 µm for Coarse Adults. The *Capra hircus aegagrus*, which is a near relative of the cashmere and certain types of Himalayan goats [17], is of the same species as the European milk breeds and all other breeds of domesticated goat but, uniquely, it has a single coat. The flocks are harvested by shearing the animals once or twice per year. Adult goats produce 4-5 kg of greasy mohair per year and the fibre growth rate is about 25 mm each month, although the quality of the fleece is influenced by the age of the animal [4]. Cashmere is one of the finest and softest animal fibres used by the textile industry [16]. Cashmere fibre is produced from the down hair of a form of domesticated, double-coat goat (*Capra hircus laniger)* indigenous to Asia. The subspecies from which the *Capra hircus* goat originally derived is impossible to determine. Some authors have concluded that the classification of the Cashmere goat would be more correctly designated by the utility of the animal in the amount of down undercoat fibres produced by secondary follicles, rather than by a zoological classification [1]. Cashmere is principally produced in China, Mongolia, Afghanistan and Iran. The down undercoat typically grows from mid-summer, when fibres growing secondary follicles become active, until late autumn or early winter when follicle activity declines. Harvesting is carried out by combing the animals after the season moulting; medullated coarse hairs are removed from the down as the first step in the textile processing. The average fibre diameter of dehaired cashmere ranges from 13 to about 19 µm, and the fibre length ranges from 20 to 50 mm. Cashmere fibre yield and colour differ significantly for the different breeds; the maximum yield (about 500 g/year) is harvested from the Chinese “Liaoning” breed. The predominant colour is white, although there are also blond, fawn, brown, grey and black cashmeres. Due to its economical importance in the luxury textile market, stringent legal definitions and regulations are in force for cashmere in many countries, principally aimed to limit the maximum fibre diameter and the coarse hair content [2]. Cashgora is the name given to the fibre produced by cross-breeding Angora goats (domestic goat) with feral Australian or New Zealand goats, resulting in something similar to a superfine Mohair. The mean fibre fineness of this fibre type ranges from 18 to 23 µm, and the fibre length ranges from 30 to 90 mm [4]. Similarly to Mohair, Cashgora grows fibres that do not differ widely between the primary and secondary follicles and can be regarded as a single coat goat. Yangir, i.e. the “wild Cashmere” fibres, are obtained predominantly from an Asiatic sub-specie of *Capra ibex*, the wild goat Siberian ibex *Capra ibex sibirica*. Although named after Siberia, the Siberian ibex lives in mountainous areas from India to Mongolia. These animals are widely distributed and are hunted by local populations, as well as foreign trophy hunters. Fibres are removed from the animals, allegedly killed for meat, and dehaired manually in the country of origin. Dehaired Yangir is very short and fine, ranging in average diameter from 13 to 15 µm; its natural colour is light blonde. No data is available on the annual crop and fibre yield per animal [15].

This work investigates the morphology and the structure-related thermal behaviour of the textile fibres from the domestic Angora and Cashmere goats, the crossbreed Cashgora, and the wild goat Yangir. Its aim is to point out differences due to heritability, hybridisation and the environmental conditions of the hair growth.

Materials and methods

Samples of Mohair (25.2 µm), Cashgora (20.8 µm), Cashmere (13.9 µm) and Yangir (13.6 µm) were first cleaned with petroleum-ether for 2 hours in a Soxhlet, then dried and conditioned in standard atmosphere at 20 °C, 65% R.H. for 24 h.

Microscopic investigation of the fibre surface was performed using a LEO 135 VP Scanning Electron Microscope, at an acceleration voltage of 15 kV and 30-35 mm working distance. Fibres were cut into snippets of 0.4 mm length, fixed on aluminium specimen stubs with double adhesive tape, then coated with a 2-300 nm thick gold layer in rarefied argon, using an Emitech 550 Sputter Coater at 500V for 3 min. Internal fibre morphology was investigated by a Leica DM-LP Transmitted Light Microscope, using silicone oil as a mounting medium. Histology differences were enhanced by staining the fibres with 1 % (on weight fibre) Methylene Blue (C.I. 52015) in neutral, BR 1:80 boiling liquor for half an hour [9]. Differential Scanning Calorimeter (DSC) analysis was performed using a Mettler Toledo DSC 821, flushing the calorimeter cell with 150 ml/min of nitrogen. The temperature program was set in the range from 30 to 400 °C, at a heating rate of 10 °C/min, and the instrument was calibrated with indium as a standard. All tests were repeated three times, and the repeatability of the DSC traces was confirmed.

Results

SEM investigation of the fibres showed clear species-specific cuticle scale patterns [11, 17, 19]: the surface morphology of the cuticle cells reflected variation in length, shape, orientation and frequency. Mohair (Fig. 1) had a relatively low scale frequency, with a wide distance between the cuticle scale margins. The number of scales per 100 µm was generally of the order of 5, compared with between 10 and 12 in fine wools [7], with the scale lengths ranging from 18 to 22 µm. The cuticles scales were quite thin and flat, generally being less than about 0.6 µm in thickness and hardly any overlap.

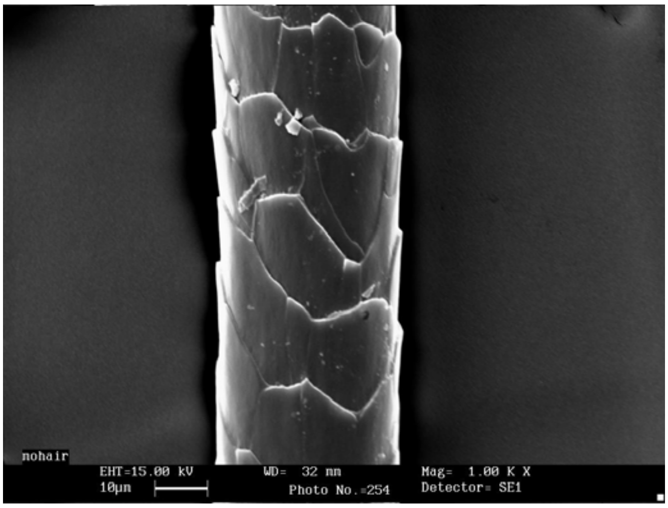

Figure 1. Mohair (SEM 1000X).

Cashgora (Fig. 2) showed a surface morphology very similar to that of Mohair for coarse fibres, but cashmere-like shaped scales were observed on the surface of fine fibres. Generally, cuticle cells of Cashgora were a little more oriented and elongated than Mohair, but no differences were found in the scale frequency and thickness, thus a microscopic differentiation of these fibres is very difficult to perform.

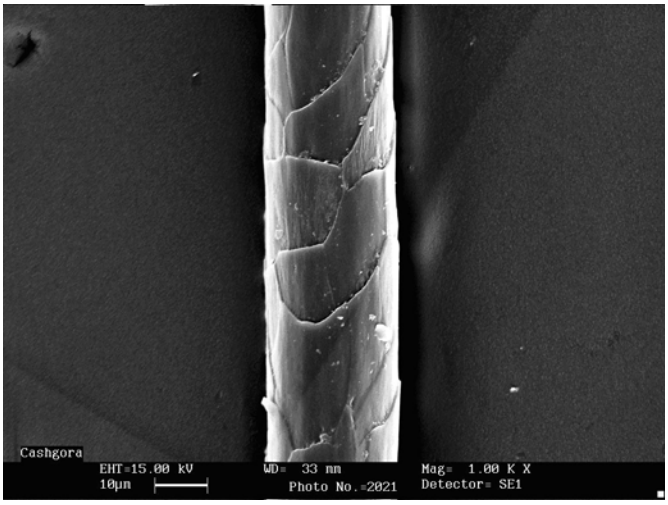

Figure 2. Cashgora (SEM 1000X).

The surface morphology of Cashmere (Fig. 3) has been extensively described in the technical literature [7, 10, 17, 19]. Fibres were even in diameter, cylindrical, and showed cuticle cells with relatively distant and smooth margins, often so wide that they appeared to entirely envelop the finer fibres. The mean scale frequency was 6-7 per 100 µm and the thickness of the cuticle cells at the distal edge was less than 0.5 µm.

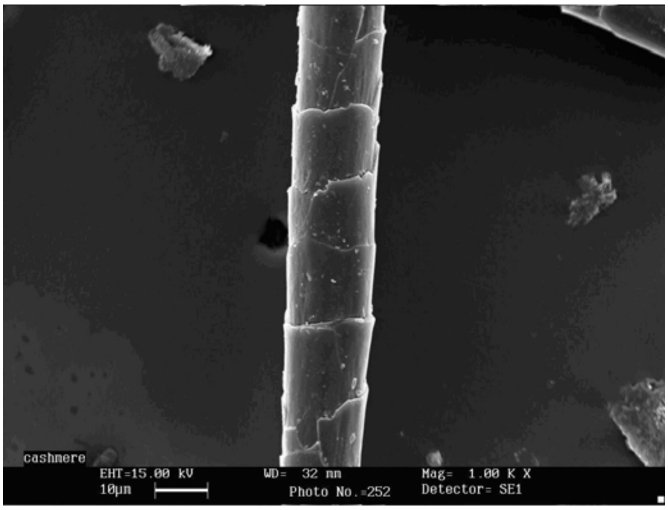

Figure 3. Cashmere (SEM 1000X).

The cuticle scale patterns of Yangir fibres (Fig. 4) were very distinctive, although a certain morphological variability was observed: the cuticle cells appeared strongly oriented and elongated in the direction of the fibre axis (Fig. 2). The scale density ranged from 5-6 to 18-20 scales per 100 µm length of fibre. The most typical morphological properties revealed by SEM, however, were the thickness of the scale edge (more than 0.8 µm), which was higher than that of Cashmere and associated with changes in the apparent fibre diameter along the fibre axis, a morphology never found in Cashmere.

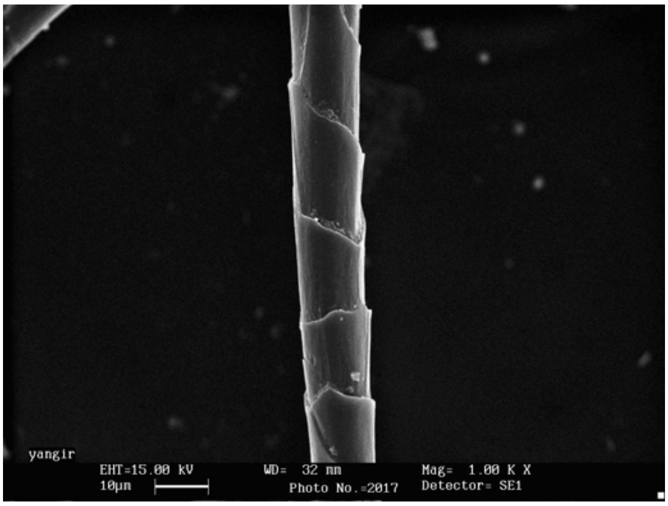

Figure 4. Yangir (SEM 1000X).

Transmitted Light Microscopy of the fibres stained with Methylene Blue are reported in Fig. 5. As expected, Cashmere and Yangir revealed the existence of two bilateral histological structures, well described in the literature: the more reactive ortho-cortex, intensely stained, and the para-cortex, more resistant to stain penetration, different from Mohair and Cashgora, which showed a homogeneous internal ortho- cell structure.

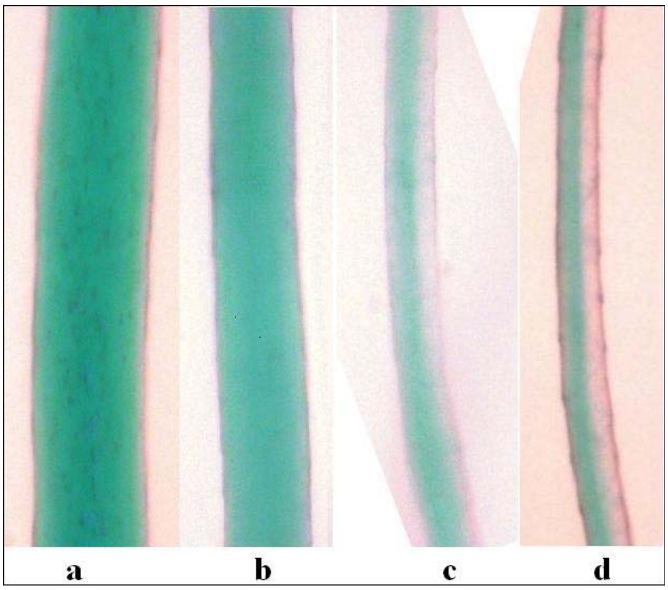

Figure 5. Mohair (a) Cashgora (b) Cashmere (c) and Yangir (d) stained with Methylene Blue (Transmitted Light Microscopy 500x).

Investigation into the thermal denaturation performances of Mohair, Cashgora, Cashmere and Yangir raw fibres, not submitted to previous thermal treatments, revealed appreciable differences of the DSC traces in the temperature range 230-250°C (Fig.6).

Also the peak widths and, as a consequence, the relevant areas and associated enthalpies, differ significantly [14]. Mohair and Cashgora showed a single endotherm peak at 239°C; Cashmere showed a trace with one endotherm peak at 241°C and a shoulder on the low temperature side, Yangir displayed a well balanced, characteristic endothermic doublet, with temperature peaks at 233 and 241°C.

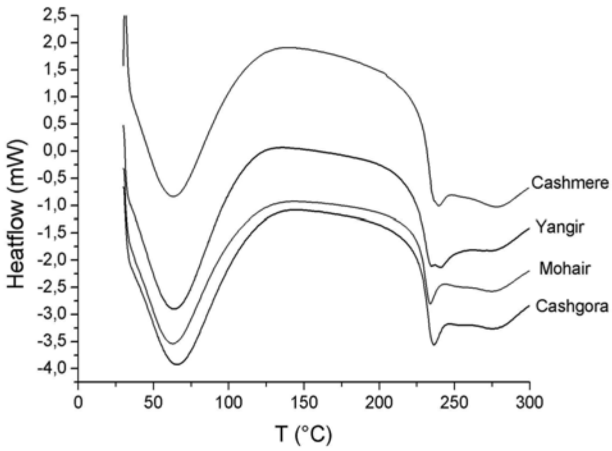

Figure 6. DSC traces in Cashmere, Yangir, Mohair and Cashgora.

Discussion

Many authors have described the relationships between fibre diameter, scale pattern type, fibre growth rate and distance between the scale ridges [12, 18]. Comparison of wild and domestic species appear to suggest a wider fibre diameter for domestic animals, associated with a less elongated shape of the cuticle scale patterns in the direction of the fibre axis, indicating a higher growth rate of hair. These differences in hair morphology could arise because nutritional stresses and exposure to thermal excursions may lead to finer hair and lower rate of growth of the undercoat in wild animals, as well as in animals living in parched highlands like cashmere goats. On the other hand, it is known that heat stress reduces wool growth by limiting feed intake, because the animal will try to reduce its metabolic activity by eating less and being less active. With such reductions in energy, wool growth slows, fibre diameter is reduced, and total production of wool decreases, but cold stress has also been shown to depress wool growth up tol 25% [13].

DSC studies on a wide variety of keratin materials have been conducted by researchers in wool science in order to characterise the composite structure of wool and other animal hairs by investigating the thermal performances of their main morphological components. The composite structure of keratin fibres is characterised by the presence of three main morphological components, namely the cuticle, the cell membrane complex, and the cortex. The cuticle consists of a thin layer of flat overlapping “cuticle cells” surrounding the cortex, which is made up of spindle shaped “cortical cells” arranged in the direction of the fibre axis. The cell membrane complex performs the function of cementing cortical and cuticle cells together [8]. Within each cortical cell, microfibrils are embedded in a matrix containing two non-filamentous protein types, one rich in cystine (high-sulphur proteins) and the other rich in glycine and tyrosine. Microfibrils are composed of multiple α-helical, closely packed, low sulphur subunits, referred to as intermediate filaments (IFs), arising from the interaction of Type I and Type II keratins, a subclass of the larger group of structural proteins called cytokeratins, which make up the cytoplasm of mammalian cells. The molecular ordered packing of α-helices into the microfibrils is identified as the crystalline fraction of the fibre [3, 5]; all keratin from mammals contains α-form crystallites, whereas both α- and β-forms occur in keratin from birds and reptiles.

Differences on the cystine (sulphur) content lead to the identification of two types of cortical cells: ortho-cortical cells, containing a lower proportion of high sulphur matrix material; and para-cortical cells, with a higher concentration of disulphide linkages, belonging to two distinctive domains called respectively the ortho-cortex, more hydrophilic and heavily stained by some dyes, and the para-cortex, more readily stained by silver's salts due to the presence of a higher amount of sulphur. While microfibrils do not appear to differ from one keratin to another, the important differences in the composition of keratin fibres seems to be mainly due to differences in the amount and type of high-sulphur proteins from the matrix [3].

The presence of two endothermic peaks in the DSC traces of Cashmere and Yangir fibres in the temperature range 230-255°C in the dry state was mainly explained by differences in the transition performances of the crystalline α-elical material contained in the ortho- and para-cortical cells [6, 20]. The comparison between the DSC traces and between the light microscopy images of stained goat hairs considered in this work leads to the conclusion that hairs of animals exposed to thermal and nutritional stresses, such as Cashmere and Yangir, tend to develop a higher amount of cross-linked paracortex. Moreover, because the keratinisation process consists primarily of the formation of disulphide links (-S-S-) by oxidation of the sulphidryl groups (-SH), cell hardening is facilitated by the lower amount of moisture in the equilibrium with the hair growth environment.

Conclusions

Morphological changes produced by hybridization, nutrition and life environment have an important influence on the pelage characteristics of the "fibre producing" goats. The morphological hair structure shows the influence of heritability between Mohair and Cashgora. In addition the strongly oriented cuticle cell shape, internal cell arrangement and proportion of ortho- and para-cortical cells found in Cashmere and Yangir suggest a slower keratinisation process, a lower hair growth rate and a higher presence of disulphide cross-linked material in the hairs of animals living in arid highlands, naturally exposed to nutritional and thermal stresses.

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Acknowledgement

This work has been carried out within the project HITEX, with the financial support of the Regione Piemonte (Italy).

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