FIBRE DIAMETER VARIATION AS A MEASURE OF RESILIENCE IN SHEEP

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SUMMARY

The ability to select sheep which have a greater capacity to overcome environmental fluctuations is topical given the severity of climatic events, labour shortages and increased productive demands (lamb, meat and wool). In this paper, we review the possibility of using variation in fibre diameter (FD), measured along the wool staple as an indicator of how sheep respond to the fluctuations of their environment.

INTRODUCTION

Production animals are exposed to significant fluctuations in their internal and external environments which can hinder their productive performance, health and well-being. Significant research efforts over the last decade have focused on quantifying the ability of animals to cope with these fluctuations and in turn, selecting those with a greater capacity to overcome them, particularly among intensively raised livestock (Berghof *et al.* 2019). The ability for animals to be minimally affected by environmental fluctuations or to promptly recover from them is referred to as resilience (Colditz and Hine 2016). Many recent studies of resilience are based on quantifying the variable rate of resource accretion into production tissues or products (muscle, milk and eggs) (Colditz *et al. in press*). In idealised form, these measures capture the animal's inherent success in maintaining homeostatic balance, as it modulates resource allocation between survival and production (Neville 1967). An animal undergoing a challenge from its internal or external environment is likely to temporarily divert resources away from non-essential functions (typically production variables), which can then be used to inform assessments of resilience. Genetically, animals with greater uniformity to these production variables have been associated with better current and future health outcomes (Berghof *et al.* 2018) and improved longevity (Adriaens *et al.* 2020; Poppe *et al.* 2020), qualities which are increasingly valued by consumers and producers alike.

Similar methodologies have yet to be investigated in extensive sheep populations, primarily due to a lack of appropriately structured data (frequent measures over long time periods). Assessment of fibre diameter variation along the wool staple is a promising avenue that offers frequent measurement intervals. Variation in FD observed along the wool staple is reflective of changes in nutrient supply and demand to the wool follicle in accordance with the sheep's interaction with its prevailing internal and external environment. In most production systems wool is harvested annually and therefore becomes an archive of these interactions over the previous 12 months. Importantly, wool is among the final stores of energy and protein in the body and unlike other tissue structures such as muscle and fat, resources accumulated in wool cannot be remobilised in times of nutritional deficits (Freer *et al.* 1997). This review will provide contextual background as to how FD variation along the staple has been measured and analysed in other applications. It will also discuss alternative methods of modelling and analysing FD variation. The paper concludes with a discussion of challenges and opportunities for refinement and validation of along-staple FD variation as a measure of resilience.

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MEASURING ALONG STAPLE VARIATION

Fibre diameter variations along staples can be assessed through a sampling technique called a fibre diameter profile (FDP). These profiles are created from repeat measures of average FD taken longitudinally and in sequence along the wool staple (Figure 1). The last 50 years have seen significant advances in the instrumentation used to measure FDP. Historically, FDPs were created by segmenting staples into snippets (2 or 5mm), individually measuring each snippet for FD and plotting the average FD against its relative position along the staple. The method was labour intensive which confined studies at the time to small numbers of animals or a reduced number of samples per staple (Brown *et al.* 2000). The commercialisation of OFDA2000 instrumentation in the early 2000's allowed FD variation along staples to be measured quickly and cheaply (Brims *et al.* 1999), and therefore on a scale sufficient to provide phenotypes for genetic evaluations. OFDA2000 generates profiles on entire, greasy or clean staples, typically at measurement increments of 5mm.

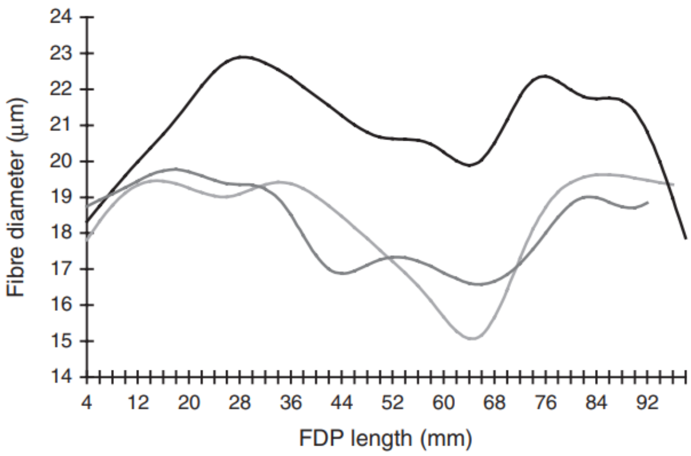

Figure 1. Example of fibre diameter profiles from three animals (Brown and Crook 2005)

GENETIC PARAMETERS OF FD VARIATION ALONG THE STAPLE

Traditionally, FD variation along the staple has been analysed as summary statistics including the minimum and maximum FD and along staple FD coefficient of variation (CV (%)) or standard deviation (SD (µm)), with the intent of investigating their relationships to staple strength. Minimum and maximum FD typically produces high to moderate heritabilities (0.47 to 0.68) (Greeff 2002; Preston and Hatcher 2013a). However, measures of variation (CV and SD) along the staple are inconsistent, ranging from 0.07 to 0.30 (Yamin *et al.* 1999; Greeff 2002; Preston and Hatcher 2013a). The latter two measures are most akin to a trait that reflects FD uniformity in response to environmental conditions throughout the year. However, both of these variation traits are potentially biased due to failures to account for the disparity of staple length between animals which influences the number of FD measures contained in the profile. Similarly, studies to date have not examined the phenotypic and genetic correlations between traits describing along staple FD variation and other important performance traits, with exception of wool quality characteristics (Greeff 2002; Preston and Hatcher 2013b). This is despite indications that reproduction, growth and health may account for some of the variation observed in the profile (Brown and Crook 2005; Gonzalez *et al.* 2020). Overall, these preliminary findings suggest that genetic variation exists for traits derived from FDP, however, for the purpose of examining resilience, further work should progress beyond summary characteristics from the FDP into more comprehensive measures of the variation over time.

POTENTIAL METHODS FOR ANALYSING ALONG STAPLE VARIATION

There are potentially many ways in which FD variation along the staple could be analysed for the purpose of examining resilience. FDP can be thought of as repeat records of FD made between two known time points. Animal breeding has several approaches for analysing longitudinal records, for instance the repeatability or multi-trait models. Perhaps the most appropriate method involves the fitting of curves to phenotypic values across time points and analysing the fitted parameters such as the slope and intercept. This may be considered optimal as it takes account of the genetic and environmental covariance structures between FD measured along the staple.

Random regression models (RRM) are among the most popular methods of analysing longitudinal data such as lactation or growth curves. RRM include a function nested inside the random effects which allows the variance components to vary along a trajectory (Schaeffer 2004). In animal breeding, this function is nested in the individual, thereby modelling the individual deviation from a fixed regression of the trait over time (Kolmodin 2002). RRM most commonly uses Legendre polynomials to fit the fixed and random regressions. The use of splines has also been advocated as an alternative to Legendre polynomials due to greater flexibility in fitting curves of arbitrary shapes (Meyer 2005), which is consistent with FDPs. The possibility remains to use the linear or curve components from RRM to determine the uniformity of animal performance across the trait trajectory, which may be interpreted as a greater ability to cope with environmental fluctuations.

Other studies on resilience have analysed deviations from longitudinal data in what is referred to as profile analysis, where deviations are calculated between reference and observed production curves (Colditz *et al. in press*). Reference curves are typically modelled based on individual or contemporary group means (Elgersma *et al.* 2018; Doekes *et al*. 2022). Statistical measures are then applied to describe the amount of deviation between the reference and observed curve including; natural log variance, skewness and lag-one autocorrelations of the deviation. Such indicators are typically shown to have heritability estimates ranging from 0.01 to 0.26 (Berghof *et al.* 2019; Poppe *et al.* 2020). Together, the performance of these methods of analysis of FD variation are yet to be determined, and each is likely to have merits and limitations.

DISCUSSION

Quantifying FD variation along the staple may offer a unique way of assessing resilience in Australian sheep. Many important questions however remain regarding the analysis and interpretation of such measures. Firstly, provided that genetic variation exists for traits describing along staple FD variation, what is a desirable amount of variation to select for, in regard to resilience? From the points raised above, it may seem that a uniform or relatively flat profile is desired, as the resilient animal is considered to defend the trait expression against the environment. However, conformity to this normative model may be explained by other factors such as inadequacy to perform other productive functions such as to rear a lamb, which is not necessarily desired. This highlights the necessity to examine both the phenotypic and genetic correlations between FD variation and other key performance traits, as well as the need to validate resilience indicators to ensure they are able to provide economic benefits in terms of better health, welfare or long-term productive outcomes.

It is also important to understand how the FD variation along staples performs both across life stages and under different environmental conditions (existence of G x E interactions). The absolute level of the FD variation shown in a contemporary group contains important information about the quality of the environment experienced. This information could not only be used to form an environmental gradient in a reaction norms analysis, but would also complement assessments of profile analysis. Other studies have shown that environmental conditions experienced during the development of young animals can have lasting consequences on the resilience of adult genotypes

(Parois *et al.* 2022). It would be extremely useful to be able to quantify such measures from FDP across years, in particular, with respect to the relationship between resilience measures and performance longevity.

Finally, it is important to remember that breeding for improved resilience to environmental fluctuations should not be interpreted as a means of "forcing" animals to endure less than optimal living or management conditions. This work merely seeks to form part of an integrated approach to helping both animals and producers achieve better production and health outcomes amidst the challenges of future farming systems.

CONCLUSION

The use of FD variation along staple as a way of quantifying the resilience of sheep remains under-explored and offers a research opportunity to inform whether genetic variation exists for such traits in Australian sheep populations. Further work is warranted to understand the most appropriate ways of analysing FDP data and the potential application of these measures in breeding programs.

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