Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Herd-level risk factors for Cryptosporidium infection in dairy-goat kids in western France

Arnaud Delafosse a,b, José Antonio Castro-Hermida a,c, Christian Baudry a, Elvira Ares-Mazás c, Christophe Chartier a,*

a AFSSA Site de NIORT, Laboratoire d’Etudes et de Recherches Caprines, 60 rue de Pied de Fond, B.P. 3081, 79012 Niort Cedex, France
b Groupe de Défense Sanitaire de l’Orne, B.P. 138, 61004 Alençon, France
c Laboratorio de Parasitología, Departamento de Microbiología y Parasitología, Facultad de Farmacia, Universidad de Santiago de Compostela, Avda. de Vigo s/n, 15782 Santiago de Compostela, La Coruña, Galicia, España

Received 10 September 2004; received in revised form 2 June 2006; accepted 5 July 2006

Abstract

We conducted a cross-sectional study of risk factors for herd-level kid positivity for Cryptosporidium parvum oocysts in dairy-goat farms (Deux-Sèvres, western France). From January to March 2003, faeces from a convenient sample of 879 5- to 30-day-old goat kids from 60 herds were examined microscopically after staining with carbol fuschin. Oocyst shedding was scored semi-quantitatively (0 to 4+) allowing us to obtain a cumulative score per herd. Standardized questionnaires with information about management practices were collected in each farm. We found positive kids in 32 of 60 herds (53.3%) and in 142 animals out of 879 (16.2%). We used logistic regression for two risk-factor model: (1) simple positive (case: herd score ≥1+, at least one positive kid in the herd, versus control: herd score = 0), (2) strongly positive (case: overall herd score ≥3+ versus control: herd score <3+). Risk factors associated with simple positive herds were period of sampling compared to the peak of births (After versus Before, OR = 4.2, 95% CI 1.2, 15.3) and practice of kid grouping by age or weight (Yes versus No, OR = 4.4, 95% CI 1.0, 19.1). Risk factors associated with strongly positive herds were period of investigation (February/March versus January, OR = 12.7, 95% CI 2.1, 76.6), exposure to graminaceous plants in forage (OR = 11.6, 95% CI 1.7, 81.0) and type of ventilation in the goat premises (Vertical versus Wind effect, OR = 14.7, 95% CI 2.1, 106.1). No important association was found between...
kid-management practices and herd positivity. These results suggest a major role of the environment of kids during their first hours of life in the adult-goat premises regarding the transmission of *C. parvum* infection.

© 2006 Elsevier B.V. All rights reserved.

**Keywords:** Cryptosporidium parvum; Dairy-goat farms; France; Logistic regression

1. **Introduction**

*Cryptosporidium parvum* infection is one of the principal enteropathogens in neonatal goats (De Graaf et al., 1999) and has been reported in French dairy goats since 1983 (Polack et al., 1983). In both natural and experimental conditions, cryptosporidial infection is associated with diarrhoea and mortality in kids aged 1–2 weeks (Nagy et al., 1984; Thamsborg et al., 1990; Koudela and Jiri, 1997; Vieira et al., 1997). As demonstrated in natural conditions in calves, oocyst excretion mainly occurs beginning on day 3–6 post-infection, continuing for 6–9 days and usually persisting at a detectable but asymptomatic level until 1 month of age (Olson et al., 1997; Uga et al., 2000; Castro-Hermida et al., 2002). However, clinical cryptosporidiosis occasionally occurs in goats >4 week old (Johnson et al., 1999). Because no fully satisfactory chemoprophylaxis is available to control neonatal cryptosporidiosis (De Graaf et al., 1999), a better knowledge of the main risk factors of *C. parvum* infection in kids is needed to allow the implementation of preventive hygienic measures both reducing the environmental oocyst burden and preventing the transmission to neonates. Such epidemiological information is relatively scarce in dairy-goat farms compared to farms with other ruminants except for some data from Spain (Matos-Fernandez et al., 1994) and from Poland (Majewska et al., 2000). Our aim was to assess herd-level risk factors for two different levels of oocyst shedding from kids.

2. **Material and methods**

We did this study between January and March, 2003.

2.1. **Target population and sampling**

The target population consisted of all dairy-goat farms of Deux-Sèvres, western France. The sampling frame contained herds from 850 owners (90% of all dairy-goat farms in Deux-Sèvres in 2003) who had a kidding period in winter.

A computed-generated list of 60 farms was selected (Epi Info Version 6.04) to be 95% confident that estimated herd-level prevalence was 40% \(\pm\) 12.

Fifteen 5- to 30-day-old goat kids were selected from each herd as a convenience sample, based on a 95% confidence in selecting at least one positive kid, should the within-herd prevalence be 20% and test sensitivity (Se) be 50% (in Toma et al., 1996).

Faecal samples were collected directly from the rectum, identified and examined by microscopy after staining the smear with carbol fuschin. Slides were examined by a single...
experienced microscopist who did not know the kid’s values on any of the other variables. Oocysts were counted in 20 fields (1000×) and samples were recorded as negative when no oocysts was found.

*Cryptosporidium* oocyst shedding was scored semi quantitatively (0 to 4+) according to the number of oocysts per microscopic field: 0: absence of oocyst in 20 fields, 1+: <1 oocyst/field, 2+: 1–10 oocysts/field, 3+: 11–20 oocysts/field, 4+: >20 oocysts/field (Heine, 1982).

Although some faecal samples contain small numbers of non *C. parvum* particulates (Maldonado-Camargo et al., 1998), specificity (Sp) of Heine technique was assumed to have perfect animal-level specificity (leading also to perfect herd-level specificity). In contrast, the animal-level sensitivity is low because the method cannot detect light infections (Farrington et al., 1995).

2.2. Data collection

Standardized questionnaires with information about management practices were systematically collected. A personal interview of the farm owner/manager was performed during the visit. Factors hypothesized to be associated with the risk of *C. parvum* infection in kids were selected after a review of the scientific literature (Garber et al., 1994; Atwill et al., 1998; Maldonado-Camargo et al., 1998; De Graaf et al., 1999; Mohammed et al., 1999; Sischo et al., 2000; Huetink et al., 2001; Castro-Hermida et al., 2002). Factors were divided into three management categories: general, adult-goat and kid-goat management (Tables 1 and 2). The questionnaire was tested on five farms (not among the 60) to identify potential sources for misinterpretation of the questions and to further refine the questions. Individual data (age, sex, breed, presence of diarrhoea) were collected for each goat sampled.

2.3. Data analysis

Individual results of the Heine technique were added to obtain a score at the herd level (cumulative score). The outcome variables in the study were the case-control status of a herd in two situations: (1) simple positive (case: cumulative herd score ≥1+, at least one positive kid in the herd, versus control: cumulative herd score = 0); (2) strongly positive (case: cumulative score ≥3+, i.e. three kids with 1+ or one with 1+ and one with 2+ or one with 3+, versus control: cumulative herd score <3+).

The approach used to deal with large numbers of independent variables was to investigate potential associations fully between the independent and dependent variables. Factors that were associated (*p* < 0.10) with the likelihood of infection in the bivariable analysis were further considered in the multivariable analysis. The choice of a screening criterion of 0.10 was designed to limit multicollinearity but to ensure that potentially important variables were included in the next analytical step, the multivariable analysis (Dohoo et al., 1996).

The bivariable association between each hypothesized factor and each *C. parvum* infection situation (1, simple positivity; 2, strong positivity) was obtained from Student *t*-test, Wilcoxon test or Chi-square test depending on whether the independent variable had a continuous distribution (Gaussian or non-Gaussian) or categorical distributions. Normality of the continuous variables was tested using the Shapiro–Wilk test (Royston, 1995).
Table 1
Categorical variables offered for the multivariable logistic-regression models using the full data set of 60 dairy-goat herds (Deux-Sèvres, France, 2003)

| Variable                        | Definition                                      | Levels            | No. of herds | Prevalence (%) |
|---------------------------------|-------------------------------------------------|-------------------|--------------|----------------|
|                                 |                                                 |                   |              | Simple positivity | Strong positivity |
| General management              |                                                 |                   |              |                |                   |
| Period<sup>a</sup>              | Season sampling                                 | January           | 30           | 43             | 23                |
|                                 |                                                 | February/March    | 30           | 63             | 53                |
| Birth peak<sup>a,b</sup>        | Sampling after the peak of births               | No                | 23           | 35             | 22                |
|                                 |                                                 | Yes               | 37           | 65             | 49                |
| Breed                           | Breed type dominating                           | Saanen            | 29           | 45             | 34                |
|                                 |                                                 | Alpine            | 31           | 61             | 42                |
| Change                          | Change in herd size (in the last 5 years)       | No                | 33           | 52             | 39                |
|                                 |                                                 | Yes               | 27           | 56             | 37                |
| Purchase                        | Goats purchased the previous year               | No                | 49           | 49             | 35                |
|                                 |                                                 | Yes               | 11           | 73             | 56                |
| Separation 1                    | Separation goat/others ruminants                | No                | 25           | 48             | 32                |
|                                 |                                                 | Yes               | 35           | 57             | 43                |
| Separation 2                    | Separation adults/kids housing                  | No                | 20           | 40             | 30                |
|                                 |                                                 | Yes               | 40           | 60             | 43                |
| Separation 3                    | Separation lactating goats/others               | No                | 38           | 53             | 37                |
|                                 |                                                 | Yes               | 22           | 55             | 41                |
| Water<sup>b</sup>               | Water source (municipal)                        | No                | 20           | 35             | 25                |
|                                 |                                                 | Yes               | 40           | 63             | 45                |
| Employee                        | Employee in the farm                            | No                | 49           | 51             | 37                |
|                                 |                                                 | Yes               | 11           | 64             | 45                |
| Adult goat management           | Autumn kidding<sup>a</sup>                      | No                | 42           | 50             | 29                |
|                                 |                                                 | Yes               | 18           | 61             | 61                |
| AI                              | Use of the artificial insemination              | No                | 45           | 49             | 36                |
|                                 |                                                 | Yes               | 15           | 67             | 47                |
| Grouping<sup>a</sup>            | Birth grouping                                  | No                | 50           | 50             | 40                |
|                                 |                                                 | Yes               | 10           | 70             | 70                |
| Grazing                         | Use of pastures                                 | No                | 53           | 53             | 40                |
|                                 |                                                 | Yes               | 7            | 29             | 29                |
| Leguminous                      | Leguminous plants in the diet                   | No                | 17           | 71             | 47                |
|                                 |                                                 | Yes               | 43           | 47             | 35                |
| Graminaceous<sup>a</sup>        | Graminaceous plants in the diet                 | No                | 19           | 39             | 5                 |
|                                 |                                                 | Yes               | 41           | 61             | 51                |
| Corn silage                     | Corn ensilage in the diet                       | No                | 38           | 55             | 39                |
|                                 |                                                 | Yes               | 22           | 50             | 25                |
Table 1 (Continued)

| Variable                      | Definition                                      | Levels                  | No. of herds | Simple positivity | Strong positivity |
|-------------------------------|------------------------------------------------|-------------------------|--------------|-------------------|-------------------|
| Cereals                       | Cereals in the diet                             | No                      | 11           | 64                | 36                |
|                               |                                                | Yes                     | 49           | 51                | 39                |
| Concentrates                  | Presence of commercial concentrates in the diet | No                      | 15           | 33                | 9                 |
|                               |                                                | Yes                     | 45           | 60                | 44                |
| Floor                         | Type of floor in goat housing                   | Cement                  | 19           | 42                | 26                |
|                               |                                                | Ground                  | 41           | 59                | 44                |
| Wall<sup>b</sup>              | Type of wall in goat housing                    | Wood/sheet              | 14           | 29                | 10                |
|                               |                                                | Cement/stone/brick      | 46           | 61                | 43                |
| Roof                          | Type of roof in goat housing                    | Sheet                   | 41           | 51                | 37                |
|                               |                                                | Wood                    | 19           | 58                | 42                |
| Insulation                    | Heat insulation in goat housing                 | No                      | 52           | 52                | 40                |
|                               |                                                | Yes                     | 8            | 63                | 50                |
| Ventilation<sup>a,b</sup>     | Type of ventilation                             | Only wind effect         | 44           | 43                | 30                |
|                               |                                                | Vertical (ridge tile)   | 16           | 81                | 63                |
| Disinfectant                  | Regular use of disinfectant in goat housing     | No                      | 46           | 59                | 43                |
|                               |                                                | Yes                     | 14           | 38                | 21                |
| Kid goat management           | Fattening of the male kids                     | No                      | 41           | 51                | 34                |
|                               |                                                | Yes                     | 19           | 58                | 47                |
| Bovine colostrums             | Distribution of bovine colostrum                | No                      | 53           | 57                | 40                |
|                               |                                                | Yes                     | 7            | 29                | 29                |
| Colostrum bottle              | Distribution of colostrum with feeding-bottle   | No                      | 43           | 47                | 33                |
|                               |                                                | Yes                     | 17           | 71                | 53                |
| Colostrum bucket              | Distribution of colostrum with bucket           | No                      | 45           | 51                | 36                |
|                               |                                                | Yes                     | 15           | 60                | 47                |
| Milk dispenser                | Distribution of milk with automatic milk dispenser | No                    | 24           | 58                | 42                |
|                               |                                                | Yes                     | 36           | 50                | 36                |
| Milk bucket                   | Distribution of milk with bucket                | No                      | 38           | 45                | 37                |
|                               |                                                | Yes                     | 22           | 68                | 43                |
| Kid grouping<sup>a,b</sup>    | Grouping of kids by age or weight               | No                      | 14           | 29                | 14                |
|                               |                                                | Yes                     | 46           | 61                | 46                |
| Kid floor                     | Type of floor in kid housing                    | Cement                  | 40           | 58                | 40                |
|                               |                                                | Ground                  | 20           | 45                | 35                |
| Kid wall                      | Type of wall in kid housing                     | Wood/sheet              | 11           | 46                | 27                |
|                               |                                                | Cement/stone/brick      | 49           | 55                | 41                |
Multivariable analysis consisted in a backward stepwise logistic regression with a procedure minimizing the Akaike Criterion (AIC) (Akaike, 1974). The stepwise method based on AIC that we used was based on the stepAIC function (Venables and Ripley, 1999) (STEP procedure for glm models, R statistical software). The R function calculates the AIC according to the formula (R Documentation): 
\[
\text{AIC} = -2 \times \text{log-likelihood} + k \times \text{npar},
\]
where \( npar \) represents the number of parameters in the fitted model, and \( k = 2 \) for the usual AIC.

The starting candidate model was based on all of the predictors with \( p < 0.10 \) in the screening. Subsequent models were based on omitting a variable from the current candidate model or adding a variable that was not in the model, with the choice based on minimizing AIC. The final model was found when adding or omitting a variable did not reduce AIC further.

The linearity assumption for continuous variables selected for testing in the models was assessed by categorizing each continuous variable into multiple dichotomous variables of equal units and plotting each variable’s coefficient against the midpoint of the variable. We also performed the Chi-squared test for trend in proportions (R statistical software).

For dealing with potential multicollinearity, the bivariable associations between factors retained and not retained in the logistic models were studied from Student \( t \)-test, Wilcoxon test, Chi-square test or Rank Correlation test depending on the distributions of the variables (Table 4).

### 3. Results

#### 3.1. Descriptive epidemiology

In total, 879 goat kids were tested by Heine’s technique. Of these, 142 (16.2%) were positive from 32 herds, out of a total of 60 herds sampled (53.3%). The number of goat kids
Table 2
Continuous variables offered for the multivariable logistic-regression models using the full data set of 60 dairy-goat herds (Deux-Sèvres, France, 2003)

| Variable          | Definition                                           | Quartiles                  | Normality |
|-------------------|------------------------------------------------------|----------------------------|-----------|
|                   |                                                      | Minimum 25% 50% 75% Maximum|           |
| Goat number       | Number of adult goats                                | 41 131 200 292 830         | No        |
| Cattle number     | Number of cattle                                     | 0 0 12 36 150              | No        |
| Sheep number      | Number of sheep                                      | 0 0 0 0 300                | No        |
| General management|                                                      |                            |           |
| Kidding duration  | Duration of the kidding period (in months)           | 1 3 3 4 7                 | No        |
| Surfacea,b        | Surface available per goat (in m²)                   | 0.8 1.2 1.5 1.7 2.4        | Yes       |
| Volume            | Volume available per goat (in m³)                    | 3.1 8.1 9.8 13.7 36.2      | No        |
| Bedding           | Adding bedding (number by week)                      | 1 3 7 7 14                | No        |
| Daylight          | Natural daylight in the goat housing (ratio transparent sheet surface/surface on the ground) | 0.005 0.030 0.050 0.080 0.290 | No        |
| Change            | Frequency of bedding change (number for year)        | 2 4 5 6 365               | No        |
| Kid goat management|                                                      |                            |           |
| Dam contact       | Contact duration between kids and their dam (in days) | 0.1 0.2 0.5 3.0 10.0       | No        |
| Colostrum duration| Duration ofcolostrum feeding (in days)               | 0.2 1.0 2.0 7.2 30         | No        |
| Kid surface       | Surface available for the kids (in m² per adult goat)| 0.02 0.15 0.22 0.33 0.60  | No        |
| Kid volumeb       | Volume available for the kids (in m³ per adult goat) | 0.1 0.70 1.40 1.90 20.50   | No        |
| Kid bedding       | Adding bedding (number per week)                     | 2 7 7 7 14                | No        |
| Kid daylight      | Natural daylight in the kid housing (ratio transparent sheet surface/surface on the ground) | 0 0.01 0.03 0.07 0.48 | No        |
| Kid changeb       | Frequency of bedding change (number per year)        | 0.2 0.5 1.0 2.0 60.0       | No        |

* a p < 0.10, therefore offered to the second multivariable model (strong positivity).
* b p < 0.10, therefore offered to the first multivariable model (simple positivity).
sampled was <15 in 7 farms (10 in 1 farm; 11 in 2 farms; 12 in 1 farm; 13 in 2 farms and 14 in 1 farm).

One hundred and three (11.7%), 24 (2.7%), 13 (1.5%) and 2 kids (0.2%) had respectively a score of 1+, 2+, 3+ and 4+.

Twenty three herds (38.3%) were classified as strongly positive (cumulative herd score ≥3+).

The highest prevalence for diarrhoea (51.9%) was detected in strongly positive herds compared with 17.0 and 8.1% in the low-positive (cumulative herd score <3+) and negative herds, respectively ($\chi^2 = 442, p < 0.001$).

3.2. Analytical epidemiology

Categorical and continuous variables are presented in Tables 1 and 2.

Four variables were retained in model 1 (simple positivity) and 5 in model 2 (strong positivity). Only one variable was selected in both models (Table 3).

Mainly retained factors were general management or adult goat management factors. Herds sampled in February/March (versus January) or After (versus Before) peak of births were at higher risk of infection. Risk also increased with characteristics of goat housing (wall in cement–stone–brick, vertical ventilation, large surface available by goat) and with breeding practices (birth grouping, forage with graminaceous plants) (Table 3). The only kid goat management factor identified was the practice of kid grouping by age or weight (Table 3).

Although water and kid change were not retained in model 1 (Table 3), each was associated with another risk factor that was retained (Table 4); so, these have not truly been ruled out as having association with simple herd positivity. Similarly, birth peak, autumn kidding, and kid grouping (Table 4) were associated with factors retained in the final version of model 2.

### Table 3
Factors associated with simple\(^a\) and strong\(^b\) positivity to *C. parvum* in 60 dairy-goat herds (Deux-Sèvres, France, 2003)

| Variable            | $b$   | $p$   | Odds ratio | 95% CI  |
|---------------------|-------|-------|------------|---------|
| **Model 1 (simple positivity)** |       |       |            |         |
| Intercept           | -3.13 | 0.002 | –          | –       |
| Birth peak          | 1.46  | 0.02  | 4.2        | 1.2, 15.3 |
| Wall                | 1.23  | 0.09  | 3.4        | 0.8, 14.1 |
| Ventilation         | 1.46  | 0.08  | 4.3        | 0.8, 22.6 |
| Grouping kids       | 1.48  | 0.05  | 4.4        | 1.0, 19.1 |
| **Model 2 (strong positivity)** |       |       |            |         |
| Intercept           | -8.24 | 0.001 | –          | –       |
| Period              | 2.54  | 0.005 | 12.7       | 2.1, 76.6 |
| Birth grouping      | 1.41  | 0.13  | 4.1        | 0.7, 26.2 |
| Graminaceous        | 2.45  | 0.01  | 11.6       | 1.7, 81.0 |
| Ventilation         | 2.69  | 0.008 | 14.7       | 2.1, 106.1 |
| Surface\(^c\)       | 2.35  | 0.04  | 10.5       | 1.1, 98.8 |

\(^a\) Model 1: residual deviance with 51 degrees of freedom: 63.76, AIC: 73.76.

\(^b\) Model 2: residual deviance with 54 degrees of freedom: 48.40, AIC: 60.40.

\(^c\) Linearity assumption for continuous variable (trend test, $\chi^2 = 4.96, p = 0.03$).
4. Discussion

Extrapolation of our results to kidding in the autumn should be done only with care. Many other agents (Escherichia coli, rotavirus, coronavirus) are involved in diarrhoea of neonatal ruminants. It would have been relevant to include these factors in our statistical analysis. However, this information in goat is extremely scarce (Millemann et al., 2003). In a few herds, the sample of 15 5- to 30-day-old kids was not achieved with an increased risk of misclassification in the negative group (sensitivity of the diagnosis at the herd level lower than the expected value of 0.95).

One of the objectives of our study was the identification and quantification of risk factors for *C. parvum* infection at the herd level. Many factors were investigated. In such a situation, the possibility of finding associations ‘due to chance alone’ goes up substantially (Dohoo et al., 1996). The other problem is multicollinearity which occurs when predictor variables are not statistically independent and which results in unstable estimates of regression coefficients in logistic-regression models (Dohoo et al., 1996).

Several variables eliminated by the backward-elimination process were highly collinear with variables retained by the modelling (Table 4). The information from the variables “Birth peak” and “Period” was probably redundant because the birth peak generally occurs before the end of the winter period (February/March). In the same way, “Autumn kidding” and “Birth grouping” variables included similar information because birth in autumn is allowed by non natural methods (photoperiod control or hormonal treatments) on groups of goats. To simplify our statistical approach, we could have preserved only one of the redundant variables, and discarded the other one, before the backward-elimination process. On the other hand, no obvious relationship appeared between the variables “Water” and “Birth peak” on the one hand and “Kid grouping” and “Graminaceous” on the other hand.

Our strategy for reducing the number of independent variables was to screen potential predictor variables using simple (unconditional) statistics and then select a subset of independent variables for inclusion in the final analysis. Another approach would be to create indices or scores which combine data from multiple factors into a single variable or to create a smaller set of independent variables through the use of multivariable techniques...
such as principal-components analysis or factor analysis (Dohoo et al., 1996). However, those techniques do not assess the statistical significance of the direct associations between specific independent variables and the dependent variable.

Variable-selection methods attempt to balance the goodness-of-fit of a model with considerations of parsimony. However this is done, in theory one could look at all possible logistic-regression models to find the “best” one, but this becomes computationally prohibitive when $p$ is large. For this reason, it is more classical to use a stepwise procedure, where candidate models are based on adding or removing a term from the current “best” model.

A flaw in this approach is that it does not directly address the crucial balance of goodness-of-fit versus parsimony. Akaike (1974) proposed a measure (AIC) based on information considerations that explicitly quantifies this balance. Model selection using AIC does better, more often resulting in improved performance relative to using the full logistic-regression model, particularly for smaller samples sizes (Perlich et al., 2003).

We acknowledge that we did not have random sampling at each step of our selection process. However, the specificity was good enough that we are confident that, where positive kids were found, the herds truly were infected. The problem remaining is that because of uncertain sensitivity and the convenient sampling of kids, there might also be infected herds among those used as controls in our models. The effect, we feel, would have been to diminish the contrast between the control and the positive herds. With such large ORs as we found especially in the model for strong positivity, we believe that we have identified a few risk factors worthy of additional examination.

The period of sampling was linked to the risk of $C.\ parvum$ infection with February/March period being more at risk than January (OR = 12.7). Monthly variations in prevalence were also recorded by Bourgoïn (1996) and Lefay et al. (2000) in cattle in France and by Causape et al. (2002) in lambs in Spain. One of the likely explanations is the hygienic degradation of the neonates’ environment and the simultaneous increase in disease incidence during the whole kidding or calving period especially when parturition is highly seasonal. This is particularly the case in dairy-goat breeding where kidding period mainly extends from November to March with the neonates’ premises not being cleaned during this period. Otherwise, changes in crowding of premises or multiple peaks of newborn animals may account for seasonal variations in Cryptosporidium oocyst shedding (Huetink et al., 2001).

When examining the risk factors of Cryptosporidium infection in farms, none of the parameters related to the management of goat neonates, except the practice of kid grouping by age or weight, was significant in our study. This surprised us, because an extensive previous study of Atwill et al. (1998) performed in a similar system where dairy calves are immediately separated from their dams brought some evidence of the key role of environment in the contamination with Cryptosporidium. Those authors demonstrated the role of the floors and the walls of calf hutches in the transmission of cryptosporidial infection to neonates whereas the dam excretion was undetectable. Similarly, significant relationships between some calf-environment factors such as ventilation, frequency of disposal or addition of bedding, feeding, calf-to-calf contact and the odds of shedding $C.\ parvum$ oocysts have been described (Maldonado-Camargo et al., 1998; Mohammed et al., 1999; Sischo et al., 2000).
In contrast, other results suggest an important role of the dam in the direct contamination of their offsprings. According to both the prepatent period of *C. parvum* infection and the breeding conditions of dairy calves in the Netherlands (immediate removal of calves from their dams, rearing in individual hutches), Huetink et al. (2001) considered that direct or indirect cow-to-calf transmission was probably the most important route of infection followed by indirect calf-to-calf transmission through vectors (caretakers, insects). Asymptomatic adult cattle or sheep can be inapparent carriers especially around parturition when an increase in oocyst output generally occurs (Xiao et al., 1994; Ortega-Mora et al., 1999; Ralston et al., 2003; Faubert and Litvinsky, 2000). Similarly, >25% of the goats >1 year old shed oocysts (Noordeen et al., 2001). Thus the risk factors we found (which mainly involved adult-goat management) have to be interpreted in relation with oocyst contamination, i.e output and persistency in adult premises. The vertical ventilation (ridge tile) appeared as a risk factor and this might be related to a more efficient system (compared to horizontal ventilation) leading to a paradoxically more favourable environment for the oocyst survival due to a lower level of ammonia in the litter (Jenkins et al., 1999; Walker et al., 1998). We also found that the type of the diet given to the adult goat was associated with an increased risk of *C. parvum* infection prevalence in kids. Forages might be involved through a direct (contaminated feed) or an indirect effect. Very little information is available on survival of oocysts in forage except the data of Merry et al. (1997) on ryegrass ensilage showing a 30% survival after 3 months. Except for contamination with rodent or pet faeces after collection, the survival of oocysts on hay is expected to be very low if any because of the dryness of such a material. The impact of graminaceous versus leguminous in the diet on oocyst excretion remains to be investigated.

Knowledge of transmission routes of *C. parvum* infection remains essential for the development of a control program on farms. Our results suggest a major role of the environment of the first hours of kids life regarding the transmission of *C. parvum* infection in the adult-goat premises.

Acknowledgements

We thank Frantz Jénot (Chambre d’Agriculture of Deux-Sèvres, France) for his technical assistance. J.A. Castro-Hermida is supported by Xunta de Galicia (Spain) by means of the Conselleria de Politica Agroalimentaria e Desenvolvemento Rural (PGIDIT02RAG20301 PR) and Post-Doctoral fellowship of the Conselleria de Presidencia e Administracion Publica (PR409A2002/7-0). We are indebted to Conseil Régional Poitou-Charentes (France) for additional financial support.

References

Akaike, H., 1974. A new look at statistical model identification. IEEE Trans. Autom. Control AU-19, 716–722. Atwill, E.R., Harp, J.A., Jones, T., Jardon, P.W., Checel, S., Zylstra, M., 1998. Evaluation of periparturient dairy cows and contact surfaces as a reservoir of *Cryptosporidium parvum* for calfhood infection. Am. J. Vet. Res. 59, 1116–1121.
Bourgoin, H., 1996. La place de la cryptosporidiose dans les maladies néo-natales du veau en Corrèze. Bull. Groupements Tech. Vétérinaires (France) 2, 19–41.

Causape, A.C., Quilez, J., Sanchez-Acedo, C., Del Cacho, E., Lopez-Bernad, F., 2002. Prevalence and analysis of potential risk factors for Cryptosporidium parvum infection in lambs in Zaragoza (northeastern Spain). Vet. Parasitol. 104, 287–298.

Castro-Hermida, J.A., Gonzalez-Losada, Y.A., Mezo-Menendes, M., Ares-Mazas, E., 2002. A study of cryptosporidiosis in a cohort of neonatal calves. Vet. Parasitol. 106, 11–17.

De Graaf, D., Vanopdenbosch, E., Ortega-Mora, L.M., Abbassi, H., Peeters, J.E., 1999. A review of the importance of cryptosporidiosis in farm animals. Int. J. Parasitol. 29, 1269–1287.

Dohoo, I.R., Ducrot, C., Fourichon, C., Donald, A., Hurnik, D., 1996. An overview of techniques for dealing with large numbers of independent variables in epidemiologic studies. Prev. Vet. Med. 29, 221–239.

Farrington, M., Lloyd, S., Winters, S., Smith, J., Rubenstein, D., 1995. Patterns of Cryptosporidium antigen and oocyst excretion in calves studied by reverse passive haemagglutination and light microscopy. Vet. Parasitol. 60, 7–16.

Faubert, G.M., Litvinsky, Y., 2000. Natural transmission of Cryptosporidium parvum between dams and calves on a dairy farm. J. Parasitol. 86, 495–500.

Garber, L.P., Salman, M.D., Hurd, H.S., Keefe, T., Schlater, J.L., 1994. Potential risk factors for Cryptosporidium infection in dairy calves. JAVMA 205, 86–91.

Heine, J., 1982. An easy technique for the demonstration of Cryptosporidia in faeces. Zentralbl. Veterinaermed. Reihe B 29, 324–327.

Huetink, R.E.C., van der Giessen, J.W.B., Noorduizien, J.P.T.M., Ploeger, H.W., 2001. Epidemiology of Cryptosporidium spp. and Giardia duodenalis on a dairy farm. Vet. Parasitol. 102, 53–67.

Jenkins, M.B., Bowman, D.D., Ghiorse, W.C., 1999. Inactivation of Cryptosporidium parvum oocysts by ammonia. Appl. Environ. Microbiol. 64, 784–788.

Johnson, E.H., Muirhead, D.E., Windsor, J.J., King, G.J., Al-Busaidy, R., Cornelius, R., 1999. Atypical outbreak of caprine cryptosporidiosis in the Sultanate of Oman. Vet. Rec. 145, 521–524.

Koudela, B., Jiri, V., 1997. Experimental cryptosporidiosis in kids. Vet. Parasitol. 71, 273–281.

Lefay, D., Naciri, M., Poirier, P., Chernet, R., 2000. Prevalence of Cryptosporidium infection in calves in France. Vet. Parasitol. 89, 1–9.

Maldonado-Camargo, S., Atwill, E.R., Saltijeral-Oaxaca, J.A., Herrera-Alonso, L.C., 1998. Prevalence of and risk factors for shedding of Cryptosporidium parvum in Holstein Freisian dairy calves in central México. Prev. Vet. Med. 36, 95–107.

Majewska, A.C., Werner, A., Sulpina, P., Luty, T., 2000. Prevalence of Cryptosporidium in sheep and goats bred on five farms in west-central region of Poland. Vet. Parasitol. 89, 269–275.

Matos-Fernandez, M.J., Ortega-Mora, L.M., Pereira-Bueno, J., Gonzalez-Paniello, R.M., Reguera de Castro, E.N., Reyero-Fernandez, F., Alvarez-Pacios, C., Rojo-Vasquez, F.A., 1994. Epidemiologica de la criptosporidiosis en el ganado, ovino y caprino de la montana de Leon. Med. Vet. 11, 147–154.

Merry, R.J., Mawdsley, J.L., Brooks, A.E., Davies, D.R., 1997. Viability of Cryptosporidium parvum during ensilage of perennial ryegrass. J. Appl. Microbiol. 82, 115–120.

Millemann, Y., Adjou, K., Maillard, R., Polack, B., Chartier, C., 2003. Les diarrhées néonatales des agneaux et des chevreaux. Point Vet. 233, 22–29.

Mohammed, H.O., Wade, S.E., SchAAF, S., 1999. Risk factors associated with Cryptosporidium parvum infection in dairy cattle in southeastern New York State. Vet. Parasitol. 83, 1–13.

Nagy, B., Bozso, M., Palfi, V., Nagy, G., Sahiby, M.A., 1984. Studies on cryptosporidial infection of goat kids. Les maladies de la chèvre, Niort, France, 9–11 octobre 1984, Ed. INRA Pub. (Les colloques de l’INRA, 828), pp. 443–451.

Noordeen, F., Faizal, A.C., Rajapakse, R.P., Horadagoda, N.U., Arulkanthan, A., 2001. Excretion of Cryptosporidium oocysts by goats in relation to age and season in the dry zone of Sri Lanka. Vet. Parasitol. 99, 79–85.

Olson, M.E., Guselle, N.J., O’Handley, R.M., Swift, M.L., McAllister, T.A., Jelinski, M.D., Morck, D.W., 1997. Giardia and Cryptosporidium in dairy calves in British Columbia. Can. Vet. J. 38, 703–706.

Ortega-Mora, L.M., Requejo-Fernandez, J.A., Pilar-Izquierdo, M., Pereira-Bueno, J., 1999. Role of adult sheep in transmission of infection by Cryptosporidium parvum to lambs: confirmation of periparturient rise. Int. J. Parasitol. 29, 1261–1268.
Perlich, C., Provost, F., Simonoff, J.S., 2003. Tree induction versus logistic regression: a learning-curve analysis. J. Machine Learn. Res. 4, 211–255.

Polack, B., Chermette, R., Savey, M., Bussieras, J., 1983. Les cryptosporidies en France. Techniques usuelles d’identification et résultats préliminaires d’enquêtes épidémiologiques. Point Vet. 15, 41–46.

Ralston, B.J., McAllister, T.A., Olson, M.E., 2003. Prevalence and infection pattern of naturally acquired giardiasis and cryptosporidiosis in range beef calves and their dams. Vet. Parasitol. 114, 113–122.

Royston, P., 1995. A remark on algorithm AS 181: the W test for normality. Appl. Stat. 44, 547–551.

Sischo, W.M., Atwill, E.R., Lanyon, L.E., George, J., 2000. Cryptosporidia on dairy farms and the role these farms may have in contaminating surface water supplies in the northeastern United States. Prev. Vet. Med. 43, 253–267.

Thamsborg, S.M., Jorgensen, R., Henriksen, S., 1990. Cryptosporidiosis in kids of dairy goats. Vet. Rec. 127, 627–628.

Toma, B., Dufour, B., Sanaa, M., Benet, J.J., Ellis, P., Moutou, F., et Louza, A., 1996. Epidémiologie appliquée à la lutte collective contre les maladies transmissibles majeures. AEEMA, Maisons-Alfort, France, 551 p.

Uga, S., Matsuo, J., Kono, E., Kimura, K., Inoue, M., Rai, S.K., Ono, K., 2000. Prevalence of Cryptosporidium parvum infection and pattern of oocyst shedding in calves in Japan. Vet. Parasitol. 94, 27–32.

Venables, W.N., Ripley, B.D., 1999. Modern Applied Statistics with S-Plus, 3rd ed. Springer-Verlag, New York.

Vieira, L.S., Silva, M.B.O., Tolentino, A.C.V., Lima, J.D., Silva, A.C., 1997. Outbreak of cryptosporidiosis in dairy goats in Brazil. Vet. Rec. 140, 415–418.

Walker, M.J., Montemagno, C.D., Jenkins, M.B., 1998. Source water assessment and nonpoint sources of acutely toxic contaminants: a review of research related to survival and transport of Cryptosporidium parvum. Water Resour. Res. 34, 3383–3392.

Xiao, L., Herd, R.P., McClure, K.E., 1994. Periparturient rise in the excretion of Giardia sp. cysts and Cryptosporidium parvum oocysts as a source of infection for lambs. J. Parasitol. 80, 55–59.