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Indices for the identification of biologically productive cashmere goats within farms

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Short title: Effective clean cashmere weight
Abstract

Objectively comparing cashmere goats with different cashmere production, mean fibre diameter (MFD) and staple length (SL) is difficult for farmers. We aimed to develop indices to enable cashmere producers to identify productive goats within their own farms once adjustments had been made for the primary determinants of cashmere production. That is we aimed to develop indices that identify goats and herds that biologically have a high fleece weight in relation to MFD and SL. We used a sample of 1244 commercial cashmere fleeces from goats originating from many Australian farms based in different environmental zones and a previously developed general linear model that related the logarithm of clean cashmere production (CCMwt) and any other potential determinant. In the present study, sub-models were investigated in order to develop new indices for comparing goats in the same farm, based on fleece characteristics and biological efficiency. New Index (MFD), equal to \( \frac{6.02 \times \text{CCMwt}}{1.1531^{\text{MFD}}} \), was developed to identify animals of biologically high CCMwt in relation to their MFD. Unlike previously reported results that MFD is not a useful measurement for comparing the biological efficiency of cashmere goats across farms, the New Index (MFD) allows comparison of the biological efficiency of cashmere goats within farms. New Index (SL), equal to \( \frac{2.70 \times \text{CCMwt}}{1.1414^{\text{SL}}} \), was developed to identify animals of biologically high CCMwt in relation to their SL. New Index (SL) is very similar to the Clean Cashmere Staple Length Index (CCSLI) that had been previously reported for comparison of cashmere goats across farms, and thus the CCSLI can be usefully used for comparing the biological efficiency of cashmere goats both across and within farms. New Index (MFD, SL) = \( \frac{8.90 \times \text{CCMwt}}{1.243^{\left(\frac{\text{MFD}+\text{SL}}{2}\right)}} \) was developed to identify animals of biologically high CCMwt in relation to both their MFD and SL within farms, and provides useful information above using either New Index (MFD) or CCSLI. The indices can be presented in the same measurement units as fleece weight, which is a biological concept easily understood by cashmere
producers, and enable comparisons to be made between animals using just one attribute, clean cashmere weight.

Keywords: Cashmere; Evaluation; Farm; Fibre diameter; Productivity; Staple length
1. Introduction

The mean fibre diameter (MFD) is the primary determinant of the price of cashmere as it affects the processing route, processing efficiency and the ultimate use and quality attributes of cashmere textiles (Hunter, 1993; Schneider, 2014a). Other attributes are also important in affecting the price, processing, softness and quality of cashmere textiles including staple length (SL), fibre curvature (FC) and the colour of the cashmere (Watkins and Buxton, 1992; Dalton and Franck, 2001; McGregor 2000, 2014; McGregor and Butler, 2008a; McGregor and Postle, 2008, 2009).

The importance of MFD in affecting market demand for cashmere has led to a range of genetic studies on the inheritance of MFD and genetic improvement programs to reduce MFD in cashmere producing goats (Pattie and Restall, 1989; Bigham et al., 1993; Zhou et al., 2002; Tseveenjav et al., 2004; Younesi et al., 2008; Allain and Renieri, 2010; Wang et al., 2013). These developments have also led farmers to use the MFD of their cashmere to compare their goats both within and between farms. In Australia, cashmere farmers have compared the productivity of individual cashmere fleeces and stud breeding using the Patrick Index (Anonymous, 1989, 1990; Graham and Bell, 1990). The Patrick Index (PI = 4277.335 × [cashmere weight (g) / (MFD)$^{3.3}$]) was designed as a biological index that balanced the amount of fleece with the MFD of fleece. Two fleeces with the same PI should be equally difficult to produce. The PI is standardised to a MFD of 12.6 μm which it means that, at 12.6 μm, the PI equals the weight of clean cashmere.

In Australian, cashmere goats have been farmed in the western, southern and eastern regions of the continent. The determinants of cashmere production of commercially farmed Australian goats have been recently quantified (McGregor and Butler, 2008b,c) and research shows that cashmere production had not increased during the previous 25 years. The lack of improvement may be a consequence of the slow rate of progress predicted from selection studies, the cost of testing cashmere fleeces, or a lack of producer skills in undertaking the
genetic evaluation of animals. For example, when the generation interval was fixed at 4 years, Pattie and Restall (1984) predicted responses of 4 g of cashmere per year in the best system using a selection index maintaining MFD, and 12 g per year if MFD was allowed to increase 1.1 µm per generation. In such cases cashmere production should have increased by about 100 g over the intervening 25 years, but such progress was not evident.

McGregor and Butler (2008c) developed a relationship between clean cashmere production and other fleece characteristics using fleeces sourced from 11 Australian farms and showed that cashmere weight is related to a range of fleece measurements and to animal growth measurements. Further, once these fleece and growth measurements are taken into account there are no longer any age or sex cohort effects observable (McGregor and Butler, 2008b) thus indicating fleece characteristics and animal growth are primary determinants of cashmere production. Subsequently it has been shown that cashmere SL is important for comparisons between farms not the MFD of the cashmere. The use of a Clean Cashmere SL Index provided a more robust comparison of cashmere productivity between farms as it is an indirect indicator of desirable skin secondary follicle development (Butler and McGregor, 2014).

Australian cashmere growers have been unable to increase cashmere production when there are a multiple of ‘competing’ biological attributes to evaluate. How can farmers compare goats within their herds which display large variation in productivity, MFD and SL (e.g. goat producing 130 g of 14 µm versus 250 g of 17.5 µm cashmere)? We aimed to develop indices to enable cashmere producers to identify biologically productive cashmere goats within their own farm herds once adjustments had been made for the primary determinants of cashmere production. The resulting statistical models were used to develop new indices for effective clean cashmere weight, and to compare these indices with PI, and indices that have been developed for comparing cashmere goats between farms (Butler and McGregor 2014). The use of one term, effective clean cashmere weight, would allow farmers to focus genetic selection upon one parameter, rather than a diversity of parameters such as greasy cashmere weight, cashmere yield, MFD and SL, which may result in less selection
differential for each parameter and possibly less improvement in the selection of productive goats (Turner and Young 1969).

2. Materials and methods

2.1. Data

Fleece and live weight data were analysed from commercially managed cashmere goats from 11 farms in 4 States of Australia (Western Australia, Victoria, New South Wales and Queensland). Full details are provided elsewhere (McGregor and Butler, 2008c). At shearing, greasy fleece weight (g) was measured and fleeces were sampled. Cashmere fibre SL (cm) was measured to the nearest 0.5 cm. Fleece samples were sent to a commercial fibre-testing laboratory and measurements recorded for clean washing yield (CWY; %, w/w), MFD (µm), fibre diameter standard deviation (FDSD; µm), fibre curvature (FC; °/mm) and fibre curvature standard deviation (FCSD; °/mm). Clean cashmere yield (%) was determined as: clean washing yield × Optical Fibre Diameter Analyser (OFDA100) cashmere yield (determined using fibre diameter profiles (Peterson and Gheradi, 1996)). Clean cashmere production (g) was determined as: $\text{CCMwt} = \text{greasy fleece weight} \times \text{clean cashmere yield}$. Live body weight (LW; kg) was measured and LW change (LWC; kg) was determined as the difference between the Initial LW (taken in January; kg) and the final LW in June.

2.2. Statistical analysis

McGregor and Butler (2008c) developed a general linear model with normal errors to determine the relationship between the logarithm of clean cashmere production and any other potential determinant. The form of this model was:
\[
\log_{10}(\text{CCMwt}) = \alpha + \beta_1 \text{MFD} + \beta_2 \text{FDSD} + \beta_3 \text{FC} + \beta_4 \text{FCSD} + \beta_5 \text{SL} + \beta_6 \text{CWY} + \\
\beta_7 \text{LWC} + \beta_8 \text{InitialLW} + \beta_9 (\text{FDSD} \times \text{FC})
\] (1)

where the parameters \( \alpha, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6 \) and \( \beta_7 \) differed between farms, the parameters \( \beta_8 \) and \( \beta_9 \) were the same for all farms, and \( \alpha, \beta_3, \) and \( \beta_4 \) also differed for 2-year-old goats on farm 7. According to McGregor and Butler (2008c), this model accounted for 67.6% of the variation of \( \log_{10}(\text{CCMwt}) \). Least squares models that included \( \alpha \) differing with farm, \( \alpha, \beta_3 \) and \( \beta_4 \) differing with 2-year-old goats on farm 7 and either (i) prescribed subsets of the other ‘\( \beta \)’ parameters in model (1) but not allowing those parameters to differ with farm, or (ii) prescribed subsets of the ‘\( \beta \)’ parameters in model (1) but allowing those parameters to differ with farm if they differed with farm in model (1) were fitted and compared using percentage variance accounted for (Payne, 2012). Models in option (i) can be described as having an additive effect of farm, while models in option (ii) can be described as having different responses for each farm. All these models are calculated with the separate terms for 2 year old goats from Farm 7 being a priori included in the models because they are considered to be an anomalous group of animals \((n=25)\) (McGregor and Butler, 2008c). They have been included in the analysis to improve the precision of the estimates of residual variance. Percentage variance accounted for were calculated compared to both a null model (the standard calculation) as well as compared to a model that had only a farm effect. The second of these calculations is appropriate for evaluating the contribution of effects within farms.

These models were used to develop and examine biological indices (effective clean cashmere weight indices) that balance the amount of fleece with the quality of fleece. For MFD we used the same standard MFD (MFD\(_s\)) as the PI, namely 12.6 \( \mu \)m (noting that the standard MFD is defined as the MFD when the PI equals CCMwt). Thus indices were developed so that at 12.6 \( \mu \)m, PI = effective clean cashmere weight indices = CCMwt. In developing indices we used the typical SL of 7.5 cm for low MFD cashmere (12.6 \( \mu \)m; McGregor and Butler, 2008b,c) as the standard for SL (SL\(_s\)).

3. Results
3.1. General results

Irrespective of whether farm is included as an additive effect or whether there is a separate response for each farm the most important measurements for maximising the variance accounted for were MFD and SL (Table 1). Models involving MFD and SL that restrict the farm effect to being additive, are not much worse than those models that allow separate MFD and SL coefficients for each farm. That is, if MFD and/or SL are measured, there is little benefit in having the responses of CCMwt to MFD and SL calibrated separately for each farm (Table 1). It turns out that all these models also have additive terms for MFD and/or SL.

3.2. Indices for comparing goats within farms

The relative costs of measuring MFD and SL will differ depending on situation. In a developed economy, measuring SL can be relatively expensive because of the labour involved in measurement. MFD requires either laboratory measurement or field equipment, which may involve prohibitive costs to many farmers in developing countries. We have thus chosen to develop indices that are derived from (i) an additive model involving only farms and MFD, (ii) an additive model involving only farms and SL, and (iii) an additive model involving farms, MFD and SL.

3.2.1 MFD index

The least squares additive model involving only farms and MFD is:

\[
\log_{10}(CCMwt) = \alpha + 0.06187 \times (MFD - MFDS); \quad (2)
\]

where the intercept \( \alpha \) differs with farm.

Since \( MFDS = 12.6 \), this implies that \( CCMwt = 10^{\alpha} \times 10^{0.06187 \times (MFD - 12.6)} \).
Thus within any farm, CCMwt is proportional to:

\[ 10^{0.06187 \times (MFD - 12.6)} = 1.1531^{(MFD - 12.6)} \]

Noting that this constant of proportionality is 1 at the standard MFD, it is appropriate to adjust clean cashmere weight for MFD by a factor

\[ \frac{6.02 \times CCMwt}{1.1531^{MFD}} \]

Thus, the New Index (MFD) = \( \frac{6.02 \times CCMwt}{1.1531^{MFD}} \) \hspace{1cm} (3)

3.2.2 SL index

The least squares additive model involving only Farms and SL can be written as:

\[ \log_{10}(CCMwt) = \alpha + 0.05742 \times (SL - SLS) \]

where the intercept \( \alpha \) differs with farm.

Thus within any farm, CCMwt is proportional to:

\[ 10^{0.05742 \times (SL - 7.5)} = 1.1414^{(SL - 7.5)} \]

Noting that this constant of proportionality is 1 at the standard SL, it is appropriate to adjust clean cashmere weight for SL by a factor \( \frac{2.70 \times CCMwt}{1.1414^{SL}} \).

Thus, the New Index (SL) = \[ \frac{2.70 \times CCMwt}{1.1414^{SL}} \] \hspace{1cm} (4)

3.2.3 MFD and SL combined index

The least squares additive model involving only Farms, MFD and SL can be written as:

\[ \log_{10}(CCMwt) = \alpha + 0.04848 \times (MFD - MFD_3) + 0.04453 \times (SL - SLS) \] \hspace{1cm} (5)

where the intercept \( \alpha \) differs with farm.

Thus within any farm, CCMwt is proportional to:

\[ 10^{0.04848 \times (MFD - 12.6) + 0.04453 \times (SL - 7.5)} = 1.1181^{(MFD - 12.6)} \times 1.1080^{(SL - 7.5)} \approx 1.115^{MFD + SL} \].
Noting that this constant of proportionality is 1 at the standard SL and MFD, it is appropriate
to adjust CCMwt for MFD and SL by a factor

\[
\sqrt[1.115]{(MFD - 12.6) + (SL - 7.5)} = \frac{8.90}{1.243^{(MFD+SL)/2}}.
\]

Thus, the New Index (MFD, SL) = \[\frac{8.90 \times CCMwt}{1.243^{(MFD+SL)/2}}\] (6)

3.3. A comparison of New Index (MFD) and Patrick’s Index (PI)

The New Index (MFD) = \[\frac{6.02 \times CCMwt}{1.1531^{MFD}}\], and PI = \[\frac{4277.335 \times CCMwt}{MFD^{3.3}}\]. At a fixed
MFD, both these indices are proportional to CCMwt. Also, both indices equal CCMwt at a
MFD of 12.6 \(\mu\)m. Thus it is sensible to graph both \[\frac{\text{New Index (MFD)}}{CCMwt}\] and

\[\frac{\text{Patrick’s Index}}{CCMwt}\] against MFD, so as to compare their sensitivity to MFD. The relationship
between the New Index (MFD), the PI and CCMwt are shown in Fig.1.

Clearly, while the New Index (MFD) is sensitive to MFD, it is considerably less so than
PI. Fig. 1 shows the correction factor used to convert CCMwt to effective clean cashmere
production at a range of fibre diameters. Therefore, with the New Index (MFD), for each 100
\(g\) of cashmere production at 12.6 \(\mu\)m, cashmere production must be equal to 140 \(g\) at 15.0 \(\mu\)m
(100/0.71 \(\approx\)140), 160 \(\mu\)g at 16 \(\mu\)m (100/0.62 \(\approx\) 160) and 200 \(\mu\)g at 17.5 \(\mu\)m (100/0.50 \(\approx\) 200). In
comparison, the corresponding values with the PI are 180 \(\mu\)g at 15.0 \(\mu\)m (100/0.56 \(\approx\)180), 220
\(\mu\)g at 16 \(\mu\)m (100/0.45 \(\approx\) 220) and 300 \(\mu\)g at 17.5 \(\mu\)m (100/0.34 \(\approx\) 300).

3.4. A comparison of New Index (SL) and Clean Cashmere Staple Length Index.

10
The New Index (SL) = \( \frac{2.70 \times CCMwt}{1.1414^{SL}} \), and is for use within farms. McGregor and Butler (2014) defined the Clean Cashmere Staple Length Index (CCSLI) for use between farms, as \( CCSLI = \frac{2.823 \times CCMwt}{1.1484^{SL}} \).

At a fixed SL, both these indices are proportional to CCMwt. Also, both indices equal CCMwt at a SL of 7.5 cm. Thus it is sensible to graph both \( \frac{New \ Index \ (SL)}{CCMwt} \) and \( \frac{CCSLI}{CCMwt} \) against SL, so as to compare their sensitivity to SL. The relationship between the New Index (SL), the Clean Cashmere Staple Length Index and CCMwt are shown in Fig. 2. Clearly, the New Index (SL) and CCLSI are almost identical.

4. Discussion

New indices have been formulated to enable the biological comparison of animals within farms using the main economic parameters, namely cashmere weight, MFD and SL. The indices can thus be considered as an ‘effective clean cashmere weight’ that enables the relative performance of animals, of different ages and sexes to be compared. These indices appear to have four advantages.

1. The indices relate to biology rather than market prices and thus are stable over time. For many cashmere attributes, market price discounts and premium are not available for cashmere attributes evaluated by farmers, such as cashmere yield and cashmere SL and so these cashmere attributes cannot be used in economic indices to compare cashmere goats.

2. The indices can be presented in the same measurement units as fleece weight, which is a biological concept easily understood by cashmere producers.

3. The indices enable comparisons to be made between animals using just one attribute, clean cashmere weight and so may enable selection between animals to be more effective; and

4. The indices are simple to determine and apply with computer managed spreadsheets.
The New Index (SL) developed to compare animals within farms is almost identical to the CCSLI which was developed to compare animals across farms. This implies that a single index based on SL is applicable to both between and within farms.

The percent of variation accounted for by MFD within farms (23%) is almost identical to the percent of variation accounted for by SL within farms (22%). This indicates that New Indices based on MFD and SL are almost equally effective for evaluating the biological efficiency of animals within a flock. This indicates that where testing for MFD is either not available or is too expensive, that farmers can measure SL and obtain similar results.

However, Butler and McGregor (2014) found that MFD was very poorly related to CCMwt across farms (MFD accounted for 2% of the variation of CCMwt), and consequently MFD cannot be used to assess biological efficiency of animals when comparing animals across farms.

Within a flock, combining MFD and SL together explains much more of the within flock variability (35%) than either MFD (23%) or SL (22%). Thus New Index (MFD, SL) can use MFD and SL together to provide considerable more information about biological efficiency of animals, than can be obtained from measuring MFD or SL alone. There appears to be considerable advantage in assembling the resources to measure both MFD and SL when evaluating animals within a farm.

In contrast, the extra effects of measuring FDSD, FC, FCSD, CWY appear to be minor (Table 1). The results also suggest this is true for live weight measurements. However, some caution is needed with this conclusion for live weight measurements because the live weight measurements may be related to the amount of feed consumed, to reproductive performance and the financial return from meat production and these direct contributors to productivity are not part of the present analysis.

Indices based on biological productivity might not be the same as traditional selection indices based on historic price differentials for MFD and SL. A difficulty of traditional selection indices is that premiums for MFD and SL may not be stable over time. In fact, MFD and SL premiums over the long-term might be endogenous to biological productivity, in that
market forces might lead to premiums for MFD that maintain a similar total fleece value for all cashmere goats with the same biological productivity. This appears to be the case with Merino wool over the past decade where production of finer wool has dampened the relative premium for finer wool (Schneider, 2014b). Of course this endogenicity is limited by the existence or creation of markets for premium cashmere textiles at all fibre diameters. In other words, the price discount curve for animal fibres will reflect the scarcity of the product, and in the long-term a competitive market will ensure that scarcity is related to the biological resources needed in producing the cashmere.

At a fixed MFD, the ratio of the New Index (MFD) to clean cashmere weight is different to the ratio of the PI to clean cashmere weight (Fig. 2). The PI was determined on the fleeces submitted to the National Fleece Competition during the early years of the Australian cashmere industry. It can be expected that the fleeces submitted were more productive than the population mean, as it would be expected that producers would choose fleeces to win a particular competition. Consequently there is no way of knowing what biases exist in the sample used to determine the PI. The PI also has the disadvantage that there is no adjustment for attributes other than MFD.

The present results suggest that the PI appears to discriminate against coarser fleeces compared with finer fleeces. A consequence of this discrimination would be the likelihood that farmers would place more emphasis on finer MFD, compared with the production of clean cashmere, than is warranted by biological efficiency as determined by the New Index (MFD). If this scenario has played out over the past decades it may help explain why there has been little progress in improving clean cashmere fleece weights over this period (McGregor and Butler 2008b).

Of course equivalence in the biological production of cashmere is not the same as economic equivalence and so in any breeding program economic indices would be preferable if they were to exist. Unfortunately there are no detailed marketing data to enable economic indices for cashmere length, cashmere yield and other parameters of importance.
5. Conclusions

Effective clean cashmere production indices provide cashmere farmers with the ability to make biological comparisons that are adjusted for the main determinants of cashmere growth, rather than using subjective methods of identifying more productive goats. The results suggest that a single index based on SL is applicable to both between and within farms identification of more productive cashmere goats. There appears to be considerable advantage in assembling the resources to measure both MFD and SL when identifying animals that efficiently produce clean cashmere within the same farm.

Conflict of interest statement

None of the authors has a financial or personal relationship with other people or organisations that could inappropriately influence or bias this paper.

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6. References


Fig. 1. The ratio of New Index (MFD) (solid line) or Patrick Index (dashed line) to clean cashmere production at different cashmere mean fibre diameters. Values for each Index are standardised to a mean fibre diameter of 12.6 μm where the indices always equals the weight of clean cashmere and the ratio between the Patrick Index and the weight of clean cashmere equals 1. The indices diverge as mean fibre diameter increases. Using the Patrick index, a fleece with a fibre diameter of 15.6 μm will need to have twice the clean cashmere weight as a fleece with a fibre diameter of 12.6 μm to attain the same index value. This compares with the New Index (MFD) where a fleece with a fibre diameter of fibre diameter of 17.4 μm will need to have twice the clean cashmere weight as a fleece with a fibre diameter of 12.6 μm, to attain the same index value.
Fig. 2. The ratio of New Index (SL) (dashed line) or Clean Cashmere Staple Length Index (solid line) to clean cashmere production at different cashmere staple lengths. Values for each Index are standardised to a mean staple length of 7.5 cm where the value of both indices always equals the weight of clean cashmere. Using these indices, a fleece with a 12.5 cm staple length will need to have twice the clean cashmere weight as a fleece with a staple length of 7.5 cm, which in turn will need to have twice the clean cashmere weight as a fleece with a staple length of 2.5 cm, to attain the same index value.
Table 1

Variance in the logarithm of clean cashmere weight accounted for by terms involving age, fibre diameter (mean, MFD; SD, FDSD), staple length (SL), fibre curvature (FC, FCSD), and other measurements (clean washing yield, initial live weight, live weight change) but either (i) including an additive effect of farm or (ii) including a different response for each farm. All values are calculated with the separate terms for 2 year old goats from Farm 7 being *a priori* included in the models.

<table>
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<th>Terms in model</th>
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<th>Percentage variance accounted for</th>
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<td><em>(i) Models with additive effect of farm</em></td>
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<tr>
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<tr>
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<td>MFD + SL + Farm effect</td>
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*Except for terms involving 2 year old goats from Farm 7.