THE USE OF K-CASEIN GENOTYPES IN DAIRY CATTLE BREEDING

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SUMMARY

The B allele of the K-casein gene has been shown in several studies to increase protein yield in milk by about 3%. It has also been suggested that it improves cheese yield independent of any effects on protein yield. A deterministic computer simulation of dairy cattle breeding with progeny testing was constructed to evaluate the economic gains of including selection on K-casein genotype. The simulation created annual cohorts of animals in a four path system with generation intervals of 7, 7, 6 and 5 years in the sire to sire, sire to dam, dam to sire and dam to dam paths and proportions selected of 0.05, 0.15, 0.05 and 0.9. The build up of differential quantitative gametic phase disequilibrium between genotypes and a negative correlation between quantitative genetic affects and the K-casein genotype were allowed for. If K-casein only effects protein yield, incorporation of K-casein genotype into an optimum selection index has almost no effect on genetic improvement in the cow population. With an additional 3.3% improvement in cheese yield of the BB genotype, improvements of economic genetic gain in the first cohort of up to 8% are possible when a high proportion of milk goes to cheese manufacture. Improvements in later cohorts and in other milk markets are substantially reduced. If the gene effect is overestimated, genetic responses are reduced, rapidly becoming less than if the genotype is ignored. It would likely be cost beneficial to genotype bulls provided that the B allele has an economic advantage other than through increasing protein yield. Genotyping of dams of sires may also be worthwhile where a high proportion of milk goes to cheese manufacture, but not elsewhere.

INTRODUCTION

A review of the literature (J.P. Gibson, P. Rozzi and G. Jansen, unpublished) found that the B allele of the K-casein gene increases protein yield in the milk, with the average difference between AA and BB genotypes being about 3%. The evidence that the B allele also increases cheese yield independent of its effect on protein yield was less conclusive. Published evidence indicated a difference between AA and BB in cheese yield, adjusted for milk composition, of between 0 and 4%. The frequency of the B allele is typically around 0.22, with a BB genotype frequency of about 0.05 in Holstein-Friesian breeds.

There has been considerable interest on selecting for the B allele, particularly in those countries where a high proportion of the milk goes to cheese production. However, the cost-benefits of such selection are not clear.
MODEL.
A deterministic computer simulation was constructed to model dairy cattle improvement with progeny testing and selection for a single quantitative trait, economic merit, with a single major gene also affecting economic merit. Annual cohorts of males and females were produced in a four path system with generation intervals of 7, 7, 6 and 5 years and proportions selected of 0.05, 0.15, 0.05 and 0.9 in the sire to sire, sire to dam, dam to sire and dam to dam paths. Each cohort consisted of three genotypes, AA, AB, and BB, with separate genotypic means due to the major gene, genetic means due to quantitative genetic effects and quantitative genetic variances. When the genotype was assumed known, selection was on the sum of estimated quantitative economic genetic merit plus the major gene effect on economic merit. Otherwise the major gene effect on phenotype was allowed for in the index estimate of quantitative genetic economic merit. Genetic evaluations of sires were based on 50 half-sib daughters and of dams on 2 (dam to sire) or 1 (dam to dam) lactation records.

Within each cohort, selection was from three overlapping normal distributions of genetic evaluations, one distribution for each genotype. Given the frequency, mean and variance of each distribution, the truncation point corresponding to the predetermined overall proportion selected was found by iteration assuming infinite population size. The decline in variance due to gametic phase disequilibrium, the "Bulmer" effect, was calculated separately for each progeny genotype depending on the index variance, correlation between index and aggregate genotype and selection intensity in the parent genotypes, weighted by their proportional contribution to the progeny genotype. Similarly, quantitative genetic means were derived separately for each genotype. A simplifying assumption was that there was only a single quantitative genetic mean for each genotype with the variance between means due to variation among parent genotypes being put into the additive genetic variance.

PARAMETERS.
For economic merit only milk production traits were considered. Parameters were derived for the Italian market assuming average milk yield of 6595 L at an average price of 660 Lira (£)/L, a phenotypic c.v. of 18% and marginal cost at 0.5 x returns, giving a phenotypic standard deviation (s) = £.391743. Heritability was set at 0.3 and repeatability at 0.55.

The gene effect was estimated in two parts, that on protein yield and that on cheese yield, independent of the effect on protein yield. The effect on protein yield affects economic returns on all milk produced and incurs the same marginal cost per unit as quantitative genetic improvement of protein output. The additional effect on cheese yield economically affects only milk going to cheese manufacture. It is assumed to increase the yield of cheese from a given quantity of milk, incurring no extra cost.

The economic value of increased protein yield was estimated as (t p s)/cv where t is the proportional increase in protein yield, s is the phenotypic standard deviation of economic value, p is the proportion of the returns of normal milk due to its protein content and cv is the coefficient of variation of production. This approximation assumes that the costs of extra protein production are the same as other milk components. The value of increased cheese yield was estimated as c w v y where c is the proportional increase in cheese yield, w is proportion of milk going to cheese manufacture, v is the value of cheese at time of processing (= returns per L milk) and y is average milk yield.
Four situations were considered:

A: gene effect on protein yield only, \( t = 0.033 \), \( c = 0.0 \)

B: gene effect on protein yield plus cheese yield, \( t = 0.033, c = 0.033, \)
\( w = 0.67 \) (corresponds to Italian market), \( v = £.700 \)

C: gene effect on protein yield plus cheese yield, \( t = 0.033, c = 0.33, w = 0.27 \) (Canadian average), \( v = £.700 \)

D: A, but gene effect overestimated by \( x2 \).

In all cases, gene effects were additive and \( p \) was assumed to be 0.5.

The simulation was run for 40 years without any gene effect (assumes no effective direct selection on protein yield till the present) to create the base population, and for 20 years thereafter. Initial B allele frequency was 0.22.

RESULTS AND DISCUSSION

The results are summarised in table 1 as responses in years 1, 10 and 20. Year 1 is the first year in which animals are born as a result of parents of known genotype. In each case, the "base" is the response of the population assuming the given gene effect on recorded phenotype and true economic merit but no knowledge of any animal’s genotype. For the cases with known genotypes, economic responses are expressed as deviations from the appropriate base. \( S \) indicates that sires’ genotypes are known, \( d \) indicates that genotypes of dams of sires are known.

For situation A, where \( K \)-casein genotype affects only protein yield, there is no advantage to recording the genotype of sires (situation A.s) and almost none when dams of sires are also recorded (situation A.s.d.). Genetic evaluations in the absence of known genotypes are fairly accurate and knowing the genotype for one gene of modest affect gives little gain in accuracy of evaluation.

For the same gene effect, if the effect is overestimated two-fold, economic responses are slightly less than if the genotype had been ignored (situation D.s). This is essentially the situation of acting as though \( K \)-casein genotype affects cheese yield independently of any effect of protein yield if in reality \( K \)-casein has no additional effect on cheese yield.

In situations where \( K \)-casein has a 3.3% effect on protein yield and an additional 3.3% effect on cheese yield there are substantial short-term increases in genetic response in both bulls and cows when a high proportion (65%) of milk goes to cheese, as in northern Italy (situation B.s. and B.s.d.). Responses are considerably less when only 27% milk goes to cheese, as in Canada (situation C.s).

Direct selection on the \( K \)-casein genotype substantially increases the B allele frequency. The response of total economic merit is, however, less than the change in allele frequency would suggest because of a substantial negative genetic correlation built up between the \( K \)-casein genotype and quantitative genetic effects.

For the Italian situation (B.s. and B.s.d.) with 10⁶ cows as progeny of selected bulls, 10 years of genotyping parents, 20 years of progeny production, a 30% culling rate, 300 sires and 6000 dams of sire genotyped per annum and a cost of £.123000 per sire (molecular genetic probe) and £. 10000 per dam (protein electrophoresis of milk sample) for genotyping, approximate discounted cost-benefit ratios are 1:65 or 1:119 for sires and 1:18 or 1:41 for dams of sires with interest rates at 10% and 5% respectively. Ratios for the Canadian situation would be about 5 to 6 times lower.
Interpretation of these results depends on the validity of the approximate economic values used here. Allocating 50% of the value of milk to protein would seem to be a reasonably assessment of trends in milk pricing. However, in both Canada and Italy, farmers are currently paid very little for milk protein. A lower value of protein would reduce the change in allele frequency in the absence of genotyping and thereby increase the economic advantage of genotyping if the B allele improves cheese yield. Also, in the Italian market some cheeses of high value are produced by cooperatives which pay a considerably higher price for milk than the Italian average which would increase the value of a gene affect on cheese yield in cows producing for this market.

In conclusion, if a substantial effect of K-casein on cheese production can be demonstrated, genotyping of sires would seem to be cost-beneficial in both countries. Genotyping of dams of sires would be cost beneficial in Italy but of marginal value in Canada. However, at present all the returns accrue to the processor since farmers are not paid according to K-casein genotype of the milk they sell. Also there are risks of substantial financial losses if in practice the K-casein genotype has little or no effect on cheese making other than through its effects protein yield.

Table 1 Economic and allele frequency responses to selection with and without knowledge of some animals genotypes¹.

<table>
<thead>
<tr>
<th>Situation</th>
<th>B freqn (%)</th>
<th>Economic gain</th>
<th>B freqn (%)</th>
<th>Economic gain</th>
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<tr>
<td></td>
<td>Year</td>
<td>Year</td>
<td>Year</td>
<td>Year</td>
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<tr>
<td>Base</td>
<td>25 26 28</td>
<td>30.9 319.5</td>
<td>637.2</td>
<td>25 25 27</td>
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<td></td>
<td>1 10 20</td>
<td></td>
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<tr>
<td>A.s</td>
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<td>0.0</td>
<td>1 1 2</td>
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<tr>
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<td>0.3</td>
<td>0.3</td>
<td>1 2 5</td>
</tr>
<tr>
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<td>-0.8</td>
<td>2 5 9</td>
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<tr>
<td></td>
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<td>-1.2</td>
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</tr>
<tr>
<td>Base</td>
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<td>33.5</td>
<td>323.5</td>
<td>643.4</td>
</tr>
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<td>15.8</td>
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</tr>
<tr>
<td>Base</td>
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<td>31.9</td>
<td>321 639.5</td>
<td></td>
</tr>
<tr>
<td>C.s</td>
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<td>1.1</td>
<td>2.0</td>
</tr>
</tbody>
</table>

¹ Results are the means of the cohort born in the year defined.

² Lira (€) * 10^-3, deviation from cohort in year 0, for "base" response, or from "base" response.