COMBINED EFFECT OF THE INVERDALE AND BOOROOLA PROLIFICACY GENES ON OVULATION RATE IN SHEEP

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SUMMARY

The effects of the Booroola and Inverdale prolificacy genes, individually and in combination, on the ovulation rate of 1/4 Merino 3/4 Romney were measured. The data were analysed according to a multiplicative model, which better fitted the data, and an additive model which has been the generally accepted model. With the multiplicative model the effect of the Booroola gene was to increase ovulation rate by 90 % (95 % confidence interval: 70 %, 113 %) and the effect of the Inverdale gene was to increase ovulation rate by 44 % (95 % confidence interval: 29 %, 61 %). On a proportional basis the effects of each gene were unaffected by the presence or absence of the other gene. In contrast, the additive model showed that the effect of the two genes in combination was 34 % ($P<0.01$) higher than the sum of the effects in the absence of the other gene, suggesting an epistatic effect between the Booroola and Inverdale loci.

Keywords: Sheep, prolificacy, Booroola gene, Inverdale gene

INTRODUCTION

The Booroola gene (Fec^B) was first reported by researchers in Australia and New Zealand (Piper and Bindon 1982; Davis *et al.* 1982) in Merinos and was the first major gene for prolificacy identified in sheep. The effect of the gene is additive for ovulation rate, with the ovulation rate of heterozygous (B+) ewes increased by about 1.65 and homozygous ewes by about 3.30 (Piper *et al.* 1984). The Booroola gene is autosomal, mapping to chromosome 6 (Montgomery *et al.* 1993). The Inverdale gene ($FecX^I$) located on the X-chromosome was discovered in Romney sheep (Davis *et al.* 1991a). Heterozygous (I+) ewes have ovulation rates about 1.00 higher than non-carriers (++), but homozygous (II) ewes have hypoplastic ovaries and are sterile (Davis *et al.* 1992).

Ovulation rates of ewes with the Booroola gene have previously been compared with ewes carrying the Inverdale gene (Davis *et al.* 1991a), but the effect of these prolificacy genes was confounded with breed type because the Booroola rams were Merino x Romney and the Inverdale rams were Romney. It has been shown that ewes which are heterozygous for both genes (I+/B+) have apparently normal ovaries (Davis *et al.* 1992), but the effect of one copy of both genes on ovulation rate has not been measured. An experiment was carried out to compare the ovulation rates of 1/4 Merino 3/4 Romney ewes carrying either the Booroola or Inverdale genes, and to determine whether the effect on ovulation rate of the two genes was additive.

MATERIALS AND METHODS

In April 1992 three Inverdale carrier rams (I) and three Inverdale non-carrier rams (+) were each joined with BB and ++ 1/2 Merino 1/2 Romney ewes. Each of the six mating groups comprised 8-9 BB ewes and 9-10 ++ ewes. The Inverdale Romney rams were assigned a genotype on the basis of

their previous progeny test (Davis *et al.* 1991a). Booroola ewes were from the known genotype flock described by Davis *et al* (1984), which was established by mating progeny tested Booroola rams with ewes assigned a Booroola genotype using the criteria of Davis *et al* (1982). Additional progeny were generated from 1993-1995 using a further four I rams and six + rams over BB and ++ ewes from the same Booroola flock.

Thus all progeny were descended from both Inverdale and Booroola sheep and were of 1/4 Merino 3/4 Romney breed type. The female progeny genotypes for the two major genes were I+/B+, I+/++, ++/B+ and ++/++, which were assigned from parentage. Progeny were tagged at birth, and following tailing at about three weeks of age were managed as one flock through until mating at 19 months of age. From 1994-1997 ewe live weights and ovulation rates (number of corpora lutea observed per ewe ovulating) were measured at the time of joining with rams and ovulation rates were measured again 18 days after joining. In 1998 ovulation rates were measured only once, 18 days after joining. All genotypes were unculled apart from ewes that became reproductively unfit due to vaginal prolapses or udder problems.

Statistical Methods. Data were analysed by residual maximum likelihood with ewe as a random (repeated) effect. All analyses included Booroola, Inverdale and their interaction as fixed effects. Analysis of live weight included year by age subclasses as a fixed effect; analysis of ovulation rate included time of measurement and age as fixed effects. Residuals analysis indicated that ovulation rate was more appropriately analysed on the log rather than untransformed scale. Box-Cox transformation methods (Draper and Smith 1981) were used to further investigate transformations.

The optimal transformation indicated by the Box-Cox methodology was $y^{0.3}$, but a log-transformation was chosen on the basis of the residual analysis, for ease of interpretation, and because it was closer to optimal than using untransformed data.

RESULTS AND DISCUSSION

During the four years 1992-1995 the total number of females retained for breeding was 23 I+/B+, 39 I+/++, 43 ++/B+ and 55 ++/++. The untransformed live weights at joining and ovulation rates (unadjusted for live weight) are summarised in Table 1.

Table 1. Least squares means (± s.e.) for joining weight and ovulation rate in the four genotypes

Genotype	Joining weight (kg)	Ovulation rate	Change in ovulation rate relative to ++/++
I+/B+	46.9 ± 1.1	4.36 ± 0.14	+2.67
I+/++	49.7 ± 0.8	2.36 ± 0.12	+0.67
++/B+	46.0 ± 0.8	3.01 ± 0.12	+1.32
++/++	49.2 ± 0.7	1.69 ± 0.12	

Joining live weights were significantly lighter in the two groups carrying the Booroola gene compared with those without the Booroola gene (46.5 kg v 49.4 kg; P<0.001). This is likely to be a carryover from birth rank/rearing rank effects because both of these groups were generated from BB ewes and many were born in large litters (mean birth rank = 2.7 and rearing rank = 2.0) whereas the ewes in the groups without the Booroola gene were the progeny of less prolific ++ Booroola ewes (mean birth rank = 1.5 and rearing rank = 1.4). The lower joining weight in the groups carrying the Booroola gene could have reduced ovulation rates in these groups by about 0.09 because Kelly and Johnstone (1982) have measured an increase in ovulation rate of 0.034 (SE = 0.006) per kilogram live weight at joining. The difference in liveweight between groups with and without the Inverdale gene was small and nonsignificant (48.3 kg v 47.6 kg; P= 0.47).

Analysis of log ovulation rate, adjusted for liveweight at joining, showed that there was no Booroola genotype x Inverdale genotype interaction. Thus log ovulation rate was additive which shows that the effects of the two genes were multiplicative for ovulation rate. The effect of the Booroola gene was to increase ovulation rate by 90 % (95 % confidence interval: 70 %, 113 %) and the effect of the Inverdale gene was to increase ovulation rate by 44 % (95 % confidence interval: 29 %, 61 %). On a proportional basis the effects within genotype for the other locus (e.g. Inverdale effect within ++ Booroola genotypes) were almost identical. From log ovulation rate analysis, liveweight effects on ovulation rate within genotype showed that ovulation rate increased by 1.4 % per kg liveweight increase (P<0.001). This is equivalent to 0.023 per kilogram and 0.041 per kilogram at the ++ and B+ levels respectively.

Overall, the difference between B+ and ++ genotypes was 1.66 ovulations and the difference between the I+ and ++ genotypes was 1.01 ovulations. These values are almost identical to the increase in ovulation rate in B+ ewes of 1.65 reported by Piper *et al* (1984) and the increase in I+ ewes of 1.00 reported by Davis *et al* (1991a). However, because the effects of both genes were multiplicative for ovulation rate, the effects of the genes in absolute terms were lower for ++/B+ versus ++/++ and I+/++ versus ++/++ (1.32 and 0.67 for Booroola and Inverdale respectively), than for I+/B+ versus I+/++ and I+/B+ versus ++/B+ (2.00 and 1.35 for Booroola and Inverdale respectively).

According to the multiplicative model, which our data more strongly support, the effect of the Booroola gene in either the presence or absence of the Inverdale gene was to increase ovulation rate by 90 % and the effect of the Inverdale gene in either the presence or absence of the Booroola gene was to increase ovulation rate by 44 %. This implies no interaction between the two genes. Our results contrast with previous studies of the Booroola gene (Piper *et al.* 1984; Davis *et al.* 1991b), which have suggested that the effect of the B gene on ovulation rate at different levels of prolificacy appeared to be additive rather than multiplicative.

If the effect of each of the genes was additive for ovulation rate, as suggested by Piper *et al* (1984) for the Booroola gene, the difference in ovulation rate between the I+/B+ and ++/++ genotypes would be expected to be the sum of the B effect (+1.32) and the I effect (+0.67) i.e. +1.99. However when analysed for ovulation rate rather than log ovulation rate, there was a significant interaction between the two genes (P<0.01). Table 1 shows that the effect of the two genes in combination was

+2.67 which is 34 % higher than the additive model. This would suggest an epistatic effect between the Booroola and Inverdale loci.

Although the ovulation rate increase in the ++/B+ genotype (+1.32) was less than the average value of +1.65 cited by Piper *et al* (1984), it was within the range of recorded effects of the gene and was higher than the +1.24 reported by Davis *et al* (1982) in their early study of the effect of the gene on ovulation rate. The increase of 0.67 in the I+/++ group is within the range of values measured in progeny tests of Inverdale carrier rams. For example, in a progeny test of 11 Inverdale rams the 1.5 year old daughters of the three carrier rams had ovulation rates that averaged 0.49 higher than daughters of the eight non-carrier rams at the first laparoscopy and 0.75 higher at the second laparoscopy (G.H. Davis, unpublished data).

In conclusion, our study shows that with the multiplicative model, which better fits the data, there was no interaction between the Booroola and Inverdale genes, but using an additive model as suggested by some previous Booroola studies, there was a positive interaction between the two genes.

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