Microbial risk assessment: a chain perspective on improving the safety of broiler meat

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Abstract

This paper focuses on the safety of broiler meat, and especially on the presence of Salmonella on the meat. In the past, numerous researchers studied the factors affecting Salmonella colonisation of broilers, Salmonella transfer in the slaughterhouse, Salmonella transfer in the consumer home, etc. Nevertheless, it is unclear how the Salmonella risk to the consumer is reduced most (cost) effectively: e.g. by slaughterhouse measures or by lowering the prevalence at farm-level? Microbial risk assessment (MRA) can assist with this kind of problems, since it estimates the public health risk by linking the various stages of the supply chain together (using experimental data, predictive microbiology models, etc). An overview of quantitative models in literature is given and finally future applications are discussed.

Introduction

Non-typhoidal Salmonella bacteria are recognised world-wide as a major cause of human diarrhoeal illness (Nauta et al., 2000). Salmonella bacteria live in the intestinal tracts of their hosts (humans and other animals) and spread via the contaminated faeces into the environment, where they survive or multiply if conditions are favourable. Humans can obtain Salmonella infection (salmonellosis) via a variety of routes, but generally foods of animal origin are considered a major source. In the Netherlands only, Salmonella causes 50000 illnesses, more than 8600 visits to the general practitioner and 50 deaths per year (van Pelt et al., 2003). According to recent Dutch (van Pelt, 2004) and Danish (Ministry of Food, 2003) studies, approximately 10% of these human cases are due to Salmonella serotypes originating from broilers and chicken meat products. This clearly indicates that it is of importance to improve the safety of chicken meat. But to do that, it is necessary to have insight in the transmission of Salmonella along the supply chain of broiler meat.

Description of the transmission route of Salmonella in the broiler supply chain

The transmission route considered here starts with the broiler farm on which the chickens are raised. On the broiler farm, chickens are housed and managed together in groups (flocks) for approximately 6 weeks. They can already be contaminated when they arrive on the farm (vertical transmission) or get contaminated via the feed and the farm environment (horizontal transmission). Once Salmonella infection is introduced, within-flock transmission will occur: the faeces of infected chickens will spread Salmonella through the flock either via direct contact between birds or via indirect contact (litter, air, feed and water). After a while, the number of positive chickens can decrease again, because infected chickens can loose their infectivity (carrier-state) or recover totally from infection. When the chickens reach slaughter age, they are caught and transported to the slaughterhouse. Due to stress, some carrier chickens start excreting Salmonella again.

In the slaughterhouse, there are 5 main stages regarding Salmonella contamination, namely scaling, defeathering, evisceration, washing and cooling (FAO/WHO, 2002). During scaling, the chickens are led through warm water for several minutes in order to ease feather removal. The faeces from the intestines and feathers leaks into the scalding water, leading to cross contamination of other chickens. During plucking, rotating rubber fingers remove the feathers of the chickens. Cross-contamination can occur via aerosols transferring material to other chickens, faeces that is leaking from the chickens and rubber fingers that can act as a growth or transfer surface for Salmonella. During evisceration, the intestines are removed. If these are damaged, this leads to considerable...
contamination of the carcass. Washing and cooling leads to reduction in numbers, although cross-contamination can occur when the chicken is immersed in water.

Between slaughterhouse and consumer, a too high storage temperature will increase numbers on contaminated meat. During preparation by consumers or caterers, incomplete inactivation or cross-contamination can lead to a contaminated serving. Depending on the number of *Salmonella* on the serving, the food consumed and the immune status of the consumer, diarrhoeal illness or more severe consequences (e.g. reactive arthritis, death) can occur.

### Qualitative or semi-quantitative assessment of the transmission route

The description of the transmission identifies possible measures to prevent *Salmonella* contamination. For instance, farm management should prevent introduction (vertical and horizontal transmission) and spread (within-flock transmission) of *Salmonella* within the flock to reduce contamination at the end of the farm. The choice of certified feed and chicken suppliers reduces vertical transmission, while hygienic measures reduce horizontal transmission. Within-flock transmission can be reduced by decreasing the *Salmonella* in the environment or by increasing the resistance of the chickens against colonisation. This assessment can be elaborated further and for other stages in the chain, see CAC (2003) for other possible reduction strategies.

The next step is to examine to what extent these reduction strategies are already implemented in practice. Sauli *et al.* (2003b) developed a semi-quantitative approach to assess the level of safety assurance in food production chains, based on the effects of production processes on *Salmonella* contamination and the sampling strategies and hygiene measures put in place. Their evaluation of the Swiss situation showed that safety assurance level was satisfactory in chicken meat production chain, but weak in the pork production chain (Sauli *et al.*, 2003a). This indicates that it would be more worthwhile to implement measures in pork production than in chicken production, especially since pork probably contributes evenly or more to human cases than chicken (KVW/RIVM, 2001).

If stakeholders agree to take measures in a certain stage in the transmission route, then a limited additional study can be done to determine the most (cost-) effective measure. Monitoring can indicate how this measure affects *Salmonella* prevalence and public health (Wegener *et al.*, 2003).

If one wants to compare measures at different stages in the transmission route or if one just wants to collate available information into an overview of the transmission route, quantitative microbial risk assessment (QRMA) techniques can be useful.

### Principle quantitative microbial risk assessment

Microbial risk assessment is a method that developed rapidly during the last years as a result of the WTO-SPS agreement signed in 1994 (WTO, 1994). This agreement states that countries can only reject imported products if that is necessary for the protection of public health. This rejection should be based on a risk assessment, according to the standards and guidelines developed by the relevant international organisations. The relevant organisation for food hygiene is the Codex Alimentarius, which released principles and guidelines for the conduct of microbial risk assessment in 1999 (CAC, 1999). Microbial risk assessment consists of four steps:

1. The *hazard identification* step identifies the microbial hazard (pathogen) by examining epidemiological data, surveillance studies etc.
2. The *hazard characterisation* step relates the ingested number of the pathogen (dose) to the probability and severity of the response of the consumer (i.e. illness or death). This response of the host is dependent of the characteristics of the pathogen (e.g. virulence), host susceptibility (e.g. concomitant infections) and interaction of the pathogen with the food matrix (Benford, 2001). Generally, the so-called dose-response relation is estimated by fitting empirical models on dose-response data from volunteer studies or from food-borne outbreaks.
3. The *exposure assessment* step estimates how likely it is that the consumer is exposed to the pathogen and to which extent he is exposed. It is practically impossible to measure this exposure, so generally the exposure is estimated by using predictive models in combination with data from earlier in the food chain (for instance, retail contamination data, consumption data etc.).
4. The *risk characterisation* step combines the results of the previous steps to give an estimate of the final risk. For instance, the risk of illness after consumption of a contaminated food product is estimated by the multiplying the chance of consuming a contaminated product (exposure
assessment) and the chance of becoming ill of that contaminated product (hazard characterisation). Note that the risk is determined by the prevalence as well as the number, as is illustrated in Table 1.

Table 1 Illustration of the relationship between number on a positive serving, prevalence of a positive serving and risk of illness after consumption of a serving.

<table>
<thead>
<tr>
<th>Number</th>
<th>Pill *</th>
<th>Risk per serving (Prev = 0.50)</th>
<th>Risk per serving (Prev = 0.25)</th>
<th>Risk per serving (Prev=0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>0.503</td>
<td>2.51E-1</td>
<td>1.26E-1</td>
<td>2.51E-2</td>
</tr>
<tr>
<td>1000</td>
<td>0.329</td>
<td>1.65E-1</td>
<td>8.23E-2</td>
<td>1.65E-2</td>
</tr>
<tr>
<td>100</td>
<td>0.133</td>
<td>6.66E-2</td>
<td>3.33E-2</td>
<td>6.66E-3</td>
</tr>
<tr>
<td>10</td>
<td>0.023</td>
<td>1.16E-2</td>
<td>5.81E-3</td>
<td>1.16E-3</td>
</tr>
<tr>
<td>1</td>
<td>0.003</td>
<td>1.27E-3</td>
<td>6.36E-4</td>
<td>1.27E-4</td>
</tr>
</tbody>
</table>

* Calculated using dose response relationship: Pill = 1-(1+(number/51.45))^-0.1324 (FAO/WHO, 2002)

More details about microbial risk assessment can be found in (Lammerding and Fazil, 2000) and (Buchanan et al., 2000).

Quantitative assessment of the transmission route

In literature, the transmission route has been assessed considering prevalence only or considering prevalence and number (microbial risk assessment models) This section gives a brief overview of quantitative models used, their main conclusions and the advantages and disadvantages of the model type.

MODELS BASED ON PREVALENCE

A basic approach is use of prevalence estimates to determine to which extent the current stage of the chain amplifies the prevalence of the previous stage chain (vertical transmission) and to which extent additional contamination occurs (horizontal transmission).

Nauta et al. (2000) developed such a model for the broiler meat chain, where they considered three types of measures: those targeting the prevalence at a stage (e.g. removal of positive flocks), those targeting amplification (e.g. logistic slaughter: slaughtering negative flocks before positive flocks) and those targeting horizontal transmission (e.g. additional hygiene measures). Expert opinion was used to evaluate the baseline situation and the effect of control measures in the chain from grandparents till slaughterhouse. Ranta and Maijala (2002) elaborated the model by including test sensitivity and temporal aspects, like persistence in the flock, and used observed data from grandparents till broiler farm to evaluate the situation in Finland. They also modelled the effect of removing control measures (not eliminating Salmonella positive breeder flocks). Both studies show that elimination of positive breeder flocks is highly effective in reducing the prevalence in subsequent stages, which is logical since this measure blocks vertical transmission to the subsequent stages. The effects of the other measures are also mentioned in Nauta et al. (2000), but the foundation of this effect estimates proved to be difficult. However, the model might be useful to monitor the effect of implemented measures, since the data (prevalence) to put in the model are mostly readily available from surveillance programs.

Berends et al. (1998) noticed strong correlation between the percentage of Salmonella positive pigs and the percentage Salmonella positive pig carcasses. They used this empirical model together with performance estimates of improved practices to evaluate different control strategies. Good manufacturing practices (GMP) from transport to retail combined with either strict hygiene (SPF concept) on the farm or decontamination in the slaughterhouse would result in 99% lower prevalence of cuts. GMP measures alone were estimated to be less effective.

Another way to use prevalence is to implement it in a Bayesian network (Barker et al., 2002), as Parsons et al. (2004) did for the chain from parent flock till portioned and packed chicken meat. The model estimates were derived from expert opinion and data if available. Special features were the
presence of sample and management nodes in the network. The sample nodes make it possible to “reason back”, for instance to determine the chance that an end-product is contaminated given that all samples at the hatchery are negative. The management nodes allow the inclusion of different management options, e.g. soft scald or hard scald. Depending on the choice made, the chance of environmental and cross-contamination changes. In this way, management options were explored. Again here it was concluded that contamination early in the chain showed the largest effect, although the portion-and-pack operation with the potential for (cross)contamination could also be important.

Advantages of the prevalence-based models are that they:

- Are conceptually simple and easy to understand
- Incorporate data that is available via surveillance systems

Disadvantages of prevalence-based models are that they:

- Are often based on empirical results, what makes them trustworthy in the current situation, but it is uncertain if the same relationship still holds under other circumstances
- Do not include the number, which is relevant for the public health effect (Table 1).

MODELS BASED ON PREVALENCE AND NUMBER

In an event model, one lists all the events that could have an effect on the occurrence of the hazard (nodes) and defines the probability that this event occurs and the extent of the effect (e.g. 1 log reduction). Oscar demonstrated the application of event models in the route from hatchery (1997a) and raw chicken (1998) to illness and in the slaughterhouse in relation to HACCP (1997b). Recently, he demonstrated how existing data and predictive models are used to define the input settings of an event model describing the retail-to-table pathway (2004).

It is also possible to follow the number of bacteria throughout the slaughter process, as is done for *Campylobacter* during chicken processing in multiple studies (Hartnett, 2001; Rosenquist et al., 2003; Nauta et al., 2005). The latter two studies show that redistribution processes occur during processing, e.g. the number on positive carcasses decreases during defeathering, but these contaminate uncontaminated carcasses with a low level contamination resulting in an increase in prevalence. The first two studies combined the slaughterhouse studies with models of consumer exposure and response and concluded that a reduction treatment at the end of processing (i.e. freezing) can be highly effective in reducing human illness. Note that in case of *Salmonella* this reduction should be a real decontamination step, because *Salmonella* is able to multiply at ambient temperatures in retail and homes.

A similar kind of assessment is done for the retail to consumption pathway by FAO/WHO (2002); the broiler farm and the slaughterhouse were not considered due to lack of data. The assessment showed that measures reducing the prevalence or number at the end of processing affect the human health risk: e.g. a 50% reduction in prevalence at the end of processing would result in a 50% reduction of risk. In the home environment, cross contamination seems to pose a larger risk as undercooking.

Advantages of the prevalence/number models are that they:

- Show the effect of interventions on the public health risk
- Make it possible to compare the effect of interventions that act on the prevalence and interventions that act on the number of *Salmonella*.

Disadvantages of the prevalence/number models are that they:

- Need a great amount of data, and often recent, representative data is lacking.
- Need a lot of time to develop
- Are sometimes very complex and detailed, which does not add to insight in the process

Discussion

The present paper has briefly discussed the *Salmonella* transmission in the broiler meat supply chain and the possible methods that can be used to identify reduction measures. Summarising can be said that qualitative or semi-quantitative assessment of the chain can already give indications about possible interventions strategies, but that quantitative assessments are useful to compare the effect of interventions at different places in the supply chain. General conclusion of the different quantitative models was that all stages in the chain are related and that prevention of contamination in early stages prevents amplification of problems/risk in later stages.

But where to go from here: considering the transmission route from broiler farm till consumer, where should measures be taken? Taking measures at the consumer stage is likely not to be effective in the short term, since cross-contamination possibilities are numerous and behaviour change of consumers
is a difficult, long term activity. It is thus better to prevent *Salmonella* from entering the consumer stage, for instance by application of decontamination at the end of processing. However, chemical decontamination reaches only a reduction of 1-2 log cycles, which might not be sufficient to eradicate *Salmonella* from the carcass. Mead (1991) stated that cross-contamination in the slaughterhouse cannot be prevented with current procedures and equipment, so also here applies that it is better to prevent *Salmonella* from entering the slaughterhouse process in the first place. This can be done by using new processing equipment that removes faeces from the chickens before the process starts or by interventions at the farm level attacking prevalence and concentration in the faeces. From viewpoint of effectiveness, the best intervention would be at the farm followed by new equipment or decontamination.

However, for the choice of a reduction measure not only the theoretical effectiveness is of importance. Other aspects also play a role, e.g.:

- **Compliance**
  Farm measures might be really effective, but if a percentage of farmers do not comply to these measures, will the effect on public health still be the same?

- **Feasibility**
  The risk is dependent on the prevalence and the number. Theoretically, it could be very effective to lower the prevalence at the farm, but from a practical point of view it might be more feasible to lower the number at the end of processing by decontamination.

- **Product quality**
  Decontamination might be really effective against *Salmonella*, but what if it affects the appearance of your product?

- **Costs**
  A measure might be very effective, but very expensive. This results in a safe, but expensive product, which may cause the consumer to switch to other products.

It can be concluded that microbial risk assessment can play a useful role in assessing the effect of compliance or to compare the effect of various measures. However, previous assessments were hampered by a lack of recent, representative data in the highly relevant farm and slaughterhouse stage. Future research should thus combine risk assessment models and data collection in order to make valid statements about *Salmonella* transmission in these stages. Furthermore, the aspects mentioned above should also be included in the analysis.

**References**


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