Reduction of Enteropathogenic *Yersinia* in the Pig Slaughterhouse by Using Bagging of the Rectum

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**ABSTRACT**

To evaluate the effectiveness of bagging of the rectum in mitigating the contamination of carcasses with enteropathogenic *Yersinia* at the slaughterhouse and to estimate the hidden prevalences of these pathogens in different farm types and capacities, samples from pigs, carcasses, and slaughterhouse environment were collected, and a Bayesian probability model was constructed. In addition, the contamination routes were studied with molecular typing of the isolated strains. According to the model, bagging of the rectum reduced carcass contamination significantly with pathogenic *Yersinia enterocolitica*, but not with *Yersinia pseudotuberculosis*, and alone it was insufficient to completely prevent the carcass contamination with enteropathogenic *Yersinia*. The hidden prevalence of pathogenic *Y. enterocolitica* was higher at high production capacity than it was in low production capacity, but the 95% credible intervals overlapped. Slaughterhouse environments can contaminate carcasses with enteropathogenic *Yersinia*, but the plausible main contamination source is the pig carrying the pathogen.

Enteropathogenic *Yersinia*, i.e., pathogenic *Yersinia enterocolitica* and *Yersinia pseudotuberculosis*, are zoonotic pathogens that cause yersiniosis, the third most frequently reported notified zoonosis in the European Union (8). Enteropathogenic *Yersinia* are frequently isolated from the tonsils and intestinal contents of pigs worldwide (5, 10, 14, 16, 28, 30–32). Similar *Y. enterocolitica* genotypes have been identified in both pig and human samples (11, 15), and human yersiniosis caused by *Y. enterocolitica* has been associated with the consumption of pork products in case-control studies (6, 33, 37), indicating that pigs and pork products are important sources of human *Y. enterocolitica* infections. *Y. pseudotuberculosis* has been isolated from pig carcasses and pork (16, 21), suggesting a possible route from pigs to humans. At the slaughterhouse, pigs infected with enteropathogenic *Yersinia* on farms have been identified as a major source of enteropathogenic *Yersinia*–contaminated carcasses (21, 22), and so far, practical and cost-effective ways to prevent enteropathogenic *Yersinia* on farms are scarce (26). Therefore, intervention at the slaughterhouse is needed to prevent *Yersinia* contamination of carcasses. Bagging of the rectum and removal of the head have been suggested as means of reducing carcass contamination with *Y. enterocolitica* (1, 7, 13, 27). Based on modeling, the combined prevalence of *Listeria monocytogenes* and enteropathogenic *Yersinia* in Finnish pork was estimated to be reduced from 1 to 11% to 0 to 2% if the head was removed intact and the rectum sealed off (35).

A pig as a whole (or a particular sampling site) may carry pathogenic *Y. enterocolitica* or *Y. pseudotuberculosis*, although it may be undetected in the sample, because the entire pig and carcass are impossible to sample, and the sensitivity of the detection methods is less than 100%. True prevalence is therefore not observable, but it does contribute to risk. With Bayesian modeling, deficiencies in the detection methods and sampling can be accounted for and thus, estimates more relevant for risk assessment may be obtained. Simultaneously, the model accounts for clustering of the pigs by farms, with random effects. This is needed for properly dealing with the uncertainty that is due to clustered sampling and variability among farms. Moreover, the model incorporates causal assumptions, expressed as conditional probabilities, including environmental effects. Bayesian inference provides a joint probability distribution of all model parameters, conditional on data and prior distribution. Several uncertainties and conditional dependencies are thus integrated in a holistic approach.

The objective of this study was to investigate the effect of bagging of the rectum and the slaughterhouse environment on the contamination of carcasses with enteropathogenic *Yersinia*. This was accomplished by tracing contamination sources with pulsed-field gel electrophoresis (PFGE) typing of isolated strains and constructing a Bayesian probability model. In the model, the observed prevalence of...
Y. enterocolitica and Y. pseudotuberculosis on different sampling sites was dependent on the true prevalence, the slaughterhouse environment, and the bagging intervention, accounting for clustering of the pigs by farms.

**MATERIALS AND METHODS**

The effect of sealing the rectum with a plastic bag on contamination of carcasses with enteropathogenic *Yersinia* was evaluated in a U.S. Department of Agriculture–audited pig slaughterhouse in Finland over a 2-month period in 2007. The samples were collected in two rounds. In the first sampling round, the rectum was circumcised with a bung cutter, but not bagged. In the second sampling round, the rectum was manually sealed by placing a plastic bag onto the rectum after the circumcision. The rectum removal system tested (circumcision or bagging of the rectum) was used at least 2 weeks prior to the sampling to ensure that the system was being used properly. In both sampling rounds, the sampling was dispersed over 6 different days over 2 weeks to make certain that the sampling represents the general manner of production of the slaughterhouse.

**Samples from pigs.** On each sampling day, 25 pigs from 2 to 8 farms were sampled. The pigs sampled were from 55 farms, with 1 to 18 pigs from each farm. The intestinal contents, tonsils, and three carcass samples were collected from 151 pigs without bagging and from 150 pigs with bagging. The intestinal contents and tonsils were collected on the slaughter line immediately after meat inspection. The carcasses of the pigs sampled were tagged with a running number on the slaughter line at the meat inspection and routed to the side lane, where the carcasses were swabbed. All samples were placed in disposable, clean plastic bags or boxes, with the running number of each pig. From each carcass, the farm name from the tattoo and the running slaughter line number were recorded, and production type and capacity of the farm were checked. Production capacity was categorized as small (<1,000 slaughtered pigs per year) or large (≥1,000 slaughtered pigs per year), and farm type as slaughter production or farrow-to-finish production. Farms without piglet production were defined as slaughter production, and all farms that produced piglets and sent pigs to slaughter were considered farrow-to-finish production.

The intestinal contents were collected with a clean, disposable spoon from an incision into the colon area. The tonsils were cut from the pluck set with a knife, which was washed and sterilized in hot (82°C) water before each sampling. The carcass samples were collected from both halves of the carcass by swabbing with a sponge swab premoistened with sterile phosphate buffer (Polywipe MW729, Medical Wire and Equipment Co., Corsham, Wiltshire, UK). For pelvic and abdominal samples, the pelvic and abdominal cavities down to the diaphragm and along the cut surface of the abdominal skin were swabbed. The thoracic cavity, skin from the cut surface of the thorax, neck, and split surface of the head, except the oral cavity, were swabbed to obtain chest and head samples. Finally, to obtain a skin sample, the skin of the carcass was swabbed from the rectal circumcision to the level of the diaphragm. The samples were transported in a cooler to the laboratory and analyses were commenced the same day, except for the tonsil samples, which were frozen after arrival and analyzed later. *Y. enterocolitica* O:3, which is the most common serotype in Finland, survives freezing well (3, 4).

**Environmental samples.** On each sampling day, 10 air samples were collected during slaughtering from three sites: near carcass splitting, near bung cutting, and at the entrance of the refrigeration passage. Three sampling methods were applied: (i) sedimentation for approximately 1.5 h onto a cefsulodin-irgasan-novobiocin (CIN; *Yersinia* selective agar base [Oxoid, Ltd., Basingstoke, UK]; *Yersinia* selective supplement) agar plate and onto a CIN plate without antibiotic supplement; (ii) Andersen two-stage cascade impactor onto CIN agar plates at a sampling flow rate of 28.3 liters/min for 15 min; and (iii) liquid impingement by using an AGI-30 impinger (Ace Glass, Vineland, NJ) into 20 ml of phosphate-buffered saline with 0.5% peptone, 1% mannitol, and 0.15% bile salts (PMB) at a flow rate of 12.5 liters/min for 15 min. Each day, 11 surface samples were collected. Floor samples were collected at the side lane during sampling of the carcasses, at the entrance of the refrigerating passage, and from the floor next to the slaughter line at the site of the carcass splatter and gutting stand during slaughtering, by using boot sock swabs made from tubular elastic material (latex and polyester; Stockinette Elastic Casing Net, Trunature Holdings, Ltd., Swadlincote, Derbyshire, UK) moistened with peptone water and pulled over shoes for sampling. A gutting knife, brisket saw, edge of the gutting stand, automatic stamping machine, computer keyboard at the meat inspection, and abdominal fat remover were swabbed with sponge swabs during slaughtering. In addition, 2 samples were taken from the carcass splatter during a break.

**Isolation of pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis*.** Cold enrichment for 7 and 14 days has been the most effective method in the isolation of pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis* from porcine samples (20, 21, 28, 30–32). Therefore, all samples were cold enriched in PMB. The carcass and environmental swabs were aseptically transferred into 90 ml of PMB, except the floor swabs, which were transferred into 225 ml of PMB. The tonsils were cut with sterile scissors and 10 g of tonsil material was transferred into 90 ml of PMB. A 5-g sample of intestinal contents was weighed and transferred into 45 ml of PMB. The PMB broth samples were cold enriched at 4°C for 7 and 14 days. Alkaline treatment (17) was used after 14 days of cold enrichment. A 0.1-ml volume of enrichment culture was streaked after 1 and 2 week(s) onto a CIN agar plate. All CIN plates were incubated at 30°C for 18 to 20 h, and further at 22°C for 24 h. One to three suspect colonies were pure cultured onto blood agar plates (Columbian blood agar base [Difco, BD, Sparks, MD] supplemented with blood).

**Identification, bioserotyping, and virulence of pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis* strains.** The isolates were tested for urea hydrolysis. Urease-positive isolates were further identified as *Y. enterocolitica* or *Y. pseudotuberculosis* by using the API 20E test kit (bioMérieux, Inc., Marcy l’Etoile, France), according to the manufacturer’s instructions, with the exception of incubation at 25°C instead of 37°C. *Y. enterocolitica* was biotyped with xylose, trehalose, salicin, esculin, Tween, and pyrazinamidase reactions, per the protocol of Wauters et al. (39).

The *Y. enterocolitica* isolates were serotyped with a slide agglutination test by using commercial polyvalent O:1 and O:2, O:3, O:5, O:8, and O:9 antisera for *Y. enterocolitica* (Denka Seiken Co., Ltd., Tokyo, Japan). *Y. pseudotuberculosis* isolates were serotyped with O:1 to O:6 antisera for *Y. pseudotuberculosis* (Denka Seiken). *Yersinia* isolates were tested for pathogenicity by using PCR assays that targeted the chromosomal virulence genes *ail* for *Y. enterocolitica* and *inv* for *Y. pseudotuberculosis*, and the virulence plasmid (pYV) gene *virF* (18, 24) for both.
PFGE typing of pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis*. A total of 466 isolates were characterized with PFGE, as described by Fredriksson-Ahomaa et al. (9) and modified by Niskanen et al. (28) by using NotI and XhoI restriction enzymes (New England Biolabs, Ipswich, MA) for *Y. enterocolitica* (433 isolates) and SpeI and NotI for *Y. pseudotuberculosis* (33 isolates). From each enteropathogenic *Yersinia*-positive sample, 1 to 2 isolates were characterized. The restriction patterns were analyzed with the assistance of BioNumerics (Applied Maths, Sint-Martens-Latem, Belgium) software, version 5.10, and confirmed visually.

Hidden variable model and bagging effect. WinBUGS (23), version 1.4.3, was used to compute a hidden variable model of enteropathogenic *Yersinia* in pigs at the slaughterhouse at the animal-specific level. The observed prevalence of pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis* in different sample types is dependent on the true prevalence, the bagging intervention, and the slaughterhouse environment. The dependency relationship is illustrated in Figure 1. Pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis* were modeled separately, and only farms with *Yersinia* contamination at the slaughterhouse were used. The sampling site-specific detection probabilities are modeled by writing the following probabilities:

\[
p^i_j = P(Y_j = 1)p^i\]

\[
p^b_j = P(Y_j = 1)p^b\]

\[
p^p_j = 1 - \left[1 - P(Y_j = 1)p^p\right]\left(1 - p_{\text{enviro}}\right)\]

\[
p^*_{ij} = 1 - \left[1 - P(Y_j = 1)p^*\right]\left(1 - p_{\text{enviro}}\right)\]

where \(p^i\), \(p^b\), \(p^p\), and \(p^*\) are conditional probabilities of detection at a site, given that the animal was a hidden carrier; \(p_{\text{enviro}}\), global environmental parameter describing the probability of environmental contamination at the slaughterhouse.

The probability of occurrence enteropathogenic *Yersinia* in any of the five samples (intestinal contents, tonsils, skin, chest and head, or pelvic and abdominal cavities) at the slaughterhouse is conditional on the hidden variable, \(Y_{ij}\), of the same animal. Due to the low number of positive environmental samples, the observed data on environmental contamination could not be included in the model, and therefore a global environmental parameter, \(p_{\text{enviro}}\), describing the probability of environmental contamination at the slaughterhouse was used. The sampling site-specific detection probabilities are modeled by writing the following probabilities:

\[
Y_{ij} | P(Y_{ij} = 1) \sim \text{Bernoulli} \left( \theta_{ij} \right)
\]

where \(Y_{ij}\) is the probability of a hidden variable for pig \(i\) and farm \(j\), and \(\theta_{ij}\) is the probability of occurrence of enteropathogenic *Yersinia* at any site, and \(0 < \theta_{ij} \leq 1\). The probability of occurrence enteropathogenic *Yersinia* is dependent on the true prevalence, the bagging intervention, and the slaughterhouse environment. The dependency relationship is illustrated in Figure 1. Pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis* were modeled separately, and only farms with *Yersinia* contamination at the slaughterhouse were used. The sampling site-specific detection probabilities are modeled by writing the following probabilities:

FIGURE 1. Graphical presentation of conditional dependencies in the model. Arrows denote a stochastic dependence. Observed data variables are shown boxed; unknown variables and parameters are in ellipsoids. Upper indices: c, chest and head; i, intestinal contents; p, pelvis and abdomen; s, skin; t, tonsils. Lower indices: i = ith animal, j = jth farm. a, parameter of hidden status model; F, farm-specific random effect; b, bagging effect. p\(^i\), p\(^b\), p\(^p\), and p\(^*\), conditional probabilities of detection at a site, given that the animal was a hidden carrier; p\(_{\text{enviro}}\), global environmental parameter describing the probability of environmental contamination at the slaughterhouse.
The bagging effect (i.e., the odds ratio in equation 4) was defined separately for tonsils and intestinal contents, and for the carcass samples. Parameter \( b^{(1)} \) thus evaluates the multiplicative effect of bagging on the odds. In equation 4, the possible values of \( b^{(1)} \) range from 0 to \( \infty \). If \( b^{(1)} = 1 \), bagging has no effect on sample-specific prevalence. A level of \( b^{(1)} \) greater than 1 means increased prevalence, whereas \( b^{(1)} \) less than 1 means reduced prevalence. A reasonable uninformative prior density of \( b^{(1)} \) is defined on \( R^{+} \), with 1 as the median. We adopted the prior distribution from a previous study (35):

\[
\log \left( b^{(1)} \right) \sim N(\psi^{(1)}, 1) I(-4.60517, 4.60517) \tag{5}
\]

where \( \psi^{(1)} \sim N(0, 0.1) \) (i.e., variance = 10).

The posterior distribution of all unknown model parameters was computed by Markov chain Monte Carlo methods provided in WinBUGS, using 20,000 iterations (200,000 with thin = 10).

**RESULTS**

**Descriptive data.** Pathogenic (ail and virF positive) *Y. enterocolitica* was isolated without bagging from 45 (30%) intestinal content samples and 89 (59%) tonsils, and with bagging from 45 (30%) intestinal content samples and 88 (59%) tonsils (Table 1). In all, 94 (62%) pigs without bagging and 96 (64%) pigs with bagging were positive in either the tonsils or intestinal contents for pathogenic *Y. enterocolitica*. Thirty-nine (26%) carcasses were pathogenic *Y. enterocolitica* positive without bagging, and 26 (17%) were positive with bagging. All pathogenic *Y. enterocolitica* isolates represented bioserotype 4/O:3. Pathogenic (inv and virF positive) *Y. pseudotuberculosis* was isolated from 7 (5%) intestinal contents and 6 (4%) tonsil samples without bagging. With bagging, the corresponding figures were 6 (4%) and 2 (1%). Four (3%) carcasses were pathogenic *Y. pseudotuberculosis* positive without bagging and 2 (1%) carcasses with bagging (Table 2). All pathogenic *Y. pseudotuberculosis* isolates represented serotype O:3. Eight (6%) environmental samples were positive for pathogenic *Y. enterocolitica* when bagging was not used and 5 (4%) samples when bagging was used (Table 3). *Y. pseudotuberculosis* was not isolated from the environment.

Twenty-three different *Y. enterocolitica* PFGE types were obtained by combining 18 *NotI* and 13 *XhoI* profiles, and five different *Y. pseudotuberculosis* PFGE types were obtained by combining three *SpeI* and two *NotI* profiles. The same PFGE type was found from the carcass and intestinal contents or tonsils from 48 (74%) of 65 pathogenic *Y. enterocolitica*–positive pigs with contaminated carcasses. Of the 17 carcass-positive pigs that did not

**TABLE 1. Observed prevalence of pathogenic *Yersinia enterocolitica* in different sample types**

<table>
<thead>
<tr>
<th>Bag</th>
<th>Production type</th>
<th>Production capacity</th>
<th>No. of farms</th>
<th>No. pigs sampled</th>
<th>Intestinal content</th>
<th>Tonsils</th>
<th>Total</th>
<th>Pelvis and abdomen</th>
<th>Chest and head</th>
<th>Skin</th>
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<td>58</td>
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**TABLE 2. Observed prevalence of pathogenic *Yersinia pseudotuberculosis* in different sample types**

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<th>No. pigs sampled</th>
<th>Intestinal content</th>
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</table>
harbor the same pathogenic *Y. enterocolitica* PFGE type in the intestinal contents or tonsils, 12 harbored different genotypes, and in 5 pigs, pathogenic *Y. enterocolitica* was not detected in the intestinal contents or tonsils. Of the pathogenic *Y. enterocolitica* carcass–positive pigs that did not carry the same PFGE type in intestinal contents or tonsils, 10 carried *Y. enterocolitica* only on the head and chest, 3 only on the pelvis and abdomen, and 4 on two different carcass samples. Of these, 11 were detected without bagging and 6 with bagging. All pigs with pathogenic *Y. pseudotuberculosis*–positive carcasses harbored the same PFGE type in the tonsils or intestinal contents. Four different PFGE types were detected in the slaughterhouse environment. All except one environmental sample harbored the same *Y. enterocolitica* PFGE type as pigs sampled the same day.

Estimates from the Bayesian probability model. According to model-based estimates, bagging of the rectum reduced the prevalence of pathogenic *Y. enterocolitica* on carcasses significantly, but did not affect the prevalence of pathogenic *Y. enterocolitica* in tonsils or intestinal contents (Table 4). The hidden prevalence of pathogenic *Y. enterocolitica* in pigs at the slaughterhouse varied from 70 to 77\% in high capacity production (87 to 91\%) over the four farm categories (Table 5). According to the model, the prevalence of pathogenic *Y. enterocolitica* in high capacity production (87 to 91\%) in both farrow-to-finish and slaughter production was higher than in low capacity production (70 to 77\%), but the marginal 95\% credible intervals overlapped (Table 5). The prevalence (posterior means) of pathogenic *Y. enterocolitica* in any of the five sample types (intestinal contents, tonsils, pelvis and abdomen, chest and head, and skin) was essentially the same within low capacity production in both farrow-to-finish and slaughter production as well as within high capacity production. Based on the posterior means of the prevalences, bagging of the rectum reduced the prevalence of pathogenic *Y. enterocolitica* in the pelvis and abdomen, chest and head, and skin from 10 to 13\% to 5 to 7\%, from 24 to 30\% to 15 to 19\%, and from 5 to 7\% to 3 to 4\%, respectively (Table 6). According to the model, the hidden prevalence of pathogenic *Y. pseudotuberculosis* was practically 0\% in all four farm categories, and bagging of the rectum had no significant effect on the prevalence of pathogenic *Y. pseudotuberculosis* in either pig tonsils and intestinal contents or carcasses (Table 4).

**DISCUSSION**

Estimates of bagging effect and hidden prevalences from the Bayesian probability model. The effects of bagging the rectum on carcass contamination with pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis* were estimated for the first time, using Bayesian inference with a hidden variable model, in which the observed prevalence of these pathogens on different sample types is dependent on the true prevalence, bagging intervention, and slaughterhouse environment. According to the model, bagging the rectum significantly reduces contamination of carcasses with pathogenic *Y. enterocolitica*, but does not markedly affect the prevalence of pathogenic *Y. enterocolitica* in pig intestinal contents and tonsils. Since pigs already carry enteropathogenic *Yersinia* in the tonsils and intestinal contents at the farm (21, 22, 25), bagging is not expected to affect the prevalence at these sites, which is in agreement with model estimates of pathogenic *Y. enterocolitica* and *Y.

| TABLE 3. Pathogenic Yersinia enterocolitica in the slaughterhouse environment and slaughtering equipment |
|---------------------------------------------------------------|---------------------------------------------------------------|
| **Sample type** | **No. of samples** | **No. (%) of positive samples** | **No. of samples** | **No. (%) of positive samples** |
| Splitting saw | 12 | 0 (0) | 12 | 1 (8) |
| Automatic stamping machine | 6 | 0 (0) | 6 | 0 (0) |
| Edge of gutting platform | 6 | 3 (50) | 6 | 4 (67) |
| Brisket saw | 6 | 0 (0) | 6 | 0 (0) |
| Gutting knife | 6 | 0 (0) | 6 | 0 (0) |
| Abdominal fat remover | 6 | 2 (33) | 6 | 0 (0) |
| Computer keyboard | 6 | 0 (0) | 6 | 0 (0) |
| Floor | 18 | 2 (11) | 18 | 0 (0) |
| Air | 60 | 1 (2) | 60 | 0 (0) |
| **Total** | 126 | 8 (6) | 126 | 5 (4) |

| TABLE 4. Estimates for the bagging effect for pathogenic Yersinia enterocolitica and Yersinia pseudotuberculosis in pigs and carcasses, according to the Bayesian probability model |
|---------------------------------------------------------------|---------------------------------------------------------------|
| **Site of effect** | **Pathogenic Y. enterocolitica** | **Pathogenic Y. pseudotuberculosis** |
| | Odds ratio | 95\% credible interval | Odds ratio | 95\% credible interval |
| Tonsils and intestinal content | 0.90 | 0.51–1.51 | 1.387 | 0.10–7.01 |
| Carcass<sup>a</sup> | 0.54 | 0.32–0.86 | 1.123 | 0.14–4.70 |

<sup>a</sup> Pelvis and abdomen, chest and head, and skin.
The observed prevalences of pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis* in pigs were similar, with and without bagging (Tables 1 and 2), suggesting that the sampling of pigs was not distorted. Previous studies performed on *Y. enterocolitica* in Denmark, Sweden, and Norway support the finding that bagging reduces the contamination of carcasses. In Denmark, the prevalence of *Y. enterocolitica* in different carcass parts decreased from 7 to 12%, without bagging to 1 to 2% with bagging, but at the same time, the prevalence of *Y. enterocolitica*–positive rectal samples decreased from 26 to 19% (1). Nesbakken et al. (27) reported the prevalence of *Y. enterocolitica* on carcasses to be reduced from 2 to 8% to 0% in Norway and from 2 to 7% to 0 to 2% in Sweden. The prevalence of *Y. enterocolitica* in tonsils or feces was not recorded in the study. Although the bagging effect for pathogenic *Y. enterocolitica* in our study was significant, the estimated prevalences (posterior means) of *Y. enterocolitica* after bagging remained from 3 to 19% in different sample types. The higher prevalence after bagging in this compared with previous studies may be due to the larger sampling surface area on each carcass. In the previous studies, sampling of carcasses was restricted to areas 10 by 10 cm, and usually split surfaces or skin were sampled, whereas in our study the surface of almost the entire carcass with head (pelvic, abdominal, and thoracic cavities, skin from the rectal circumcision to the level of the diaphragm and from the cut surfaces, neck, and split surface of the head, except the oral cavity from both carcass halves) was sampled. Tonsils are a likely contamination source of the head area of the carcass, resulting in high prevalence, particularly in chest and head samples, both with and without bagging of the rectum. Unlike in pathogenic *Y. enterocolitica*, bagging did not significantly affect the prevalence of pathogenic *Y. pseudotuberculosis* on carcass samples, although the prevalence observed was slightly lower with bagging than without. The lack of significance was most likely due to the low observed prevalence of pathogenic *Y. pseudotuberculosis* in this study. While bagging of the rectum is useful in reducing carcass contamination with pathogenic *Y. enterocolitica*, alone it is insufficient to completely prevent the transmission of pathogenic *Y. enterocolitica* from pigs to carcasses. High contamination rates of enteropathogenic *Yersinia*, pathogenic *Y. enterocolitica* in particular, may remain in the head and thorax area of the carcass.

The hidden prevalence of pathogenic *Y. enterocolitica* and *Y. pseudotuberculosis* in pigs at the slaughterhouse was calculated by taking into account that the observed prevalence (at a specific sampling site) is inevitably lower than that of the true prevalence (of contamination anywhere on the pig) for such practical reasons as inability to sample the entire pig and lack of sensitivity of isolation methods (20, 29). The mean hidden prevalence gives an estimate of the general carriage (i.e., hosting) of pathogenic *Y. enterocolitica* or *Y. pseudotuberculosis* in pigs at the slaughterhouse from different production types and capacities, based on the prevalences observed at several sampling sites and clustering of the pigs on farms. Clustering of the pigs on farms should be considered when a relatively high number of pigs are sampled from each farm, and sampling is not random over the entire population of pigs in the country, but conditional on the farm.

The hidden prevalence of pathogenic *Y. enterocolitica* in pigs at the slaughterhouse is greater in high capacity production (87 to 91%) than in low capacity production (70 to 77%). However, the 95% credible intervals of all hidden prevalences overlapped, suggesting that the differences are not significant. No clear difference in the prevalence of pathogenic *Y. enterocolitica* between farrow-to-finish (70 to

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### TABLE 5. Hidden prevalence estimate for pathogenic *Yersinia enterocolitica* from different farm types and capacities, according to the Bayesian probability model

<table>
<thead>
<tr>
<th>Production type</th>
<th>Production capacity</th>
<th>Pathogenic <em>Y. enterocolitica</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (%)</td>
</tr>
<tr>
<td>Farrow-to-finish</td>
<td>Low</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>87</td>
</tr>
<tr>
<td>Slaughter pig</td>
<td>Low</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>91</td>
</tr>
</tbody>
</table>

### TABLE 6. Prevalence of pathogenic *Yersinia enterocolitica* in different sample types at the slaughterhouse, according to Bayesian probability model

<table>
<thead>
<tr>
<th>Bagging, farm type</th>
<th>Intestinal content</th>
<th>Tonsil</th>
<th>Pelvis and abdomen</th>
<th>Chest and head</th>
<th>Skin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Production capacity</td>
<td>Mean</td>
<td>95% credible interval</td>
<td>Mean</td>
<td>95% credible interval</td>
</tr>
<tr>
<td>No bagging, farrow-to-finish production</td>
<td>Low</td>
<td>32</td>
<td>13–49</td>
<td>59</td>
<td>25–83</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>40</td>
<td>26–52</td>
<td>74</td>
<td>52–86</td>
</tr>
<tr>
<td>No bagging, slaughter production</td>
<td>Low</td>
<td>35</td>
<td>11–51</td>
<td>65</td>
<td>22–87</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>42</td>
<td>28–54</td>
<td>77</td>
<td>55–89</td>
</tr>
<tr>
<td>Bagging, farrow-to-finish production</td>
<td>Low</td>
<td>29</td>
<td>12–44</td>
<td>56</td>
<td>22–80</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>37</td>
<td>25–48</td>
<td>71</td>
<td>50–84</td>
</tr>
<tr>
<td>Bagging, slaughter production</td>
<td>Low</td>
<td>32</td>
<td>10–47</td>
<td>62</td>
<td>19–84</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>39</td>
<td>26–51</td>
<td>75</td>
<td>52–87</td>
</tr>
</tbody>
</table>

* Values are posterior means (percentages) and 95% credible intervals.
87%) and slaughter production was detected (77 to 91%). Previously, the prevalence of pathogenic Y. enterocolitica has been suggested to be greater in high capacity production (22, 36) and specialized slaughter production (36), although not all studies have found similar differences between production types or capacities (2, 40). The hidden prevalence of pathogenic Y. pseudotuberculosis was estimated to be practically 0% for all four farm categories, and pathogenic Y. pseudotuberculosis was observed only on high capacity farms. The prevalence of Y. pseudotuberculosis has been suggested to be higher in high capacity farms than in low, but the difference was not significant when clustering of the pigs by farms was considered (21). Differences in the prevalence of pathogenic Y. enterocolitica have been described among slaughterhouses in Finland and among states in the United States (5, 10, 19), although within a province in Canada, pathogenic Y. enterocolitica–positive farms did not cluster spatially (34). The differences in prevalence of enteropathogenic Yersinia in production types and capacities may therefore be local.

Contamination routes of enteropathogenic Yersinia in a pig slaughterhouse. The isolates of pathogenic Y. enterocolitica and Y. pseudotuberculosis were PFGE typed to determine the possible contamination sources and effect of bagging on the distribution of different Yersinia PFGE types at the slaughterhouse. In total, 60 (92%) of 65 pigs with Y. enterocolitica–positive carcasses carried pathogenic Y. enterocolitica in the intestinal contents or tonsils and all pigs with pathogenic Y. pseudotuberculosis–positive carcasses harbored the same PFGE type in the intestinal contents or tonsils. However, 17 (26%) of 65 pathogenic Y. enterocolitica–positive carcasses harbored a PFGE type not found in the intestinal contents or tonsils of the same pig. Of these 17 pigs, pathogenic Y. enterocolitica could not be isolated from the intestines or tonsils of 5 pigs, whereas 12 pigs harbored a different PFGE type, suggesting possible cross-contamination, i.e., contamination from some source other than the pig in question, e.g., the slaughterhouse environment or other carcasses. However, since not all colonies can be isolated and PFGE typed, the possibility of detecting only the predominant type in the tonsils and intestinal contents cannot be excluded. The number of pathogenic Y. enterocolitica–contaminated carcasses from pigs that did not carry the same PFGE type in the intestinal contents or tonsils decreased from 11 without bagging, to 6 with bagging, suggesting that bagging the rectum may to some extent reduce cross-contamination at the slaughterhouse. All but one of the Y. enterocolitica PFGE types detected in the slaughterhouse environment were also present in the intestinal contents or tonsils of pigs sampled the same day, suggesting pigs as a source of the environmental contamination during slaughtering. Pathogenic Y. enterocolitica was isolated from the slaughterhouse environment both with and without bagging, suggesting that bagging does not completely prevent the spread of pathogenic Y. enterocolitica in the slaughterhouse environment, although the prevalence was slightly lower when bagging was used. However, the prevalence of pathogenic Y. enterocolitica in the environment was low both with and without bagging. Pathogenic Y. pseudotuberculosis was not isolated from the slaughterhouse environment, possibly due to the low prevalence of the pathogen in pigs.

Although possible cross-contamination of pathogenic Y. enterocolitica was observed in our study, using PFGE typing, the plausible main source (in 74% of cases) of contamination of carcasses is the same pig carrying enteropathogenic Yersinia, as also detected previously (21, 22). Previously, all but one PFGE types detected from carcasses were also detected from the pig intestinal contents or tonsils in question, but 30% of the pluck sets harbored a PFGE type that could not be detected in the intestinal or rectal contents or tonsils of the same pig and thereby suggesting cross-contamination of pluck sets (22). The sampling of carcasses was somewhat different in these two studies, possibly resulting in higher numbers of possible cross-contamination in this study. In the previous study, only the inner part (from the thoracic cavity to the pelvic cavity) of the carcass was sampled, whereas our study also included parts of the skin for all carcass sample types, and the neck and head were sampled with the thoracic cavity in the chest and head sample. The prevalence (9%) of pathogenic Y. enterocolitica on carcass samples from conventional farms in our previous study (22) is similar to the prevalence (9%) of pathogenic Y. enterocolitica in the pelvis and abdominal samples in the present study, whereas the prevalence (22%) of pathogenic Y. enterocolitica in chest and head samples was notably higher. This suggests that the higher prevalence of pathogenic Y. enterocolitica in the present study may derive from the head area, which was additionally swabbed. Y. enterocolitica can easily be isolated from the masseter muscles, while in tongues the prevalence of pathogenic Y. enterocolitica can be very high (12, 38). Of the 17 pathogenic Y. enterocolitica–positive carcasses harboring a PFGE type not present in the intestinal contents or tonsils, 10 were found only in the chest and head samples, which may indicate cross-contamination, particularly in the head area. However, the tonsils carry many Y. enterocolitica PFGE types that are not found in the intestinal contents of the pigs (22), and since the sensitivity of isolation methods is less than 100% and not all colonies were isolated and typed, some of the less frequent PFGE types may have been omitted.

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