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Economics of Reducing *Campylobacter* at Different Levels within the Belgian Poultry Meat Chain

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ABSTRACT

Campylobacter infections pose a serious public health problem in Belgium. Poultry meat is most likely responsible for 40% of human campylobacteriosis cases in Belgium. On a yearly basis, consumption of poultry meat causes at least 22,000 campylobacteriosis cases, with a cost of illness of €10.9 million. Several intervention measures have been proposed in literature, aiming to reduce the contamination of poultry meat and thus lead to significant reductions of human campylobacteriosis cases. This study aimed to evaluate the cost-benefit ratio, i.e., the ratio of reduced costs of illness on intervention costs of various intervention measures. These measures were selected by representatives from the poultry meat sector and experts in the field of poultry science. The selection comprised measures at the farm level (phage therapy), at the processing plant (spraying of carcasses with lactic acid or electrolyzed oxidizing water, crust freezing, or irradiation), and at the consumer level (improving kitchen hygiene and application of home freezing). Among these measures, the decontamination of carcasses with electrolyzed oxidizing water applied in the processing plant was the most efficient (17.66), followed by the use of lactic acid (4.06). In addition, phage therapy generated a positive cost-benefit ratio (2.54). Irradiation indicated the highest efficacy, but its cost-benefit ratio was rather low (0.31). There seems to be less gain by trying to improve food handling in the kitchen. The cost to reach consumers is large, while only a very limited fraction of the consumers is willing to change its behavior. The outcome of this study poses valuable information for future risk-management decisions in Belgium.

Campylobacter is the leading cause of zoonotic enteric human infections in most developed countries *(52).* In Belgium, *Campylobacter* enteritis is mainly caused by *Campylobacter jejuni* (80% of the isolates) and *Campylobacter coli* (12%) *(15).* The most common clinical symptoms of campylobacteriosis are fever, abdominal pain, and diarrhea, occurring within 2 to 5 days after ingestion of food or water contaminated with *C. jejuni (6, 41).* Symptoms are usually self-limiting and are resolved within a period of 3 to 10 days. The infection may lead to serious ongoing sequelae and may even be fatal. The most common complications are reactive arthritis (ReA), Guillain-Barré syndrome (GBS), and inflammatory bowel disease (IBD) *(40).*

In Belgium, the incidence of laboratory-confirmed cases of *Campylobacter* infections quadrupled from 1984 to 2004, reaching 65 cases per 100,000 inhabitants *(15).* As most *Campylobacter* infections are not part of recognized outbreaks, the incidence may be much higher. In The Netherlands, the actual incidence of *Campylobacter* infections is estimated to be 500 cases per 100,000 inhabitants, resulting in a total social cost of €21 million in 2000 *(32).*

Handling and consumption of poultry meat have been identified as important sources of human campylobacteriosis. In Belgium, a dramatic decline of 40% was noticed in the number of infections in 1999, and it has been attributed to the withdrawal of poultry from the shops related to the dioxin crisis *(49).* Several case-control studies have shown that consumption of poultry meat is one of the principal sources of infection *(13, 16, 17, 45, 52).* Reducing the contamination of *Campylobacter* in the poultry production chain may be obtained by interventions (i) at the farm and during transport, (ii) at the processing plant, and (iii) during storage and meat preparation *(25).* Several quantitative microbial risk assessment (QMRA) studies have been undertaken to assess the risk of human infection with *Campylobacter* upon the consumption of poultry meat and used to investigate the effect of interventions *(23, 36, 42).* The cost of illness of *Campylobacter* infections and sequelae were already estimated in previous studies *(8, 25, 46).*

The aim of this study was to estimate the cost-benefit ratio of various intervention measures in Belgium to control *Campylobacter* in the poultry meat chain. The cost-benefit ratio is defined as the ratio of reduced costs of illness on intervention costs. Available models for risk assessment and cost of illness of *Campylobacter* infections and sequelae served as input for the current calculations.

MATERIALS AND METHODS

Figure 1 presents the framework for calculating the cost-benefit ratio of various selected intervention measures. The year 2004 is used as reference in this economic evaluation.

Reduced cost of illness. The QMRA model is based on the model developed by Hartnett *(23, 24),* and describes the chain

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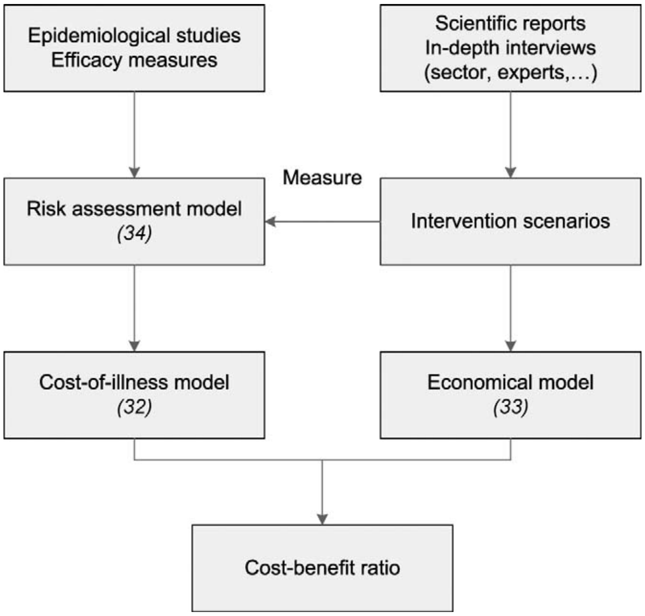

FIGURE 1. *Framework for calculating the cost–benefit ratio of various intervention measures.*

from farm to fork in a modular fashion. The modules considered are (1) rearing and transport, (2) slaughter and processing, (3) preparation and consumption, and finally, (4) health consequences. At each stage, the model estimates the probability that a bird, carcass, or product is colonized or contaminated with campylobacters and the associated microbial levels. Both fresh and frozen whole carcasses and filets, consumed at home, were included. The original model was adapted to the Belgian situation and updated to incorporate results of recent studies *(34).* At the rearing stage, the transmission rate of *Campylobacter* in broiler flocks was changed to Uniform(1.04;1.13) *(47).* The flock prevalence was modeled as Beta(8;12) using Belgian data *(27).* The flock size was derived from data from 502 Belgian flocks. The age of depopulation was estimated by Triang(35;40;45). At the slaughterhouse, a nonparametric second-order distribution was used for hard scalding because more data became available recently *(53).* The probability of damage to the viscera during evisceration was 0.0275, as assessed by a Belgian slaughterhouse. In Belgium, only air cooling of the carcasses is used, which is assumed to have no effect on the contamination levels on the carcass *(12).* For portioning, the model described in the Campylobacter Risk Management and Assessment (CARMA) project *(36)* was used. For duration of refrigerated and frozen storage at home, our own Belgian data involving 471 respondents was used *(21).* For reductions by refrigeration, the *D*-values in the Bigelow model were derived from a nonparametric second-order distribution. The *D*-values ranged from 2.88 to 63.64 days. Next to carcasses, chicken filets were incorporated in the model. In Belgium, 68.1% of broiler meats are bought as cuts. It is estimated that 95 and 80% of the carcasses and cuts, respectively, are bought fresh. At the preparation and consumption stage, only poor hygiene during cooking was considered, as inadequate cooking poses a much lower risk, as shown by Hartnett *(23).* Cross-contamination to raw vegetables was modeled as described in the CARMA project *(36).* This can be either from the raw meat through hand–salad contact or from raw meat via the cutting board to the salad. Consumer data was used to make the model applicable to the Belgian situation *(5).* The beta-Poisson model *(6)* for probability of infection was used. The probability of illness given infection was assumed as 0.338.

The QMRA model was constructed using @Risk 4.5.5 (Palisade, Ithaca, N.Y.), an add-in for Microsoft Excel. Model results were obtained by running five simulations of 50,000 iterations each. The baseline model was run to calculate the human campylobacteriosis cases on a yearly basis in Belgium. Next, the effect of each intervention was expressed in terms of reduction of *Campylobacter* counts on the exterior of the carcass or meat. For each intervention, a best estimate as most likely value is defined, being the average of all effects reported in literature. Next, to explore the uncertainty of the estimated effects, pessimistic and optimistic values are defined, being the lowest and highest reported effects in literature. Finally, these were incorporated in the model, and the model was run. The QMRA then calculates the yearly number of cases when the intervention would be applied. Finally, the output is expressed as percentage reduction in human campylobacteriosis cases as compared to the baseline model.

The annual incidence of human campylobacteriosis was also estimated based on epidemiological studies. Priority is given to Belgian data published in the scientific peer-reviewed international literature, describing the base year 2004. If not available, data from other (recent) years or from other European countries are used. The annual incidence of human campylobacteriosis when the intervention measure is applied can be calculated using the percentage reduction in human cases as derived from the QMRA model.

A final step consists in translating the reduced number of human cases into monetary values. The latter is expressed as reduced cost of illness and can be estimated using the prevalence approach and the incidence approach *(26).* In the prevalence approach, illness costs are defined as ''health care costs resulting from all patients alive during a specific time period'' (e.g., the annual disease costs for all IBD patients alive in 2004), taking into account the proportion of patients in each disease state during the specified time period. Under the incidence approach, disease costs are defined as ''the present discounted expected sum of current and future costs resulting from all incident cases of disease in a specific time period'' (e.g., the IBD incidence cohort of 2004) *(26).* Both methods produce the same results. The cost of illness includes direct health care costs, direct non–health care costs, and indirect non–health care costs. The direct health care costs include doctor consultations, hospitalization, drugs, rehabilitation, and other medical services. Direct non–health care costs are travel costs of patients and any copayments for costs such as informal care. Indirect non–health care costs are defined as the value of production lost to society due to disease. Production losses can be the consequence of (i) temporary absence from work, (ii) disability, and (iii) premature mortality. Since the medical care costs and the gross national income per capita are comparable between Belgium and The Netherlands *(3),* the estimates of Mangen et al. *(32)* are used in the current study.

Estimating the intervention costs. The annual total cost (TC) for an intervention *m* comprises the estimated annuity (*A*) of the nonrecurrent costs (NRC) for intervention *m* and the recurrent costs (RC) of intervention *m (33)*:

$$TC_m = A_m + RC_m \quad (1)$$

The NRC includes purchase costs and installation and reorganization costs and are mostly long-lasting investments (lifetime of ≥8 years). These investment costs will be depreciated over the lifetime (*n*) of the equipment at an interest rate (*i*) of 4%. For fiscal technical reasons, it might be attractive (and appears to be the current practice) to depreciate such investment over a shorter period than the actual lifetime. In the sensitivity analysis, shorter

TABLE 1. *Efficacy (pessimistic, most likely, and optimistic scenario) of the various selected intervention measures*

Stage	Intervention	Efficacy			Reference(s)	% reduction in campylobacteriosis cases		
		Pessimistic	Most likely	Optimistic		Pessimistic	Most likely	Optimistic
Farm	Phage therapy	1[a]	2[a]	2[a] + 1[b]	*33, 51*	53	76	82
Processing plant	Lactic acid	0.3[c]	1.3[c]	2[c]	*44, 48*	0	38	72
	EO water	1.1[c]	2.3[c]	3[c]	*29, 37*	28	80	91
	Crust freezing	0.4[c]	1.1[c]	1.7[c]	*11*	32	61	82
	Irradiation	4.7[c]	10.5[c]	20.8[c]	*11, 18, 19, 28*	99.8	100	100
Consumer	Kitchen hygiene	0%[d]	3%[d]	7%[d]	*14*	0	3	9
	Home freezing	0%[d] (0.13[c])	3%[d] (0.24[c])	7%[d] (0.46[c])	*14, 44*	0	6	9

[a] Log reduction of *Campylobacter* in the feces of broilers.
[b] Log reduction of *Campylobacter* on the exterior of the birds.
[c] Log reduction of *Campylobacter* on the carcass or meat.
[d] Change in behavior after one communication campaign.

and a longer-lifetime periods of 6 and 10 years are analyzed as well as interest rates of 2 and 6%. The equation used in basic notation for the annuity of intervention *m* is:

$$A_m = \mathrm{NRC}_m \times \left[\frac{i \times (1 + i)^n}{(1 + i)^n - 1}\right] \tag{2}$$

The RC comprises the annual maintenance costs and operational costs. The cost for the sector (SC) is equal to the sum of the TC for intervention *m* applied on all broiler farms and all processing plants, respectively:

$$\mathrm{SC}_m = \sum_v \mathrm{TC}_m \tag{3}$$

RESULTS AND DISCUSSION

Reduced cost of illness. Based on epidemiological studies, the annual incidences of *Campylobacter*-associated gastroenteritis and sequelae in Belgium are calculated. It is estimated that 30 to 40% of GBS are attributable to *Campylobacter* infections and that about 1 out of 1,000 patients with campylobacteriosis develops GBS *(35)*. The annual incidence of GBS in Belgium is 1.5 cases per 100,000 inhabitants *(4)*. Consequently, the annual incidence of *Campylobacter*-associated GE cases in Belgium (with a population of 10.5 million) is about 55,000 cases. Among these cases, about 19,300 patients visit a general physician (GP), 345 are hospitalized, and 20 cases are fatal. (The latter distribution is obtained from Mangen et al. *(32)*.) Only the parameter ''proportion people visiting the GP'' is multiplied by 1.5, since Belgian people visit the GP more frequently than do Dutch people *(3)*. The annual incidence of *Campylobacter*-associated GBS is estimated to be 56 cases.

Based on a Belgian 3-year prospective study, the annual incidence of Crohn's disease and ulcerative colitis is estimated at 4.5 and 3.6 cases per 100,000 inhabitants, respectively, giving a total of 8.1 cases of IBD per 100,000 inhabitants *(31)*. *Campylobacter* is involved in up to 6.2% of Crohn's disease and up to 3.7% of ulcerative colitis *(7)* cases. Accordingly, the estimated annual incidence of *Campylobacter*-associated IBD in Belgium is 43 cases. The rate of ReA associated with *Campylobacter* is low, ranging from 0 to 2.6% *(22, 43)*, resulting in an average of about 700 cases of *Campylobacter*-associated ReA in Belgium.

When assessing the intervention measures, many factors should be taken into account such as efficacy, levels of microbial contamination, potential for introducing other food safety hazards, impact on the environment, effect on sensory properties and quality of the product, feasibility, and consumer perception *(2)*. Information and data for the selection of the various intervention measures and estimates of efficacy are obtained from scientific reports, in-depth interviews with representatives from the Belgian poultry sector, and from experts in the field of poultry science. A summary of the intervention measures studied together with their efficacy (pessimistic, most likely and optimistic scenario) is presented in Table 1. In addition, the reduction in human campylobacteriosis cases as compared to the baseline model (percentage) is given. At the farm level, phage therapy would most likely lead to a 76% reduction in the number of cases. At the processing plant, the number of cases would most likely be reduced by 38 and 80% when applying decontamination of the carcasses at the end of the slaughter line, with lactic acid and electrolyzed oxidizing (EO) water, respectively. Crust freezing gives reductions of 61%, whereas irradiation would lead to a 100% reduction in number of cases. At the consumer level, two interventions are analyzed, i.e., mass media campaigns to improve kitchen hygiene and home freezing of poultry meat. As only a very limited fraction of the consumers is willing to change its behavior, these have a limited reduction in number of campylobacteriosis cases.

The cost of illness associated with *Campylobacter* infections and sequelae in Belgium is estimated at €27.3 million for the year 2004 (Table 2). Under the current assumptions, 54% of the costs of illness are caused by GE cases, 32% by IBD cases, and 14% by GBS cases. ReA cases only account for 0.06% of the cost of illness. As mentioned above, 40% of these costs are attributable to the consumption of poultry meat, resulting in a yearly cost of illness of €10.9 million. The reduced cost of illness of the different intervention measures is obtained by multiplying this value with the percentage risk reduction of the intervention measure. The results are presented in Table 3.

Intervention costs. One potential approach to control *Campylobacter* colonization at the farm level is phage therapy as described by Wagenaar et al. *(51)*. Results indicate

TABLE 2. *Estimated cost of illness associated with GE, GBS, IBD, and ReA*

Description	Cases/yr	Cost/case (€)	Total cost (thousand €)
GE case not visiting GP	35,445	126	4,466
GE case visiting GP only	19,314	485	9,367
Hospitalized GE case	345	2,661	918
Fatal GE case	21	1,774	37
GBS	56	67,852	3,799
IBD	43	202,385	8,712
ReA	714	23	16
Total cost			27,317

a significant drop in the number of campylobacter in already-colonized chicken ceca. The costs are comparable to an antibiotic cure given via the water and may vary between €0.0027 and €0.036 per treated chicken. Given a livestock of about 220 million broilers in 2005, intervention costs are estimated to amount to between about €5.84 million and €440,000. At the processing plant, several interventions were studied: acid decontamination of carcasses, decontamination of carcasses with EO water, crust freezing, and irradiation. For acid decontamination of carcasses, a spraying device is installed immediately at the end of the slaughter line, before entering the chilling tunnel. According to the suppliers' instruction, each carcass needs to be sprayed with 50 ml of lactic acid solution *(39),* but practices in the slaughterhouse show a surplus of 20%, i.e., 60 ml per carcass. However, this surplus is wastewater and needs to be treated. The lactic acid solution (2%) is prepared by a dilution of 80% lactic acid in water. The cost of lactic acid is assumed to range between €1.50 and €2.50 per kg of product (Purac, The Netherlands). The temperature of the solution at the moment of spraying is 45°C. The purchase cost of the spraying device (with pump and control apparatus) is €20,000 to €30,000, and the installation cost is assumed to be 5% of this purchase cost. The maintenance costs (cleaning and replacement of filters, spray, impeller, etc.) are assumed to be 2 to 3% of the purchase cost. The operational costs are mainly the electricity use of the spraying device (0.12 kWh, €0.058/kWh) and heating device (1 kWh), and the costs of lactic acid. Other operational costs are costs for additional water (€1.50/m^3 and costs for additional sewage water (€1.5/m^3) (Spraying Systems, Belgium). With a total of 38 slaughter lines, the sector cost is about €1.02 million, a range of €0.98 to €1.06 million.

The EO water generator and spraying device would also be installed before entry to the chilling tunnel. Each carcass is sprayed with 0.1 liter of EO. The average capacity of a Belgium slaughter line is 6,000 to 9,000 broilers per h. Consequently, the minimal capacity of the EO water generator should be 10 to 15 liters/min. The purchase cost of such an apparatus is €40,000. The installation cost is estimated at 5% of the purchase cost. The maintenance costs are assumed to be 2 to 3% of the purchase cost. The operational costs are electricity (0.05 kW), water (0.1 liter per carcass; €1.50/m^3) and salt costs (if necessary 0.5 g/m^3, €0.19/kg), giving a total of €1.50/m^3 (Ecodis, Belgium). The sector cost is about €490,000, a range of €450,000 to €540,000.

In the slaughterhouse, crust freezing would be applied after cooling the carcasses and possible portioning. The purchase and installation costs are estimated between €1.5 million and €3 million per piece of equipment (Air Products, Surrey, UK). Apart from the maintenance costs, there are only additional electricity costs. The most likely value of a regular air-chilling system without crust freezing is around 490 kWh, with a variation of 50 kWh. Implementing crust freezing in a regular air-chilling system is estimated to increase energy use for chilling up to 200%. The sector cost is about €18 million, a range of €13.7 to €22.3.

Since the purchase cost per piece of equipment used for irradiation is rather high (several millions euros), it is assumed gamma irradiation would not be applied in the processing plant, itself but being subcontracted to a specialized company. Isotron is Europe's leading provider of contract sterilization services. The closest site is in Etten-Leur (Breda, The Netherlands). Depending on the quantity irradiated and the dose applied, the price varies between €40 and €100 per pallet. The doses recommended by Farkas *(18, 19)* for organoleptic acceptability of irradiation processes of 1.5 to 2.5 kGy for poultry are simulated. A pallet is assumed to be approximately 975 kg of meat, including 25 kg for the pallet itself. Apart from the treatment costs, costs for loading and discharging, transporting to and from the irradiation plant, and the waiting time of the lorry at the irradiation plant should be considered.

TABLE 3. *Estimated reduced cost of illness and cost-benefit ratio for the different interventions*

		Reduced cost of illness: X (million €/year)		Treatment costs: Y (million €/year)			Cost-benefit ratio[a]	
Stage	Intervention	Belgian consumer: X_1	All consumers: X_2	Farmer	Industry	Government	X_1/Y	X_2/Y
Farm	Phage therapy	8.28	12	3.26	—	—	2.54	3.68
Processing plant	Lactic acid	4.15	6.01	—	1.02	—	4.06	5.89
	EO water	8.74	12.67	—	0.49	—	17.66	25.62
	Crust freezing	6.66	9.66	—	18	—	0.36	0.53
	Irradiation	10.92	15.84	—	35.1	—	0.31	0.45
Consumer	Kitchen hygiene	0.33	—	—	—	1.85	0.18	—
	Home freezing	0.66	—	—	—	1.85	0.35	—

[a] The intervention measure is efficient if the ratio is >1.

The average distance to Breda is estimated as 100 km (90 min). With an average usage of 35 liters of diesel fuel per 100 km (€1.10/liter) and a gross income of €10 to €12.5/h, the transport cost is estimated at €110. The estimated costs for charge and discharge are €1.80 per pallet (20 pallets per lorry, 10 min per pallet) and for waiting €3.60 per pallet (time to threat a pallet is assumed to be 0.35 h). The sector cost is about €35.1 million, a range of €20.6 to €49.6 million.

At the consumer level, communication campaigns can be applied. According to Allos *(1)* and Peterson *(38),* poultry meat should be adequately cooked, and cutting boards and utensils used in handling uncooked poultry or other meats should be washed with hot soapy water before being used again in the preparation of salads or other raw foods. Another possible intervention measure is the freezing of fresh meat at home by the consumer. Freezing has a damaging effect on *Campylobacter,* resulting in fewer organisms in broiler carcasses *(20).* Both intervention measures presume a change in consumer behavior. Such a change might be realized through communication campaigns. The annual cost of such a national communication campaign is €1.85 million (Interministerieel Commissariaat Influenza, Belgium, 2006).

Cost-benefit ratio and sensitivity analysis. Dividing reduced cost of illness by intervention costs indicates the cost-benefit ratio. With a self-sufficiency degree of 145%, about one-third of the Belgian poultry meat is exported *(50).* This implies that measures taken to reduce the contamination with *Campylobacter* of poultry flocks or meat will not only have a positive effect on the health risk of consumers in Belgium, but also in countries importing Belgian products. In the analysis, the benefits realized on the Belgian market and export markets are integrated. Results of the various interventions are presented in Table 3, assuming most likely values for efficacy and intervention costs. Three interventions are considered efficient, i.e., having a ratio >1. The most efficient intervention measure is the decontamination of carcasses with EO water, with a cost-benefit ratio of 17.66. The decontamination of carcasses with lactic acid has a cost-benefit ratio of 4.06, while the use of the phage therapy illustrates a score of 2.54. Some of the intervention measures might result in side effects that might not be conform to the current demand for ''fresh'' poultry meat on the Belgian market. For example, a too-high concentration of lactic acid might result in paler meat *(30)* and therefore might not be recognized by the consumer as being fresh. Moreover, irradiated poultry meat is hardly accepted by consumers *(10).* Finally, the demand for frozen poultry meat is lower than it is for fresh product. Therefore, apart from the direct costs related to the treatment itself, processing plants might suffer additional indirect costs because of being forced to sell the poultry meat at a lower price. Should these costs be considered, the cost-benefit ratio of most of the interventions would be reduced. This does not hold true for EO water *(29),* however, making it an even more promising intervention measure. However, more research is needed to confirm this.

As the Belgium poultry sector acts in an open economy with imports and exports, only interventions at consumer level tackle all poultry meat sold in Belgium. Given that these interventions presume consumers are prepared to change their behavior, and mass media campaigns in general are not effective for this purpose *(14),* these interventions at the consumer level turn out not to be efficient. By applying interventions at the farm and processing levels, export of broilers and poultry meat is leading to health benefits for consumers abroad. Consequently, when taking the Belgian perspective, the relative cost-benefit ratio of these interventions is underestimated.

The social perspective is traditionally the perspective chosen in economic evaluation. It is assumed that investments are worth doing when society as a whole is better off than under a status quo situation. However, in our study, the ''benefactors'' and the ''losers'' are not identical. Costs are incurred in the food supply chain, while the benefits are realized at consumer level. The distribution of the intervention costs over the different stakeholders, namely farmers, industry, and government, are summarized in Table 3. Birds colonized by *Campylobacter* are generally not ill, and their growth and reproduction abilities are not affected. Consequently, the eradication of *Campylobacter* in broilers does not result in a reduction of production costs for farmers. Additionally, most *Campylobacter* infections in humans are sporadic. Consequently, media attention—a potential source of consumer communication—is seldom or nonexistent. Therefore, processing plants willing to differentiate their products by signaling the consumers being *Campylobacter* free would need to invest substantially in communication campaigns. In Denmark, consumers are not willing to pay for such products (Birgitte Borck, personal communication). Consumers in general already presume buying safe products. Consequently, potential financial benefits for farmers and processing plants were disregarded in the current study.

Given that most campylobacteriosis cases are sporadic, traceability to a certain product or firm might be hard to make. Therefore, the potential costs and losses related to product recalls and liability claims were not considered in the current study. Supermarkets insist on having *Campylobacter*-free products for their customers. In this perspective, the processing plants have to deliver *Campylobacter*-free poultry products. However, financial compensation for farmers for interventions is not in practice.

Model uncertainties and unavailability of some data are leading to a number of assumptions. With a sensitivity analysis, the impact of such assumptions is analyzed and discussed. The sensitivity analysis is applied for the attributable fraction poultry meat–associated *Campylobacter* infections, the efficacy of the intervention measure, the intervention costs, the lifetime of the investment, and the interest rate, whereby changing one factor at the time. Results are presented for the Belgian market (Table 4). The attributable fraction varies between 20 and 40% in literature *(13, 16, 17, 31, 45, 49, 52).* Lowering the attributable fraction to 20% results in a 50% decrease of the reduced cost of illness for all interventions. The phage therapy and the decontamination of the carcasses with lactic acid or EO

TABLE 4. *Results for cost-benefit ratio when performing a sensitivity analysis on the attributable fraction poultry meat–associated campylobacteriosis cases, on the efficacy of the intervention measure and on the intervention costs; one factor is changed at the time.*

Stage	Intervention	Baseline[a]	Risk factor poultry: 20%[a]	Pessimistic efficacy[a]	Optimistic efficacy[a]	Highest intervention costs[a]	Lowest intervention costs[a]	Worst case[a,b]
Farm	Phage therapy	2.54	1.27	1.77	2.73	1.41	18.82	0.49
Processing plant	Lactic acid	4.06	2.03	0	7.71	3.91	4.21	0
	EO water	17.66	8.83	6.06	20.1	16.1	19.57	2.41
	Crust freezing	0.36	0.18	0.19	0.5	0.3	0.48	0.06
	Irradiation	0.31	0.16	0.31	0.31	0.22	0.53	0.11
Consumer	Kitchen hygiene	0.18	0.09	0	0.41	0.12	0.35	0
	Home freezing	0.35	0.18	0	0.53	0.24	0.7	0

[a] The intervention measure is efficient if the ratio is >1.

[b] Considered for the worst-case scenario: highest intervention costs depreciated over a period of 6 years at an interest rate of 6%, highest operational costs, pessimistic efficacy and attributable fraction of poultry meat to campylobacteriosis 20%.

water remain efficient, with values of 1.27, 2.03, and 8.83 respectively.

To explore the uncertainty of the cost-benefit ratio of the interventions, pessimistic and optimistic values were defined, yielding lower and higher risk reductions, respectively. In the pessimistic scenario, the phage therapy and decontamination with EO water remain efficient. In the optimistic scenario, the phage therapy and decontamination of carcasses with lactic acid or EO water are efficient. When considering the highest intervention costs, the phage therapy and the decontamination of carcasses with lactic acid or EO water are efficient with values of 1.41, 3.91, and 16.1, respectively. When considering the lowest intervention costs, the phage therapy and decontamination of carcasses with lactic acid or EO water are efficient, with values of 18.82, 4.21, and 19.57, respectively. Changing the lifetime of the investment (6, 8, and 10 years) or the interest rate (2, 4, and 6%) has little or no effect on the cost-benefit ratios. Among the various intervention measures, the decontamination of the carcasses with EO water is the most efficient. Even in the worst-case scenario, it remains efficient with a value of 2.41 (Table 4).

Campylobacter infections pose a serious public health problem in Belgium, with poultry meat being most likely responsible for 40% of human cases of campylobacteriosis. On a yearly basis, this results in at least 22,000 campylobacteriosis cases, with costs of illness of €10.9 million a year. Of all analyzed intervention measures, the decontamination of carcasses with EO water is the most efficient, assuming that all other levels in the poultry meat chain continue with good practice behavior. Irradiation is the most efficacious intervention; however, it is one of the least efficient.

In this research, only health benefits associated with a reduced risk of *Campylobacter* infections are considered. Consequently, health benefits due to the reduction of other foodborne pathogens tackled by the applied intervention measures were not taken into account. Reduced cost of illness and efficiencies are therefore underestimated.

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