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Review

Factors affecting wool quality and quantity in sheep

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There are varieties of factors which can affect wool (macro and micro elements of wool) in sheep directly or indirectly. Genetic and environmental factors are major factors influencing wool quality and quantity. There are some bacterial, viral, fungal and espically parasitic diseases which also affect the wool. Other factors are exogenous chemicals, hormones, weather and photo period. In the present study, existing knowledge on the factors affecting wool were reviewed but there are gaps to conduct research on fundamental aspects of wool growth, which could have relevance to other areas of biology.

Key words: Wool quality, staple length, ultra high-sulphur proteins, fleece.

INTRODUCTION

There is no simple definition of fibre quality, but it is essentially the various characteristics and defects in the fleece, both inherited and acquired, which influence its end use. This section outlines the main components of quality and discusses their biological bases. The average diameter of fibres is a primary determinant of quality and is associated with spinning performance. The finest fibres of wool, mohair and cashmere are the most valuable. The mean and range of different diameters in fleece are determined initially by the genotype of the animal, which sets the size and synthetic capacity of follicles, but are also considerably modified by external factors, especially nutrition. Wool production from sheep is of prime importance especially in Pakistan because wool produced by other animals like camel has short fibre and low yield (Khan, 2011). These external factors cause variation in diameter along the fibres. Increased wool production obtained by improved nutrition is almost invariably associated with an increase in the mean diameter of the fibres. Large differences in diameter between fibres in a fleece are undesirable, except in carpet wools (Chapman and Ward, 1999).Staple length is another important determinant of quality; it influences the type of manufacturing process used. Staple length is a function of individual fibre lengths and the extent of crimping; the fibre length component is related to growth rate and the duration of the growth period. Large variations in fibre length within a staple are undesirable, except in carpet wools. The length of a staple could theoretically be varied at will by varying the period of growth but in practice, most fleeces are harvested annually. However, 6-monthly shearing is usually practiced with the Angora goat and sometimes with long wool and carpet wool sheep in New Zealand, all of which have a high fibre length growth rate (Doney et al., 2000). Several other fibre characteristics can influence quality. Clean scoured yield is obviously important in determining the amount of finished product obtained from a given weight of greasy wool. Pigmented fibres cause problems in dyeing and, in general, non-pigmented fibres have more value. In cashmere, a major factor reducing its value is contamination with coarse, medullated fibres. Medullation is also undesirable in mohair and most types of wool, apart from carpet wool. Staple crimp, both with respect to frequency and amplitude, has traditionally been used as an indicator of fibre fineness. However,

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while the relationship with fineness frequently applies, it is by no means invariable.

The origin of the crimping of individual fibres resides in the follicle, but the precise mechanism is still discussed. 'Doggy wool' is a condition characterized by loss of crimp; its cause is not known but the incidence increases with age.

FACTORS AFFECTING FIBRE GROWTH RATE AND QUALITY

Environmental influences can cause a number of faults in wool which reduce the value of the fleece (Bottomley, 2001; Yeates et al., 1999). Stains can be produced by a variety of biological and non-biological agents (for example, bacteria, urine and dipping solutions). Other common faults are vegetable contamination and weathering of wool by exposure to sunlight. Diseases such as fleece rot and mycotic dermatitis can lead to damaged fibres. Steely wool is caused by copper deficiency in sheep and results in loss of crimp and reduced tensile strength. This weakened wool also has a reduced content of the ultra-high- sulphur proteins (Gillespie, 1999). However, the general question of wool protein composition as a quality factor remains open. There is no clear evidence that the large variations in the high-sulphur and high-tyrosine proteins that can occur in wool (Reis, 1998) influence mechanical properties of fibres or textile processing. Tender wool, which has a low tensile strength, can break readily during processing. Apart from conditions such as fleece rot and copper deficiency referred to above, others are mainly due to stress associated with cortisol secretion and severe undernutrition. In the latter situation, the precise nutritional deficiencies involved have not been defined.

The rate of wool growth can vary over a wide range due to genotype and the influence of various physiological and environmental factors. Robards (1998) quotes annual clean fleece weights for several breeds and crosses of sheep in many environments in Australia; most values fall in the range 2 to 5 kg. For Lincoln and Merino (South Australian strain) sheep, the highest recorded rates are 22 to 23 g/day of clean, dry wool (Daly and Carter, 1999; Hogan et al., 1999). This rate corresponds to an annual clean fleece production of about 8 kg. The available data on weights of fleeces produced by Angora goats indicate that they are probably capable of rates of fibre production comparable to those of sheep. The rate of cashmere fibre production has not been studied, but maximum annual yields of cashmere from goats appear to be about 1 kg and are usually below 500 g (Burns et al., 1999; Von Bergen, 1999). This low production is partly due to inefficient harvesting and a period of follicle inactivity, as well as the fact that cashmere fibres do not represent the total production of the animal.

GENETIC INFLUENCES

The maximum rate at which an animal can produce wool or hair, and the range of variation possible in several characters related to quality, are set by its genotype. There are definite differences between breeds of sheep in the capacity to grow wool and in various fleece characteristics. Thus, Merinos, which have a much greater follicle density than Down and long wool breeds, grow a similar mass of wool but more than the Down breeds. Likewise, within a breed, there is considerable variation in the rate of wool growth between strains and individual sheep. In the Australian Merino, a comparison of the fine, medium and strong wool strains shows an increasing clean fleece weight associated with increased fibre diameter, staple length and body weight. Genetically high-producing Merino sheep have follicles which are usually straighter and deeper in the skin, grow wool of a lower sulphur content and have a lower concentration of cystine in plasma than low-producing sheep; the number of follicles per unit area of skin is sometimes, but not invariably, greater (Williams, 2000).

The lower sulphur content of the wool is due to a lower content of ultra high-sulphur proteins. If enhanced wool production is achieved in a breeding program without an increase in the number of follicles, the rate of fibre production by individual follicles must be enhanced. An inevitable result is an increase in mean diameter or length growth rate of fibres, or both. Many characteristics of the fibre and follicle are highly heritable and significant changes can be made by selection for the desired characteristics. The heritability of wool traits such as greasy or clean wool weight, number of follicles per unit area of skin, S/P follicle ratio, fibre diameter, staple length and crimp frequency are in the region of 0.3 to 0.6 (Brown and Turner, 1999; Yeates et al., 1999). Many of these traits are correlated and account must be taken of this, if it is desired to increase wool weight without altering various characteristics of the fleece.

PHYSIOLOGICAL AND ENVIRONMENTAL INFLUENCES

Effects during foetal and early post-natal life

During the period when the follicle is developing, it can be adversely affected by an inadequate supply of nutrients. Undernutrition of the ewe during the latter part of pregnancy, and of the lamb during the first few months of life, can prevent or retard development of some follicles. Most studies have been done with Merino sheep (Corbett, 2001). The major effect of poor nutrition during pregnancy is on the initiation and maturation of secondary follicles during the latter third of pregnancy, when the nutrient demands for growth of the foetus are greatest. Severe nutritional restriction at this time permanently reduces adult wool production due to reduced follicle numbers, and is associated with reduced body size and skin area. As all follicles are initiated by birth, post-natal restriction of nutrient supply does not reduce follicle numbers but may permanently impair the capacity of some follicles to produce fibres. In addition, the maturation of the post natal wave of secondary follicles may be delayed by up to 6 to 12 months. The biological basis of a permanent reduction in the capacity of follicles to produce fibres has not been elucidated, but it may be a reduction in the size of the population of follicle bulb cells. The studies of Schinckel and Short (2001) with Merino sheep illustrate the magnitude of the effects of pre and post-natal nutrient restriction on adult wool production. Ewes were well or poorly fed during pregnancy and their lambs were similarly treated during the first 16 weeks of post-natal life. Sheep reared in the poor regime throughout produced 20% less wool at maturity than those reared on the good regime throughout. This experiment illustrated that the characteristics of the adult fleece can also be modified by early nutrient restriction. Sheep subjected to good/poor or poor/good regimes grew similar amounts of wool, but the fleeces of the latter group consisted of fewer, coarser fibres.

It has also been observed that adult wool production is less in sheep born and reared as twins than in single born lambs, and in sheep born to young ewes than in the progeny of mature ewes (Corbett, 2001). These ‘maternal handicaps’ usually amount to a reduction in annual clean fleece weight of 0.1 to 0.2 kg, and are presumably related to restricted nutrient supply in uterus and during early lactation. The effects of early nutrient restriction in low density breeds of sheep are not well documented and may be less than in the Merino. There is no information for goats, but the potential for cashmere production in particular may be influenced by nutrition in early life, as these fibres are produced by secondary follicles. Experiments with Merino ewes exposed to high ambient temperatures during the latter part of gestation (Cartwright and Thwaites, 2000) have shown that such conditions can appreciably reduce the number of secondary follicles in lambs at birth. The effects on the foetus appear similar to those of restricted maternal nutrient supply and may be a result of placental blood flow or in nutrient uptake by the foetus. It is not known whether the reduction in follicle numbers permanently reduces adult wool production. Such information is needed, as many sheep are subjected to hot environments.

Effects during adult life

The amount and type of fibre grown by the adult animal is markedly influenced by a variety of physiological and environmental factors. These influences are considered following:

Nutrition

Variations in the supply of nutrients to the follicles can exert a considerable influence on the rate of fibre production and the characteristics of the fleece. The herds with higher diseases and ill health have lover production such as growth rate, meat and wool production (Khan et al., 2010). Most sheep and goats are kept under free-ranging conditions and the quantity and quality of feed available to them may vary considerably throughout the year. Consequently, the peak rate of wool growth is frequently two to three times the minimum rate for grazing sheep (Brown and Williams, 2000; Black and Reis, 2001). Controlled feeding experiments have established the large effect of feed intake on the rate of wool growth; three to four-fold changes in the rate of wool growth may be induced in an individual animal. High-producing animals respond to a greater extent to increased feed intake. The wool growth of Merino sheep will respond to changes in nutrition throughout the year, but breeds with a large inherent rhythm in wool growth rate, such as the Cheviot or Scottish Blackface, show little or no response to changes in nutritive status during winter (Allden, 2001). There is less experimental evidence available regarding the effects of nutrition on fibre production by goats. Mohair production is influenced by nutrition and season, but the effects have frequently been confounded (Stapleton, 1999). By analogy with breeds of sheep like the Cheviot, fibre growth by Angora goats may be less responsive to nutrition during winter.

There is no general agreement on the precise form of the relationship between wool growth and feed intake. Allden (2001) concluded that the available evidence points to a positive linear relationship between intake of digestible dry matter and wool growth, and states there is no unequivocal evidence for a curvilinear relationship although, this may occur at rates of wool growth approaching the genetic potential. It has been suggested that wool growth rate is influenced by the extent and direction of body weight change. However, Allden (2001) has concluded that ‘there is no convincing evidence that weight change per say has any effect on wool growth rate”. The relative importance of energy or protein supply for wool growth remained unresolved until the special features of ruminant digestion were taken into account. When ruminal degradation of protein is avoided, substantial increase in wool growth rate can be obtained with protein, and only small responses are associated with energy (Allden, 2001). Reis (2000) showed that very high rates of wool growth could be obtained with moderate energy intakes when casein was given through the abomasum. As protein available for digestion and absorption in the small intestines is related to digestible energy intake, energy frequently appears to be the main dietary factor correlated with wool growth. Both length growth rate and diameter of fibres are increased. These changes represent a three-fold increase in volume of fibre produced. In contrast to these effects, some protein or amino acid treatments, given post-ruminally, can adversely affect wool growth and may also produce differential effects on length growth rate and diameter of fibres (Reis and Panaretto, 2001).

While a balanced mixture of essential amino acids is required for high rates of wool growth, the supply of sulphur-amino acids plays a major role in regulating the growth and composition of wool. The major requirement is for cystine, but methionine, which can be readily converted to cystine, is equally effective for stimulating wool growth. However, excessive amounts of methionine are inhibitory. It has been suggested that some effects of amino acids on wool growth may be mediated through the endocrine system, but clear evidence is lacking. The manure ensiled wheat straws treated with 04% urea may contain maximum true protein nitrogen (Khan and Qadir, 2008) . This may be helpful to increase the wool and mohair production by sheep and goats because the composition of wool is markedly influenced by the nutrition of the sheep. An increase in the supply of cystine to the follicles increases the proportion of ultra-high-sulphur proteins and hence the sulphur content of wool. The proportions of high-tyrosine proteins in wool are also influenced by various nutritional treatments, but a control mechanism has not been identified.

Many of the effects of minerals appear to be due to changes in the supply of major nutrients brought about by changes in feed intake or in the balance of nutrients flowing from the rumen. Specific effects on fibre growth have only been demonstrated for zinc and copper, and even some of these may be related to changes in feed intake. Zinc deficiency in sheep causes brittle wool and loss of crimp; extreme deficiency causes cessation of fibre growth and fleece shedding. In goats of an undefined breed, zinc deficiency has been reported to cause reduced length growth of hairs. There is no evidence that higher than adequate levels of zinc influence wool growth. Copper deficiency causes depigmentation of wool in black sheep and the steely wool syndrome. Wool growth rate is reduced by this deficiency but a reduction in feed intake may be involved. Copper supplementation may specifically stimulate wool growth but the evidence is meager (Purser, 2000). Various B vitamins may impair hair growth and are important for maintaining high rates of hair growth because of its role as a co-factor for enzymes involved in the metabolism of methionine and cystine. However, there is no experimental evidence for an effect of the supply of individual vitamins on wool growth. It has generally been assumed that the rumen micro-organisms synthesize sufficient B vitamins for the animal's needs, but proof is lacking for high rates of wool growth.

Hormones

Fibre growth is markedly hormone dependent, and experimental manipulation of hormone status causes large changes in the rate of wool growth. The pituitary hormones, including thyroid stimulating hormone, adrenocortico-trophic hormone (which act on target glands) and growth hormone, exert a controlling influence on wool growth (Wallace, 2000). From thelast few decades, the pituitary extracts have also been utilized for different purposes like growth and breeding (Naeem et al., 2011). Removal of the pituitary gland causes wool growth rate to decline to zero, and thyroidectomy reduces, but does not abolish wool growth. In both situations, normal wool growth is restored by administration of thyroxine or its active form, tri-iodothyronine. Adrenocorticotrophic hormone causes increased secretion of glucocorticoids by the adrenal gland; in sheep, high concentrations of cortisol in plasma (30 to 50 ng/ml) are associated with depression or complete cessation of wool growth. Growth hormone stimulates wool growth in normal sheep, by stimulating secretion of polypeptides known as somatomedjns. Wallace (2000) concluded that differences in endocrine status do not contribute significantly to variations in wool growth between individual sheep maintained under similar conditions.

Physiological state

Wool production is influenced by the age and sex of animals, and by reproduction in the ewe. Less wool is grown by young animals per unit of feed intake, presumably due to competition for nutrients between follicles and other tissues. Maximum fleece weights in sheep have been observed as from three to five years of age, with variable rates of decline in wool production thereafter (Corbett, 2001). The number of active follicles decreases with age (Corbett, 2001) but there is no clear evidence that the synthetic ability of follicles also decreases. Reductions in wool growth with age could be related to changing patterns of feed intake and diet selection. Various quality characteristics tend to deteriorate with age, and crimp abnormalities may appear. As Angora goats are usually shorn twice a year, the effects of age and season of shearing are confounded. Nevertheless, it is clear that fleece weights of Angora goats increase appreciably during the first three 6-monthly shearings (Stapleton, 1999). This increasing fleece production is offset by a steadily increasing fibre diameter with age, which reduces the value of the fleece. Rams tend to produce more wool than wethers and ewes, due mainly to their greater size and the better feeding given to rams. Differences between wethers and ewes, once the effects of reproduction in ewes are allowed for, are probably small.

There can be substantial reductions in wool growth rate during both the latter half of pregnancy and early lactation. Overall, reproduction usually reduces annual fleece growth of ewes by 10 to 14%; the greatest reduction being for ewes rearing twins (Corbett, 2001). Similar effects occur in Angora does (Stapleton, 1999). Increased feed intake can compensate for the effects of pregnancy and lactation on wool growth in low-producing, but not in high-producing sheep (Oddy and Annison, 2000).

Exogenous chemicals

A variety of exogenous chemicals have been observed to influence fibre growth. In sheep, the most notable effect is shedding of the fleece, but the growth of substantially weakened wool can also be induced. Attempts have been made to utilize these effects for 'chemical defleecing' as an alternative procedure to conventional shearing for harvesting wool (Reis and Panaretto, 2001). Among the compounds shown to be effective are thallium salts, cyclophosphamide, analogues of cortisol (dexa methasone and flumethasone), and mimosine and related compounds. Most of these compounds inhibit cell division and do not act specifically on the wool follicle. Comparable studies with goats have not been undertaken, but any practical procedure which may be developed for sheep should also have application for Angora goats.

Parasites and diseases

Various microbial infections and external parasites can reduce wool production, but little quantitative information is available (Dc Bersaques, 1999). Infections with internal parasites can considerably reduce wool growth and virtually, all grazing sheep are affected to some extent. Effects are greatest in young sheep undergoing their first infections where wool growth may be reduced by as much as 60% (Dc Bersaques, 1999). Research is needed to establish whether infections during early life permanently impair adult wool production since there are also specific effects on protein metabolism associated with loss of blood proteins at sites of infection. A comparison of Angora goats with Merino sheep grazing infected pastures indicated that the goats were unable to develop levels of resistance, compared to sheep (Le Jambre and Royal, 2000). However, when goats are allowed to utilize their natural browsing habit, worm burdens may be substantially lower. Reductions in mohair production due to internal parasites presumably occur but no quantitative data are available.

Weather and photoperiod

Exposure of areas of skin to heat or cold, or experimentally induced localized changes in skin temperature, indicate that wool growth, especially length growth rate, is specifically retarded by low temperatures (Bottomley, 2001). The effects are presumably related to reduced blood flow and hence nutrient supply. Localized high temperatures do not influence wool growth until unphysiologically high values are reached. In practice, wool production other than by newly-shorn sheep, is not directly influenced by weather conditions; however it can indirectly influence wool growth by altering feed intake. Different weather conditions of the area may influence the water quality. Carbonates and bycarbonates in pond water show higher values during summer season (Naeem et al., 2011) influencing the wool composition. The effects of photoperiod on wool growth have already been mentioned in the section on cyclic activity of follicles. Seasonal cycles of moulting and the annual rhythm of wool growth rate are controlled by daylength so, any change in daylength is probably the important factor (Ryder, 2000; Hutchinson, 1999). These effects are mediated through hormonal secretions, most likely from the pineal gland. Breeds of sheep exhibiting a large annual rhythm of wool growth may also exhibit cyclic changes in the composition of wool. Thus, Doney and Evans (2000) observed a seasonal cycle in sulphur content of wool grown by Cheviot sheep given a constant ration, which was the reverse of the wool growth rhythm; sulphur content was highest in winter when wool growth was low.

CONCLUSION

If wool is to continue to compete with other fibres, it is important to maintain efficient production. To this end, a more detailed knowledge of the process of wool growth and the manner in which various factors influence it are required. The physiological basis of genetic differences in the capacity to grow wool needs to be studied in more detail. More quantitative data are needed in sheep of different breeds and of different wool producing capacities, on the number and size of cells in the follicle bulb and the proportion of cells migrating from the bulb which actually enter the fibre. The integrated synthesis of the proteins of the microfibrils and matrix needs to be understood and more information is required on the substrates which provide energy for the process. Also, there is no information on the effects of the formation and breakdown of the inner root sheath on the nutrient demands of the follicle; while skin structure and follicle development have been studied in detail in various breeds of sheep and the Angora goat and also for goats producing cashmere fibres.

More information is needed on the location of specific proteins in wool and their role in influencing the physical properties of fibres. In particular, the importance of variations in the proportions of high-sulphur and high tyrosine proteins needs to be assessed. The effects of nutrient restriction during foetal and early post-natal life needs to be assessed in more detail for breeds other than the Merino. The precise mechanisms by which the supply of specific nutrients influences the rate of growth or composition of wool in adult animals need to be studied further. The importance of an adequate supply of minerals and vitamins has received little attention. The role of hormones in regulating wool growth and possible interactions between hormones and nutrient supply are still poorly understood. If the effects of pregnancy and lactation on wool growth are to be minimized, the roles of specific nutrients and hormones need to be defined. As well as being of direct benefit to the wool industry, research on fundamental aspects of wool growth could have relevance to other areas of biology. Examples are utilization of nutrients for growth, and the solution of problems associated with cancer and baldness.

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