Nutrition and wool quality

DG Masters[1], *PI Hynd*[2]

[1]CSIRO Livestock Industries, Private Bag No 5, Wembley, WA, 6076
[2]Dept of Animal Science, University of Adelaide, Roseworthy Campus, Roseworthy SA 5371.

Summary

Fibre diameter, staple length and strength, yield and colour contribute to the efficiency of processing, the production of processing waste and the comfort and value of the fabric. Nutrition influences the length and diameter of wool and the relationship between the two through cell division and protein synthesis in the follicle. Nutrient intake contributes to strength through effects on fibre diameter variability and possibly keratin composition. Specific proteins and amino acids influence the amount and composition of non-fibre material or yield. This non-fibre material then contributes to the production and penetration of coloured pigments into the fibre.

What is wool quality?

Wool quality describes a number of raw wool characteristics that influence the processing of wool and the comfort and attractiveness of the final product. These characteristics include fibre diameter (D), staple length and strength, vegetable matter, chemical contamination, yield and colour (1). D is the most important as fine wool is used to make lightweight, high value products (2). Even a small percentage of fibres over 30 μm in the final fabric (1-2%) is sufficient to cause a prickle sensation in the skin (3). Low D is usually associated with low rates of wool growth meaning that there is trade-off between quantity and quality of wool produced. Staple length, strength and vegetable matter contribute to the length of fibre in the processed top (hauteur) and longer tops can be spun and woven more efficiently (2). Low staple strength results in breakage of fibres during processing reduced hauteur and increased short fibre wastage. Colour influences dyeing potential. Vegetable matter, chemical contamination and yield are important environmental considerations in the disposal of scoured waste. Nutrition plays a major role in determining D, staple length and strength and may influence colour and yield.

Fibre length and diameter

Fibre diameter, rate of fibre elongation (L), follicle density and fibre specific gravity are the major determinants of wool production. Wool growth responds rapidly to changes in nutrient supply, but the full effects on D and L may not be realised for up to 12 weeks (4). Given the close relationship between follicle bulb dimensions and fibre D and L (5) this may reflect the time required for bulbs to equilibrate with the new cell number and size. L responds to an immediate increase in cortical cell length (5) and possibly an increase in the proportion of dividing cells entering the fibre (6) while D responds more slowly to an increase in the total number of cells being produced in the follicle bulb and is related to the slower changes in bulb dimensions (5). For these reasons, the ratio L/D may, for short periods at least, be variable. Over the longer term, as there is an upper limit to the size of the follicle bulb, at high levels of nutrition exceeding the requirement for maximum bulb size, maximum D will be reached. L on the other hand, is governed by cortical cell length and the proportion of cells entering the fibre, and may continue to increase. The result would be an increase in the L/D ratio at high levels of

nutrition as found in some studies (7, 8). One might speculate that the maximum bulb size will be attained more rapidly in low D, high follicle density genotypes. By maximising the nutrient supply in these animals, full advantage might be taken of increasing the L/D ratio.

Specific nutrients play key roles in wool follicle function. Sulfur amino acids are usually first limiting for wool growth at least in Merinos, presumably because cysteine is required as the major substrate for keratin synthesis. However simply providing more substrate for cell-filling without a concomitant increase in the rate of cell division would not achieve the rates of wool growth apparent during methionine supplementation. Methionine not only produces cysteine through transsulfuration, but also acts as a precursor for polyamine synthesis (9). Polyamines appear to be important in fibre growth. Inhibition of the rate-limiting enzyme, ornithine decarboxylase, results in decreases in L and an increases in D in the absence of any change in feed intake (10, 11). The composition of the fibres, the proportion of paracortical cells in the fibre, and the expression of a cysteine-rich family of keratin genes were also altered, suggesting that the polyamines are intimately involved in both cell division in the follicle and in gene expression. Spermidine, in particular, accounts for at least some of the requirement for methionine for fibre growth (11). Other possible functions for methionine in wool production exist. As a precursor for S-adenosylmethionine, it is the major donor of methyl groups in the body and through methylation of cytosine may regulate gene activity and DNA repair. There are also many other key metabolites produced from methyl reactions involving methionine. Supplementation with methylated products of methionine (creatine and choline) however, does not increase wool growth, and may even reduce it, indicating the possible disruption in transsulfuration caused by the slowing of methionine recycling. (12). Methionine is also converted to methionyl tRNA and in this form participates in the initiation of protein synthesis.

Lysine also plays a pivotal role in fibre production. Provision of a lysine-deficient protein, zein, results in a marked decrease in D and an increase in L (13). The rate of cell division is significantly reduced suggesting that lysine is involved in mitosis presumably via a role in histone synthesis for DNA replication. The fact that radiolabelled lysine is taken up in the lower germinative region of the follicle bulb (14) lends support to this role. A reduction in the number of cells entering the keratogenous zone with no change in sulfur amino acid supply would allow greater filling of the cortical cells (J.L Black pers. comm) resulting in increased cortical cell and fibre length (15). Lysine is also a major component of the proteins of the inner root sheath. A lysine deficiency therefore may result in a change in the relative synthesis of the inner root sheath versus fibre, one of the factors likely to alter fibre growth and efficiency.

The non essential amino acid serine is also found in high concentrations in the wool fibre, provides the carbon skeleton for the production of cysteine from methionine, and is reduced in plasma during methionine supplementation. However additional serine does not increase fibre growth directly or the rate of transsulfuration (16).

Given the high rate of cell division and protein synthesis in the wool follicle, an involvement of vitamin and mineral cofactors in fibre growth and quality would be expected (17). The vitamins directly involved in the metabolism of amino acids (particularly methionine), DNA and RNA are most likely to influence fibre growth. The strongest candidates are folic acid, cyanocobalamin (B_{12}), and pyridoxine (B_6). Folic acid is essential for transferring one-carbon fragments from serine, glycine and histidine to other amino acids, purines and thymidine, thereby contributing to cell division and protein synthesis. Vitamin B_{12} is involved in methionine conservation via

interaction with tetrahydrofolate and in energy metabolism through the conversion of propionate to methylmalonylCoA. Pyridoxine catalyses a range of amino acid transformations including two steps in the transsulfuration pathway. Pyridoxine is also essential for activity of the rate-limiting enzyme in polyamine synthesis, ornithine decarboxylase.

While the B vitamins are synthesised by microbes and therefore unlikely to be deficient in ruminants, vitamins A, D and E may affect wool quantity and quality in grazing animals. The retinoids (vitamin A) have direct effects on the growth and differentiation of keratinocytes; their binding proteins and receptors are present in hair follicles, they interact with growth factors known to alter fibre growth, and they influence fibre growth in feeding trials (17). 1,25-cholecalciferol (Vitamin D_3) also accumulates in follicles, it's receptor is found in the outer root sheath, bulb and dermal papilla, and it alters fibre growth in cultured follicles (17). Little has been reported on the effects of vitamins D or E on wool quality, although supplementation of sheep showing signs of nutritional myopathy with α tocopherol (vitamin E) had no effect on wool growth (18). Further studies on vitamins and wool growth and quality are warranted.

In summary, nutritional manipulation that alters the balance of cell division, keratinisation and cell distribution within the follicle will result in changes in the L/D relationship. Targeted manipulation of key metabolic processes or of the relative synthesis of the root sheaths and fibre may achieve desirable changes in L and D in the future. However, the current options for decreasing D while producing an acceptable fibre length, are either through breeding or grazing management. Increased stocking rates, while decreasing D, staple length and wool production per sheep may result in higher wool production per hectare.

Staple strength

Staple strength is the force required to break the staple corrected for the linear density or average thickness of the staple. This means that staple strength is influenced by variation in diameter along the fibre, the presence of specific narrow weak points in the fibres and short-term shutdown of wool follicles (causing discontinuous fibres in the staple). Changes in the intrinsic strength of wool keratins would also be expected to influence staple strength (19).

Intrinsic fibre strength

The wool fibre is made up of intermediate filaments (or microfibrils) composed of a keratin α helix embedded in a matrix of proteins and minerals. It has been proposed that the longitudinal properties (eg strength) are dependent on the microfibrils while the matrix composition is important for compression and swelling properties (20). Fibres with a higher intrinsic strength have increased density of microfibrils with better alignment to the fibre axis (21). The proportions of high sulfur and high tyrosine proteins in the matrix are influenced by the supply of amino acids to the follicle (22) however, changes in matrix composition have not been shown to influence the strength of the fibre. Similarly, overexpression or ectopic expression of cysteine rich proteins through transgenesis has failed to improve the extension or load bearing capacity of individual fibres (23). The matrix also contains significant quantities of calcium, potassium, sodium, zinc, copper, manganese, iron and selenium (24). Of these, only zinc and copper have been shown to play a specific role in fibre production (see below) but there is no evidence that these elements directly contribute to the physical properties of the fibre. Differences in intrinsic strength between sheep have been reported, but these have not been explained in terms of wool

composition (25, 26). For this reason nutritional effects on intrinsic strength cannot be entirely discounted and examples do exist. Severe copper deficiency in the wool follicle causes weak fibres through impaired formation of disulphide bonds cross linking proteins (27) and infusion of lysine-deficient zein results in a substantial reduction in fibre strength independent of changes in cross-sectional area (13). However, there is a lack of conclusive evidence that intrinsic strength is a major component of staple strength under practical conditions. This means that force required to break a staple is primarily dependent on D at the narrowest point along the fibre rather than variation in the strength of keratin within the microfibrils (21)

Variation in fibre diameter

Any of the events that cause short-term changes in the availability of specific nutrients to the wool follicle and subsequent changes in D, will influence staple strength. Seasonal changes in pasture quality and availability result in variation in diameter along the fibre and reduced staple strength (28). Nutritional management of the variation has traditionally focussed on increasing D at the minimum through feed supplements or the management of amino acid stores within the body (29). More recently, practical solutions have switched to reduction of diameter variability by reducing the maximum D through increased stocking rates in winter and spring (28).

Within these seasonal changes, competition for nutrients within the body varies according to the growth potential (age) and reproductive status. For reproducing ewes, wool growth is particularly sensitive to feed intake near the end of pregnancy (30, 31). The depression in wool growth and staple strength in late pregnancy can be partially or fully reversed by the provision of rumen-protected protein in the diet (32), or adequate pasture supply and quality during lambing (31, 33, 34). Interestingly, wool growth at this time is not responsive to increased availability of sulfur amino acids (35, 36), indicating that other amino acids are the primary limitation. These have not been identified although supplements with valine, arginine, lysine and threonine further depressed wool growth, demonstrating that these are not limiting either (36).

Because staple strength is dependent on the weakest point along the staple, short-term changes in D may dramatically change staple strength. Reis and Tunks (37) showed that infusion with amino acid mixtures lacking in methionine reduced D by 2-3 μm in 4 days. Cross sectional area, and therefore force to break, would be expected to change by 30-50% in these fibres. Increased cysteine supply may also result in marked changes in fibre growth rate within 4 days with the effects of cysteine on keratin gene expression and fibre composition apparent only one day post infusion (38). Liu et al (39), using fractional protein synthesis (FSR) in the skin to indicate short-term changes in wool growth, also showed rapid but small changes in protein synthesis. Reducing feed intake from maintenance (M) to 0.6M resulted in a reduction in the FSR in skin of 15% within 4 days. In the muscle, FSR fell by 32% within 4 days. When feed intake was increased from 0.6M to 1.6M, FSR in skin increased by 9% in 4 days with muscle increasing by 57%. Overall the results indicate that the rate of change in wool protein synthesis is low relative to muscle but the initial response occurs quickly. Under the circumstances, a short-term change in feed supply, as occurs when sheep receive supplementary feed infrequently, would lead to variation in wool growth and possibly reduce D and staple strength. This does not occur and there is no difference in staple strength in sheep fed large quantities of supplement once per week, compared to those fed smaller amounts each day (40). It may be that the rapid reduction in protein synthesis within 4 days results in reduced L with little or no change in D. This is

consistent with the hypothesis that D is related to follicle dimensions while L is more responsive to short term changes in keratin synthesis in the inner root sheath (5)

Fibre continuity

Discontinuous fibres within a staple contribute to the linear density but not to the force required to break the staple. Large number of discontinuous fibres can dramatically reduce staple strength. Severe deficiencies or imbalances in a number of nutrients will disrupt fibre production. Zinc deficiency results in impaired keratinisation of fibres within the follicles and shedding of the fleece (41). Similar distortion and degradation of fibres results from folic acid or lysine deficiency (42), probably due to a reduction in mitotic activity in the bulb cell and reduced keratin synthesis. Under normal grazing conditions, the extremes in nutrient deficiency and imbalance needed to completely disrupt wool production do not occur. However, it is normal for a proportion of follicles (0-35%) to enter a catagen-like inactive state and shutdown for part of the year (43). The mechanisms causing shutdown have yet to be elucidated. Schlink reported reduced shutdown in pregnant ewes supplemented with methionine (43) and increased shutdown in underfed sheep treated with cortisol (44). Similarly, Hynd et al (45) reported an increase in abnormal follicles at high stocking rates and suggested that, while low nutrition was a predisposing factor, other stresses also contributed to the differences within a flock.

Yield

Yield values differ within sheep flocks due to varying contents of suint, wax and dust. Suint, which is produced by the sweat glands, consists mainly of water soluble potassium salts of fatty acids and peptides, and urea. Wax is produced by the sebaceous glands and consists of lipid and the waste from fibre synthesis. There is evidence that nutrition alters the amounts and proportions of non-fibre material. Abomasal infusion of the low-lysine protein zein resulted in a reduction in clean wool yield of 13-22%, fibre growth decreased by approximately 11% at the same time (13). Conversely, infusion with cysteine decreased non-fibre material and increased yield in Romney ewes (46). Similar changes have been observed when the additional sulfur amino acids are provided as methionine (Mata unpublished) or through feeding canola meal (47). The increase in yield with canola meal feeding is caused by a decrease in wax (48).

Colour

Yellowing has been associated with the photo-oxidation of the aromatic amino acids phenylalanine and tyrosine (49) and microbial activity in the fleece (50). There is limited evidence that changing composition of the fibre through nutrition will alter susceptibility to yellowing. Min et al. (51) reported a trend towards reduced yellowness in wool with increased levels of sulfur amino acids, possibly due to high sulfur wools being more resistant to penetration by microbial by-products or through a change in the levels of aromatic amino acids in the wool matrix. This result has not been confirmed in subsequent studies (46). Similarly there is limited evidence that nutrition alters microbial activity and the production of coloured pigments. A high wax/suint ratio increases resistance to yellowing (52), with the high wax providing a barrier to the absorption of pigments produced by microbes and the low level of suint reducing microbial activity. The potassium and protein in suint are metabolised by the bacteria to produce high pH organic acids that may remove wax and damage the fibre allowing coloured compound to enter (53). Nutritional treatments that influence yield therefore have the

potential to change colour. Paganoni et al. (48) using protein type to change the wax:suint ratio, observed no difference in wool colour or susceptibility to yellowing when comparing wool with different ratios. Given the importance of potassium in suint, the role of nutrition in the amount of this element secreted requires investigation. Potassium in plasma and saliva is dependant on potassium and sodium intakes and if sweat gland secretions are similarly controlled, potassium and sodium consumption may be important in the susceptibility of wool to yellowing.

Conclusion

While nutritional effects on fibre growth and properties have been reported and described, the full functional roles of most nutrients used for wool are poorly understood. What is clear is that the nutrients rarely function simply as substrates for fibre synthesis. Most notable examples are methionine and lysine but also a range of trace elements and vitamins. To take advantage of new molecular technologies, which will enable us to manipulate pathways within the animal and to customise nutrient supplies from plants, a clear understanding of the biochemical processes involved in fibre construction and architecture is essential.

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