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Cost-effectiveness of *Campylobacter* interventions on broiler farms in six European countries

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A B S T R A C T

Broilers are an important reservoir for human *Campylobacter* infections, one of the leading causes of acute diarrheal disease in humans worldwide. Therefore, it is relevant to control *Campylobacter* on broiler farms. This study estimated the cost-effectiveness ratios of eight *Campylobacter* interventions on broiler farms in six European countries: Denmark, the Netherlands, Norway, Poland, Spain, and United Kingdom. The cost-effectiveness ratio of an intervention was the estimated costs of the intervention divided by the estimated public health benefits due to the intervention, and was expressed in euro per avoided disability-adjusted life year (DALY). Interventions were selected on the basis of a European risk factor study and other risk factor research. A deterministic simulation model was developed to estimate the cost-effectiveness ratio of each intervention, if it would be implemented on all broiler farms in a country where it isn't implemented yet and implementation is possible. The model considered differences between countries in number and size of broiler farms and established practices, in import, export and transit of live broilers, broiler meat and meat products, in effect of interventions on *Campylobacter* prevalence in broilers, in disease burden of *Campylobacter* related human illness, in national economic factors, such as interest rate and general cost levels, and in technical and economic farm performance. Across interventions, cost-effectiveness ratios were the lowest for Poland and Spain, and highest for Norway and Denmark. Across countries, applying designated tools for each farm house and building an anteroom with hygiene barrier in each farm house had the lowest cost-effectiveness ratios, whereas a ban on thinning (partial depopulation), slaughter at 35 days, replacing old houses by new houses, and applying drink nipples without cup had the highest. Applying fly screens in Denmark had an intermediate cost-effectiveness ratio. A maximum downtime between flocks of ten days had a negative cost-effectiveness ratio (i.e. revenue) in Poland, a low positive cost-effectiveness ratio in Spain and high positive cost-effectiveness ratios in Denmark, the Netherlands and United Kingdom. Estimated cost-effectiveness ratios of *Campylobacter* interventions on broiler farms differed substantially between the six countries, but the order of interventions in increasing cost-effectiveness ratio was generally similar across the countries.

1. Introduction

Campylobacter is one of the leading causes of acute diarrheal disease in humans worldwide which can result in severe sequelae of campylobacteriosis, such as Reactive Arthritis, Irritable Bowel Syndrome and Guillain–Barré Syndrome (Mangen et al., 2013). Because broilers are an important reservoir for human *Campylobacter* infections (Mangen et al., 2013, EFSA Panel on Biological Hazards 2011), it is relevant to control *Campylobacter* on broiler farms. A number of risk factors for *Campylobacter* infections on broiler farms and on-farm interventions to control these risk factors have been proposed (EFSA Panel on Biological Hazards 2011, Adkin et al., 2006, McDowell et al., 2008). The cost-effectiveness of such interventions on broiler farms, i.e. the costs of an intervention divided by the public health benefits, has been estimated in several studies. Mangen et al. (2007) estimated the cost-effectiveness of improving hygiene and applying phage therapy in the Netherlands quantifying public health benefits in avoided disability-adjusted life year (DALY). Gellynck et al. (2008) estimated the cost-effectiveness of applying phage therapy in Belgium quantifying the public health benefits by the cost-of-illness. These studies only estimated the cost-effectiveness in a single country. Elliott et al. (2012) estimated the cost-effectiveness of enhanced biosecurity, slaughter at 35 days, stop thinning, applying vaccination,

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and applying bacteriocins in 27 European Union (EU) member states, quantifying public health benefits in avoided DALY and avoided cost-of-illness. They identified that the cost-effectiveness of interventions varied with the country due to differences in national economic factors, such as labour costs and prices for electricity and water, in number and size of broiler farms and established practices, in prevalence of *Campylobacter* in broilers and in incidence of *Campylobacter* related human illness. However, Elliott et al. (2012) did not consider country specific technical and economic farm performance on intervention costs and country specific effectiveness of interventions. Hence, it remains unclear if general recommendations on cost-effective interventions to control *Campylobacter* on broiler farms can be made on EU level or if specific recommendations should be made for regions within the EU. Therefore, as part of the CamCon project (EU Seventh Framework Programme (FP7/2007–2013) under grant agreement no. 244547), the objective of this study was to analyse the cost-effectiveness ratios of *Campylobacter* interventions on broiler farms in six European countries: Denmark, the Netherlands, Norway, Poland, Spain and United Kingdom. Our study considers differences between these countries in national economic factors, in number and size of poultry farms and established practices, in technical and economic farm performance, in human disease burden, and in effectiveness of interventions. In this study, only interventions at broiler farms were analysed, so potential interventions at processing (e.g. freezing and chemical treatment of meat and meat products) or consumer level (consumer campaigns) were outside the scope of our study.

The interventions on broiler farms considered in our study were those that were associated with significant risk factors in these six countries by Sommer et al. (2016b) based on the risk factor study of Sommer et al. (2016a) and a questionnaire survey performed by Høg et al. (2011) in 2011. The interventions with significant effect in terms of reduction of *Campylobacter* flock prevalence were: building an *anteroom with hygiene barrier* in each individual broiler house on farms at which the newest house is not older than 15 years, establishing a *maximum downtime of 10 days* between flocks including rodent control more than 6 times per year and cleaning and disinfection between flocks, replacing all broiler houses by *new houses* on farms with all houses older than 15 years, applying *drink nipples without cup* and using *designated tools* in each individual broiler house on farms at which the newest house is not older than 15 years. Additionally, we included three interventions that could not be studied by Sommer et al., (2016b), but have previously been identified as promising: a ban on partial depopulation (*stop thinning*) (Adkin et al., 2006, Elliott et al., 2012, Hald et al., 2000, Katsma et al., 2007), *slaughter at 35 days* (McDowell et al., 2008, Elliott et al., 2012), and the application of *fly screens* (Hald et al., 2007, Rosef and Kapperud, 1983). Although some of these *Campylobacter* interventions have been known for years, the questionnaire survey performed by Høg et al. (2011) showed that still part of the broiler farmers in each of the six countries had not yet implemented these interventions in 2011.

2. Materials and methods

2.1. Model to estimate the cost-effectiveness ratio

A deterministic simulation model was developed to estimate the cost-effectiveness ratios of the selected interventions in the six countries. The cost-effectiveness ratio $CER_{int_i,c}$ of an intervention i in a country c is calculated as the estimated annual costs $Costs_{int_i,c}$ of intervention i in country c divided by the annual public health benefits $PHB_{int_i,c}$, i.e. the estimated annual reduction in *Campylobacter* related disease burden (Eq. (1)). The human disease burden of campylobacteriosis was measured in DALY (Murray, 1994), a metric that encompasses the number of healthy years of life lost due to premature death and disability. In this study, the cost-effectiveness ratio is expressed in euro per avoided DALY. We did not monetize a DALY. The lower the estimated cost-effectiveness ratio of an intervention, the lower the costs for each avoided DALY and the more favourable the intervention. $CER_{int_i,c}$ is estimated for the situation where the intervention i would be implemented on all broiler farms in a country c where the intervention is not yet implemented, given that implementation is possible.

$$CER_{int_i,c} = \frac{Costs_{int_i,c}}{PHB_{int_i,c}} \quad (1)$$

where

$CER_{int_i,c}$ = Cost-effectiveness ratio of intervention i in country c (€/avoided DALY),
$Costs_{int_i,c}$ = Annual costs of implementation of intervention i on all broiler farms involved in the intervention in country c (€/year),
$PHB_{int_i,c}$ = Annual public health benefits due to implementation of intervention i on all broiler farms in country c (avoided DALY/year),
i = index for interventions,
c = index for countries.

Annual costs of intervention i in country c $Costs_{int_i,c}$ are estimated by multiplying the estimated number of farms in country c that can implement intervention i with estimates of the annual intervention costs $CF_{int_i,c}$ on such a farm (Eq. (2)). The estimated number of farms in country c that can implement intervention i is the number of broiler farms F_c in country c multiplied by the estimated fraction of these farms $FF_{int_i,c}$ involved in intervention i in country c.

$$Costs_{int_i,c} = F_c \cdot FF_{int_i,c} \cdot CF_{int_i,c} \quad (2)$$

where

F_c = Number of broiler farms in country c,
$FF_{int_i,c}$ = Fraction of farms in country c on which intervention i is not yet implemented and implementation is possible (i.e. fraction involved in the intervention),
$CF_{int_i,c}$ = Costs to implement intervention i on a broiler farm in country c (€/farm/year).

Interventions should reduce the probability of *Campylobacter* colonization of broiler flocks and reduce flock prevalence of *Campylobacter*. Based on risk assessment studies (Nauta et al., 2009, Rosenquist et al., 2003), it was assumed that the *Campylobacter* related disease burden obtained by the consumption of broiler meat, is proportional to the flock prevalence. The reduction in this disease burden is estimated with Eq. (3). The method proposed by Mangen et al. (2007) was used to relate disease burden on national level to *Campylobacter* flock prevalence on farms involved in an intervention in a country. This method considers the relative risk of *Campylobacter* infection after implementation of an intervention $RR_{int_i,c}$, the *Campylobacter* related disease burden DB_c, the fraction of the *Campylobacter* related human disease burden which is attributable to broiler meat AF_c, and the fraction of broiler meat and meat products consumption coming from domestically raised broilers $FMDR_c$ in country c. Part of the annual human disease burden of campylobacteriosis can be attributed to consumption of chicken meat contaminated with *Campylobacter*. If interventions to control *Campylobacter* are effectively implemented at broiler farms, the prevalence of contaminated chicken meat decreases, which in turn will decrease the annual human disease burden. This decrease in annual disease burden (public health benefits $PHB_{int_i,c}$) due to an intervention in a country was estimated by multiplying the decrease in relative risk $(1 - RR_{int_i,c})$ of