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*Original article*

# Multivariate model for the assessment of risk of fetal loss in goat herds

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## Abstract

The observational study was carried out in a population of Polish breeding goats in 2007 to determine the prevalence of fetal loss and identify risk factors contributing to its occurrence. The multivariate model allowing to predict the risk of the occurrence of fetal loss in a herd in a study population was developed. Data on the occurrence of fetal loss, as well as of 28 hypothesized risk factors were collected from goat owners using standardized questionnaire during face-to-face reviews on farms. Moreover, data on the herd-level seroprevalence of four abortifacient infections – *Chlamydophila abortus*, *Leptospira* spp., BVDV-1 and *Neospora caninum* – were included in the final analysis. Fetal loss was reported as occurring often in 12 of 49 goat herds (24.5%). The relationship between the hypothesized risk factors and the occurrence of fetal loss was verified in the multivariate logistic regression ($\alpha$=0.05). Final analysis yielded four risk factors: regular veterinary supervision at least twice a year (OR 0.188; CI 95% 0.054 – 0.656), frequent occurrence of injuries and fractures (OR 3.172; CI 95% 1.081 – 9.310), frequent occurrence of respiratory signs in adult goats (OR 4.848; CI 95% 1.353 – 17.377) and presence of antibodies to *C. abortus* in a herd (OR 58.116; CI 95% 1.369 – 2466.438). The accuracy of the multivariate model was analyzed using receiver operating characteristic (ROC) curve technique. Area under the curve was 0.895 (CI 95% 0.801-0.981). For optimal cut-off value of 0.20-0.35 the multivariate model had sensitivity of 75.00% and specificity of 89.19% in predicting fetal loss in a herd.

**Key words**: goat, abortion, fetal loss, logistic regression, multivariate analysis

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## Introduction

Many infectious agents are considered responsible for fetal loss in goats, however only few have been experimentally proven to cause such condition. Several experimental studies confirmed that infections with *Chlamydophila abortus* (Rodolakis et al. 1984), *Coxiella burnetii* (Sánchez et al. 2006), bovine viral diarrhea virus (Løken and Bjerkåss 1991), caprine herpesvirus type 1 (Tempesta et al. 2004), *Toxoplasma gondii*, *Neospora caninum* and *Sarcocystis* sp. (Dubey et al. 1986, Lindsay et al. 1995, Buxton 1998) may result in an intrauterine embryonic and fetal death, abortion and delivery of dead or week kids.

In Poland the seroprevalence of eight infectious or parasitic diseases, which could be responsible for fetal loss in goats has recently been described by the authors in five original articles. These were enzootic abortion and Q fever (Czopowicz et al. 2010a), caprine herpesvirus type 1 infection and bluetongue (Czopowicz et al. 2010b), pestivirus infection (Czopowicz et al. 2011b), leptospirosis (Czopowicz et al. 2011c), toxoplasmosis and neosporosis (Czopowicz et al. 2011a).

A few studies have been carried out to identify risk factors for particular abortifacient infections, namely *C. burnetii* (Cantas et al. 2011), *T. gondii* (Neto et al. 2008, Anderlini et al. 2011, Abu-Dalbouh et al. 2012) and *N. caninum* (Abo-Shehada and Abu-Halaweh 2010). They allowed to identify contact with dogs and cats, extensive and semi-intensive herd management, poor hygiene and lack of mineral and vitamin supplementation as risk factors. Regular veterinary supervision was found protective against *N. caninum* infection (Abo-Shehada and Abu-Halaweh 2010). On the other hand, fetal loss may have non-infectious etiology as well, to mention only mechanical injuries, vitamin and mineral deficiencies and poisonings (Smith and Sherman 2009). As an infectious etiological agent can be identified in a small proportion of cases of fetal loss (Chanton-Greutmann et al. 2002, Masala et al. 2007), it is suggested that non-infectious causes predominate in etiology of the condition in goats (Waldeland and Løken 1991). An analysis carried out by Engeland et al. (1998) indicated inferior natural lighting in the stables, pre-heated drinking water and a building design with a combined feeding and milking platform involving large and crowded pens to be risk factors for non-infectious fetal loss. Links between various hypothesized risk factors and clinical cases of fetal loss at herd-level, irrespectively of its etiology, have not been evaluated by now.

The objective of the study was to determine the prevalence of fetal loss in breeding goat population in Poland, identify risk factors contributing to its occurrence and develop a multivariate model allowing to assess the risk of the occurrence of fetal loss as an important health problem in a herd.

## Materials and Methods

### Goat herds

The collection of field data was held in June and July 2007. The entire population of Polish breeding goats was studied. To be called a breeding goat herd it had to be registered in Polish Association of Sheep Breeders and participate in the milk recording program. The breeding population included 51 goat herds at the end of 2006. However, due to the fluctuation in their number final analysis totally embraced 49 herds counting 4685 adult females (older than 1 year).

### Occurrence of abortifacient infections in goat breeding population in Poland

Four pathogens whose prevalence was described by Czopowicz et al. (2010a, 2011a, 2011b, 2011c) – *C. abortus*, *Leptospira* spp., BVDV-1 and *N. caninum* – were included in the analysis as hypothesized health risk factors. Since no cases of Q fever, CpHV-1 infection and bluetongue had been detected, they were not considered as hypothesized risk factors. Similarly, toxoplasmosis was excluded from the further analysis due to 100% true herd-level seroprevalence.

### Questionnaires

Standardized questionnaires were prepared to gain knowledge on the occurrence of 12 hypothesized production risk factors, 16 hypothesized health risk factors and fetal loss. Fetal loss was defined as the delivery of a dead fetus during pregnancy, regardless of the phase of pregnancy in which it occurred, including a situation in which a dead kid was delivered at full term. Thus this category covered both abortions and stillbirths.

In each herd, face-to-face interview with the owner was conducted by visiting veterinarians to collect data from previous 5 years. Answers to questions on health conditions could be “never/rarely” or “often”. To be classed as occurring often the health condition had to be reported in at least 5% of adult females in a herd during at least one mating season or, unless any records were available, be perceived by the owner as a cause of an important health problem for a herd. If possible, the answers referring to the present situation were verified by visiting veterinarians themselves. The results of interviews on reproductive failures during preceding 5 years had already been published by Czopowicz et al. (2010a) but for the purpose of the present analysis they were updated by one additional herd in which fetal loss was often. Moreover, a representative sample of 22 goats from this herd (selected using simple random sampling method) was serologically tested for *C. abortus* and *C. burnetii*, according to the method provided by Czopowicz et al. (2010a). The herd was positive to *C. abortus* but negative to *C. burnetii*.

## Epidemiological analysis

For virtually all statistical calculations IBM SPSS 19.0.0. was used. A multivariate logistic regression was used to analyze data. First, the univariate analysis for all hypothesized risk factors and the occurrence of fetal loss was carried out using Chi-square test or Fisher exact test. The latter test was used only if expected number of elements in any cell of two-by-two contingency table was lower than 5.

Subsequently, a multivariate model was built by including every hypothesized risk factor which had p-value of $< 0.1$ from univariate analysis. Variables were retained, if p-value from the logistic regression was $< 0.05$, otherwise they were removed from the final model ($\alpha=0.05$). Backward stepwise elimination based on likelihood ratio test was applied (Noordhuizen et al. 2001).

The Chi-square goodness-of-fit test was performed to check if the multivariate model fit the data well ($\alpha=0.05$) (Hosmer and Lemeshow 2000). Moreover, pseudo-$R^2$ generalized coefficient of determination was calculated to provide quantitative information on the goodness of fit (possible range between 0 and 1) (Nagelkerke 1991).

Final multivariate model was presented as a formula:

$$P(Y = 1) = \frac{1}{1 + \exp\left[-(B_0 + B_1 \times X_1 + \ldots + B_n \times X_n)\right]}$$

$P(Y=1)$ – probability of a final outcome (fetal loss)
$B_0$ – intercept
$B_1$, $B_n$ – regression coefficients for individual risk factors
$X_1$, $X_n$ – risk factors
$\exp(a) = 2.718^a$

The receiver operating characteristic (ROC) curve was drawn in IBM SPSS 19.0.0. basing on the multivariate model equation results for each individual herd and the actual occurrence of fetal loss according to the questionnaires, which were considered a gold standard. Sensitivity (Se) and specificity (Sp) of the multivariate model for each subsequent cut-off value were calculated using Win Episcope 2.0 (EPIDECON).

## Results

Analysis of questionnaires showed that fetal loss was reported as occurring often in 24.5% (12/49) of goat herds.

As a result of the univariate analysis six hypothesized risk factors – two associated with production (Table 1) and four associated with health (Table 2) were offered to the multivariate analysis.

The multivariate logistic regression ended at the third step and yielded four final risk factors for the occurrence of fetal loss in a herd: regular veterinary supervision at least twice a year, frequent occurrence of injuries and fractures, frequent occurrence of respiratory signs in adult goats and presence of antibodies to *C. abortus* in a herd (Table 3). Out of these four risk factors the first one was negatively associated with fetal loss (i.e. it protected from fetal loss), whereas the remaining three used to predispose to fetal loss.

The Chi-square goodness-of-fit test and Nagelkerke pseudo- $R^2$ generalized coefficient of determination showed that the multivariate logistic regression model fit the data well ($\chi=1.314$, $p=0.859$ at the third step and $R^2=0.611$, respectively).

The multivariate model is provided by the equation:

$$P(Y = 1) = \frac{1}{1+2.718^{(-1.637+1.673\times X_2-1.579\times X_2-4.062\times X_3-1.154\times X_4)}}$$

where:

$X_1$ – presence of regular veterinary supervision at least twice a year (0-no, 1-yes)
$X_2$ – occurrence of injuries and fractures (0-never/rarely, 1-often)
$X_3$ – occurrence of respiratory signs in adult goats (0-never/rarely, 1-often)
$X_4$ – presence of antibodies to *C. abortus* in a herd (0-no, 1-yes)

The multivariate model can be considered as a diagnostic test and therefore appropriate ROC curve was drawn. Its Se and Sp values calculated for predetermined cut-off values on the basis of the ROC curve are provided in Table 4. ROC curve is shown in Fig. 1. AUC was 0.895 (CI 95% 0.801-0.981).

Table 1. Relationships between hypothesized production risk factors and the occurrence of fetal loss revealed in the univariate analysis.

| No. | Hypothesized production risk factor | Category | Herds with often fetal loss | | p-value |
|---|---|---|---|---|---|
| | | | No./total | % | |
| 1. | Herd size (number of adult females) | Small <100 (0)<br>Large ≥100 (1) | 7 / 37<br>5 / 12 | 18.9<br>41.6 | 0.111 |
| 2. | Goat replacement from other herds in Poland | No (0)<br>Yes (1) | 7 / 28<br>5 / 21 | 25.0<br>23.8 | 1.000 |
| 3. | Goat replacement from abroad | No (0)<br>Yes (1) | 11 / 47<br>0 / 2 | 23.4<br>0.0 | 1.000 |
| 4. | Housing system | Stanchion-type (0)<br>Free-stall (1) | 0 / 2<br>12 / 47 | 0.0<br>25.5 | 1.000 |
| 5. | Hygienic conditions | Good (0)<br>Poor (1) | 9 / 31<br>3 / 18 | 20.0<br>16.7 | 0.332 |
| 6. | Access to a pasture | No (0)<br>Yes (1) | 6 / 20<br>6 / 29 | 30.0<br>20.7 | 0.512 |
| 7. | Contact with other farm animals | No (0)<br>Yes (1) | 8 / 35<br>4 / 14 | 22.9<br>28.6 | 0.721 |
| 8. | Feeding with silage | No (0)<br>Yes (1) | 4 / 31<br>8 / 18 | 12.9<br>44.4 | 0.019* |
| 9. | Regular mineral and vitamin supplementation | No (0)<br>Yes (1) | 6 / 18<br>6 / 31 | 33.3<br>19.3 | 0.316 |
| 10. | Milking system | Manual (0)<br>Machine (1) | 1 / 17<br>11 / 32 | 5.9<br>34.4 | 0.037* |
| 11. | Annual worming | No (0)<br>Yes (1) | 1 / 9<br>11 / 40 | 11.1<br>27.5 | 0.420 |
| 12. | Dehorning | No (0)<br>Yes (1) | 10 / 39<br>2 / 10 | 25.6<br>20.0 | 1.000 |

* risk factors offered to the final multivariate analysis

The most optimal cut-off providing the highest Se by the highest Sp ranged from 0.20 to 0.35. The distribution of herds in the contingency table for the cut-off value of 0.20-0.35 (probability of fetal loss) is indicated in Table 5.

## Discussion

Questionnaire studies always raise doubts on their credibility. Our study also bears considerable risk of erroneous classification of herds as it is based on farmers' opinions on events, which had occurred during preceding 5 years. Several means were taken to limit the risk of misclassification of herds. The interviews were only personal, carried out by two veterinarians on each farm. If only possible the interviewers attempted to verify the answers with the actual condition of a herd. Not more than two herds were visited each day to have enough time for an interview and herd inspection. Most of questions were closed. Even though there were usually three possible answers in the questionnaire (the condition occurs "never", "rarely", "often"), they were finally grouped into two classes – "never/rarely" and "often", since it was impossible to set a clear borderline between the answer "never" and "rarely". The recipients might forget single cases of a disease and say "never" instead of "rarely" but they rather wouldn't have forgotten the real outbreak of a condition or frequently re-occurring problem. Only one type of reproductive failures – fetal loss – was investigated. This was chosen as the clearest and simplest to recognize for farmers without medical education. Both abortions and stillbirths were combined within this category as farmers could have easily mistaken these two conditions.

Fetal loss was reported from one fourth of all breeding herds in Poland. Two epidemiological studies form Norway revealed that fetal loss was common (i.e. involved ≥ 10% of goats) in roughly 50% of goat herds (Waldeland and Løken 1991, Engeland et al. 1998). These studies substantiate our thesis that fetal loss is an important health problem in goat breeding. Therefore, the evaluation of contributory factors is

Table 2. Relationships between hypothesized health risk factors and the occurrence of fetal loss revealed in the univariate analysis.

| No. | Hypothesized health risk factor | Category | Herds with often fetal loss | | p-value |
|---|---|---|---|---|---|
| | | | No./total | % | |
| 1. | Regular veterinary supervision at least twice a year | No (0)<br>Yes (1) | 5 / 35<br>7 / 14 | 14.3<br>50.0 | 0.023* |
| 2. | Superficial abscesses | Never/rarely (0)<br>Often (1) | 6 / 28<br>6 / 21 | 21.4<br>28.6 | 0.739 |
| 3. | Joint swelling | Never/rarely (0)<br>Often (1) | 7 / 36<br>5 / 13 | 19.4<br>38.5 | 0.259 |
| 4. | Lameness | Never/rarely (0)<br>Often (1) | 10 / 43<br>2 / 6 | 23.3<br>33.3 | 0.626 |
| 5. | Injuries and fractures | Never/rarely (0)<br>Often (1) | 8 / 42<br>4 / 7 | 19.1<br>57.1 | 0.051* |
| 6. | Neurological signs | Never/rarely (0)<br>Often (1) | 11 / 45<br>1 / 4 | 24.4<br>25.0 | 1.000 |
| 7. | Respiratory signs in adult goats | Never/rarely (0)<br>Often (1) | 4 / 31<br>8 / 18 | 12.9<br>44.4 | 0.019* |
| 8. | Diarrhea in adult goats | Never/rarely (0)<br>Often (1) | 7 / 37<br>5 / 12 | 18.9<br>41.7 | 0.136 |
| 9. | Wasting | Never/rarely (0)<br>Often (1) | 9 / 42<br>3 / 7 | 21.4<br>42.9 | 0.340 |
| 10. | Bloats | Never/rarely (0)<br>Often (1) | 11 / 45<br>1 / 4 | 24.4<br>25.0 | 1.000 |
| 11. | Dystocia | Never/rarely (0)<br>Often (1) | 11 / 47<br>1 / 2 | 23.4<br>50.0 | 0.434 |
| 12. | Malformations | Never/rarely (0)<br>Often (1) | 12 / 49<br>0 / 0 | 24.5 | –** |
| 13. | Mastitis | Never/rarely (0)<br>Often (1) | 9 / 42<br>3 / 7 | 21.4<br>42.9 | 0.340 |
| 14. | Respiratory signs in kids | Never/rarely (0)<br>Often (1) | 11 / 48<br>1 / 1 | 22.9<br>100 | 0.245 |
| 15. | Diarrhea in kids | Never/rarely (0)<br>Often (1) | 11 / 47<br>1 / 2 | 23.4<br>50.0 | 0.434 |
| 16. | Presence of ticks | Never/rarely (0)<br>Often (1) | 9 / 39<br>3 / 10 | 23.1<br>30.0 | 0.690 |
| 17. | Antibodies to *C. abortus* | No (0)<br>Yes (1) | 9 / 45<br>3 / 4 | 20.0<br>75.0 | 0.041* |
| 18. | Antibodies to *Leptospira* spp. | No (0)<br>Yes (1) | 1 / 5<br>11 / 44 | 20.0<br>25.0 | 1.000 |
| 19. | Antibodies to BVDV | No (0)<br>Yes (1) | 11 / 45<br>1 / 4 | 24.4<br>25.0 | 1.000 |
| 20. | Antibodies to *N. caninum* | No (0)<br>Yes (1) | 12 / 45<br>0 / 4 | 26.7<br>0 | 0.560 |

* risk factors offered to the final multivariate analysis
** p-value impossible to calculate due to lack of observations in herds with frequent fetal loss

Table 3. Final multivariate logistic regression model of relationships between hypothesized risk factors and the occurrence of fetal loss.

| No | Risk factor | Regression coefficient (B) | p–value | Odds ratio (OR) | 95% confidence interval (CI 95%) |
|---|---|---|---|---|---|
| 0. | Intercept | –1.637 | – | – | – |
| 1. | Regular veterinary supervision at least twice a year | –1.673 | 0.009 | 0.188 | 0.054 – 0.656 |
| 2. | Injuries and fractures | 1.154 | 0.036 | 3.172 | 1.081 – 9.310 |
| 3. | Respiratory signs in adult goats | 1.579 | 0.015 | 4.848 | 1.353 – 17.377 |
| 4. | Antibodies to *C. abortus* | 4.062 | 0.034 | 58.116 | 1.369 – 2466.438 |

Table 4. Sensitivity (Se) and specificity (Sp) and their 95% confidence intervals (CI 95%) of the multivariate logistic regression model for subsequent cut-off values.

| Cut-off value | Number of herds | | Se | | Sp | |
|---|---|---|---|---|---|---|
| | with often fetal loss | with none / rare fetal loss | % | CI 95% | % | CI 95% |
| 0.10 | 0 | 19 | 100 | 100-100 | 51.35 | 35.25-67.46 |
| 0.15 | 2 | 8 | 83.33 | 62.25-100 | 72.97 | 58.66-87.28 |
| 0.20* | 1 | 6 | 75.00 | 50.50-99.50 | 89.19 | 79.18-99.19 |
| 0.25* | 0 | 0 | 75.00 | 50.50-99.50 | 89.19 | 79.18-99.19 |
| 0.30* | 0 | 0 | 75.00 | 50.50-99.50 | 89.19 | 79.18-99.19 |
| 0.35* | 0 | 0 | 75.00 | 50.50-99.50 | 89.19 | 79.18-99.19 |
| 0.40 | 3 | 2 | 50.00 | 21.71-78.29 | 94.59 | 87.31-100 |
| 0.45 | 0 | 0 | 50.00 | 21.71-78.29 | 94.59 | 87.31-100 |
| 0.50 | 3 | 1 | 25.00 | 0.50-49.50 | 97.30 | 92.07-100 |
| 0.55 | 0 | 0 | 25.00 | 0.50-49.50 | 97.30 | 92.07-100 |
| 0.60 | 0 | 0 | 25.00 | 0.50-49.50 | 97.30 | 92.07-100 |
| 0.65 | 0 | 0 | 25.00 | 0.50-49.50 | 97.30 | 92.07-100 |
| 0.70 | 0 | 1 | 25.00 | 0.50-49.50 | 100 | 100-100 |
| 0.75 | 0 | 0 | 25.00 | 0.50-49.50 | 100 | 100-100 |
| 0.80 | 0 | 0 | 25.00 | 0.50-49.50 | 100 | 100-100 |
| 0.85 | 0 | 0 | 25.00 | 0.50-49.50 | 100 | 100-100 |
| 0.90 | 1 | 0 | 16.67 | 0-37.75 | 100 | 100-100 |
| 0.95 | 1 | 0 | 8.33 | 0-23.97 | 100 | 100-100 |
| 1.00 | 1 | 0 | 0 | 0 | 100 | 100-100 |
| Total | 12 | 37 | | | | |

* the most optimal cut-off values for the multivariate logistic regression model

justified. Moreover, the multivariate model allowing to work out the overall risk that fetal loss will become an important health problem in a herd may be useful for both veterinarians and farmers.

The univariate analysis was based on Chi-square test. As this statistical method gives the most reliable results when data are allocated in two-by-two contingency tables all input variables (including ordinal and numerical) were re-classified to have dichotomous outcome (Thrusfield 2007).

The final multivariate model was constructed and checked according to recommendations given by Kalil at al. (2010). As the overall number of elements offered to the multivariate analysis (49 herds) was slightly too small to perfectly satisfy the requirements of goodness-of-fit test, another measures of model fit, namely Nagelkerke pseudo-R2 generalized coefficient of determination and ROC curve were employed. The final multivariate model proved to fit the observations and to explain the observed variations well – the result

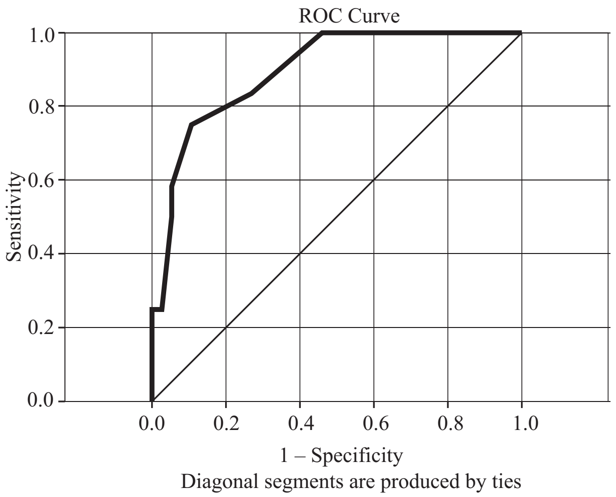


Fig. 1. Receiver operating characteristic (ROC) curve.

gets, compared with a baseline, when a particular risk factor emerges. OR higher than 1 indicates that a hypothesized risk factor occurs more often in a group of elements (animals or herds) which suffer from a health problem, compared with a healthy group and hence implies predisposing influence of a factor. On the other hand, OR lower than 1 suggests protective influence of a factor. However, OR values must be analyzed in conjunction with the confidence intervals (CI) which define the actual value of OR – the narrower CI the more accurate the inference (Thrusfield 2007). In our study CI are wide, especially for the presence of antibodies to *C. abortus* (Table 3), and thus the results should be interpreted with caution. Wide CI may result from low refinement of collected data, which is a common problem in questionnaire surveys. The statement "respiratory signs" is of low precision and does not specify their type, etiology, anatomical location or severity. The same pertains tò injuries and fractures'. On the other hand, the goal of the study was to identify situations, which may predispose to the emergence of fetal loss as an important problem in a herd. If very precise hypothesized risk factors (such as etiological or anatomical diagnoses) had been included, the results would have been of no practical value for goat breeders.

Table 5. Classification contingency table for the multivariate logistic regression model including four risk factors for cut-off from between 0.20 and 0.35 (Se 75.00%, Sp 89.19%).

| | | Actual occurrence of fetal loss | | Total |
|---|---|---|---|---|
| | | Often | Never/rarely | |
| Occurrence of fetal loss estimated using the multivariate model | Often | 9 | 4 | 13 |
| | Never/rarely | 3 | 33 | 36 |
| Total | | 12 | 37 | 49 |

of goodness-of-fit test was insignificant and pseudo-R2 coefficient was quite high (0.611). The model was also fairly reliable in predicting the risk of fetal loss in a herd, being able to identify 75% of herds with frequent fetal loss and almost 90% of herds free from fetal loss, when the optimal cut-off value was applied (Table 5). AUC was also large approaching 90%. By changing cut-off values the multivariate model can act either as one-hundred-percent-sensitive (cut-off = 0.10) or one-hundred-percent-specific (cut-off = 0.70) diagnostic tool (Fig. 1 and Table 4). Nonetheless, not only Se and Sp are responsible for the credibility of a single final prediction (diagnosis) for a particular herd. Another important factor is the prevalence of fetal loss in a population. Along with rising prevalence the probability that a positive result is true also increases, while the probability that negative result is true falls (Noordhuizen et al. 2001). If this multivariate model is to be used in other goat populations in other countries prevalence of fetal loss must be taken into account. Moreover, if the model is to be applied in different climate zones other risk factors not included in the model, in particular infections typical for a particular region, should be considered first.

Odds ratio (OR) is an indirect estimate of relative risk, which shows how much higher the overall risk

As far as we know, our study is the first epidemiological risk analysis for fetal loss in goats conducted in Poland. It yielded four risk factors. Only one of them accorded with results of the studies regarding risk factors of particular abortifacient infections conducted by other authors (Neto et al. 2008, Abo-Shehada and Abu-Halaweh 2010, Anderlini et al. 2011, Cantas et al. 2011, Abu-Dalbouh et al. 2012) – regular veterinary supervision was negatively associated with frequent fetal loss. It is possible that regular veterinary visits help farmers to deal with health problems of a herd more effectively, providing them with practical assistance and education. On the other hand, the relationship does not have to be causative – maybe these farmers who are willing to spend money on veterinary supervision are also more eager to take care of their herds. This conclusion seems to be reasonable as two other risk factors – the occurrence of respiratory signs in adult goats and the occurrence of injuries and fractures – may indicate the overall condition of a herd. There are many causes of respiratory tract diseases but the vast majority of them results from poor environmental conditions. Also frequent mechanical injuries are caused by unadjusted surrounding of goats. On the other hand, lack of association between hygienic condition, system of housing or dehorning and fetal loss may suggest that not the poor management of a herd but other unknown causative factor common for abortions, respiratory signs and higher susceptibility to injuries exists. *C. abortus* could be incriminated of abortions and respiratory symptoms, however its actual role in respiratory tract diseases is unclear (Smith and Sherman 2009). Moreover, it has no documented ability to weaken musculoskeletal system and predispose to injuries. Indeed no such factor has been identified by now. Much more likely solution is that there is no single cause of frequent fetal loss on farms and several different factors must coexist to result in a problem significant for a health condition of a herd.

Out of four infections taken into analysis only the presence of antibodies to *C. abortus* was associated with higher risk of fetal loss. The pathogen is experimentally proven to cause abortions (Rodolakis et al. 1984) and has been frequently isolated from clinical cases of abortions in goats (Moeller 2001, Szeredi et al. 2006, Navarro et al. 2009). Epidemiological confirmation of its role in fetal loss, given that apparent herd-level prevalence was very small, seems to be very important information and raises concerns as to the situation in forthcoming years. Border disease (BVDV-1 infection in goats) and neosporosis are both potential abortifacient diseases but at the moment they seem to be very rare in Poland (Czopowicz et al. 2011a,b). As they run rife their contribution to fetal loss is anticipated. *Leptospira* spp. infection is widespread in Poland but our results seem to accord with commonly acknowledged fact that leptospirosis is usually subclinical in goats (Czopowicz et al. 2011c).

Univariate analysis suggested that feeding with silage was a significant risk factor but it was denied by logistic regression (Table 1). However, given that spoiled silage is a main source of *Listeria monocytogenes* and listeriosis can cause fetal loss in small ruminants the initial result should not be neglected (Gray et al. 1956, Wiedmann et al. 1999). There is no good epidemiological method to assess the prevalence of *Listeria* sp. infection in goat population, however our clinical practice shows that this pathogen is common in Poland (unpublished own data).

Toxoplasmosis is frequently considered as one of the most important abortifacient agents in small ruminants (Chanton-Greutmann et al. 2002, Masala et al. 2007). Our previous studies confirmed that the infection with *T. gondii* is widespread in the population of breeding goats in Poland – true herd-level prevalence was 100% (Ryniewicz et al. 2003, Czopowicz et al. 2011a). Due to the lack of seronegative herds this hypothesized risk factor could not be included in the analysis. Nevertheless, it is very plausible that the infection contributes to the overall prevalence of fetal loss.

Concluding, this epidemiological analysis implies that the etiology of fetal loss in breeding goat population is complex and multifactorial. Although several potentially abortifacient infections exist in the population, only the role of *C. abortus* infection could be revealed. Relationship between fetal loss and three other identified risk factors does not have to be causative. They may simply coexist and only long-lasting prospective studies are able to establish the nature of relationships indicated in our analysis. However, no matter what kind of relationships they are, a practical conclusion is that by regular veterinary supervision over a herd combined with efforts to prevent goats from mechanical injuries and respiratory diseases a farmer can considerably reduce the risk of fetal loss in a herd.

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