RESEARCH PROJECTS

A Review of Interventions in the Food Chain With the Potential to Reduce *Campylobacter* Levels in Chicken Meat

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FSA Research and Evidence

1. Background

The Food Standards Agency (FSA) is the UK government department responsible for protecting public health with regards to food safety. *Campylobacter* species, particularly *Campylobacter jejuni* and *Campylobacter coli*, are the leading cause of foodborne illness in the UK. Chicken is consistently identified as the most common vehicle of infection.

As part of the FSA's strategy to reduce human campylobacteriosis, industry-government coordination successfully reduced the proportion of highly contaminated birds (>1000 CFU/g neck skin) at retail by 17% to <7% over the period 2008-2015. Although this was predicted to result in up to 30% fewer cases of campylobacteriosis in humans (ACMSF, 2019), human campylobacteriosis cases did not noticeably decrease despite the target being met. This highlights the complexity of interventions against *Campylobacter*.

To consider possible further actions to reduce *Campylobacter* illness in the UK, the FSA undertook a project to collect and analyse information to answer the following question:

What interventions have been tested for reducing *Campylobacter* load in chicken meat and which have been found to be effective?

The question was answered in 6 workstreams:

1. An expert elicitation workshop with the aim to generate hypotheses on why campylobacteriosis cases have not reduced despite the successful efforts to reduce levels on highly contaminated carcasses.
2. Four systematic literature reviews covering interventions across the food chain stages as follows:

a. On the farm
b. At slaughterhouse
c. At cutting and processing plants
d. At retail, consumer, restaurant and catering level

3. A survey of Food Business Operators (FBOs) across the farm, slaughterhouse and retail sectors to understand the industry experience.

Results were reported as prevalence % for the farm report and as $\log_{10}$ reductions/unit for the other three reports. A reduction of one $\log_{10}$ is equivalent to 90% reduction, while a reduction of two $\log_{10}$ is equivalent to 99% reduction.

2. Key findings

2.1. Expert elicitation workshop

For this exercise, experts were invited to propose hypotheses to answer the question: "What are the most likely explanations for campylobacteriosis case numbers not following the trends seen with *Campylobacter* levels in chickens at retail?"

Participants identified 25 hypotheses, ranked them, and summarised the availability of evidence to investigate the eight hypotheses considered most promising.

The hypothesis ranked most likely to explain the observation was that a narrow focus on reducing the proportion of highly contaminated whole chickens had little effect due to the role of exposure via other routes. However, when also considering the evidence available for investigation, experts recommended exploring the hypothesis that an increase in exposure via imported poultry meat was responsible.

A number of the hypotheses identified in this workshop as feasible to investigate with available data are now the subject of internal analysis.

2.2. Farm

Approximately 60% of broilers are already *Campylobacter*-positive by time of slaughter. This report reviewed published evidence on factors that are associated with the introduction and spread of *Campylobacter* into broiler farms, grouping them into eight categories: animal-related; vertical transmission; water, feed and litter; environmental; equipment and

vehicle; external and regional; farm management and biosecurity; pests and wildlife. Epidemiological studies and genetic linkages explaining transmission pathways were assessed when available.

Overall, the group of factors considered to be most important was farm management and biosecurity. Although firm conclusions could not be drawn on which specific biosecurity interventions were most effective at reducing *Campylobacter* prevalence in broiler flocks, hygiene barriers and staff training were consistently mentioned as effective. The evidence for the relative importance of different sources of *Campylobacter* was mixed due to a lack of investigations into genetic linkage and directionality of spread between broiler farms and external *Campylobacter* sources. Transmission of *Campylobacter* during transport from the farm to the slaughterhouse was also identified as a risk factor. Vertical transmission and transmission via feed, water and litter were considered unlikely to be important risk factors.

Overall, this report highlighted the need for future studies on the sources of *Campylobacter* introduction into broiler houses to be large enough to draw robust conclusions and to adhere to community standards on design and reporting. Studies into genetic linkage and the directionality of spread, and the effectiveness of biosecurity and hygiene interventions in preventing colonisation of broilers by *Campylobacter*, are recommended.

2.3. Slaughterhouse

This report reviewed published evidence on the effect of slaughterhouse-level interventions on *Campylobacter* contamination on broiler carcases. It considered interventions across five processing stages: scalding, defeathering, evisceration, washing, and chilling.

Scalding was associated with some of the highest reductions in contamination; however, the effect varied based on scalding method. Hard scalding achieved the highest reductions of up to 1.85 $\log_{10}$ CFU/unit, whereas soft scalding achieved reductions up to 1.15 $\log_{10}$ CFU/unit. Scalding with additives showed the largest reductions overall, with reported reductions of 3.30 $\log_{10}$ CFU/unit. However, scalding conditions and parameters were often inconsistently described across studies, making it difficult to isolate the effect of specific scalding methods. Defeathering was associated with increased contamination, with reviews reporting increases in levels ranging from -0.88 to -1.65 $\log_{10}$. Evisceration also showed inconsistent effects: reductions ranged from -0.15 to 0.49 $\log_{10}$. These findings highlight scalding as a key control point, defeathering as a higher-risk stage requiring targeted interventions, and evisceration as an area needing further optimisation to ensure microbial control.

Washing and chilling were identified as critical control points, with their effectiveness strongly influenced by operational parameters such as temperature, duration, and the use of antimicrobial chemicals. While several chemical interventions demonstrated high antimicrobial efficacy, it is important to note that these substances are not approved for use in poultry processing within the United Kingdom. Their inclusion in this review reflects global practices.

Immersion chilling was found to be effective, particularly when combined with antimicrobial chemicals and extended exposure times. When storing the products, freezing was also found to be more effective than refrigeration. Crust freezing emerged as a promising alternative, achieving up to 2 $\log_{10}$ CFU/unit reduction while maintaining the product's "fresh" classification under assimilated EU Regulation (EC) 543/2008.

2.4. Cutting and processing plants

This report reviewed interventions to reduce *Campylobacter* levels in cutting and processing plant settings. It considered three intervention types: chemical treatments, non-chemical processes (other than chilling and freezing), and packaging technologies. Since chilling and freezing interventions are considered a relevant type of control in all food chain stages post-slaughter, relevant publications were considered in the retail, consumer and catering report below.

Chemical interventions – including organic acids, oxidising agents, and plant-based extracts – generally achieved reductions of 1–2 $\log_{10}$ CFU, with some outliers such as sorghum extract reporting up to 7 $\log_{10}$ CFU reduction. Combined treatments (e.g., eugenol with chitosan or pectin) also demonstrated promising results, although data on the efficacy of the individual compounds were not always reported.

In comparison, non-chemical interventions such as high-pressure processing (HPP) and ultrasound showed limited efficacy when used alone (<0.5 $\log_{10}$ reduction), but improved performance when combined with chemicals.

Packaging technologies, including modified atmosphere packaging (MAP) and vacuum packaging (VP), primarily extended shelf life rather than significantly reducing *Campylobacter* levels, while novel approaches like zinc oxide nanoparticle pads warrant further investigation.

Conclusions were limited by the high heterogeneity in study design parameters and inconsistent reporting of numerical data and statistical results, and a general absence of larger-scale pilot studies. Due to limitations such as small sample sizes, limited number of trials and interventions not conducted under real-world manufacturing conditions, further research is required before conclusions in this report can be

confidently generalised. Our findings also highlighted the importance of standardised protocols and reporting guidelines and large-scale validation of results obtained in small laboratory and pilot studies.

However, based on the evidence available, no single intervention can eliminate *Campylobacter* risk at the processing stage. A multi-barrier approach across the food chain therefore remains essential.

2.5. Retail, consumers, restaurant and catering

This report reviewed interventions to reduce *Campylobacter* levels at the retail, consumer, restaurant and catering stages. Cooking remains the most reliable intervention, particularly at temperatures above 70°C, which consistently eliminate *Campylobacter* within minutes. Lower temperatures (50–70 °C) showed mixed outcomes, and product structure (minced vs fillet) influenced heat penetration and microbial inactivation. Studies indicated some rapid declines to undetectable levels even when core temperatures were below 60 °C, but reliance on visual cues alone is unsafe.

Refrigeration and freezing offer reductions but are not sufficient as standalone interventions. Their effectiveness is influenced by storage duration and initial contamination levels, with freezing for more than 3 weeks offering consistently larger reductions in bacterial levels compared to chilling. The effects of refrigeration vary widely – for three days or less in particular, while longer periods of more than seven days may be impractical.

Consumer handling of raw chicken poses a significant risk of *Campylobacter* cross-contamination, with modelling studies predicting cross-contamination as the main pathway for campylobacteriosis (rather than undercooking). Observational studies reveal a gap between reported and actual hygiene behaviours, with proper handwashing (hot water and soap) inconsistently practiced. Short-term educational interventions improve behaviour temporarily, but sustained change may require a different approach such as early food safety education and continuous reinforcement through public health messaging. Modelling studies can guide prioritisation of interventions for risk reduction, but the predictions need validation with experimental studies.

2.6. FBO survey

This part of the study aimed to gather insights from food business operators (FBOs) on the perceived effectiveness of current *Campylobacter* control measures at each stage of the supply chain.

A qualitative survey approach was followed, involving three tailored questionnaires targeting farms, slaughterhouses, and retailers. The survey captured FBOs' opinions based on their operational practices, without independently verifying the efficacy of reported interventions.

It was evident throughout that industry stakeholders are continuously trying to improve standards across the supply chain, by trialling new protocols and technologies, and communicating and collaborating on a regular basis. Findings also revealed a disconnect between sectors: farms often viewed interventions as ineffective and expressed frustration over limited outcomes, while downstream stakeholders emphasized the importance of farm-level controls. Slaughterhouses and retailers reported proactive measures such as audits, sourcing policies, and routine testing, with interventions like neck skin removal and temperature control seen as effective.

Despite progress, several knowledge gaps persist. These include uncertainties, as highlighted by the FBOs, such as around the effectiveness of farm-level interventions. Seasonal variation and consumer behaviour also remain critical but poorly understood factors. The study participants highlighted the need for improved communication across the supply chain, renewed collaboration—including smaller retailers and food service providers—and continued research to inform evidence-based policy and enhance *Campylobacter* control efforts.

3. Conclusions

All studies concluded that interventions against *Campylobacter* are complex and that no single intervention is likely to represent a "silver bullet"; instead, controls and monitoring across all stages of production are required.

A common theme across these reviews was that published studies of interventions are often underpowered, variable in design, not reflective of real-world conditions, and/or do not publish raw data which therefore limited the robustness of conclusions in our analysis. Further formal meta-analysis is recommended to draw robust conclusions about the relative effectiveness of interventions. Other improvements could include open access to data, the development of community standards for reporting, and larger-scale trials under real-world conditions through research partnerships with farmers, industry and retailers. A technology readiness assessment (TRA) exercise to identify the maturity of intervention technologies might help to structure research in the area.

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