# STRAIN COMPARISONS AND GENETIC PARAMETERS FOR CASHMERE GOATS

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## SUMMARY

The large differences in productivity which exist between strains of cashmere goats are summarised in this paper, and approaches for choosing appropriate genotypes are discussed. Evidence is presented that there is little useful heterosis for fibre production traits, however heritabilities for these traits are consistently high, with most estimates being in excess of 0.5 for cashmere weight and fibre diameter, the two most important traits. These two traits are unfavourably correlated however. The impact of these genetic parameters on the genetic improvement of cashmere goats is considered.

## INTRODUCTION

Cashmere is the undercoat, or down, produced from the secondary fibre follicles by a wide variety of goats, loosely termed "cashmere" goats. To be marketed as cashmere, the fibre must generally have a mean diameter less than 18.5μ. Although the description "cashmere" goat was originally used for goats originating from Kashmir, it is now used generally to describe any goats which produce cashmere meeting the market specifications. The biological role of cashmere is for thermal insulation, as opposed to the physical protection role of the primary follicle fibres, hence the general observation that cashmere goats are generally found in areas which experience harsh winters. The growth of cashmere is correspondingly seasonal, normally being confined to the period between the summer and winter solstices, with moulting occurring before the initiation of the next growth phase.

The majority of the world's cashmere production currently originates from China and Mongolia, however, most of the processing of cashmere currently takes place in Europe, especially in the UK. The production of cashmere, as an alternative but complementary enterprise to sheep production, has in recent years been investigated in Australia, New Zealand and the UK, with the latter attempting to exploit the home market for cashmere. The genetic problems facing a cashmere goat industry are twofold. Firstly, the identification of appropriate genotypes and, secondly, the definition of optimal selection objectives for the genetic improvement of the chosen genotype. This paper considers both the choice of genotype, or strain, and the subsequent genetic improvement of this genotype.

The value of cashmere is a function of several variables, the most important being fibre quantity and fibre diameter. Fibre diameter is the primary measure of fibre quality, with fine cashmere being more valuable. Other traits of importance include colour (white fibre is more valuable), fibre length, yield (i.e. the proportion of the fleece that is cashmere), contamination, "handle" and "lustre". Non fibre traits of importance include meat production, kidding rate and survival rate. For the choice of genotype, this paper will concentrate on fibre quantity and quality, but for the section on genetic improvement it will widen its scope to include other traits of possible importance.

## STRAIN COMPARISONS

Published reports on the productivity of cashmere goats are available from the main cashmere producing regions of Asia, as well as Australia, New Zealand and, more recently, the United Kingdom. A comprehensive summary of the performance of goats from Asia, including China, Mongolia, Siberia and Kirgizia is given by Millar (1986). Although many key details are often missing in these reported results, e.g. sample size, age of animals, sex, etc, several broad conclusions may be drawn. For example, the cashmere goats from the former Soviet Union tend to have a high productivity, often producing in excess of 500g/year of cashmere, but many of the reports indicate that fibre diameter is very coarse, well in excess of 20μ, and hence not marketable as cashmere. Many of the Chinese and

Mongolian breeds of cashmere goat produce cashmere of a much higher quality, less than 16μ, but much smaller quantities - usually between 100 and 300 g/year. Exceptions to this are the Liaoning and Xinjiang breeds which are reported to produce up to 500 g/year of cashmere which is between 15 and 17μ. More recently, the AErBaSi breed has been reported to produce between 400 and 600 g/year of 14.5μ cashmere (Shaoqing, 1994).

Published reports on the productivity of cashmere goats in Australia, New Zealand and the U.K. are shown in table 1. The cashmere goats from Australia and New Zealand tend to be of feral origin and, with the exception of those with Angora infusion, the fibre diameter is relatively fine but the total production is low. In marked contrast are the results reported for goats of Siberian origin by Bishop and Wray (1993). These goats were very productive, producing in excess of 500 g/year as yearlings, but this was very coarse cashmere and unlikely to be acceptable to manufacturers.

Table 1. Productivity of cashmere goats in Australia, New Zealand and the United Kingdom

| Source | Category | n | Cashmere Production (g) | Fibre Diameter (μ) |
|---|---|---|---|---|
| Baker *et al* (1991) (feral) | Yearlings | 623 | 93 | 15.8 |
| Bigham *et al* (1993) (feral) | Kids | >260 | 37 | 15.1 |
| | Yearlings | >800 | 71 | 15.8 |
| Couchman & Wilkinson (1988) (feral with Angora infusion) | Yearlings | 375 | 133 | 15.4 |
| | Adult males | 16 | 339 | 18.3 |
| | Adult females | | 163 | 16.9 |
| Eady *et al* (1988) (feral) | Yearling females | 91 | 73 | 17.1 |
| | Kid females | c. 70 | 95 | 16.7 |
| | Kid males | c.100 | 135 | 16.9 |
| Restal & Pattie (1989) (feral) | Mixed age females | 586 | 75 | 15.5 |
| | Mixed age males | 583 | 79 | 15.5 |
| Bishop & Wray (1993) (Siberian - Gorno Altai) | Kid females | 44 | 462 | 18.2 |
| | Kid males | 62 | 414 | 18.5 |
| | Yearling females | 43 | 606 | 19.6 |
| | Yearling males | 23 | 577 | 19.9 |

None of the studies described so far has afforded the opportunity to compare contrasting genotypes under identical conditions. The only study which appears to have done this is described by Bishop and Russel (1994), which will be summarised here. In this study, cashmere goats were imported into Scotland from Iceland (I), Tasmania (T), New Zealand (N) and Siberia (S), and compared in a crossbreeding programme alongside Scottish feral (F) goats. Kids in this trial were evaluated on the basis of 10 $cm^2$ mid-side patch fleece samples taken at 5 months of age, on which a number of measurements were taken, including cashmere weight and fibre diameter. Estimated annual cashmere production (EAP) was calculated by relating skin area of the animal to liveweight (see Couchman and McGregor, 1983) and assuming that 0.40 of total adult annual cashmere production is present in 5 month old kids. Thus, cashmere production from this trial was predicted, as opposed to directly measured as in the studies mentioned above. Data was gathered on a total of 827 kids of both sexes and a large variety of genotypes, including purebred kids, two-, three- and four-way crosses. The F, I, N, T and S lines contributed 0.28, 0.19, 0.10 and 0.16 of the genes of the sampled kids, respectively.

Residual maximum likelihood (REML) techniques were used to calculate genotype means for each trait, which in turn were used to calculate line means (F, I, T, N and S) and heterosis effects for all two-way crosses, where heterosis was defined as the difference between a two-way cross mean and the two parental line means, assuming no epistatic interactions between loci. Solutions for all line means and heterosis effects were calculated using Generalised Least Squares. Line means for fibre diameter, cashmere in the patch sample, EAP and live weight are shown in table 2. Huge variation was apparent between the evaluated lines, especially for the quantity of cashmere in the patch sample and EAP. These results follow the trends observed in previously published reports, with the Siberian goats having high production of coarse fibre and feral goats producing small quantities of fine fibre.

Table 2. Line means (and s.e.s) for cashmere goats kids from different sources

| Source: | Feral | Iceland | Tasmania | New Zealand | Siberia |
|---|---|---|---|---|---|
| Fibre Diameter (μ) | 13.8 (0.82) | 14.0 (0.41) | 16.1 (0.35) | 16.6 (0.49) | 18.0 (0.50) |
| Cashmere in patch sample (g) | 0.107 (0.063) | 0.087 (0.031) | 0.234 (0.027) | 0.280 (0.038) | 0.475 (0.043) |
| Estimated annual production (g) | 37 (71.3) | 91 (31.7) | 227 (28.1) | 275 (42.5) | 579 (44.7) |
| Liveweight at 5 months (kg) | 15.7 (2.16) | 17.7 (0.93) | 16.4 (0.83) | 16.5 (1.28) | 21.9 (1.28) |
| Cashmere Production Index[1] (g) | 50 | 118 | 199 | 213 | 293 |

1. See below for description of this trait

Heterosis effects were estimable for all combinations of two-way crosses, however many of these effects had very large standard errors. It was also observed that the N and T lines were similar both in terms of their productivity and their heterosis trends, and they also showed minimal heterosis with each other. Therefore, to get biologically more meaningful results, all heterosis effects reestimated after recoding the N and T lines to be the same genotype. This reduced the number of heterosis effects for each trait from 10 to 6 and, hence, increased the precision of each estimate. These heterosis effects are shown in table 3. The heterosis effects for fibre diameter and cashmere in the patch sample are, in general, small in relation to their standard errors. For live weight, however, there are several large and significant effects, especially for crosses involving either the feral or Icelandic lines. As a result, EAP shows large heterosis effects, although these are also accompanied by large standard errors and only the FxI and IxN/T crosses show significant effects. Interestingly, the Icelandic goats were sampled from a very small and inbred population.

Mean values for individual traits, alone, do not indicate which lines or crosses are the most valuable. Bishop and Russel (1994) derived a descriptive index, the Cashmere Production Index (CPI), for this purpose as follows: CPI = EAP x (1 + k x (fibre diameter - mean fibre diameter)), where k describes the price differential paid per unit decrease in fibre diameter, relative to the average market price. Both the price values presented by MacLeod (1988) and the 1991 UK prices indicated a k value of -0.2. CPIs for the lines described by Bishop and Russel (1994) are shown in table 2, assuming a mean fibre diameter was 15.5µ. Although the S line is still the highest ranking, its advantage has been reduced considerably. Crude CPIs can also be calculated for other lines of goats mentioned above, with the caveat that these figures are very approximate because of the differences in husbandry, ages and measurement techniques between each study. Of the studies reported from Australia and New Zealand, probably only the feral goats with an Angora infusion reported by Eady *et al* (1988), are comparable to those described by Bishop and Russel (1994), even after allowing for the commonly observed increase in fibre diameter with age. Some of the reported Chinese breeds appear to be markedly superior to those described by Bishop and Russel (1994), however. For example, even ignoring age effects on fibre diameter, the Liaoning, Xingjiang and AErBaSi breeds would appear to have CPIs close to 400, 500 and in excess of 600 g, respectively.

Table 3. Heterosis effects (and s.e.s) between lines of cashmere goat kids from different sources[1]

| | FxI | FxN/T | FxS | IxN/T | IxS | N/TxS |
|---|---|---|---|---|---|---|
| Fibre Diameter (µ) | 0.72<br>(0.51) | 0.53<br>(0.47) | 0.01<br>(0.53) | -0.09<br>(0.29) | 0.18<br>(0.60) | -0.73<br>(0.52) |
| Cashmere in patch sample (g) | 0.051<br>(0.040) | 0.034<br>(0.036) | **-0.087**<br>(0.043) | 0.031<br>(0.021) | 0.025<br>(0.047) | 0.023<br>(0.041) |
| Expected Annual Production (g) | **100.8**<br>(43.7) | 76.1<br>(41.0) | -89.9<br>(58.5) | **72.9**<br>(23.9) | 19.0<br>(67.5) | 0.1<br>(64.4) |
| Liveweight (kg) | **4.38**<br>(1.30) | **3.20**<br>(1.23) | -0.25<br>(1.66) | **4.14**<br>(0.75) | 1.59<br>(1.86) | -1.14<br>(1.73) |

1. Heterosis effects larger than twice their standard error are shown in bold type.

Two additional factors affecting the choice of genotype, in fibre production terms, are the fibre colour and the stability of the ranking of the genotype to fluctuations in the premium paid for high quality cashmere, which is a measure of risk. White fibre colour is thought to be controlled by a single dominant allele, and in the lines described by Bishop and Russel (1994) this allele is present in the T and N lines, some of which produce white cashmere, but not in the other lines. This decreases the relative advantage of the S line, compared to the T and N lines. Rescaling the CPIs, assuming that white fibre commands a 36% price advantage (from 1991 UK prices) and also that half of the goats in the T and N lines produce white fibre, then the CPIs for the F, I, T, N and S lines were 44, 102, 215, 232 and 227g, respectively. The susceptibility of genotypes to changes in the price differential ratio is proportional to EAP x (fibre diameter-mean) and as such changes in k will affect high producing but coarse fibred genotypes more. The effects of altering k on the ranking of lines is discussed in detail by Bishop and Russel (1994). In summary, assuming that future market trends favour higher quality fibre in the future, then high producing genotypes with coarse fibre may not represent a prudent choice for future breeding purposes.

The study reported by Bishop and Russel (1994) also investigated the productivity of various two- and three-way crosses, constructing the mean values for each cross from the constituent line means and heterosis effects. It was found that no single cross stood out as being superior, however there were several crosses which had CPIs similar to the S line, but had the additional advantage of potentially producing white fibre as well as being less susceptible to fluctuations in market prices. Because of this observation, and also because little desirable heterosis was expressed between the higher producing lines, it was concluded that future genetic improvement of this population should concentrate on selecting animals of high merit, irrespective of their genetic background.

## GENETIC PARAMETERS

Published heritability values for various production traits of interest are shown in table 4. These values represent a mixture of age groups. In general, all the fibre traits appear to be strongly inherited, with the values for live weight being similar to those for other species. All published studies also show the fibre traits to be consistently strongly positively correlated with each other, a result implied by the line comparisons tabulated above. Especially important is the strong correlation observed between cashmere weight and fibre diameter, which arises from the fact that weight is proportional to $(\text{diameter})^2$ x fibre length x no. of follicles. Correlations between fibre traits and live weight tend to be weak and negative.

Table 4. Published heritability values for cashmere goats

| | Fibre Diameter | Cashmere Weight | Yield | Fibre Length | Diameter Std. Dev. | Live Weight |
|---|---|---|---|---|---|---|
| Pattie & Restall (1989) | 0.47 | 0.61 | 0.90 | 0.70 | - | 0.29 |
| Bigham *et al* (1993) | 0.99 | 0.62 | 0.57 | 0.57 | 0.49 | 0.39 |
| Baker *et al* (1991) | 0.79 | 0.45 | 0.52 | - | - | 0.22 |
| Couchman & Wilkinson (1988) | 0.68 | 0.38 | 0.30 | - | - | - |
| Gifford *et al* (1990) | 0.70 | 0.36 | 0.23 | - | - | 0.26 |

Genetic parameters for the population described by Bishop and Russel (1994) were calculated using derivative-free REML techniques. As well as known fixed effects, genetic groups were also included in the model to account for the diverse genetic background of the goats, as well as the heterosis effects. Ten genetic groups were coded, viz the 5 pure lines, the 4 crosses with the feral line, with all remaining goats in the last group. Traits analysed included live weight, EAP, cashmere weight in the patch sample, fibre diameter, the standard deviation of the fibre diameter and fibre length, of which EAP, cashmere weight in the patch sample, fibre diameter, the standard deviation of the fibre diameter were log transformed prior to analyses. The results for fibre length should be treated with caution, as only a small number of animals had this measurement taken, and no animals had both fibre length and yield recorded.

The genetic parameters calculated are shown in table 5. Ignoring genetic group inflated the heritability estimates by between 0.01 and 0.04. The heritabilities for the fibre production traits are of a similar magnitude to those summarised in table 4, however the heritability for live weight is high, compared to previous published values. It is possible that preferential treatment of cohorts of kids sired by bucks that were perceived to be superior, e.g. S line bucks, occurred on some commercial farms. This result will be reevaluated as more data on these goats becomes available. The correlations show the strong relationships between EAP and each of the fibre traits which jointly define total fibre weight, i.e. fibre length, fibre diameter and fibre yield. The genetic correlation between EAP and Diam is especially strong, as expected. Noticeable is the lack of relationship between live weight and EAP, considering that EAP is calculated as a multiplicative function of live weight. Suffice it to say that the genetic and phenotypic correlations presented here are all of a similar magnitude to previously published values.

Table 5. Genetic parameters for production traits for Scottish cashmere goats

| | Live Weight | EAP | Fibre Diameter | Patch sample Cashmere | Yield | Diameter Std. Dev. | Fibre Length |
|---|---|---|---|---|---|---|---|
| Liveweight | 0.67 (.13) | -0.03 | -0.01 | -0.29 | -0.27 | -0.25 | n.e.[2] |
| Expected annual production | 0.18 | 0.56 (.07) | 0.80 | 0.92 | 0.77 | 0.49 | 0.60 |
| Fibre Diameter | 0.15 | 0.52 | 0.54 (.08) | 0.79 | 0.46 | 0.69 | 0.76 |
| Patch sample cashmere | -0.14 | 0.94 | 0.49 | 0.55 (.06) | 0.87 | 0.52 | 0.27 |
| Yield | -0.22 | 0.64 | 0.36 | 0.74 | 0.84 (.06) | 0.45 | |
| Diameter standard dev. | 0.00 | 0.21 | 0.52 | 0.21 | 0.19 | 0.33 (.08) | 0.60 |
| Fibre Length | n.e. | 0.48 | 0.34 | 0.43 | | -0.03 | 0.53 (.25) |

1. Heritabilities on the diagonal, phenotypic correlations below and genetic correlations above.
2. correlation not estimable

These genetic parameters can be used in selection indices to improve the profitability of cashmere production. Defining the selection objective as overall productivity of a herd of goats, using genetic parameters described above and calculating economic weights in the standard way, the traits of EAP, fibre diameter, live weight and kidding rate were found to contribute 83.7, 6.8, 1.1 and 0.8%, respectively, of the overall genetic gain. Similarly, Ponzoni and Gifford (1990) found relative contributions of 56.0, 33.4, 0.1 and 0.4%, respectively, for the equivalent traits, indicating that non fibre traits contribute little to the index. For simplicity, the selection objective for genetically improving cashmere goats may, therefore, be restricted to improving the value of fibre produced per animal. Independently measured traits in the Scottish goats which may be included in the index are fibre diameter, EAP, fibre length and diameter standard deviation. The contribution of diameter standard deviation to the index was found to be negligible and that of fibre length small, although this effect altered dramatically with small changes in the genetic correlation assumed with EAP.

The impact of various selection objectives when the index is restricted to cashmere weight (i.e. EAP) and fibre diameter is considered in more detail, here, with selection objectives including fibre diameter, cashmere value and cashmere weight. Responses to selection on such indices are shown in figure 1, for a selection intensity of $i$=1. Predicted responses to selection for cashmere value are indicated by the open circle, and the values marked by shaded diamonds show incremental 10% decreases in the relative economic values for EAP (to the left) and fibre diameter (to the right). The effects of selection designed solely to increase EAP or to decrease fibre diameter are indicated by the points at the right and left of the figure, respectively. When selection is designed to increase cashmere value, the impact of reducing the relative economic value for fibre diameter is small. However, if the importance of fibre weight has been overestimated the impact on the responses to selection in these two traits can be seen to be dramatic.

Figure 2 shows the impact of altering the selection objectives on the correlation between the index and the aggregate genotype, i.e. the accuracy of the selection index. The points marked on this figure correspond to the same points on figure 1. Pushing the selection objective away from cashmere value towards cashmere weight substantially increases the accuracy of the index. The accuracy of the index is minimised by reducing the relative economic value for EAP by 30%, i.e. this is the index which will be least effective in jointly improving EAP and fibre diameter, and this point corresponds on figure 1 to a small increase in EAP and a small decrease in fibre diameter. Effectively what is being observed in figure 2 is the impact of the strong, unfavourable, genetic correlation between fibre diameter and EAP which limits the genetic progress that can be made simultaneously in both traits.

Fig. 1. Joint responses to selection for fibre diameter and estimated annual cashmere production (EAP)

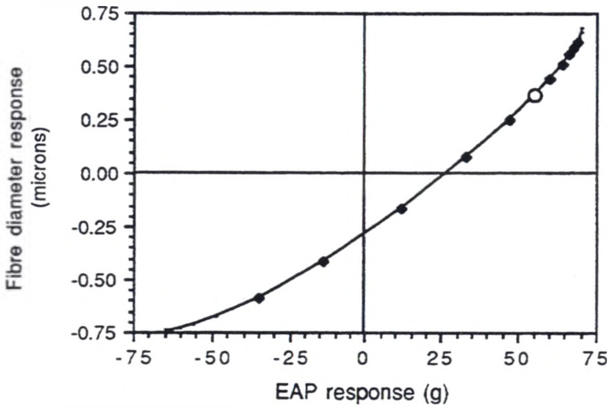
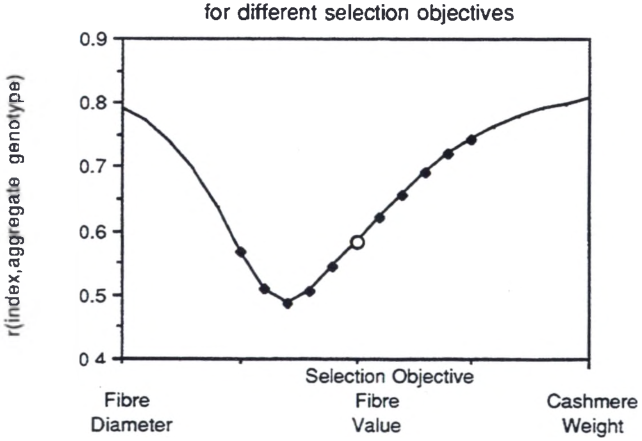



Fig. 2. Correlation between index and aggregate genotype for different selection objectives



## CONCLUSIONS

The results presented above indicate that substantial variation exists between genotypes for all aspects of fibre production, although identifying and obtaining the appropriate genotype for any production situation may prove more problematic. Despite the diverse origins of the goats producing cashmere, the evidence available indicates that there may be little heterosis for fibre production traits, a result perhaps explained by the strong additive genetic control of these traits. The growing body of genetic parameters for cashmere traits are remarkably consistent, with high heritabilities for all traits and a strong unfavourable relationship between fibre diameter and cashmere weight. Selection to improve any one trait should, therefore, be straightforward, however a problem arises when attempting to jointly improve cashmere weight and fibre diameter.

Further work is required in both the definition of breeding objectives and in fibre biology. Long term selection objectives with respect to fibre diameter must be reevaluated so that selection does not result in fibre that is too coarse to be marketed as cashmere. This may involve redefining the selection objectives and economic values for each trait periodically, as genetic change is achieved. The effect of including fibre colour (white vs coloured) in the selection objective must also be addressed. With regard to the biology of fibre growth, the genetic control of the growth period of cashmere as well as the onset of fibre shedding need to be elucidated and, perhaps, manipulated in order to improve productivity and the ease of fibre harvesting.

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