A Review of Sheep Wool Quality Traits

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ABSTRACT

The commercial value of unprocessed wool is determined by its intrinsic quality; an indication of capacity to meet both processor and consumer demands. Wool quality is evaluated through routine assessment of characteristics that include mean fibre diameter, coefficient of variation, staple characteristics, comfort factor, spinning fineness, fibre curvature and clean fleece yield. The association between these characteristics with wool quality stems from their correlation with raw wool processing performance in terms of speed, durability, ultimate use as apparel or carpet wool, and consumer satisfaction with the end-product. An evaluation of these characteristics allows wool quality to be objectively quantified prior to purchase and processing. The primary objective of this review was to define and explore these aforementioned key wool characteristics, focusing on their impact on quality, desirable parameters and methodology behind their quantification. An in-depth review of relevant published literature on these wool characteristics in sheep is presented.

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1. INTRODUCTION

Wool is a versatile product in demand mainly because of its physical characteristics that directly influence wearer comfort (Hatcher et al., 2010; Swan, 2010), processing performance, durability (Swan et al., 2008) and textile attributes (Wood, 2003; Warn et al., 2006). Wool processing performance is particularly important as wool buyers explore means of limiting production costs by improving efficiency and profitability through preferential utilisation of wool that requires less processing. However, wool is not a uniform biological product because its physical characteristics vary depending on sheep genetics, environment and management strategies (Warn et al., 2006; Poppi and McLennan, 2010). Wool value is intrinsically linked to its characteristics and the ability to meet commercially pre-determined parameters (Wood, 2003; Jones et al., 2004; Purvis and Franklin, 2005; Bidinost et al., 2008). Routine evaluation and quantification of wool characteristics is undertaken to permit quality and price differentiation at the market level (Angel et al., 1990; Snowder, 1992; Kelly et al., 2007).

The decline in economic value (Harle et al., 2007) following the demise of the Australian wool reserve price scheme (Bardsley 1994) has been exacerbated by increasing competition from artificial fibres (Purvis and Franklin, 2005; Valera et al., 2009), limited market expansion (Swan 2010), and rising production costs (Rowe 2010). Therefore, the Australian national flock numbers have shrunk (Martin and Phillips 2011) and sheep production focus is now shifting towards dual-purpose systems with meat and wool interests (Fogarty et al., 2006; Safari et al. 2005). Dual-purpose sheep production systems in Australia generally join meat breed terminal sires to Merino dams (Daetwyler et al., 2010; Kopke et al., 2008) permitting the blending of desirable meat and wool characteristics (Mortimer et al. 2009; Refshauge et al., 2010) and the full exploitation of heterosis (Ingham et al., 2007; Thornton, 2010) in the F_1 prime lambs.

Key wool characteristics include: fibre diameter, fibre diameter coefficient of variation, comfort factor, fibre curvature, spinning fineness, staple length, staple strength, and clean fleece yield (Denney, 1990; Anderson et al., 2009). While the influence of these characteristics on wool quality and value differs, they all contribute (Mortimer et al., 2010) to an entire fleece's attributes (Baxter and Cottle, 1997; Snowder et al., 1997; Cottle, 2010). The main objective of this paper was to review and provide an insight into these primary wool characteristics, their specific measurements, commercially desirable parameters, and influence on wool quality and value.

2. FIBRE DIAMETER

Fibre diameter (FD) refers to the average width of a single cross section of wool fibre (Gillespie and Flanders, 2010). It is measured in microns (µm) which equates to one thousandth of a millimetre (Cottle, 1991; Cottle, 2010; Poppi and McLennan, 2010; Rowe, 2010). FD is widely acknowledged as the most important wool characteristics when assessing wool quality and value (Lee et al., 2001; Edriss et al., 2007; Kelly et al., 2007; Rowe, 2010) accounting for approximately 75% of the total price of raw wool (Jones et al., 2004; Cottle, 2010; Mortimer et al., 2010).

FD value is an indicator of the fineness with which a yarn can be spun. It is influenced by the amount, or weight, of wool that can move through the processing machinery at any given time (Warn et al., 2006; Cottle, 2010). Consequently, low FD wools (or finer wools) can be

processed into yarns which are aptly suited for high value apparel textile end uses (Warn et al., 2006; Rowe, 2010). Thus, finer wools can produce fabrics of characteristically light weight, soft, with superior handle and drape (Cottle, 2010). Paradoxically, coarser wools with high FD values are particularly suited for less luxurious and lower valued uses such as carpeting, outerwear or bedding (Poppi and McLennan, 2010). FD exerts a great influence on post-processing wool value, hence its large influence on overall wool quality (Angel et al., 1990; Rowe, 2010).

FD can be measured relatively rapidly, accurately and cheaply, through utilisation of three predominant instruments: 1) LASERSCAN, the most commonly employed technology whereby a laser quantifies FD values; 2) Optical Fibre Diameter Analysis (OFDA), using an automated scanning light microscope; and 3) AIRFLOW, which has been less utilised with the advent of the two previously mentioned instruments. It uses gravitational variation between wool fibres to determine FD (Larson, 1992; Hatcher and Atkins, 2000; Botha and Hunter, 2010; Tester, 2010; Li et al., 2011).

3. WOOL VARIATION

3.1 Entire Fleece Fibre Diameter Variation

Over an entire fleece, or even within a representative wool sample, fibre diameter is not homogenous, but ranges from 10-70 µm (Wood, 2003). Consequently, fibre diameter values from either OFDA or LASERSCAN, are best represented as normal distributions, which permit evaluation of the degree of variation present (Aylan-Parker and McGregor, 2002; Greeff, 2006; Botha and Hunter, 2010). This level of variation can be expressed in terms of fibre diameter standard deviation (SD) or coefficient of variation (CV). Both provide different values but are still reflective of actual fibre diameter variation, affirmed by their typical positive correlation to FD (Baxter and Cottle, 1998; Wood, 2003).

SD is a measurement of fibre diameter variation within a normal distribution which has been standardised with 66% of fibres isolated within one SD from FD value, and 95% represented within two SD (Greeff, 2006). Subsequently, these derived values are indicative of variation, with high SD values demonstrating higher fibre diameter variation compared to low SD which is associated with a contracted fibre diameter range.

CV is a refinement of SD because it is derived from SD values divided by FD and expressed as a percentage. Unlike SD, CV permits a comparison of fibre diameter variations among wools with different FD values (Baxter and Cottle, 1997, 1998; Brown et al., 2002; Cottle, 2010). As a 'rule of thumb', each increase in CV by 5% is equivalent to a one micron reduction of FD regarding wools processing performance (Denney, 1990; Naylor et al., 1995; Butler and Dolling, 2002; Wood, 2003; Greeff, 2006; Wood, 2010). The lesser the fibre diameter variation in wool, the higher the market demand (Aylan-Parker and McGregor, 2002), price and the better the wool quality. Therefore, premiums are offered for wools with low SD and high CV values (Snowder, 1992; Edriss et al., 2007).

3.2 Single/Staple Fibre Diameter Variation

Variation of wool fibre diameter is not exclusive to an entire fleece, but also within a single fibre, and measured as the fibre diameter profile (FDP) (Brown et al., 2000). Interestingly, the FDP of a single wool fibre is typically shared over its staple being a 'lock' or where a

group of wool fibres seem to connect; and the FDP of constitutive fibres varies in unison (Jackson and Downes, 1979). FDP provides insight into the deviations which naturally occur during wool growth and development (Brown et al., 2000).

FDP is commercially important as a wool characteristic because of its strong correlations with CV and staple strength (Brown et al., 2002; Greeff, 2006), hence its indirect impact on wool quality and value. However, regardless of this strong relationship, FDP can be independently evaluated. This involves a process of segmenting an entire wool fibre or staple into a sequence of snippets defined as fibre fragments of approximately 2 mm lengths (Cottle, 1991), which are sequentially analysed for their FD and outcomes amalgamated into FDP (Brown et al., 2000). This technique relies on OFDA methodology. A modified OFDA software which scans and quantifies a single wool fibre's diameter at 40 μm intervals was developed and named the 'single fibre analyser' (SIFAN) (Peterson et al., 1998; Deng et al., 2007). Nevertheless, widespread analysis of FDP has not yet become routine within the wool industry, but ideally, wool FDP would be uniform, and wools meeting this criterion are typically deemed to be of higher quality.

4. STAPLE LENGTH

Wool fibre staple length (SL) is becoming an increasingly important determinant of wool quality and value (Edriss et al., 2007; Valera et al., 2009; Gillespie and Flanders, 2010), and is expressed in millimetre (mm) units (Thompson et al., 1988). SL can be quantified using the CSIRO instrument known as the 'Automatic Tester for Length and Strength' (ATLAS) (Thompson et al., 1988; Pfeiffer and Lupton, 2001). SL's importance as a wool characteristic is linked to its indication of wool processing performance. Wool with long SL are more commercially desirable as they tend to be easier to spin, give fewer stoppages and ultimately can form stronger and more even yarns (Angel et al., 1990; Wood, 2003; Edriss et al., 2007; Wood, 2010) when compared to shorter SL wools. When present in high levels, shorter SL wools typically result in surface fuzzing and piling in apparel fabric surfaces, and fibre loss from woollen carpets (Wood, 2003; Valera et al., 2009; Cottle, 2010).

Unfortunately for wool processors, many mainstream techniques during processing promote fibre breakage which causes the shortening of otherwise long SL fibres, especially during carding and scouring phases (Botha and Hunter, 2010; Wood, 2010). Consequently, some topmakers preserve SL through employing more gentle scouring methods, via better lubrication and lower card loading. However, these can result in a decline in wool processing performance (Wood, 2010). Therefore, SL's influence on wool quality and price is closely associated with staple strength (Brown et al., 2002; Gillespie and Flanders, 2010), as the interaction between the two impact processing.

5. STAPLE CHARACTERISTICS

5.1 Staple Strength

Staple strength (SS) is widely recognised as second only to FD, regarding wool characteristics that influence wool quality and price (Pfeiffer and Lupton, 2001; Brown et al., 2002; Friend and Robards, 2005; Botha and Hunter, 2010). It is a measurement of the degree of resistance a staple of wool has against severing upon the application of incremental force (Reis, 1992; Thompson and Hynd, 2009). Wool SS is objectively measured as the maximum force required to break a staple, with the force measured as

Newtons per kilotex (N/ktex). It is essentially a measurement of linear staple density, cross-sectional thickness or area, which has been standardised at one gram of clean dry wool per metre of SL (Reis, 1992; Masters et al., 1998; Adams et al., 2000). The ATLAS machine is now employed for SS quantification in Australia (Thompson et al., 1988; Pfeiffer and Lupton, 2001), but traditionally, SS values were subjectively derived by implementing the 'flick test' whereby personal appraisal was used for quantification by an experienced wool handler (Denney, 1990; Cottle, 1991). SS value permits the accurate estimation of wool performance during processing, especially in the early processing stages (Angel et al., 1990) where carding and combing noilage are the most severe phases (Edriss et al., 2007; Cottle, 2010).

Commercially, high SS wools, called 'sound wools', are considered of markedly greater value than their low SS or tender wool counterparts (Reis, 1992; Masters et al., 1999; Jones et al., 2004). To aid determination of SS value, wools are routinely allotted into one of four main descriptive categories; 1) Sound, including staples stronger than 25-30 N / ktex; 2) Part-tender, whereby SS equates to approximately 20 N / ktex; 3) Tender, being SS values around 15 N / ktex; and 4) Rotten, referring to staples breaking with less than 10 N / ktex of force (Cottle, 2010). On-the-whole, wool quality and price declines with progression down these aforementioned categories, from sound to rotten (Denney, 1990). The majority of variations in SS between wools are thought to be based on differences in intrinsic fibre strength (Gourdie et al., 1992; Schlink et al., 2002). However, some thought towards the stretchability or 'give' of fibres is beginning to be investigated.

5.2 Staple Breakage Region

The location within a staple where breakage occurs during SS evaluation, commonly referred to as the 'staple breakage region' (SBR), is useful in estimating wool processing performance (Snowder, 1992; Wood, 2003; Cottle, 2010). This relates to SBR's linkage to the level of wool wastage. When SBR is located at the tip of a staple, shorter fibre fragments will form. During processing, particularly carding, SL reduces by 10-50%, and is removed (Wood, 2003; Cottle, 2010). It is more commercially desirable that SBR are situated in the middle of a staple, with appropriate price incentives for this position over tip SBR; however, centre SBR still causes a decline in mean wool SL (Cottle, 1991; Snowder, 1992; Wood, 2003).

While investigating SBR, Thompson and Hynd (2009) found that staple fracture surfaces were generally smooth and occurred either perpendicular or oblique to the fibre. Also, a strong relationship between SBR and FDP has been reported, with staples of particularly varied FDP found to have greater prevalence to breakages (Deng et al., 2007), particularly where fibre diameters were at their fineness (Jackson and Downes, 1979; Cottle, 1991; Gourdie et al., 1992). However, recent thought has indicated that these finer regions have more flexibility than the coarser regions. However, SBR is mainly dependent on determined SS values, and subsequently SBR's relevance to processing can potentially be voided depending on SS findings.

6. WOOL COMFORT FACTOR

Inherent in wool fabrics is raised wool fibre ends which protrude from their surface. On occasions where these protrusions exert a force greater than 75mg/cm2 upon a wear's skin (Naylor, 2010), nerve and pain receptors are stimulated and the formation of an irritation or prickling sensation is commonplace (Rogers and Schlink, 2010; Tester, 2010). Evidence

suggests that protruding wool fibres with diameters less than 30µm are deflected upon contact with the skin and avoid irritation (Naylor, 2010). Therefore, limiting wool fibres greater than 30 µm to less than 5% ensures wearer comfort and improves product value and marketability (Naylor et al., 1995; Greeff, 2006; Malau-Aduli and Deng Akuoch, 2010; Rogers and Schlink, 2010). Consequently, 30 µm has been benchmarked as the threshold level indicating wool comfort and the percentage of fibres with diameters lower than this threshold are collectively referred to as comfort factor (CF) (Naylor et al., 1995; Holst et al., 1997; Wood, 2003; Malau-Aduli and Deng Akuoch, 2010).

In contrast to CF is prickle factor (PF), the term sometimes used to describe the percentage of fibres with diameters greater than the 30 µm threshold (Bardsley, 1994; Baxter and Cottle, 1997; Wood, 2003). However, PF terminology has been somewhat over-shadowed by the development of CF definition. CF is particularly beneficial in developing future market demand for wool with the emergence of next-to-skin wool fabric applications while maintaining traditional market focus on luxurious apparel (Broega et al., 2010; Mahar and Wang, 2010; Rowe, 2010; Tester, 2010). Consumer demand and therefore price incentives exist for wools with the highest possible CF values.

Wool CF is readily measured through fibre analysis for FD, using previously mentioned LASERSCAN and OFDA techniques, and by assessing the normal distribution curve (Malau-Aduli and Deng Akuoch, 2010; Tester, 2010). Recently, the CSIRO division of Material Science and Engineering, in Geelong, Victoria, Australia, has developed a 'Comfort Meter' instrument, which measures fabric surface anomalies including protruding fibre ends (Tester, 2010). This is achieved by moving a suspended sensory wire over a fabric at precisely 1.5 mm elevation, at a tension of 2 g / cm2 and gauging its deflections as an indication of actual CF (Tester, 2010). Subsequently, this method may also prove beneficial in determining other wool characteristics (Tester, 2010) because of the well documented strong correlations between CF and other wool characteristics (Wood, 2003; Greeff, 2006; Malau-Aduli and Deng Akuoch, 2010). However, this strategy has the disadvantage that it can only quantify CF once a finished fabric has been produced, thereby voiding the potential to evaluate wool prior to processing.

7. SPINNING FINENESS

Spinning fineness (SF), previously called 'effective fineness' is a refinement of FD and CV into a single value (Aylan-Parker and McGregor, 2002; Deng et al., 2007). SF makes allowance for the '5% rule' ensuring an evaluation of processing performance indicators such as speed, cost and yarn evenness (Naylor et al., 1995; Baxter and Cottle, 1997, 1998; Deng et al., 2007). SF is derived analytically using second-order statistical theory (Butler and Dolling, 2002) and calculated from wool FD and normalised CV of 24% with the exception of Merino wool where 19% is used to avoid potential misrepresentation and misinterpretation concerns (Baxter and Cottle, 1997; Butler and Dolling, 2002). SF is advantageous as it can be directly compared between wools since its unit of measurement is micron units. Thus, high SF indicates coarser FD and more intensive processing required than in low SF wools (Butler and Dolling, 2002). Therefore, markets demand and reward providers of low SF wools.

There currently exists some schools of thought which propose SF as an ideal wool characteristic representative of wool quality, because of its incorporation of both FD and CV into a single value (Butler and Dolling, 1992; Butler and Dolling, 2002; Holman, 2010; Malau-Aduli and Holman, 2010), which has been advocated to be used in selective breeding

programs. Nevertheless, for the most part, scepticism remains on SF's merits as a wool quality indicator due to concerns that it just complicates otherwise basically interpretable FD and CV data.

8. FIBRE CURVATURE

Upon visual appraisal of wool staples, waviness or crimped appearance is evident (Rogers, 2006). Traditionally, the frequency of these crimps was utilised as an indirect marker of FD during selective breeding or in sale lots (Cottle, 1991; Hatcher and Atkins, 2000). However, over recent decades, staple crimp is being evaluated in terms of fibre curvature (CURV), which describes crimp frequency (McGregor, 2003) as the number of crimps per unit of length (Hatcher and Atkins, 2000), amplitude, and aggregation (Rogers, 2006).

CURV quantification is achieved using LASERSCAN and OFDA instrumentation (Hatcher and Atkins, 2000; McGregor, 2003; Wang et al., 2004), which makes CURV evaluation now more affordable than previously (Huisman and Brown, 2009). CURV's importance as a wool quality indicator wool characteristics stems from its influence on wool processing performance, with wools of high CURV value performing marginally poorer than those with lower CURV (Wood, 2010).

CURV has an impact on the probability of fibre entanglements during scouring, resulting in more frequent fibre breakages during carding (Wang et al., 2004). This in turn, causes increased wool wastage, produces yarns with 'hairy' appearance due to protruding fibre ends causing the fuzzing and piling of knitted fabrics (Botha and Hunter, 2010), negates fabric softness, handling and resistance to compression (Liu et al., 2004) and overall, compromises wool processing performance.

Higher CURV wools have limited end applications and are therefore less desired. However, many wool treatments during processing have been found to affect CURV, for example, wool tops are found to develop increased CURV during scouring compared to simple immersion in hot water (Botha and Hunter, 2010). Regardless, it is thought that once other wool characteristics deemed more influential over wool quality have reached their target values, CURV will become increasingly utilised in differentiating quality and prices among wools (Hatcher and Atkins, 2000).

9. CLEAN FLEECE WEIGHT

Clean fleece weight (CFW) refers to total greasy wool yield minus wax, suint, dust and vegetable matter contaminations expressed as a percentage (Thornberry and Atkins, 1984; Jones et al., 2004; Rogers and Schlink, 2010). CFW thus refers to the yield of usable wool fibres within unprocessed wool (Cottle, 1991), hence it is a function of non-fibre constituents level flux within a fleece (Thornberry and Atkins, 1984; Rogers and Schlink, 2010).

Hatcher et al. (2008) investigated the potential use of post-shearing applied sheep coats and found that their utilisation limits the occurrence of dust and vegetable contamination within a fleece, proving more effective in specific environmental and seasonal conditions. This finding may benefit farmers because CFW is directly responsible for determining the commercial value of wool (Banks and Brown, 2009; Mortimer et al., 2010) as prices are related to the amount of wool fibre, such that higher prices are offered for wools with greater CFW yields (Johnson and Larsen, 1978; Snowder et al., 1997; Rogers and Schlink, 2010).

Originally, CFW was evaluated by scouring a whole individual fleece (Johnson and Larsen, 1978), however, this process was time consuming and expensive. Instead, it has been found that using just a small representative sample commonly taken as a 'core sample' from a wool bale (Johnson and Larsen, 1978), can provide a highly accurate indication of CFW (Sidwell et al., 1958).

10. CONCLUSION

Analysis of wool characteristics is an effective means of determining and differentiating wool quality. Knowledge of these characteristics aids management of product end-use, consumer comfort, and processing intensity. Accordingly, wool characteristics directly impact wool prices set by processors and industry.

Presently wool quality testing occurs almost entirely off-farm. Consequently, wool quality data are received almost as a by-product of shearing an intricate and slow process that is hard to actively incorporate into management systems. Hence, current methodology limits the applications of the gained knowledge. Shifting wool testing back on-farm and the development of a rapid, mobile and high through-put testing instrumentation would be highly beneficial in improving management systems. For instance, these developments would advance large-scale selective animal breeding programs for wool quality in terms of ease and precision. Wool classing could move towards more objective means of wool sorting to maximise profits. Additionally, it will assist accurate traceability of wool to its genetic source.

Achieving these outcomes presents a challenge that requires more investigation into viability and ensuring that the current testing standards are easily incorporated. Future expansion of wool testing relies on the utilisation of emerging analytical techniques such as proteomics and electron-microscopy. These analyses can enhance our current understanding of associations between wool quality, fabric and the actual fibre's physical attributes. The wool industry would profit immensely from future investment in research into wool testing science by aiding and tailoring wool production to best match evolving market demands.

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COMPETING INTERESTS

The authors have declared that no competing interests exist.

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