The Metrology and Potential for Genetic Improvement of Felting in Superfine/Fine Wool Merino Sheep

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I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree of qualification.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

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Abstract

Potential sales of woollen garments are reduced due to the perception that woollen garments require special laundering to avoid shrinkage. Shrinkage, otherwise known as felting, is a result of interaction between adjacent fibres. Felting is not always undesirable. However, a significant proportion of superfine/fine Merino wool is manufactured into garments in which shrinkage is unwanted. The propensity for a garment to shrink can be reduced through chemical shrinkproofing but these techniques are not only detrimental to the dye affinity of the fibre and handle of the fabric but produce environmentally degrading residues and, as such, are an environmental and economic burden to the international and Australian wool industry. This thesis investigates selective breeding for animals with reduced loose-wool felting propensity as a means of reducing the need for harmful chemical shrinkproofing techniques. Initially, the variance components of the cuticle scale characteristics of superfine/fine wool Merino fibres are quantified and optimal sampling schemes established. The economic cost of measurement and the poor correlated response of loose-wool felting to selection for cuticle scale characteristics ($< 0.24 g/cm^3$) leads to the conclusion that the measurement and inclusion of cuticle scale characteristics in superfine/fine wool Merino breeding programs is not a viable means of reducing loose-wool felting. Consequently, previously reported methods of measuring loose-wool felting are investigated. These methods involve the measurement felt ball density. Felt ball density is proportional to the likelihood of that sample felting. Parameter estimation studies, aimed at quantifying the relationships between felt ball density and routinely measured traits of superfine/fine wool Merinos, are conducted. In agreement with previous studies involving medium to broad wool animals, the genetic correlation between felt ball density and mean fibre diameter is unfavourable (r_g = -0.95±0.14) suggesting that finer micron wools are more likely to felt. Clean fleece weight is favourably correlated with felt ball density (r_g = -0.27±0.23) implying that heavier fleeces are less likely to felt. The heritability of loose-wool felting in superfine/fine wool Merinos is estimated to be very low (h^2 = 0.05±0.01) when estimated across age groups. The relationships between loose-wool felting and top and fabric characteristics are investigated. Felt ball density is favourably related to hauteur (r_p = -0.16±0.17) but unfavourably related to fabric shrinkage (b = -656.3±181.7, $P < 0.05$). The parameter estimates are used to predict the potential genetic change in loose-wool felting when included in superfine/fine Merino wool breeding programs with economically important traits. The predicted reduction in loose-wool felting was minimal. Regardless, loose-wool felting would continue to deteriorate if felt ball density was not measured and not selected upon in superfine/fine wool Merino breeding programs.

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Acronyms

Organisations

AS/NZS	Australian/New Zealand Standard
ASTM	American Society for Testing and Materials
DWI	Deutsches Wollforschungsinstitut (German Wool Research Institute)
EU	European Union
IPPC	Integrated Pollution Prevention Control
IWTO	International Wool Textile Organisation
TWC	The Woolmark Company
WSR	Wool Science Review

Traits and Terms

AOX	adsorbable organic halogens
ATLAS	automatic tester of length and strength
CEFD	a function of curvature and effective fibre diameter
CF	crimp frequency
CFW	clean fleece weight
COL	subjectively assessed greasy wool colour
CRF	crevice factor
CSF	cuticle scale frequency
CSH	cuticle scale height
CSI	cuticle scale index
CSL	cuticle scale length
CSY	clean scoured yield
CURV	mean fibre curvature
CVFD	coefficient of variation of fibre diameter
CVH	coefficient of variation of hauteur
DEN	subjectively assessed wool fibre density
DFBC	day of felt ball creation
DFE	directional frictional effect
DOM	day of measurement
DRAFT TM	draft test method
DUST	subjectively assessed dust penetration
EFD	effective fibre diameter
FBCT	felt ball conditioning time
FBDEN	mean felt ball density

FBDIAM mean felt ball diameter

FBDT felt ball drying time

FBST felt ball sitting time

FL fibre length

FWP Fine Wool Project

HAUT mean hauteur

HGRP handle group

IF intermediate filament

LWB loose-wool bulk

MFD mean fibre diameter

MFDGRP mean fibre diameter group

MIDBRK mid staple breaks

NSW New South Wales

ODW oven dry weight

PILL fabric pilling

PTFE polyetrafluoroethylene

QM ¼ Merino-¾ Romney

REV relative economic value

RH relative humidity

ROM romaine

RTC resistance to compression

SCFTECH scale frequency measurement technique

SD scouring day

SDCURV standard deviation of fibre curvature

SEM scanning electron microscope

SEMMFD scanning electron microscope mean fibre diameter

SHRINK fabric shrinkage

SL staple length

SS staple strength

SSL subjectively assessed staple length

STAP subjectively assessed staple thickness

SWT suint weight

T13 Towards 13μm

TEAM Trials Evaluation Additional Measurement

TOTSCF total scale frequency

TRUESCF true scale frequency

Y-Z yellowness

Glossary of Terms

The following terms are used throughout this thesis according to the following definitions.

Accuracy: Accuracy is a measure of the closeness of a test result to the true value. The true value of a measured quantity can only be determined by measurement systems that are calibrated by direct reference to primary references such as length, weight, force etc. (AWTA 2000).

Average Yellowness (Y-Z, tristimulus values): Y-Z is the difference between the reflectance of a surface in the green and blue regions of the spectrum, expressed as the difference between the tristimulus values Y and Z. Y-Z is a good indicator of dyeing performance. However, there is a poor relationship between the greasy colour of wool and Y-Z values (AWC 1992).

Bending modulus (N/m^3): The stiffness of a fabric is dependent on its thickness, the thicker the fibre the stiffer it is if all the other factors remain the same. Bending modulus is a measure of "intrinsic" stiffness (Saville 1999):

Bending modulus = $(12 * G * 10^3)/T^3$

Where:

T = fabric thickness (mm)

G = flexural rigidity of the fabric.

Bloodline: Bloodline refers to a direct line of descent or pedigree of animals that have a sequence of direct ancestors in their pedigree, hence a family or strain (Smith 2003).

Bulk (cm^3/g): Bulk is the volume occupied by a standard mass of clean wool, compressed by a standard force. It is related to the amount of fibre crimp and is often described in conjunction with resistance to compression (RTC) (AWC 1992).

Bursting Strength (also Mullen Burst or Ball Burst) (lb/in^2 or N/m^2): Bursting strength is a measure of the pressure required to burst a fabric. Pressure is applied to the fabric in one of two ways, either a "ball" is pushed into the fabric sample or the sample is clamped onto a device and inflated with oil. The force required to burst through the fabric is measured (ASTM D751)

Carding: After wool is scoured and dried it is fed into a carding machine which opens up the wool into an even layer, removes as much vegetable matter as possible, and draws fibres parallel to each other to some degree, to form a single continuous strand of fibres known as a sliver (AWC 1992).

Clean fleece weight (CFW, kg): CFW is a function of GFW and CSY:

CFW = (GFW * CSY)/100

Where:

GFW = greasy fleece weight

CSY = clean scoured yield.

Clean scoured yield (CSY, %): CSY is calculated as follows (Lax, J. & Jackson, N. 2005, pers. comm.):

CSY = (ODM * 115)/(SWT * 10)

Where:

ODM = oven dry mass or the mass of material obtained by scouring a sample and exposing it to air at 105° C until equilibrium is reached, and corrected for the moisture content (15%) of the drying air

SWT = suint weight is the suint or water soluble component (sweat) of the wool fibre.

Coefficient of variation (CV, %): CV is a statistical measure of the variability exhibited within a set of values. It expresses the standard deviation as a percentage of the mean; the higher the CV, the greater the variability (AWTA 2005). CV is determined as follows;

CV = (SD * 100%)/μ

Where:

SD = standard deviation of the sample

μ = mean of the sample.

Coefficient of variation of fibre diameter (CVFD, %): CVFD is a statistical measure of the variability of fibre diameter between and along fibres which is exhibited in a sample. It expresses the standard deviation as a percentage of the mean, with the higher the CVFD, the greater the variation in fibre diameter (AWTA 2000) (see definition for Coefficient of Variation).

Combing: Combing is a process performed after carding and gilling (usually by a rectilinear comb) to remove most of the short fibres (noil), neps, vegetable matter and foreign matter, leaving the longer fibres lying parallel to the direction of the sliver. After two more gillings, this product is called top (AWC 1992).

Conditioning: Conditioning is a process whereby wool fibres are exposed to a conditioning atmosphere until the moisture absorbed by the fibres attains equilibrium (AWTA 2000).

Conditioning Atmosphere: A volume of air, capable of being maintained at standard temperature or humidity, or both, in which specimens are conditioned in a standard atmosphere. For wool testing this is usually a temperature of 20±2° C and a relative humidity of 65±3% (AWTA 2000).

Confidence Limits: Confidence limits are an expression of the precision of the mean of a set of values, usually associated with a stated probability, most often 95%. It is the interval around the mean within which, with the stated probability, the true value is expected to lie (AWTA 2000).

Crimp: Crimp is the waviness of a fibre, expressed numerically as the number of complete waves per unit length (AWTA 2000). Crimps vary in size and formation with factors such as breed, strain, environment and character of the wool (Smith 2003). There are many measures of crimp including crimp frequency (CF) and definition, which are regarded as style components (Smith 2003).

Crimp frequency (CF, crimps/cm): CF is the number of crimp wavelengths per unit of staple length (AWTA 2000).

Dimensional stability: Dimensional stability is the tendency of a fabric to retain its shape and size after being subjected to wear, washing and dry cleaning. This stability may be brought about by the types of fibres in the fabric, chemical treatment or different mechanical techniques used during fabric production (Segal et al. 1972).

Felt ball density (FBDEN, g/cm^3): FBDEN is a measure of felting (Chaudri & Whiteley 1970a, 1970b; Kenyon, Wickham & Blair 1998, 1999; Kenyon & Wickham 1999). A method for measuring and calculating FBDEN is described in Chapter 4 of this thesis.

Felt ball diameter (FBDIAM, mm): FBDIAM is also a measure of felting (Chaudri & Whiteley 1970a, 1970b; Kenyon, Wickham & Blair 1998, 1999; Kenyon & Wickham 1999). FBDIAM is used to calculate FBDEN (see Chapter 4 of this thesis).

Felting: Felting is the unique property of wool fibres that results from the interaction and entanglement of adjacent fibres to form a compact mass when placed under external compressive forces. Throughout this thesis, felting is also referred to as loose-wool felting or shrinkage and the ability for a sample to felt is referred to as felting propensity or feltability.

Fibre length (FL): FL is the distance along a wool fibre, as opposed to the length along a staple. FL is rarely measured on greasy wool. However, FL is routinely measured using an Almeter after early stage processing and is an important quality of wool top (Smith 2003).

Genotype: Genotype refers to the total complement of animals' genes, or its total complement of any particular site on a chromosome (Smith 2003).

Greasy fleece weight (GFW, kg): GFW is measured before the fleece is scoured and includes skirtings and belly wool. The sample removed from the mid side for further testing is also included in GFW.

Hauteur (HAUT, mm): HAUT is a term used to describe the mean fibre length in the top (AWC 1992). It is a length-biased distribution. Hauteur is widely used commercially for the specification and trading of wool tops.

Intermediate filaments (IF) or microfibrils: In a wool fibre, bundles of crystalline intermediate filaments are embedded in an amorphous matrix to form a macrofibril. Intermediate filaments are more densely packed in the orthocortex than the paracortex (Williams 1991).

International Wool Textile Organisation (IWTO): IWTO is an international forum for establishing standardised test procedures (IWTO Test Specifications), regulations governing the use of these procedures (IWTO Regulations), and procedures for arbitrating disputes over commercial transactions involving raw wool, wool sliver and wool yarns (the IWTO Blue Book). IWTO is pivotal in providing a technical and commercial framework for international and international trade involving wool. Representation within IWTO is via National Committees appointed by the Wool Industry associations within member countries (AWTA 2000).

Keratin: Keratin is a complex of fibrous proteins that form wool fibres. Keratin is characterised by high sulphur content, with cystine being the predominant amino acid. Cross-linkage between cysteine residues makes keratin more stable and less soluble than most proteins (Smith 2003).

Laserscan: The Laserscan is an instrument to measure mean fibre diameter and fibre diameter distribution by detection of shadows in a laser beam, brought about by causing snippets to be carried through the beam in a suitable liquid (AWTA 2000).

Loose-wool (or raw wool): Loose-wool refers to wool without vegetable matter and extraneous alkali-insoluble substances, mineral matter, wool waxes, suint and moisture. It includes wool which had been scoured, carbonised, washed or solvent degreased (AWTA 2000).

Mean fibre curvature (CURV, °/mm): CURV is the rate of change in fibre direction per unit length of fibre. CURV is a measurement of the size of the angle subtending the arc, per unit length of the arc is obtained (AWTA 2000).

Mean fibre diameter (MFD, µm): MFD is defined as the arithmetic mean thickness of fibres (AWTA 2000). MFD is universally regarded as the most important characteristic of wool processing and product quality.

Metrology: Metrology is the science of measurement.

Micrometre (micron) (µm): Micrometre is a unit of length measurement equal to one-millionth of a metre; it is the unit of measurement for the fibre diameter of wool. It is commonly called a micron (AWTA 2000).

Neps: Neps are small "balls" (or aggregations) of entangled fibres ranging in size from "pin points" to approximately 2mm in diameter which are created during processing. These are mostly removed from the top in the combing process (AWC 1992).

Noil (%): Noil is the short fibre which is removed in the combing operation. It is a mixture of short and broken fibres, neps, and small particles of vegetable matter. It is then used as one of the blend components in woollen system. Noil is calculated as the conditioned weight of noil divided by the net clean input, expressed as a percentage (AWC 1992).

Objective measurement: Objective measurement refers to the measurement of a particular characteristic as opposed to the subjective appraisal of that characteristic (AWC 1992).

Optical-based Fibre Diameter Analyser (OFDA): The OFDA is an instrument for measuring fibre diameter mean and distribution using an automated microscope and image analysis techniques (AWTA 2000).

Orthocortex or orthocortical cells: The orthocortex is a cortical cell of fibres which can be found on the outside of the crimp in fine wool fibres. In the orthocortex, the microfibrils display a whorl-like pattern. Microfibrils are more densely packed in the matrix in orthocortical cells (Cottle 1991).

Paracortex or paracortical cells: The paracortex is a cortical cell of fibres which can be found on the inside of the crimp in fine wool fibres. Paracortical cells have a higher matrix and sulphur content than the orthocortical cells. The microfibrils appear parallel in the paracortex (Cottle 1991).

Percentage of mid breaks (PMB, %): PMB is an indication of the percentage of staples which, when placed under a load, brake in the mid region of the staple (AWTA 2000).

Phenotype: Phenotype refers to animals' tangible features, including external appearance, measures of productivity and physiological characteristics (Smith 2003).

Pilling: Pilling is a physical process whereby small balls made up of tangled fibres form on the surface of a fabric. Pills are secured to the fabric by several anchoring fibres (WSR 1972). The number of pills attached to fabric is generally subjectively assessed.

Precision: Precision is an indicator of the repeatability of a measurement (AWTA 2000).

Quality count (number): Quality number or count is the number of hanks of wool 512m in length that can be spun from 454g of wool (Teasdale 1988).

Regain (%): Wool fibres absorb up to 33% of their own weight of moisture before becoming "wet" (AWC 1992). Standard regain is brought about when wool comes to equilibrium with air at standard atmosphere. Regain is the amount of moisture in the fibres, expressed as a percentage of clean oven dry weight (ODW). Processed wool is adjusted to a particular

regain (e.g. 18.25% for dry combed tops and 15 to 17% regain for scoured wool) (AWC 1992).

Resistance to compression (RTC, kPa): RTC is the force per unit area required to compress a fixed mass of scoured and carded wool to a fixed volume (AWC 1992).

Romaine (ROM, %): ROM is the amount of noil produced during processing, expressed as a percentage of the top and noil produced (AWC 1992).

Scouring: Scouring refers to the mechanical removal of mineral matter, suint and wax by either aqueous or solvent methods (AWC 1992). Scouring is the first stage of processing, followed by drying and carding.

Sliver: A continuous strand of loosely assembled wool fibres which may contain variable amounts of vegetable matter and is approximately uniform in cross-sectional area and with none or very low levels of twist. This includes carded sliver, combed sliver, gilled sliver, top and roving (AWTA 2000).

Standard deviation (SD, σ): SD is a measurement of the spread of values around a mean. It is the square root of the differences between each data value and the mean ($(x_i - \mu)^2$), divided by the sample size (n) minus one. It is the square root of the variance (see definition for Variance).

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{n-1}}$$

Standard deviation of fibre curvature (SDFC, µm): SDFC is a measure of the dispersion of individual fibre curvature results (see definition for Standard Deviation).

Standard error (s.e): Standard error is a measure of the standard error of the mean. Standard error is calculated by taking the standard deviation (σ) (see definition for Standard Deviation) and dividing it by the square root of the sample size (n):

$$s.e = \sigma/(\sqrt{n})$$

Staple length (SL, mm): SL is the length of a staple projected along its axis obtained by measuring the staple without stretching or disturbing the crimp of the fibres (AWTA 2000).

Staple strength (SS, N/ktex): SS is the maximum force required to rupture a staple per unit of average linear density. The unit of measurement of SS is newtons per kilotex (ktex). Newton (N) is the unit of force in the SI system. The force of 1kg is equivalent to approximately 9.8N. The 7 pound (lbs) force referred to when subjectively appraising staple strength by the "flick" test, is equivalent to approximately 30N (AWC 1992). Kilotex (ktex) is the linear density of a staple expressed in grams per metre.

Strain: Strain refers to a collective group of animals that are the descendents of a common ancestor, ancestry or lineage; usually a sub-classification within a breed (Smith 2003)

Style: Style is a term generally referring to the subjective appraisal of a combination of visual and tactile characteristics of greasy wool. Style characteristics include those relating to yield (e.g. greasy wool colour, dust penetration) the staple (e.g. crimp definition, tip shape and density) and other fleece characteristics that interact with the environment (AWC 1992).

Subjective assessment/appraisal: Subjective assessment refers to the subjective appraisal of a characteristic rather than the objective measurement of the trait (AWC 1992).

Superfine wool: Superfine wool is usually considered to be wool 18.5μm and finer (AWC 1992).

Top: Top is a continuous, untwisted strand of combed wool, in which the fibres lie parallel, with short fibres having been combed out as noil. Top is the raw material for worsted wool processing (AWC 1992).

Variance (σ^2): The variance of a sample is the square of the standard deviation and is a measure of the distribution of values around the mean. It is expressed in the units of measurement squared (AWTA 2005) (see definition for Standard Deviation).

$$\sigma^2 = \frac{\sum (x_i - \mu)^2}{n - 1}$$

Where:

$(x_i - \mu)$ = differences between each data value and the mean

n = sample size

Woollen yarn system: The wool used in the woollen yarn system generally has a shorter mean FL (e.g. approximately 40mm and less) than that used in the worsted yarn system. Fibres

within woollen yarns are less parallel, whereas they tend to be in parallel array in worsted spun yarns. The cloth produced is comparatively bulky, with many fibres extending from the surface. Woollen fabrics include tweeds, felt, flannel, blankets and knitwear (AWC 1992).

Worsted yarn system: Worsted yarn is made from top, and undergoes more stages of processing (i.e. gilling, combing and drawing) than the woollen yarn system. In worsted yarn the fibres are more parallel and tighter spun, resulting in smoother, stronger yarn than the woollen system. The fabric produced is smooth, dense and retains its shape. Products from the worsted system include suitings and some knitwear (AWC 1992).

Yarn: Yarns are threads used in weaving or knitting fabrics. They are formed by drawing fibres over each other and twisting to bind the fibres together.