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Seasonal and between sheep differences in medullation of wool fibres

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ABSTRACT

Twelve mature Romney ewes were housed and fed to maintain a constant bodyweight for 14 months. Monthly midside samples were collected and individual fibres measured by projection microscope for fibre and medulla diameter. Medullated fibres were observed in fibre diameter classes between 14 and 70 μm, and non-medullated fibres were observed within the range 10 to 68 μm. The proportion of fibre cross-section occupied by medulla was calculated from fibre and medulla diameter, assuming circularity. Within a sample, the cross-sectional area occupied by medulla was found to increase exponentially with increasing fibre diameter. There was a significant effect of season ($P < 0.001$), with the highest levels of medullation occurring in summer. Differences between sheep were significant, ($P < 0.001$) and were maintained throughout the year. These findings are discussed in relation to a model for fibre formation.

Keywords: medulla, wool fibre, fibre diameter, season, Romney.

INTRODUCTION

Medullation is an important characteristic of wool fibres, being desirable in some products such as carpets, yet undesirable in others. The medulla does not take up dyes in the same manner as non-medullated wool fibres, and also causes problems during processing because of fibre breakage (Peryman, 1952; Ross, 1990). Ince and Ryder (1984) found that although medullated fibres produce a weaker yarn, they provide better carpet compression properties.

The medulla of the wool fibre can be defined as a central core of cells which are highly vacuolated (Auber, 1950). A number of forms of medulla have been identified and labelled latticed, unbroken, interrupted, and fragmented, in order of decreasing amount of medullation (Wildman, 1954). There is a tendency for fleeces with a high average fibre diameter to contain greater levels of medullation than fleeces made up of finer fibres, although this is dependent on breed (Krishnarao *et al.*, 1960; Ince and Ryder, 1984). Medullated fibres grow from larger wool follicles (Henderson, 1965) and are generally coarser relative to non-medullated fibres of the same fleece (Hausmann, 1920 (cited by Lang (1947)); Wilson, 1928 (cited by Lang (1947)); Ahmad and Lang, 1956). However there are exceptions to this rule, notably when the number of medullated fibres are low (Lang, 1947). Orwin (1979a, 1979b) reviewed evidence to suggest that medullation is usually found in fibres greater than 35 μm in diameter, but also noted that there was considerable overlap in the range of diameters of medullated and non-medullated fibres.

Environmental influences such as nutrition (King and Young, 1955), depilation (Rudall, 1934) and shearing (Rudall, 1933; 1935) have all been shown to affect the level of medullation. Seasonal changes in medullation have been reported (Rudall, 1934), and consistent differences between flocks of one breed have been observed between seasons (Skårman and Nõmmera, 1954).

Scobie and Woods (1992) proposed a mathematical model which suggested that the various types of cells which can be found in the wool fibre form a continuum from paracortex through to medulla. In this model, formation of cell type within the fibre is governed by an interaction between the volume of fibre produced and the ability of the animal to form keratin. To test this hypothetical model, it will be necessary to achieve changes in the production of fibre volume independently from keratin volume. Seasonal changes in the proportion of the fibre which is made up of medulla, and differences between sheep within a breed will provide experimental mechanisms to accomplish this. A comprehensive data set has been analysed to test the hypothesis that the percentage of the fibre cross-section which is occupied by medulla varies with season and between animals.

METHODS

The bodyweight of twelve 4 to 5 year-old Romney ewes was held constant by adjusting the amount of chaffed lucerne (69% digestible dry matter) offered, while the animals were maintained indoors for fourteen months. A patch 100 mm x 100 mm on the left midside was clipped at monthly intervals. Fibre diameter and the width of the medulla contained within that fibre (if present) were measured by projection microscope (IWTO, 1966) for at least 500 fibres of each monthly sample.

The area of the fibre and the medulla were estimated by assuming the cross-sections to be circular. The data were anlaysed for differences between animals, the effect of season and the curvature of the relationship between the percentage of the fibre occupied by medulla and fibre diameter. The

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model fitted to the data was of the form:

$$\%M = e^{S_i} \times A_j(e^{kd}-1)$$

where $\%M$ = percent cross-sectional area of the fibre occupied by medulla, S_i = multiplicative effect of sampling date i, k = curvature, d = diameter and A_j = level for animal j. Maximum likelihood estimates were obtained for each variable using fibre/medulla diameter measurements with the Maximum Likelihood module of GAUSS (Aptech Systems, 1992). The contributions for different diameter classes were weighted according to the number of fibres measured in the class. A range of models based on the formula above were fitted. Some simpler models set S_i and A_j to be constant for each animal or sampling date respectively, or made the assumption of no curvature. Other more complicated models allowed k to vary with either animal or sampling date. These models are identified in Table 1, and labelled as to whether S_i varied between animals (S), A_j varied between dates (A) and k varied between animals (A.k) and dates (S.k) and combinations of these.

RESULTS

In more than 85,000 fibres examined, the diameter range of medullated and non-medullated fibres overlapped considerably. The finest two fibres containing a medulla lay within the 14 to 16 µm diameter class and the coarsest three medullated fibres were recorded in the 68 to 70 µm class. Most medullated fibres were in classes greater than 22 µm. Numerous fibres which contained no medulla lay within the 10 to 12 µm class, and two non-medullated fibres were observed within the 66 to 68 µm class. Indeed, samples of from one animal expressed fibres up to 67 µm and as low as 11 µm at different times of the year with medullated and non-medullated fibres across almost the entire range.

TABLE 1: Analysis of variance table for percent area of medulla (%M) in wool samples of 12 animals (A) at 15 sampling dates (S), including curvature (k) of the relationship between diameter and percent area of medulla (%M).

Model	Model d.f.	RMS	Residual d.f.	Change in RSS	F ratio	Significance
Null	1	125.2	209	-	-	-
A	12	102.5	198	533.6	38.48	***
A + k	13	52.8	197	9894.2	713.50	***
S	15	116.6	195	245.1	17.67	***
S + k	16	100.8	194	3184.1	229.62	***
A + S	26	48.4	184	813.7	58.68	***
A + S + k	27	16.7	183	5833.5	420.68	***
A + S + A.k	38	15.1	172	41.8	3.01	*
A + S + S.k	41	13.9	169	51.4	3.71	*

Note: A - varying level of A with each animal.
S - varying level of S with each sampling date.
k - curvature effect fitted.
X.k - curvature varies with either animal or sampling date.
RMS - residual mean square
d.f. - degrees of freedom
RSS - residual sum of squares

FIGURE 1: Fitted curves for the relationship between fibre diameter and the percent area of the fibre occupied by medulla for individual animals (identified by tag number) at the November sampling.

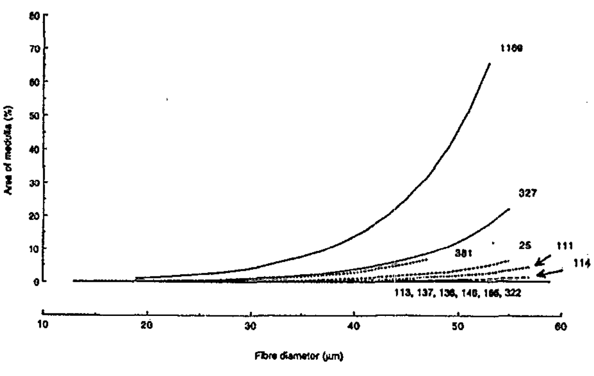


FIGURE 2: The relationship between fibre diameter and the percent area of the fibre occupied by medulla and the accompanying fitted curves for one animal at three sampling dates.

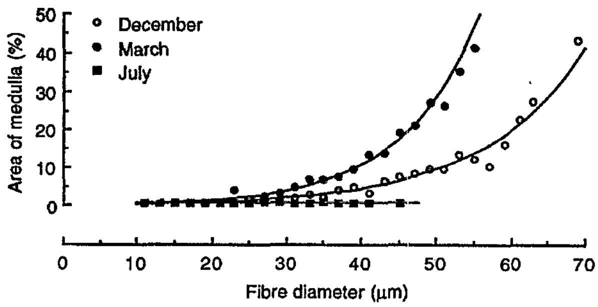
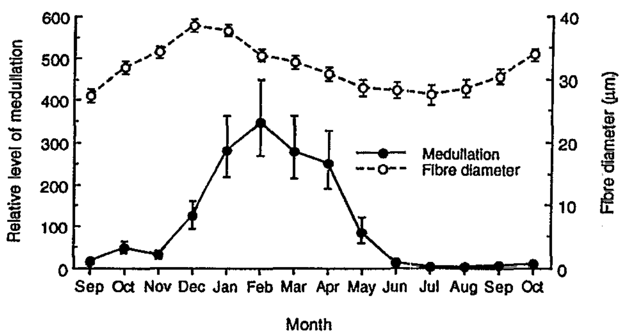


FIGURE 3: The mean area of medulla (with associated confidence limits) for all 12 sheep relative to the average (100%), and average fibre diameter (± s.e.) during the 14 month period.



The analysis of variance is provided as Table 1. There were significant differences between the curvatures of the relationship between fibre diameter and the percent area occupied by medulla. There were also significant differences between animals, clearly seen in Figure 1, which expresses the relationship between fibre diameter and percent area occupied by medulla, at one sampling date (November). The number of medullated fibres per sample varied from 0 to 79.2% for individual samples. Although most animals expressed no medullation during winter, one animal expressed some. Figure 2 shows the relationship expressed by this animal at three times during one year, clearly showing a change with season. Similar changes were evident in other animals, although they were less pronounced.

There was also a significant effect of season (Table 1) on the proportion of fibre occupied by medulla. The seasonal rhythm in medulla production averaged over all animals is illustrated in Figure 3, which also shows the seasonal changes in fibre diameter. Since there were large differences betweeen animals, the amplitude of the fluctuation relative to the average of all sampling dates (100%) was first calculated for each animal, and the overall average calculated from this and plotted against month. (The average level of medullation at the peak was 16.2%, with a range of 0 to 79.2%) Also included in Figure 3 is the monthly average fibre diameter for all animals. Clearly, the peak in fibre diameter does not coincide with the peak of medullation.

Although the interactions between curvature and animals or sampling dates were just significant, the variations in curvature only accounted for a minor proportion of the overall variation. The variations in the estimated curvatures for different animals or sampling dates were small and therefore there is very little loss in accuracy of the model through the use of a common curvature for all animals and sampling dates.

DISCUSSION

In the New Zealand Romney, the level of medullation in the fleece is clearly dependent on the animal, season and fibre diameter. As noted by Orwin (1979a, 1979b) the range of medullated and non-medullated fibre diameters overlap considerably, and the finest medullated fibres observed here at 15 μm are much finer than the 30 - 35 μm lower limit suggested previously (Auber, 1950; Orwin, 1979b). Whether the level of expression is related to the phenotype or genotype of the animal is unclear from this work, however, the strong influence of the N-genes demonstrate that genotype can be very important (Dry *et al.*, 1940), as does the heritability of hairiness (0.6) (Rae, 1958).

Since mohair tends to be used in fashion apparel, the appearance of medullation in mohair has attracted recent research. A linear relationship has been shown between mohair fibre diameter and medulla diameter (Smuts *et al.*, 1983; Blakeman *et al.*, 1988) and wool (Singh *et al.*, 1980). Since the medulla generally forms a circle within the fibre, a linear relationship is the simplest way of interpreting the data. Although such linear relationships may exist in the data set studied here, they were not examined. The reason for using percent area of the medulla in relation to fibre diameter in the present work was to make it comparable with studies of the areas of ortho-, meso- and paracortical cells of the fibre cortex. The percentage of total area of the fibre cortex occupied was used in such studies, as these cell types tend to be more irregularly distributed in the fibre cross-section than medulla cells. Orwin *et al.* (1984, 1985) found the relationship between fibre diameter and the percentage of the fibre occupied by orthcortical cells to be linear in some cases, but log-linear in most, and also dependent on season as the present work has shown for medullation. The exponential relationships between fibre diameter and the percent area of medulla observed here confirm the preliminary observations of Scobie and Woods (1992) and thus lend further support to the two compartment model for fibre formation. The next challenge is to demonstrate these effects on a three-dimensional or volume basis.

In mohair, it seems that as fibre diameter increases, the percentage of fibre occupied by medulla increases to an asymptote just less than 100% over the range 20 to 100 μm (Smuts *et al.*, 1983; Blakeman *et al.*, 1988). Over the range of fibre diameters expressed by the N-type Romney, Ross (1990) observed a sigmoidal relationship. No fibres coarser than 70 μm were observed in the present work, and fibres of such high diameter were few in number, thus the restricted range of fibre diameters observed here may prohibit us from observing a sigmoidal relationship in the New Zealand Romney. It is relevant to note that at the peak levels of medullation during the summer months, maximum likelihood estimates for a few animals yielded values greater than 100% for the percent area medullated at high fibre diameters, clearly an impossibility not resolved using the present data set and fitted model. The area of medulla, and ortho-, meso- and paracortical cell types in heavily-medullated Romney and N-type Romney animals and a more sophisticated model is anticipated to overcome these problems.

It is interesting that fibre diameter and medullation fluctuate in concert, but out of phase so that there is a pronounced lag between the peaks of these two characteristics. Woods and Orwin (1988) showed that fibre diameter also seems to vary in concert with fibre length, but out of phase. Clearly, average diameter of both the fibre and medulla vary independently between animals and seasons, as do length and diameter. It is therefore likely that the volume of the fibre, and the volume of keratin which is available to fill the fibre can vary independently as suggested in the mathematical model proposed by Scobie and Woods (1992). This highlights the need for an investigation into volume production of fibre and medulla rather than the single dimensions of length and fibre/medulla diameter if we are to understand the variations in the characteristics of wool fibres more completely.

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