Lifetime risk and cost of clinical mastitis in dairy cows in relation to heifer rearing conditions in southwest Sweden

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ABSTRACT

Relationships between heifer rearing conditions and the risk of veterinary-reported clinical mastitis (VRCM) during productive life were studied by generalized linear mixed modeling at the lactation level. Data consisted of 5,693 lactations in 2,126 Swedish Reds, Swedish Holsteins, or dairy cows of other or mixed breeds, representing all female animals born in 110 herds in southwest Sweden in 1998. During a lactation, a cow was defined as affected by VRCM if one or more cases were reported by a veterinarian, starting from 7 d precalving. The applied model of VRCM included effects of breed, parity, diarrhea between 3 and 7 mo of age, increase in body weight from weaning to first breeding, increase in daily concentrate ration before first calving, herd-level median age at first calving, cow housing, and random effects of cow and herd. The VRCM incidence was 14% in a given lactation, or 0.11 cases/cow annually; 31% of the cows had VRCM at least once during their productive life. Ninety percent of the variation in mastitis risk was due to factors at the lactation level such as parity, milk yield, cow diseases, and other disturbances, instead of cow or herd factors. Severe diarrhea between 3 and 7 mo of age was associated with 2.8-fold higher odds of VRCM compared with mild diarrhea during the same period, whereas the VRCM odds of calves with mild diarrhea were half that without diarrhea. The odds of VRCM had a predicted maximum at an estimated prepubertal growth rate of 859 g/d and increased with 10% for every 1-kg increase in concentrate ration during the last 2 mo before first calving. Costs of VRCM were estimated based on assumptions regarding veterinary service, extra labor, culling and herd replacement, discarded milk, and production loss depending on parity and lactation stage when VRCM was diagnosed. The total mean costs of VRCM were estimated to be \$735 per lactation with a diagnosis of CM, \$103 per lactation across all cows, or \$95 per cow annually during lifetime.

Key words: mastitis cost, clinical mastitis, calf rearing, replacement cost

INTRODUCTION

Despite immense research and control efforts, bovine mastitis remains the most costly disease in dairy production (Seegers et al., 2003). Estimated costs of the disease differ considerably depending on origin of data, disease definition, and sources of losses considered. In general terms, costs of clinical mastitis (CM) can be divided into reduced milk receipts, treatment costs, and premature culling (Huirne et al., 2002). Linked to treatment are costs for extra labor and discarded milk. Based on data from Ohio dairy herds, Hoblet et al. (1991) calculated the costs per case of CM to be \$107 and the costs per lactation to be \$40, whereas Kossabati and Esslemont (2000) estimated the costs in the United Kingdom to be £137 (\$225) per case or £44 (\$72) per cow annually. Huirne et al. (2002), using unspecified Dutch data, reported the losses due to CM to be \$88 per cow annually. More recently, Hagnestam (2006) computed costs of acute CM in Sweden and, in contrast to earlier Swedish estimations, included costs for reduced milk production depending on the timing of a case, with reference to Hagnestam et al. (2007). These authors derived total costs for a case of approximately \$846 in a first-calf cow contracting CM within 1 wk postcalving, and of \$971 in a cow exhibiting CM in the third week of lactation in subsequent parities.

In recent years, the udder health of primiparous cows, especially in early lactation, has attained increasing research interest (Svensson et al., 2006b; Nyman et al., 2009), with focus on heifer-rearing conditions. Group housing between 2 mo of age and start of breeding (Østerås et al., 1997), keeping heifers together with older cows (Barkema et al., 1999), and housing in free stalls instead of tie stalls 1 mo before calving (Nyman et al., 2009) have been associated with increased risk of CM. Aspects of different concentrate feeding levels for heifers before calving have also been associated with CM or elevated milk SCC in epidemiological studies (Bareille et al., 2000; Svensson et al., 2006b). Our objective was to study relationships between heifer health

Received September 2, 2008.

Accepted March 4, 2009.

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and management factors during rearing and the risk of veterinary-reported CM (VRCM) during the entire productive lifespan of dairy cows in Swedish commercial herds. Parameters of special interest included calfhod housing and disease, prepubertal heifer growth, and feeding before first calving. Costs of VRCM were analyzed in relation to the factors studied.

MATERIALS AND METHODS

Data

In 1997, we mailed a questionnaire to 485 dairy farms located in one county in southwest Sweden, asking producers for their cooperation in a long-term study of young stock housing, management, and health. Milk producer questionnaire recipients included all herds ranging from 28 to 94 cows enrolled in Swedish official milk and health recording programs (Olsson et al., 2001), except for 36 farmers whom local large-animal practitioners and agricultural advisers considered incapable of keeping reliable calf records. The response was 58%. Among the respondents, farmers who were willing to participate and housed their calves in single pens or group pens and their older calves in group pens with slatted floors or in bedded pens (by far the most common housing systems; Pettersson et al., 2001) were selected, for a total of 122 herds. In selected operations, 3,081 heifer calves were born in 1998. Of these, 2,243 calved in the study herds and were thus enrolled in the study. First and subsequent lactations were included in the data, until either the animals were removed from the herd (culled, died, or sold off; 86%) or until the recording period ended on May 31, 2006 (14%). After editing and exclusion of incomplete data, 5,693 lactation records from 2,126 cows in 110 herds were available to use. Of 28 lactations omitted, 1 was due to a calving interval <215 d and 3 to suspected but nonreported abortion. The cows were Swedish Reds (51%), Swedish Holsteins (47%), other breeds (e.g., Jersey), or milk and beef breed crosses.

Information was collected from the official milk and health recording programs, from farmer forms and interviews, and through direct on-farm observations by research staff. Data recordings, housing, grazing, management, disease definitions, and health of the same animals from birth to calving were described by Svensson et al. (2003, 2006a) and by Hultgren et al. (2008). Calf disease recordings formed 5 independent variables representing total herd-level disease incidence risk before 4 mo, and diarrhea and respiratory disease in 2 time periods—before 3 mo and from 3 to 7 mo. The first 4 mo of life were thought to encompass most clinical calfhod cases, as shown by Hultgren et al.

(2008). Mean prepubertal growth rate was estimated from heart girth measurements at weaning and at first breeding. Observations with missing values of estimated prepubertal growth rate were set to the overall mean within breed (11% of cows). Cows were housed in free-stall, short-stall, or long-stall systems. Free stalls were cubicles for lying in loose housing. Short stalls were similar to American tie stalls. In long stalls, cows were also tied but could be locked out from the manger at times. Hessle et al. (2004) described feeding regimens and daily growth rates for calves and young stock.

We defined VRCM as a binary outcome indicating one or several cases of CM during a lactation, diagnosed and reported by trained veterinary practitioners. The diagnosis was based on the presence of local inflammatory signs characterizing clinical mastitis, such as udder swelling and presence of abnormal milk. Cases ≤ 7 d precalving were considered related to calving and therefore referred to the following lactation.

Statistical Analysis

Data were edited and descriptive statistics created in JMP Statistical Discovery software (SAS Institute, 2005). Modeling was performed using the GLIMMIX procedure of SAS software (SAS Institute, 2003). We applied the following generalized linear mixed model:

$$Y_{ijk} = \pi_{ijk} + e_{ijk}$$

$$\text{logit}(\pi_{ijk}) = \beta_0 + u_{0j} + v_{0k} + \sum \beta_m X_{mijk},$$

where Y_{ijk} is the VRCM status (0, 1) of lactation i in cow j of herd k ; π_{ijk} the probability that lactation i in cow j of herd k had VRCM; e_{ijk} a random term at the lactation level; β_0 the intercept; u_{0j} and v_{0k} random-intercept effects of cow and herd; β_m regression coefficients expressing included fixed effects; and X_{mijk} fixed covariates. Satterthwaite denominator degrees of freedom were used.

Initially, 37 potentially relevant independent variables, including major confounders, were tested one by one, including only the tested effect and a random herd effect. Originally, continuous predictors were tested after categorizing them by quintiles. If the odds of VRCM increased or decreased consecutively between categories, the assumption of linearity was considered met and the continuous form was used; otherwise, the categorized variable was retained. Major confounders (breed, parity, cow housing) were selected based on earlier research (e.g., Nyman et al., 2009). Eighteen variables with a Type 3 $P \leq 0.30$ were considered eligible for further analysis, including major confounders. In the next step, the model was built by including

Table 1. Descriptive statistics of a selection of studied categorical factors by veterinary-reported clinical mastitis (VRCM), based on 5,693 lactations in 2,126 Swedish dairy cows born in 110 herds in 1998

Model covariate	Class	No. (%) of lactations	
		VRCM	No VRCM
Cow housing ¹	Free stalls	212 (27)	1,254 (26)
	Short stalls	408 (51)	2,644 (54)
	Long stalls	177 (22)	998 (20)
Breed	Swedish Red	384 (48)	2,492 (51)
	Swedish Holstein	397 (50)	2,279 (47)
	Other or mixed	16 (2.0)	125 (2.6)
Parity	1	248 (31)	1,878 (38)
	2	195 (24)	1,366 (28)
	≥3	354 (44)	1,652 (34)
Diarrhea 3 to 7 mo	No	762 (96)	4,595 (94)
	Mild	22 (2.8)	249 (5.1)
	Severe	13 (1.6)	52 (1.1)
Herd-level age at first calving, mo	≤25.7	150 (19)	768 (16)
	25.8 to 26.7	131 (16)	1,046 (21)
	26.7 to 27.7	173 (22)	1,203 (25)
	27.7 to 29.2	226 (28)	1,053 (22)
	>29.2	117 (15)	826 (17)
Herd-level milk production, kg of ECM/cow annually	≤6,792	157 (20)	978 (20)
	6,793 to 7,455	187 (23)	1,032 (21)
	7,456 to 7,797	171 (21)	1,085 (22)
	7,798 to 8,230	145 (18)	1,014 (21)
	>8,231	137 (17)	787 (16)
Normalized lactational milk yield relative to herd mean	≤−0.93	162 (20)	977 (20)
	−0.94 to 0.18	140 (18)	999 (20)
	0.19 to 0.24	170 (21)	970 (20)
	0.25 to 0.99	182 (23)	955 (20)
	>0.99	143 (18)	995 (20)

¹Prevailing housing system for cows in the herd. Free stalls were cubicles for lying in loose housing. Short stalls were similar to American tie stalls. In long stalls, cows were also tied but could be locked out from the manger at times.

initially all eligible variables, and then by excluding or reintroducing them one at a time in a manual stepwise manner, all the time forcing in the major confounders. Only effects significant at a (Type 3) F -test $P \leq 0.05$ or confounding rearing effects (i.e., changing significant coefficient estimates by >10%), and major confounders, were retained. Polynomial extensions to the third degree of continuous covariates, and relevant first-order interactions of significant covariates were tested and included if significant at $P \leq 0.05$. No significant interactions were found. Finally, a random cow effect (cow nested within herd) was included and further model adjustments were made if needed, in line with mentioned criteria. Descriptive statistics for a selection of categorical variables are presented in Table 1.

Independent variables expressing the following factors were considered for inclusion in the model, but were not classified as eligible: whether or not explicit herd aims for replacement rearing had been formulated, housing system from birth to 3 mo, diarrhea from birth to 3 mo, respiratory disease from birth to 3 mo and from 3 to 7 mo, herd-level total disease incidence risk from birth to 4 mo, grazing before first calving, grazing later in the autumn than October 31 before first calving, turning in from pasture on the day of first calving, time precalving

for introduction of heifers into the cow barn, month of calving, occurrence of retained placenta, metritis or endometritis in a given lactation, use of restraint measures at milking in first lactation, and herd-level mean milk production in a given calendar year. The following independent variables were dropped during stepwise model reduction: herd size, housing system from 3 to 7 mo, number of changes of housing environment until first calving, ammonia concentration in buildings for calves or heifers, concentrate ration at 11 to 16 mo, time precalving for daily concentrate ration increase in heifers, total increase in daily concentrate ration around first calving, season of birth, calendar year of calving, occurrence of dystocia in a given lactation, normalized lactational milk yield relative to the herd mean, herd-level SCC, and occurrence of CM in the preceding lactation.

For the presentation of effects, odds ratios, their 95% confidence intervals, and P -values for F -tests of fixed effects were calculated.

Cost Calculations

The lifetime cost of VRCM in observed cows was calculated according to Hagnestam (2006) and Hagnestam

et al. (2007). We assumed a producer milk price of \$0.43/kg of ECM. The calculations were based on assumed costs of veterinary services (\$168/case), extra labor (\$117/case), increased culling and replacement rearing (\$201/case), discarded milk (\$154/case), and production loss/305-d lactation depending on parity and lactation stage when VRCM was reported. In first parity, production loss was assumed to be \$232 for cases reported wk 1 to 3, \$225 wk 4 to 8, \$0 later in lactation, and \$342 in the following dry period. In subsequent lactations, assumed production loss was \$342 for cases in wk 1 to 3, \$235 wk 4 to 8, \$0 later in lactation, and \$342 in the following dry period. Only the first case in each lactation was considered, regardless of subsequent cases. Given the timing of VRCM cases in our data, this resulted in a mean cost of \$735 per lactation with a diagnosis of CM. Predicted costs per lactation, in total and in each class of categorical rearing factors, were then calculated based on VRCM risks, derived from estimated marginal means (denoted least squares means in SAS) in the applied VRCM model.

RESULTS

General Observations

First calvings occurred between August 1999 and April 2003. By December 31, 2001, 98% of the cows had calved. Among studied animals, 81% were slaughtered or died spontaneously and 4.9% were sold to other herds, whereas 14% were still in their home herds when recording ended. Mean observed productive lifetime was 30 mo (median 27 mo; range 2 to 2,352 d). The number of lactations with VRCM was 248 (12%) in parity 1, 195 (12%) in parity 2, and 354 (18%) in parity ≥ 3 , in total 797 (14%), resulting in an overall incidence rate of 0.11 cases/cow annually. Thirty-one percent of the cows had VRCM at least once during the observed productive life. Fourteen percent of all cases occurred within 30 d after calving. Median herd size was 65 cows (range 30 to 174 cows). Mean (SD) of prepubertal growth rate was 668 (110) g/d, and of concentrate increase during last 2 mo before calving 3.33 (2.45) kg. Dystocia, retained placenta, or metritis/endometritis was reported in 4.4% of lactations. Table 1 gives the distribution of records by relevant categorical factors studied.

The Hosmer-Lemeshow Chi-square statistic was 2.01 with 8 df ($P = 0.98$), not indicating any lack of fit. The generalized Chi-square statistic divided by its degrees of freedom was 0.85, not revealing any over- or underdispersion. Variance estimates of the herd and cow random effects were 0.22 and 0.16, respectively. Applying the latent-variable method (Goldstein et al., 2002) and an empty model (random effects only), 7.6, 2.6,

and 90% of the total variation in mastitis risk resided at the herd, cow, and lactation levels, respectively.

Studied Effects

Results from the final model are given in Table 2. Six of the covariates contributed significantly to the model ($P \leq 0.05$). Mild diarrhea between 3 and 7 mo of age reduced the odds of VRCM compared with nondiarrheic animals, whereas severe diarrhea had no significant effect. However, compared with cows with mild diarrhea, cows that had experienced severe diarrhea between 3 and 7 mo had 2.8-fold higher odds of VRCM ($P = 0.014$). Cows with an estimated prepubertal growth of 859 g/d presented the highest estimated risk of VRCM, 21% higher than cows at the median growth rate of 664 g/d (Figure 1). The model predicted cows with a 4.2-kg increase in daily concentrate ration during the last 2 mo before first calving (75th percentile) to be at a 1.2 times higher risk for VRCM than cows with an increase of 2.0 kg (25th percentile). Cows in herds with a median age of 27.7 to 29.2 mo at first calving ran a higher risk of VRCM than those in herds where cows calved earlier or later. Among confounders considered, only parity was significantly associated with VRCM, with successively higher risks in higher parities.

Costs

The estimated overall mean cost of VRCM was \$103/lactation. At a calving interval of 13 mo, this corresponds to \$95/cow annually during productive life. Based on our data, mild diarrhea between 3 and 7 mo of age decreased mean VRCM costs by, on average, \$52/lactation. On the other hand, relative to mild diarrhea, severe diarrhea increased the costs by \$100/lactation. Cows in herds with a median age at first calving of 27.7 to 29.2 mo had \$73/lactation higher VRCM costs than cows in herds where median calving age was 25.8 to 26.7 mo.

DISCUSSION

There is a well-known unfavorable genetic correlation between milk production and mastitis (Carlén et al., 2004; Negussie et al., 2008). Thus, a high milk yield is predisposing to CM, although a case of CM decreases the yield for the remainder of the lactation (Hagnestam et al., 2007). We tested herd and cow milk production for inclusion in the model and did not find them to contribute significantly. A genetic correlation between growth rate before ($r = 0.13$) and after ($r = 0.34$) breeding and milk yield was reported by Mäntysaari et al. (2002). A positive genetic correlation between growth

Figure 1. Effect of a cow's growth rate from weaning to first breeding on the predicted (solid line) and observed (dashed line) lactational incidence risk of veterinary-reported clinical mastitis, according to a multivariable logistic-regression model based on 5,693 lactations in 2,126 Swedish dairy cows born in 110 herds in 1998. The observed risk was calculated in each of 5 growth-rate intervals based on quintiles.

rate at weaning and mastitis ($r = 0.24$) was reported by Brotherstone et al. (2007). According to our model, the VRCM risk increased with increasing prepubertal growth rate up to 859 g/d. However, observed and predicted frequencies of VRCM (Figure 1) suggest that the model fit might have been poor at very low (<500

g/d; 3.7% of cows) and very high (>1,000 g/d; 0.6% of cows) growth rates. An alternative covariate structure or modeling strategy might have resulted in somewhat different estimates of this relationship. More research is needed to unravel the relationship between heifer growth and mastitis later in life.

Table 2. Final multivariable logistic regression model of the risk of veterinary-reported clinical mastitis, based on 5,693 lactations in 2,126 Swedish dairy cows born in 110 herds in 1998

Covariate	Class	Odds ratio (OR) ¹	95% confidence interval of OR	P-value ²
Intercept		0.0035	0.00038 to 0.032 ⁴	
Cow housing ³	Free stalls	1	—	0.20
	Short stalls	0.85	0.62 to 1.2	
	Long stalls	1.1	0.77 to 1.6	
Breed	Swedish Red	1	—	0.49
	Swedish Holstein	1.1	0.89 to 1.4	
	Other or mixed	0.82	0.44 to 1.5	
Parity	1	1	—	<0.0001
	2	1.1	0.90 to 1.4	
	≥3	1.7	1.4 to 2.1	
Diarrhea 3 to 7 mo	No	1	—	0.011
	Mild	0.51	0.32 to 0.82	
	Severe	1.4	0.72 to 2.9	
Prepubertal growth ⁴ × 100 g/d	Continuous	2.4	1.3 to 4.3	0.0054
Prepubertal growth ⁴ squared, × 10,000 g ² /d ²	Continuous	0.95	0.40 to 0.99	0.019
Concentrate increase precalving, ⁵ kg	Continuous	1.1	1.0 to 1.1	0.0043
Herd-level age at first calving, mo	≤25.7	1	—	0.0029
	25.8 to 26.7	0.67	0.45 to 1.0	
	26.7 to 27.7	0.69	0.46 to 1.0	
	27.7 to 29.2	1.3	0.90 to 2.0	
	>29.2	0.88	0.57 to 1.4	

¹EXP (coefficient estimate).

²Statistical significance level for fixed effect based on a (Type-3) *F*-test.

³Prevailing housing system for cows in the herd. Free stalls were cubicles for lying in loose housing. Short stalls were similar to American tie stalls. In long stalls, cows were also tied but could be locked out from the manger at times.

⁴Mean daily growth rate from weaning to first breeding, estimated from heart girth measurements.

⁵Increase in daily concentrate ration to heifers during last 2 mo before calving.

We recorded and tested several factors reflecting concentrate feeding during rearing and around first calving. A large increase in daily concentrate ration within 2 mo before first calving increased the risk of VRCM. This is in agreement with findings by Waage et al. (1998), who reported a high percentage of concentrates in the diet of the herd to be associated with an increased risk of CM in heifers. Barkema et al. (1999) found that a high level of concentrates fed the week before calving was associated with an increased risk of mastitis caused by *Streptococcus dysgalactiae*.

There was evidence that mild diarrhea between 3 and 7 mo protected from VRCM, whereas severe calf diarrhea at the same age increased the risk of VRCM. A negative effect of severe diarrhea was expected, although it has not been shown earlier. We have no good explanation for the reverse effect of mild cases of diarrhea. We also expected a negative influence of calfhoo respiratory disease, but found no such effect. Nor could we reveal any effect on VRCM of calfhoo diarrhea before 3 mo of age. Higher incidence risks would have increased the possibilities to reveal effects of early diarrhea and respiratory disease on mastitis risk.

In contrast to earlier studies, neither cow housing system nor cow breed could be shown to influence the risk of CM. We expected free-stall herds to have a lower risk of VRCM, as shown by Bendixen et al. (1988) and Valde et al. (1997). Traditional Swedish dairy herds are relatively small, with tie stalls, pasture grazing from May to September, and feeding based on grass-clover silage as roughage, but there is presently a strong trend toward larger free-stall systems. In our data, long stalls are likely to represent old barns, and free-stall systems to be new. Cow housing system was forced into the model. Bendixen et al. (1988) and Emanuelson et al. (1993) found considerably higher incidence risks in Swedish Holsteins than in Swedish Reds in all parities, which motivated the inclusion of breed in our model, although it was not statistically significant.

In accordance with Bendixen et al. (1988) and Emanuelson et al. (1993), we found a higher risk of VRCM in cows of parities ≥ 3 compared with primiparous cows. Second parity was numerically intermediate. Hitherto, there is little evidence that CM increases when a herd has a low SCC. Schukken et al. (1989) and Green et al. (1996) suggested that cows in herds with low SCC might have an increased susceptibility to CM. In contrast, we did not find herd SCC to contribute to the model.

It was not possible to show any effect of herd size, and no such predictor was included in the final model. Research at the Swedish University of Agricultural Sciences (J. Hultgren and B. Algers; Skara, Sweden; and K. Persson Waller, Uppsala, Sweden; unpublished

data) has indicated a lower risk of VRCM in Swedish herds of >115 cows compared with herds of ≤ 62 cows. It can be expected that larger herds were established more recently, which might confound an effect of herd size on CM.

Nearly all variation in mastitis risk in a given lactation was due to factors or events at the lactation level, rather than herd or cow factors, thus limiting the possibilities to influence the incidence of CM by general management routines, or even individual-directed measures during, for example, rearing. Examples of lactation factors are age, parity, milk yield, and momentary events such as cow diseases and disturbances in management or feeding. Cow factors include breed, housing during rearing, and calfhoo health. Farmer skills and herd management are likely to influence CM incidence greatly but are difficult to measure and analyze. Heterogeneity among herds might therefore contribute to differences in risk factor estimates between published studies.

The total costs of VRCM were estimated to be \$735/lactation with a diagnosis of CM, \$103/lactation or \$95/cow annually during the productive lifetime. Our figures exceed the estimates of Hoblet et al. (1991), Kossabati and Esslemont (2000), and Huirne et al. (2002), even when accounting for the change in consumer prices between publication dates and although we based our calculations only on the first case in each lactation. This difference probably reflects an increasing awareness and knowledge about actual costs. Moreover, estimates are likely to vary because of differences in regional conditions of milk production, management routines, model assumptions, and estimation methods. Severe calfhoo diarrhea was found to increase the mean cost of CM by \$50 to \$100/lactation.

CONCLUSIONS

Nearly all variation in mastitis risk is due to factors or events at the lactation level, rather than herd or cow factors. Nevertheless, this study indicates that a high growth rate before the start of breeding and large amounts of concentrates fed shortly before first calving are risk factors for CM. The risk of VRCM appears to increase up to a prepubertal growth rate of 859 g/d. The total mean cost of CM is estimated at approximately \$103/lactation or \$95/cow-year.

ACKNOWLEDGMENTS

We acknowledge the assistance of participating farmers for their interest and support and Ulf Emanuelson of the Swedish University of Agricultural Sciences, Pascal Olternacu of Cornell University (Ithaca, NY),

and Sven-Ove Olsson, Kerstin Plym Forshell, and Mats Pehrsson from the Swedish Dairy Association for contributions during the initiation and planning phases of the study. We also thank the Swedish Dairy Association and Skara Semin regional dairy services (currently Freja Husdjur) for providing us with production and health data. Karin Lundborg, Lotta Andersson, and Jonica Östlund from the Department of Animal Environment and Health, and field staff from Skara Semin regional dairy service performed valuable on-farm recordings, and Gunilla Jacobsson from the Department of Animal Environment and Health assisted in data editing. The study was supported financially by the Swedish Farmers' Foundation for Agricultural Research.

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