Artificial Insemination Results In Several Livestock Populations Studied With Product And Additive Models

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Introduction

The artificial insemination (AI) outcome is affected by the male and female fertilities. This phenotype is usually recorded as a binary variate and it is commonly analyzed assuming the threshold model (Wright, 1934), which considers that there is an underlying variable resulting from the sum of the environmental and genetic effects from the two individuals involved (Piles et al., 2005; Varona and Noguera, 2001). However, some authors have pointed out that the combination of those sources of variation may not be purely additive (Speirs et al., 1983). Recently, David et al. (2009) proposed a product threshold model that assumes that conception in a given mating is the product of the success of 2 binary unobserved phenotypes (one for each mating member). This product model of male and female components for studying this reproduction trait has the advantage of having biological sense and being easier to construe than the purely additive one. Furthermore, it is possible to investigate which sex is responsible for AI failures. However, the product threshold model has not been applied to real data yet. The purpose of this paper is a) to compare the performance, in terms of predictive ability, of the product and the additive threshold models for studying AI result and b) to evaluate the consistency of the results provided by the product model in three different species: dairy cattle, sheep and rabbit.

Material and methods

Material. AI data corresponding to dairy cattle, sheep and rabbit were used for the analysis. Dairy cattle data were extracted from the November 2008 routine genetic evaluation for fertility, implemented in the north and north-western population of Spanish Holstein-Friesian cattle. 501,284 AI records performed on 183,833 cows with frozen semen from 949 sires were used in the analysis. The observed probability of AI success was 37%. In sheep, the dataset corresponds to 13,275 records of inseminations from 12,102 ewes and 38 rams performed during the 2000 to 2004 period. Synchronized females were inseminated with standardized fresh doses made with semen selected upon its motility and concentration. The observed probability

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of AI success was 51%. Rabbit data came from a population of a sire line selected for growth rate. A total of 6,543 AI records corresponding to 2,601 dams and 300 males collected from June 2003 to December 2007 were used in this study. In this species, no evaluation of seminal characteristics was performed; only ejaculates with presence of urine or calcium carbonate were rejected. Synchronized females were inseminated immediately after semen collection. The observed probability of AI success was 72%.

**Models and methods.** Assuming that \( y \) is the vector of the binary results of inseminations; 
\[
Pr(y = 1|\theta) \text{ is the conditional probability of AI success given the genetic and environmental factors variables (}\theta). \quad \Phi \text{ is the standard cumulative distribution function of the normal distribution. } \beta_f, \beta_m \text{ and } \beta_c \text{ are vectors of systematic effects related to the female, the male or common to both genders, respectively. } \textbf{u}_f \text{ and } \textbf{u}_m \text{ are the vectors of female and male fertility additive genetic effects, respectively. } \textbf{p}_f \text{ and } \textbf{p}_m \text{ correspond to the vectors of male and female random permanent environmental effects. } \textbf{X}_f, \textbf{X}_m, \textbf{X}_c, \textbf{Z}_f, \textbf{Z}_m, \textbf{W}_f \text{ and } \textbf{W}_m \text{ are the corresponding known incidence matrices. The additive threshold model links (probit link function) the observed phenotype to a liability which is the sum of all genetic and environmental factors affecting AI result:}
\]
\[
Pr(y = 1|\theta) = \Phi (\textbf{X}_f \beta_f + \textbf{X}_m \beta_m + \textbf{X}_c \beta_c + \textbf{Z}_f \textbf{u}_f + \textbf{Z}_m \textbf{u}_m + \textbf{W}_f \textbf{p}_f + \textbf{W}_m \textbf{p}_m)
\]
Whereas the product threshold model considers that the conditional probability of AI success is the product of the probabilities of success of two binary unobserved phenotypes: the male and the female fertilities (David et al., 2009):
\[
Pr(y = 1|\theta) = \Phi (\textbf{X}_f \beta_f + \textbf{X}_c \beta_c + \textbf{Z}_f \textbf{u}_f + \textbf{W}_f \textbf{p}_f) \times \Phi (\textbf{X}_m \beta_m + \textbf{X}_c \beta_c + \textbf{Z}_m \textbf{u}_m + \textbf{W}_m \textbf{p}_m)
\]
Additive and product models were compared in the three species, considering their ability of predicting future observations. In each species, 75% of the data (training set) was used to estimate parameters, and predictions were computed in the remaining 25% of the data (testing set). This procedure was repeated five times with a different testing sample each time. A Bayesian approach was used to estimate parameters in both models via Gibbs sampling. Different statistics were computed to evaluate the predictive ability of the two models: a) the mean square error defined as 
\[
MSE = \frac{1}{n} \sum_{i=1}^{n} \left( y_i - \hat{Pr} (y_i = 1) \right)^2
\]
correspond to the observed AI outcome and predicted probability of success, respectively and \( n \) is the number of data points in a testing subset, b) the sensitivity of the prediction defined as the probability to predict a success given that the observation is a success, c) its specificity or the probability to predict a failure given that the observation is a failure. The probabilities of success estimated for the 2 unobserved phenotypes were used to evaluate the consistency of the results provided by the product model.

**Results and discussion**

Predictive abilities of the two models are presented in Table 1. MSE estimates of product and additive model were similar within species; it was lower in rabbit (0.15) compared to its
counterparts in sheep or cattle (0.24 and 0.22, respectively). Sensitivity and specificity were quite different between models and species, although, in general, the product model tended to be more sensitive and less specific than the additive one in all species. Thus, the product model showed better ability to predict a success when the observed data is a success, and a worse ability to predict a failure when the observed data is a failure than the additive model. Even though the predictive ability was similar for the 2 models and the mean correlations between EBV across the 2 models were high for female fertility (0.97, 0.98, 0.92), the mean correlations between male fertility EBV were lower (0.40, 0.69, 0.91 in cattle, sheep and rabbit, respectively).

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<th>Sheep</th>
<th>Cattle</th>
<th>Rabbit</th>
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<tbody>
<tr>
<td>MSE</td>
<td>0.24</td>
<td>0.22</td>
<td>0.16</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.71</td>
<td>0.47</td>
<td>0.99</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.45</td>
<td>0.65</td>
<td>0.06</td>
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Estimations of the probability of success for the unobserved phenotypes are quite different between species (Table 2). AI failure is mainly due to an impaired female fertility in sheep and rabbit (88 and 61% of the cases of AI failure, respectively) and a failure in male fertility in cattle (62% of the cases of AI failure). It is difficult to compare these results with those reported previously in the literature, because the only species where origin of infertility is well documented is human after natural mating. Forti and Krausz (1998) reported that in 35% of cases, infertility is mainly due to a female factor, in 30% to a male factor, in 20% to abnormalities detected in both partners, and in 15% of cases no diagnosis can be made after a complete investigation.

<table>
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<tbody>
<tr>
<td>Mean probability of success for the female fertility</td>
<td>0.54</td>
<td>0.76</td>
<td>0.81</td>
</tr>
<tr>
<td>Mean probability of success for the male fecundancy</td>
<td>0.94</td>
<td>0.49</td>
<td>0.89</td>
</tr>
<tr>
<td>Percentage of AI failure due to female fertility failure (%)</td>
<td>88</td>
<td>19</td>
<td>61</td>
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<tr>
<td>Percentage of AI failure due to male fertility failure (%)</td>
<td>6</td>
<td>62</td>
<td>32</td>
</tr>
<tr>
<td>Percentage of AI failure due to both genders (%)</td>
<td>6</td>
<td>19</td>
<td>7</td>
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The different process for preparing doses may explain the difference in male fertility between species. In sheep, semen was strongly selected upon its motility and sperm concentration, the doses contained the same number of spermatozoa, and ewes were inseminated less than six hours after collection (fresh semen). This process allows a control of the main environmental factors affecting male fertility (Briois and Guerin, 1995; Foote, 2003). Conversely in rabbit,
although does were immediately inseminated after semen collection, there was no ejaculate selection upon its seminal characteristics (except urine or calcium deposits) which may reduce the potential sperm fertility and explain the relative importance of the male in the AI failure. In dairy cattle, we observed the lowest probability of success for the male fertility. In this species, the sperm selection process is similar to the one performed in sheep, but inseminations were performed with frozen semen. This difference could explain the higher relative importance of the male fertility in AI failure in this species. For the female fertility, ovulation is induced by insemination in rabbit, therefore the probability that the oocyte is release at the appropriate time in the female reproductive tract is very high, which might explain the highest percentage of fertility success observed in this species (0.81). In sheep, even if synchronized, females were inseminated without regard to oestrus expression which might explain the lower probability of fertility success (0.54). On the other hand, the high estimate of probability of success for female fertility in cattle (0.76) is surprising, as female fertility problems have been largely reported as an explanation of the decrease of AI success observed in dairy cattle for a long time (Lucy, 2001).

Conclusion

The product model shows similar predictive ability to the additive one; furthermore it permits evaluation of which sex is responsible of an AI failure. This would help to improve much efficiency AI result. However, results obtained in cattle are not in accordance with the assumptions classically made for this species. To confirm the result obtained in this species, it is necessary to run the product model on other cattle datasets as this has already been done in sheep and rabbit with similar results.

References