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Prevalence and Risk Factors for *Salmonella* and *Campylobacter* spp. Carcass Contamination in Turkeys Slaughtered in Quebec, Canada

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ABSTRACT

An observational study was conducted to estimate prevalence and risk factors for carcass contamination by *Salmonella* and *Campylobacter* spp. in 60 lots of turkey slaughtered over 10 months in the province of Quebec, Canada. Carcass contamination was evaluated by the carcass rinse technique for about 30 birds per lot. Exposure to potential risk factors was evaluated with questionnaires, meteorological data, and cecal cultures. Multivariable binomial negative regression models were used for risk factor analysis. Prevalence of *Salmonella*-positive carcasses was 31.2% (95% confidence interval, 22.8 to 39.5%). Variables positively associated ($P \leq 0.05$) with the proportion of lot-positive carcasses were ≥0.5% of carcass condemnation due to various pathologies, cecal samples positive for *Salmonella,* low wind speed during transportation, closure of lateral curtains of truck during transportation, and slaughtering on a weekday other than Monday. When only *Salmonella*-positive cecal culture lots were considered, the proportion of carcasses positive for *Salmonella* was significantly higher in lots exposed to a >5°C outside temperature variation during transportation, slaughtered on a weekday other than Monday, and in which ≥4% of carcasses had visible contamination. Prevalence of *Campylobacter*-positive carcasses was 36.9% (95% confidence interval, 27.6 to 46.3%). The proportion of positive carcasses was significantly higher in lots with *Campylobacter*-positive cecal cultures and lots undergoing ≥2 h of transit to slaughterhouse. For lots with *Campylobacter*-positive cecal cultures, variables significantly associated with an increased incidence of carcass contamination were ≥4% of carcasses with visible contamination, crating for ≥8 h before slaughtering, and no antimicrobials used during rearing.

Campylobacter and *Salmonella* are two of the most important foodborne zoonotic pathogens worldwide *(3, 30).* In Canada, human salmonellosis and campylobacteriosis are notifiable diseases. Between 1995 and 2000, the average incidence rate was 21 cases for salmonellosis and 43 cases for campylobacteriosis per 100,000 inhabitants *(25).* However, it is believed that these estimates reflect serious underreporting *(30).*

There is evidence that eggs and poultry meat are two of the most important sources of *Salmonella* associated with human infection *(13, 30).* Consumption of poultry meat or exposure to food cross-contaminated by raw poultry are important risk factors for human *Campylobacter* gastroenteritis *(2, 9, 11, 12, 16, 18, 24, 29).*

According to studies conducted in broiler chickens, poultry carcass contamination by *Salmonella* and *Campylobacter* is mostly linked to intestinal carriage in birds during rearing and/or to cross-contamination during transportation to slaughter *(6, 8, 14, 15, 20, 22, 26–28). Campylobacter* strains detected in feces from slaughtered poultry can be recovered from poultry carcasses in the current lot and subsequent lots *(28). Salmonella* on the feet and feathers of turkeys entering the processing plant has been suspected as a source of carcass contamination *(34).*

Studies of the dynamics of bacterial contamination at various processing steps at slaughter have revealed that scalding markedly reduces *Campylobacter* counts on turkey carcasses *(1),* whereas mechanical defeathering significantly contributes to *Campylobacter* cross-contamination in both turkey and chicken carcasses *(1, 35, 37). Campylobacter* contamination of turkey skin has also been reported to increase after evisceration *(4).* However, factors influencing the prevalence of carcass contamination between lots are still poorly understood. The aims of our study were (i) to estimate the prevalence of *Salmonella* and *Campylobacter* carcass contamination in turkeys slaughtered in the province of Quebec, Canada, and (ii) to determine risk factors related to management practices at the farm, during transportation to slaughter, and during slaughtering that are associated with carcass contamination at the lot level.

MATERIALS AND METHODS

Slaughterhouse selection. From 29 April 2003 to 23 February 2004, samples were obtained from turkeys once each week in the only commercial turkey slaughtering and processing plant in Quebec. In this slaughter plant, carcasses were processed at a speed of 1,500 to 3,150 carcasses per hour depending on bird weight. All processing steps from stunning through chilling were automated except for evisceration, crop removal, and lung pumping, which were done manually.

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Flock selection. Sampling was planned for Tuesdays, but if not enough flocks were available according to the slaughterhouse schedule, another weekday was selected with the exception of Friday. Two flocks were selected for sampling at each visit to the slaughterhouse. A flock was defined as a group of birds from the same hatchery that had been raised in the same broiler house during the same period of time. Selection was restricted to broiler turkey and heavy turkey flocks slaughtered between 7 and 14 h, a window of time including the large majority of slaughtered turkeys. Only one flock per production site (i.e., farm civic address) was selected for the study. If possible, two consecutive flocks at slaughter were selected; when more than two consecutive flocks were available for selection for a sampling day, the flocks for sampling were randomly selected. Before sampling, producers were asked to participate in the study by filling out a questionnaire and giving permission to access carcass condemnation and transportation data.

Carcass selection and examination. When a flock was transported to slaughter in more than one truck, selection was restricted whenever possible to one randomly selected truck. A systematic sampling method with a random start was used for selection, with a target sample size of 30 not trimmed, not condemned carcasses per flock. Carcasses were selected after the evisceration procedure at a 45- to 60-s interval, calculated to evenly distribute sampling within the truck lot. A few more carcasses than the target sample size were selected in each flock to account for possible condemnation or downgrading of selected carcasses, which were then excluded from the study. When target sample size was not reached after sampling turkeys from one truck, the following truck lot was sampled whenever possible. For heavy turkey flocks, sampling was generally distributed in two truck lots due to the lower speed of the processing line and the lower number of birds per truck. All carcasses from the same flock transported in sampled truck(s) were defined as the lot for study purposes.

Each carcass from the lot was visually inspected immediately after evisceration, before any trimming, to evaluate the proportion of birds with visible contamination. Visible contamination was defined as macroscopic evidence of bile, digestive contents, or feces on external and/or internal surfaces of the carcasses. For selected carcasses, type of contamination and sex were also noted. After bacteriological sampling, just before chilling, selected carcasses were weighed.

Intestinal examination. Intestines of each selected carcass were placed into individually identified sterile plastic bags and put on melting ice. Proximal jejunum and distal ileum were examined within 3 h of death for external aspect (round versus flat) and content. Contents were evaluated by opening approximately 3 cm of the intestinal section and looking for food, bile, and/or feces. Two approximately 15-cm segments of intact intestine adjacent to Meckel's diverticulum (one distal and one proximal) were sampled for each bird. Samples were frozen at −70°C within 6 h of death, held for 2 to 6 months, and then analyzed for tensile strength. All tensile force tests on intestines were conducted by the same technician, one lot at a time. At the time of analysis, all intestines from the tested lot were held at ambient temperature until completely thawed and then placed on ice for a maximum of 1 h before testing. Intestines were then tested consecutively, in the same order as sampled at the slaughterhouse. Intestine diameter was evaluated in the middle of each segment with a micrometer rule (IP65, Mitutoyo, Aurora, Ill.). A resistance test was then conducted with a TAXT Plus texture analyzer (Texture Technologies, Inc., Hamilton, Mass.) and a TA-96B Mini Adjustable Dual tightening clamp set (Texture Technologies, Inc.). Clamps were put on the ends of the intestinal segment at a distance of 5 cm. Special care was taken to avoid any torsion of the intestine, as determined by visual inspection of the mesenteric attachment. Intestines were stretched at a speed of 40 mm/s for a maximal distance of 100 mm until rupture, with the break sensitivity set at 20 g. The texture analyzer was calibrated with a 2-kg calibration weight before and after the testing of each lot. When measurement error exceeded ±0.5 g, the analyzer was calibrated. Tension force at the first break, maximal force supported by the intestine, total force needed for complete rupture, and number of breakpoints detected were recorded. The two results obtained for each parameter (diameter, various forces, and number of breakpoints) were then averaged.

Questionnaires. A first questionnaire related to husbandry management practices was sent within 2 days after slaughter to the person in charge of the flock. If the questionnaire was not completed and sent back within 3 weeks, weekly reminders were sent until the completed questionnaire was received. Questionnaires were checked at the time of reception. If needed, producers were contacted by phone for clarification of any confusing or missing information. Data relative to vaccines and antimicrobials administered at the hatchery were validated directly with the hatchery manager or veterinarian, and data pertaining to medicated feed additives were validated by contacting the feed mill salesperson or veterinarian. A second questionnaire pertaining to bird transportation to slaughter and processing at slaughter was completed by the slaughterhouse quality control staff.

Carcass condemnation data. Data relative to condemnation and trimming of carcasses for the entire lot were obtained from the Canadian Food Inspection Agency after federal veterinary carcass inspection.

Meteorological data. Meteorological data during transportation of birds to the slaughterhouse were obtained from Environment Canada. Data on precipitation were obtained on a daily basis, and hourly data were used for solar radiation, temperature, and wind speed. For the first half of transit, data from the nearest meteorological station (Euclidian distance) to the poultry house were recorded from the beginning of crating to midtransit. For the second half of transit, data from the station nearest to the slaughterhouse were recorded from the midtransit point to the slaughterhouse. Meteorological data from the first half of transit were averaged with those from the second half, weighted by the proportion of time spent before and after midtransit, respectively. Length of transit was defined as the difference between average time at crating and time of arrival at the slaughterhouse. Distances were computed using latitude and longitude data, either provided by Environment Canada or obtained from civic addresses according to Microsoft Streets & Trips software (version 10.0, Microsoft, Redmond, Wash.). The mean (standard deviation) distance between poultry houses and the nearest meteorological station was 12 (7) km for daily data and 33 (17) km for hourly data. For both daily and hourly data, the nearest meteorological stations from the slaughterhouse were 11 km apart.

Bacteriology. Selected carcasses were removed from the processing line after the last inside-outside carcass washer, just before chilling. The water used for the washer was chlorinated at 25 to 50 ppm, according to the slaughterhouse quality control staff. Researchers wearing single-use gloves placed carcasses in sterile bags containing 400 ml of buffered peptone water (20 g/liter; Difco, Becton Dickinson, Sparks, Md.). Bags were vigorously shaken by hand for 30 s. Rinsates were then transferred to sterilized plas-

TABLE 1. *Risk factors evaluated in lots of turkey carcasses contaminated with* Salmonella *and* Campylobacter*, Quebec, Canada, 2003 and 2004*[a]

Variable	*Salmonella*		*Campylobacter*	
	All lots (n = 60)	Cecum culture-positive lots (n = 31)	All lots (n = 59)	Cecum culture-positive lots (n = 28)
General characteristics				
Bird wt				
Light	32	16	32	13
Heavy	28	15	27	15
Bird sex				
Male	34	17	33	16
Female	26	14	26	12
State of litter at the end of rearing (according to the producer)				
Humid or crusted	NI[b]	12	NI	9
Dry		19		18
Total mortality during rearing				
<6%	47[c]	20	46	20
≥6%	13	11	13	8
Type of coccidiostat used during rearing				
Ionophores	NI	29	NI	25
None		2		3
Use of antimicrobial as growth factor during rearing[d]				
Yes	NI	31[e]	NI	27
No		0		1
Use of antimicrobial as curative treatment during rearing				
No	48	24	48	21[f]
Yes	11	7	10	6
Carcasses condemned because of evidence of pathologic changes[g]				
<0.5%	47[h]	24[c]	46	23
≥0.5%	13	7	13	5
Coefficient of variation of eviscerated body wt				
<10%	38	21[c]	37	20
≥10%	22	10	22	8
Percentage of birds with incorrect sexing				
<3%	45	25[c]	44	22
≥3%	15	6	15	6
Lot cecal status for *Campylobacter*				
Positive	28	16	28[h]	NI
Negative	31	15	31	
Lot cecal status for *Salmonella*				
Positive	31[h]	NI	31	16
Negative	29		28	12
Intestinal characteristics				
Presence of digestive contents in jejunum				
<20% of samples	NI	15	NI	13
≥20% of samples		16		15
Presence of digestive contents in ileum				
<50% of samples	NI	8	NI	7
≥50% of samples		23		21
Avg no. of intestinal breaks until complete rupture				
<1.5	NI	7	NI	4
≥1.5		23		23
Avg intestinal diameter near Meckel diverticulum				
<12 mm	NI	11	NI	9
≥12 mm		19		18
Avg maximal tensile force supported by intestine				
<875 g	NI	14	NI	11
≥875 g		16		16
Avg force needed for complete rupture of intestine				
<300 g/s	NI	14	NI	10
≥300 g/s		16		17
Avg tensile force at the first intestinal rupture				
<875 g	NI	14	NI	11
≥875 g		16		16
Feeding and fasting				
Texture of feed				
Meal	NI	1	NI	1
Pellets		30		26
Feed withdrawal before crafting				
<4 h	NI	15	NI	17[f]
≥4 h		16		11
Total feed withdrawal[i]				
<14 h	NI	22[c]	NI	15
≥14 h	NI	9	NI	10
Texture of feed in pan or chain before feeder removal				
Pellets	NI	11	NI	8
Meal, no rest		20		19
Voluntary temporary feeding stop to remove meal in late rearing				
Yes	NI	1	NI	2
No		24		21
Temp in poultry house during feed withdrawal				
<21°C	NI	22	NI	22
≥21°C		9		6
Water fasting prior to crating				
Yes	NI	15	NI	9
No		16		19
Transport management				
Transport company				
A	12	5	12	8
B	32	18	31	11
Other	16	8	16	9

TABLE 1. *Continued*

Variable	*Salmonella*		*Campylobacter*	
	All lots (n = 60)	Cecum culture-positive lots (n = 31)	All lots (n = 59)	Cecum culture-positive lots (n = 28)
Avg speed for bird crating				
Slow	48	23	48	25
Fast	12	8	11	3
Presence of producer or producer employee(s) during bird crating				
Yes	54	28	54	26
No	5	3	4	1
Avg no. of birds per transport crate				
≤4	29	15	28	15
>4	30	16	30	13
Avg outside temp during transport				
<0°C	12	7	12	8
0–15°C	39	21	38	16
>15°C	9	3	9	4
Outside temp variation during transport				
≤5°C	35[f]	17[f]	34	16
>5°C	25	14	25	12
Avg daily precipitation during transport				
≤3.5 mm	36	19	35	15
>3.5 mm	24	12	24	13
Avg solar radiation during transport				
≤100 j	44	23	43[f]	23[c]
>100 j	16	8	16	5
Avg wind speed during transport				
≤15 km/h	44[c]	22	43	21
>15 km/h	16	8	16	7
Closure of lateral curtains of truck during transport				
Yes	17[c]	10	17[c]	12
No	43	21	42	16
Closure of top curtain of truck during transport				
Yes	14[c]	9	14	9
No	46	22	45	19
Mortality in crates during transport				
≤0.1%	21	8	21	9
>0.1%	38	23	37	19
Transit time to slaughterhouse[j]				
<2 h	34	23[c]	33[f]	13[f]
≥2 h	26	8	26	15
Avg time spent in transport crates				
<8 h	30	18	29[c]	11[c]
≥8 h	30	13	30	17
Avg time spent waiting in crates before slaughter				
<5	34[c]	19	33	15
≥5	26	12	26	13

TABLE 1. *Continued*

Variable	*Salmonella*		*Campylobacter*	
	All lots (n = 60)	Cecum culture-positive lots (n = 31)	All lots (n = 59)	Cecum culture-positive lots (n = 28)
Slaughtering				
Slaughter day				
Monday	8[h]	4[h]	8	4
Tuesday	30	16	29	11
Wednesday	16	8	16	10
Thursday	6	3	6	3
Moisture content of feathers at exit from transport crate				
Dry	50	25	49	23
Humid	10	6	10	5
Cleanliness of feathers at exit from transport crate				
Clean	53	26	52	25
Dirty	7	5	7	3
Appearance of feathers at exit from transport crate				
Smooth	55[c]	27	54	25
Ruffled	5	4	5	3
Percentage of carcasses visibly contaminated[k]				
<4%	18	12[c]	18[c]	11[c]
≥4%	30	13	30	14
Variable speed in slaughter line				
Yes	21[c]	12[c]	20	8[c]
No	39	19	39	20
Stop(s) in the evisceration line				
Yes	33[c]	17[c]	32	16
No	27	14	27	12
Mechanical breakdown of slaughter line				
Yes	2	0[e]	2	1
No	58	31	57	27
Mechanical breakdown of evisceration line				
Yes	2	1	2	2
No	58	30	57	26
Birds slaughtered between last disinfection and beginning of new lot				
No	5	3	5	4
Yes	55	28	54	24

[a] Univariate analyses (chi-square tests with exact computation) were concluded.
[b] NI, not included in the analysis.
[c] $P \leq 0.20$ for the univariate analysis.
[d] Including bacitracin, flavomycin, and/or virginiamycin.
[e] Not tested because of absence of variation. Some variables had missing values.
[f] $P \leq 0.05$ for the univariate analysis.
[g] Pathologic changes attributed to rearing only, including all condemnations except birds with contamination, bruising, loss of identity, inadequate bleeding, overscalding, and mutilation and half of the birds with cyanosis.
[h] $P \leq 0.01$ for the univariate analysis.
[i] Time between removal of feeders and slaughter of birds.
[j] Time between departure from farm and arrival at slaughterhouse.
[k] Percentage of carcasses with visible contamination was not evaluated for the first 12 lots of slaughteted birds.

tic bottles and kept on ice for a maximum of 8 h. Because of unexpected technical problems related to *Campylobacter* isolation, 1 ml of each carcass rinse sample was frozen in a sterile tube at −70°C for 5 to 7 months before culturing for *Campylobacter* for the first 13 sampled lots. Samples were thawed at room temperature before culturing.

For *Salmonella* isolation, 30 ml of each carcass rinse sample was mixed with 30 ml of buffered peptone water and incubated for 18 to 24 h at 37°C. Then, a 1-ml aliquot of preenriched culture was inoculated into 9 ml of tetrathionate brilliant green broth and a 0.1-ml sample was placed into 9.9 ml of Rappaport-Vassiliadis broth. Both broth samples were incubated for 24 h at 37°C. Each broth sample was then streaked onto BG Sulfa agar and modified lysine iron agar. After 24 to 48 h of incubation at 37°C, suspected *Salmonella* colonies were removed, inoculated onto triple sugar iron agar, lysine iron agar, and urea agar, and incubated for 24 h at 37°C. Colonies with biochemical patterns suggestive *of Salmonella* were confirmed using polyvalent O-antisera (Poly A1-Vi, Becton Dickinson) agglutination tests. Colonies positive for agglutination were inoculated onto blood agar and incubated at 37°C for 24 h to assess typical *Salmonella* colony appearance.

For *Campylobacter* isolation, 25 ml (or 1 ml for unfrozen samples) of each carcass rinse sample was mixed with 25 ml (or 1 ml for unfrozen samples) of Bolton broth (Oxoid, Unipath Ltd., Basingstoke, UK) at double concentration and incubated for 24 h at 42°C under microaerophilic conditions. The mixture was streaked onto charcoal cefaperazone desoxycholate agar (Oxoid CM739 with SR155 supplement) and incubated for 48 h at 42°C in a microaerophilic jar (Campypak, BBL, Becton Dickinson). Presumptive *Campylobacter* colonies were evaluated for Gram stain morphology and mobility with a phase-contrast microscope. Colonies with a pattern suggestive of *Campylobacter* spp. were inoculated onto 5% sheep blood agar (Quelab Laboratories, Montreal, Quebec, Canada) and incubated for 48 h at 42°C under microaerophilic conditions.

For each lot, three sample pools of cecal contents of approximately 10 birds each were cultured for the presence of *Salmonella* and *Campylobacter* as previously described *(5).*

Statistical analysis. The prevalence of carcasses positive for contamination and the 95% confidence interval (CI) based on a standard normal distribution were computed. To account for multistage sampling, each carcass was given a sampling weight equal to the reverse of the number of carcasses sampled in the lot out of the total number of carcasses within the lot. Results from light and heavy turkeys were pooled because no significant difference ($P \geq 0.25$) in results for these two groups were obtained in the risk factor analysis. The standard error of the prevalence was estimated with the Taylor expansion method to account for clustering of birds within lots. The Surveyfreq procedure of SAS version 9.1 (SAS Institute, Cary, N.C.) was used. A lot was considered positive for a bacterium if one or more carcasses produced positive bacteriological results. The prevalence in the positive lot and the 95% exact CI was computed using the Freq procedure of SAS 9.1.

For the risk factor analysis, two different models were built for each bacterium, one including all lots and the other limited to lots with culture-positive cecum contents. Potential risk factors examined are listed in Table 1. A web-causal model (not shown) was built according to biological knowledge to guide analysis, as suggested by Dohoo et al. *(10).* Variables believed to have an effect only in lots with positive cecum culture results (e.g., through an influence on flock bacterial load or on the risk of bacteria escaping from intestines during processing) were tested only in the model restricted to lots with positive cecum culture results. Some variables related to rearing (e.g., litter condition, texture of feed, withdrawal of feed and water, growth factors, and administration of coccidiostatic medications) and variables related to intestinal characteristics were tested only in lots with positive cecum culture results. All risk factors were categorized. Whenever possible, the number of categories was limited to ensure category frequencies of >10%. All variables were first tested using simple binomial negative regression analysis performed with the Genmod procedure of SAS 9.1. Only factors associated ($P < 0.20$, likelihood ratio test) with the proportion of contaminated carcasses were considered for further analysis. Among selected variables ($P < 0.20$), all bilateral relationships were checked using the chi-square test to detect potential colinearity.

A multiple binomial negative regression model was built using forward selection of risk factors based on the likelihood ratio test, with $P \leq 0.05$ as the criterion of inclusion. As a final step, variables not selected for inclusion were tested one at a time in the final model to evaluate the impact of these variables on incidence ratio estimates. Because no changes beyond 20% were observed, those variables were not kept in the final models. During the process of model selection, only observations with no missing values for covariates included in the fitted model were considered. Interactions were not tested because of the paucity of data. Goodness of fit of the final model was assessed with the Deviance and Pearson chi-square tests. As a validation step, condition of samples at the time of culture (fresh or frozen) was added to final *Campylobacter* models.

RESULTS

Selection of flocks and birds. Eighty-three turkey producers were initially selected to participate in the study; 71 agreed, 6 could not be reached in time, and 6 refused to participate. Among the 71 turkey flocks available, 60 flocks were sampled; samples were not collected from the remaining flocks for technical reasons. Of the 60 sampled flocks, 55 originated from the province of Quebec and the remaining 5 flocks were from New Brunswick or Nova Scotia. Questionnaires sent to producers and slaughterhouses were all retrieved, with the exception of one questionnaire sent to a producer. The data for the flock from this producer were included in most of the study except the risk factor analysis, in which some data were excluded because of missing values for some variables. On average, 29 carcasses were sampled by lot (range, 15 to 32), for a total of 1,736 carcasses.

Salmonella. For the study of *Salmonella,* the 60 sampled lots were included in the analysis. The prevalence of *Salmonella*-positive carcasses was 31.2% (95% CI, 22.8 to 39.5%). At least one carcass was positive for *Salmonella* in 96.7% of the 60 lots (95% CI, 88.5 to 99.6%). The distribution of carcass contamination according to cecal culture results by lot is presented in Figure 1.

The proportion of *Salmonella*-positive carcasses was significantly higher in lots with the following risk factors: ≥0.5% of the carcasses condemned because of pathologic changes, cecal culture results positive for *Salmonella,* transportation to the slaughterhouse during a period of low wind speed, and closure of truck lateral curtains during transportation. The proportion of *Salmonella*-positive carcasses was

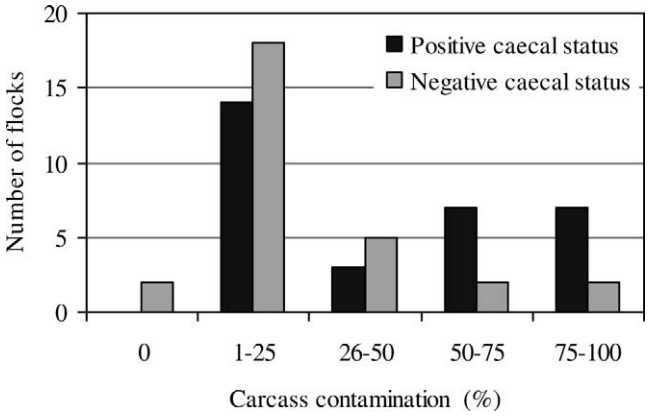

FIGURE 1. *Distribution of carcass contamination (%) according to cecal culture results for* Salmonella *in turkey lots slaughtered in Quebec, Canada, 2003 and 2004 (*n = *60 lots).*

lower for lots slaughtered on Monday. The final model is presented in Table 2.

For the risk factor analysis limited to lots in which *Salmonella* was identified in cecal contents, the number of categories for the variable describing the day of slaughter was reduced before multivariable analysis because of sample size limitation relative to the number of risk factors considered. The Tuesday, Wednesday, and Thursday categories were collapsed because no significant differences were found between these days. The proportion of *Salmonella*-positive carcasses in lots with positive cecal results was significantly higher in lots with the following risk factors: exposure to temperature variation of greater than 5°C during transport, slaughter on a weekday other than Monday, and ≥4% of carcasses with visible contamination (Table 3). For the 79 visibly contaminated carcasses, contamination was mostly due to the presence of feces (67%) or feed (33%), with no evidence of bile contamination.

TABLE 2. *Final multivariable binomial negative regression model of risk factors for* Salmonella *carcass contamination in turkeys, Quebec, Canada, 2003 and 2004 (*n = *60 lots)*[a]

Variable	Incidence ratio		
	Estimate	*P* (Wald)	95% CI
Carcasses in lot condemned for pathologic changes			
≥0.5%	1.6	0.05	1.0–2.7
<0.5%			
Lot cecal results for *Salmonella*			
Positive	2.0	<0.001	1.4–3.0
Negative			
Avg wind speed during transport			
≤15 km/h	1.60	<0.01	1.2–3.0
>15 km/h			
Slaughtering day			
Thursday	4.7	<0.001	2.3–9.9
Wednesday	5.6	<0.001	2.6–11.9
Tuesday	4.7	<0.01	1.8–12.0
Monday			
Closure of truck lateral curtains during transport			
Yes	1.6	0.03	1.0–2.4
No			

[a] Intercept, −0.6; deviance, 61.0; Pearson χ^2 = 50.2; df = 52.

TABLE 3. *Final multivariable binomial negative regression model of risk factors for* Salmonella *carcass contamination in turkey lots in which ceca were culture positive for* Salmonella*, Quebec, Canada, 2003 and 2004 (*n = *24 lots)*[a]

Variable	Incidence ratio		
	Estimate	*P* (Wald)	95% CI
Outside temp variation during transport			
>5°C	2.4	>0.001	1.5–3.8
≤5°C			
Slaughtering day			
Tuesday through Thursday	5.9	<0.001	2.6–13.6
Monday			
Visible contamination			
≥4% of carcasses	1.9	<0.01	1.2–3.0
<4% of carcasses			

[a] Intercept, −1.90; deviance, 24.7; Pearson χ^2 = 20.6; df = 20.

Campylobacter. For *Campylobacter,* samples from one lot were lost during the bacteriological procedure, resulting in 59 lots for analysis. The prevalence of *Campylobacter*-positive carcasses was 36.9% (95% CI, 27.6 to 46.3%). At least one carcass was positive for *Campylobacter* in 88.1% of the lots (95% CI, 77.1 to 95.1%). The distribution of carcass contamination according to cecal culture results by lot is presented in Figure 2.

According to the statistical model including all lots, the proportion of *Campylobacter*-positive carcasses was higher in lots with the following risk factors: positive cecal culture results and transit time to the slaughterhouse of ≥2 h (Table 4). The variable describing visible contamination of carcasses was also selected for inclusion in the final model, although it became marginally insignificant after inclusion of transit time. In the model restricted to lots in which cecal

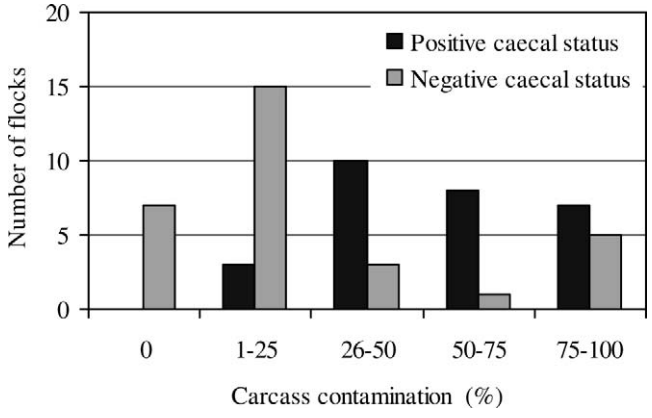

FIGURE 2. *Distribution of carcass contamination (%) according to cecal culture results for* Campylobacter *in turkey lots slaughtered in Quebec, Canada, 2003 and 2004 (*n = *59 lots).*

TABLE 4. *Final multivariable binomial negative regression model of risk factors for* Campylobacter *carcass contamination in turkeys, Quebec, Canada, 2003 and 2004 (*n = *46 lots)*[a]

Variable	Incidence ratio		
	Estimate	*P* (Wald)	95% CI
Lot cecal results for *Campylobacter*			
Positive	3.2	<0.001	1.8–5.7
Negative			
Transit time to slaughterhouse			
≥2 h	2.0	0.02	1.1–3.5
<2 h			
Visible contamination			
≥4% of carcasses	1.8	0.07	1.0–3.5
<4% of carcasses			

[a] Intercept, −0.68; deviance, 55.5; Pearson $\chi^2 = 42.5$; df = 42.

TABLE 5. *Final multivariable binomial negative regression model of risk factors for* Campylobacter *carcass contamination in turkey lots in which ceca were culture positive for* Campylobacter, *Quebec, Canada, 2003 and 2004 (*n = *22 lots)*[a]

Variable	Incidence ratio		
	Estimate	*P* (Wald)	95% CI
Use of antimicrobials as curative treatment during rearing			
No	2.5	<0.001	1.6–3.9
Yes			
Avg time spent in transport crates			
≥8 h	1.5	<0.01	1.1–2.0
<8 h			
Visible contamination			
≥4% of carcasses	1.5	<0.01	1.2–2.0
<4% of carcasses			

[a] Intercept, −1.04; deviance, 27.6; Pearson $\chi^2 = 27.7$; df = 18.

cultures were positive for *Campylobacter,* the proportion of *Campylobacter*-positive carcasses was higher in lots in which there was a higher percentage of carcasses with visible contamination and in lots transported in crates for ≥8 h. The proportion of *Campylobacter*-positive carcasses was lower in lots given antimicrobials as a curative treatment during rearing (Table 5). The variable describing the condition of the samples (fresh or frozen) was tested in all final models related to *Campylobacter* but was removed because it was not significant ($P \geq 0.12$) and resulted in only minor changes (<8%) in incidence ratio estimates.

DISCUSSION

A convenient sample of flocks was used for the study because a complete random selection among all turkey flocks processed in Quebec was not technically feasible. In 2003, the slaughterhouse included in the study processed 94% of the total volume of commercial turkeys processed in Quebec. Turkey samples were obtained from a high percentage (approximately 43%) of turkey producers from Quebec, and sampling was done over a 10-month period, which is likely to improve the internal validity of our results. Furthermore, within the group of producers asked to participate, high compliance was observed both for willingness to participate and questionnaire return, limiting possible selection bias. It seems unlikely that restriction of sampling to a weekday biased our results, because choice of the sampling day was based on practical consideration for sample collection and processing and not on any known flock characteristics. However, prevalence of *Campylobacter* might have been influenced by the sampling day, according to the risk factor analysis, and no adjustments were made because the volume of turkeys slaughtered per day in the slaughterhouse was not available.

Prevalence. Prevalence in contaminated carcasses was similar for *Campylobacte*r and *Salmonella.* Published information pertaining to lot prevalence of turkey carcass contamination is still limited. In previous surveys, 40.8% *Campylobacter* spp. carcass contamination was reported in prechill turkeys originating from the midwestern region of the United States, and 10 to 36.7% *Campylobacter* spp. contamination was reported for turkey neck skin sampled before chilling in California *(19, 37).* These results are close to the 36.9% of turkey carcasses positive for *Campylobacter* in our study. For *Campylobacter,* we cannot discount the possibility that the freezing of some samples prior to culture led to an underestimation of the prevalence, but this potential bias is likely minor because freezing was not significantly associated with the proportion of positive carcasses in the risk factor analysis.

Risk factors for *Salmonella* contamination. The proportion of *Salmonella*-contaminated carcasses was higher in turkey lots in which cecum cultures were positive for this pathogen. Bacteria present in the digestive tract of turkeys during rearing could have been transmitted on carcasses during processing. This possibility is supported by studies conducted in broiler chickens, in which *Salmonella* serovars detected on carcasses also were isolated at the hatchery and during rearing *(7, 27).* Carcasses also could be affected by cross-contamination from feathers or feet contaminated during rearing by the environment, litter, or fresh droppings from infected turkeys. Feather contamination by *Salmonella* may be more common than intestinal carriage of this pathogen, according to a study conducted in broiler chickens *(26),* and *Salmonella* serovars often are isolated in poultry houses of infected flocks. The only two turkey lots with no positive carcasses both had cecal cultures with negative results, whereas most of the lots with more than 50% carcass contamination had *Salmonella*-positive cecal cultures. The same observation applies to *Campylobacter.* However, pathogen colonization of the cecum by itself did not explain all the variation in carcass contamination, and some lots with negative cecum cultures sometimes had a high percentage of contaminated carcasses (see Figs. 1 and 2).

Lots with a higher percentage of carcasses condemned for various pathologic changes had a greater percentage of *Salmonella* carcass contamination. In *Salmonella*-colonized lots, diseases occurring during rearing may have caused the

birds to spend more time lying on the litter, leading to higher feather contamination. Prevalence of cecum culture–positive birds also may have been higher in lots having a higher condemnation rate. According to the plant manager, lots with a higher condemnation rate will spend more time on the processing line because of frequent stop(s) and line reduction speed. This increased production time can favor either contamination from the slaughterhouse environment due to longer exposure time or increases in bacterial growth due to a longer processing time. Another hypothesis to explain the high percentage of carcass contamination is the increased chance of contact between carcasses hanging on shackles because of variation in the speed line. This hypothesis is supported by the fact that space between carcasses has been reported to affect contamination level *(23).*

Meteorological conditions during turkey transport to the slaughterhouse also had an effect on the percentage of contaminated carcasses. Depending on the model, low wind speed or temperature variation beyond 5°C during transportation was associated with an increased risk of contamination. These two variables tend to be associated ($P = 0.11$, chi-square test), with low wind speed more often associated with greater temperature variation. Explanations for these findings are not obvious. Weather conditions during bird transport may affect the likelihood of crate contamination by *Salmonella* and/or the likelihood of transmission of this pathogen to the birds. Broiler chicken transport crates often have been reported to be contaminated with *Salmonella* despite washing *(8, 15, 26, 27, 31),* and a positive correlation between presence of *Salmonella* in transport crates and on carcasses after whole-bird processing has been demonstrated *(14).* Higher wind speed before birds were loaded into crates and onto the truck might have had a drying effect on crates and thus may have been detrimental to bacterial survival. Weather conditions during transport also can affect bird stress levels, leading to an increase in *Salmonella* fecal excretion and thus feather contamination during transport.

Closure of the lateral curtains of the truck during transport of turkey flocks to the slaughterhouse was positively associated with *Salmonella* carcass contamination. Because curtain closure occurs only during late fall and winter, this variable was confounded by the season. Although there is no clear explanation for this finding, we cannot exclude the possibility that crate washing and disinfection were less efficient during the cold season. Curtain closure may have influenced humidity within the truck, therefore increasing the dirtiness of the birds and the chances of feather contamination.

Slaughtering day was significantly associated with percentage of contaminated carcasses. The estimated effect of the variable was much larger than that of any other variable included in the study; the incidence of carcass contamination on Monday was five to six times lower than that for any other day. There was no slaughtering conducted on Saturday or Sunday in this slaughterhouse. Therefore, the cleaning and disinfection procedures used at the end of the week followed by the 2-day downtime may have reduced bacterial contamination of the slaughterhouse environment, mostly due to adequate drying of the sanitized environment. Because disinfection protocol includes a rinse with sanitation products just prior to slaughtering, contact time with the disinfectant was longer for lots slaughtered on Monday. Preventive maintenance of the slaughtering and processing equipment was done mostly during Saturday and Sunday, and equipment undergoing maintenance was submitted to a careful additional wash before being put back into function. Frequency and type of maintenance work done during the study were not noted. Transport crates were not used during Saturday and Sunday, and this downtime likely also favored adequate drying, hence further reducing residual bacterial contamination. Other procedures pertaining to sanitation, such as clothing or knife washing, were done in a similar manner regardless of the day.

In *Salmonella*-colonized turkey lots, the percentage of visibly contaminated carcasses was positively associated with the percentage of *Salmonella*-contaminated carcasses. This finding supports the hypothesis that carcass contamination comes from spreading bacteria already present in the digestive tract of birds. Specific causes of visible contamination were not determined in our study. However, in our database, lots in which ≥4% of the carcasses were visibly contaminated were more likely ($P \leq 0.04$, chi-square test) to have a larger average intestinal diameter and to have a greater percentage of birds with digestive contents present in the ileum. Among selected carcasses, 97.5% of those showing visible contamination were trimmed or condemned and hence rejected from our study. Because visible contamination was not directly responsible for bacteriological contamination level in our study, it probably affected slaughterhouse environmental contamination and carcass cross-contamination. Visible contamination also could be a valuable indicator for assessing fecal contamination in a slaughtered lot.

Risk factors for *Campylobacter* spp. As was found for *Salmonella* and probably for the same reasons, the proportion of *Campylobacter*-contaminated carcasses was higher in lots with *Campylobacter*-positive cecal cultures. This finding is in agreement with those of a previous study, in which the authors concluded that when chicken intestines were positive for *Campylobacter* the odds of a *Campylobacter*-positive skin culture in carcasses prior to evisceration was 35 times greater than when the intestinal culture was negative *(17).* Massive spreading and contamination of the equipment at the slaughterhouse when slaughtering a *Campylobacter*-positive lot also has been reported *(6).* As for *Salmonella,* the proportion of *Campylobacter*-positive carcasses was positively associated with the proportion of visibly contaminated carcasses in turkey lots with cecum cultures positive for this pathogen.

Depending on the model used, *Campylobacter* carcass contamination was associated with either transit time to the slaughterhouse or time spent in transport crates. These two variables were strongly associated; lots crated for at least 8 h were much more likely to have been in transit for more than 2 h ($P < 0.001$). In broiler chickens, isolation of *Campylobacter* from washed transport crates often has been re-

ported *(6, 15, 22, 33),* and there is evidence that contaminated crates are a source of poultry carcass contamination following processing *(22).* Transport crates could be contaminated by *Campylobacter* before transport, and bird contamination via transport crates probably increases with exposure time. Turkey lots crated for at least 8 h tended to be less exposed to solar radiation during crating and transport ($P = 0.07$), probably because they were transported to the slaughterhouse during the night. Absence of sunlight might have contributed to the persistence of crate contamination. Turkey lots kept in transport crates for at least 8 h were more likely to experience feed withdrawal of less than 4 h before crating ($P < 0.01$, chi-square test). A shorter feed withdrawal period before crating might have increased fecal excretion within crates and thus level of feather contamination at the time of slaughter. Transport is known to be stressful for birds and has been correlated in *Campylobacter*-colonized chicken lots with an increased rate and level of *Campylobacter* excretion *(21, 32, 36).* In chickens, transport also has been associated with an increase in *Campylobacter* carcass contamination *(32).*

In *Campylobacter*-colonized turkey lots, carcass contamination was lower when antimicrobials were given to the flock as a curative treatment during rearing. The use of antimicrobials might have lowered the number of birds colonized by the bacterium and/or the intestinal bacterial load, hence reducing the overall number of bacteria carried by the flock at the time of slaughter. Curative treatments given to flocks were effective against gram-negative bacteria in all but one treated flock. Unfortunately, the proportion of birds with *Campylobacter*-positive cecum culture results within flocks, which would have been needed to evaluate this hypothesis, was not determined during the study. However, specific use of curative antimicrobials strictly to reduce *Campylobacter* carcass contamination is highly controversial because of antimicrobial resistance and food residue issues.

Turkey carcass contamination by *Salmonella* and *Campylobacter* was associated with cecum bacteriological status, supporting the importance of preharvest control measures implemented during rearing to reduce carcass contamination at slaughter. As previously suggested, it would be valuable to assess the bacterial status of the flock at the end of the growout period but before slaughter so that pathogen-negative flocks could be processed first. Such a procedure probably would have decreased the contamination observed in the present study for cecum culture–negative lots, because many of these turkeys could have been exposed to processing equipment and/or a slaughterhouse environment contaminated by preceding pathogen-positive lots. Because no association was found between lot contamination with *Salmonella* and lot contamination with *Campylobacter,* preslaughtering testing for only one bacterium is not likely to be of diagnostic use for other bacteria. Visible contamination of carcasses was also associated with *Salmonella* or *Campylobacter* carcass contamination in lots of turkeys whose ceca were colonized by these the bacteria. Other factors related to transportation were associated with carcass contamination, but further studies are needed to fully understand the underlying mechanisms by which these factors influence carcass contamination.

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