# Literature review

Numerous studies in the literature have highlighted the occupational risks of extended-spectrum β-lactamase (ESBL) transmission among professionals working in pig farms, slaughterhouses or poultry abattoirs. A ‘top-down’ source attribution study by Mughini-Gras et al. (2019) analyzed the community-acquired ESBL-EC and pAmpC-EC in the Netherlands during 2005-2017 revealing 1,220 occurrences in humans and 6,275 in non-human sources, mainly farm animals and food.

**Evidence of occupational exposure:** Several studies were found that provide evidence of the occupational exposure of farm and slaughterhouse workers to antimicrobial-resistant bacteria. Most of these studies were based on fecal sample analysis and detailed questionnaires to assess personal and occupational exposure. Oguttu et al. (2008) investigated antimicrobial resistance in Escherichia coli from broilers and poultry abattoir workers. The study found high resistance levels in broilers, particularly to antimicrobials used on farms, and higher resistance levels in abattoir workers compared to controls. Dohmen et al. (2015) examined the prevalence of ESBL-producing Enterobacteriaceae in pig farmers and found a 6% carriage rate in humans, showing that ESBL genes in human isolates were often identical to those found in pigs. This established a strong link between the number of hours spent working on the farm and ESBL carriage, reinforcing the role of occupational exposure in AMR transmission. Later Dohmen et al. (2017) investigated the prevalence of ESBL carriage in pig slaughterhouse workers, finding a 4.8% prevalence rate among 334 workers and they identified specific job tasks, such as removing animal organs, as associated with higher ESBL carriage rates. This suggests that direct contact with animal products significantly increases the risk of ESBL transmission. These findings indicated a substantial association between job exposure and ESBL carriage, with higher prevalence in tasks involving direct animal contact compared to roles like refrigeration and packaging. Another study by Van Gompel et al. (2020) used shotgun metagenomics to analyze the fecal resistomes and microbiomes of pig and poultry farmers, slaughterhouse workers, and controls. It found higher ARG abundances in pig farmers and slaughterhouse workers compared to broiler farmers and controls. Differences in resistome and microbiome composition were observed based on occupational exposure, with significant correlations between on-farm working hours and ARG carriage.

**Air-bone transmission:** The possibility of airborne transmission of ESBL was explored by Dohmen et al. (2017). The study involved 131 individuals from 32 pig farms, analyzing stool, pig rectal swabs, and dust samples. Results showed a significant presence of CTX-M-group 1 ESBL in both human and dust samples, suggesting that inhalation of contaminated air could be an additional transmission route. This study highlighted that occupational exposure to airborne dust in pig farms could contribute to ESBL carriage in humans. Luiken et al. (2020) provided insights into the resistomes and bacterial microbiomes of farm dust from 35 broiler and 44 pig farms. The study used shotgun metagenomic analysis to reveal a rich variety of antimicrobial resistance genes (ARGs) in farm dust, more extensive than in animal feces. It demonstrated that farm dust resistomes were significantly associated with animal feces resistomes and influenced by antimicrobial usage on farms. This study suggests that dust is a critical vector for ARG transmission, posing risks to both animals and humans.

**Hygiene and biosecurity practices:** Several studies have assessed various hygiene and biosecurity protocols implemented in farms and slaughterhouses. The study by Franceschini et al. (2019) specifically evaluated turkey farmers' exposure to antimicrobial-resistant (AMR) bacteria to rank farm practices in Northern Italy. Through a literature review and interviews with veterinarians, the study identified high-risk practices, such as direct contact during vaccination and litter management, which elevate exposure to methicillin-resistant Staphylococcus aureus (MRSA) and extended-spectrum beta-lactamase (ESBL).

**Exposure quantification:** Although many studies focus on assessing occupational exposure, a robust framework for rigorously quantifying the exposure and transmission of ESBL *E. coli* from broiler production is currently lacking. Opatowski et al. (2021) proposes a stochastic quantitative risk assessment model to quantify the impacts of environmental, animal, and human sources from a One-Health perspective. This is a much more generalized and macro-analysis framework that evaluates AMR colonization in humans from five sources: water, food, livestock contact, and interhuman contacts. Another recent work by Lu et al. (2024) proposes a One Health-based quantitative microbial risk assessment (QMRA) framework, that emphasizes more in micro-analysis of the occupational exposure in order to manage health risks associated with tetracycline-resistant Aeromonas hydrophila in aquaculture. A More topic specific work in the context of ESBL *E. coli* to poultry farm and slaughterhouse workers, is produced by De Freitas Costa et al. (2022), where they proposed a multidirectional dynamic risk model for ESBL-EC transmission among broiler flocks, broiler farmers, and the open community in the Netherlands. Their work was more focues on

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However, to the best of our knowledge, no quantitative risk assessment model has been proposed dedicated to the modeling of the exposure and transmission of ESBL  *E. coli* in a farm to fork framework, that performs a micro- analysis to model the evolution of the AMR bacteria starting from the broiler farms to the professionals and consumers.

Therefore, within the context of the JPIAMR project ENVIRE, we propose the first farm-to-fork foodborne and occupational QMRA model that quantifies the risk of colonization of ESBL *E. coli* from broiler chickens to broiler meat consumers and to poultry professionals with a direct contact exposure. The ultimate objective of this work is to integrate the newly proposed model to the One health framework to contribute to the reduction of the selection and the spread of antimicrobial resistant bacteria in broiler chickens and from chicken farms to the environment, and ultimately to humans.

# Price et al. (2007) - At the end of the grow-out period, chickens are captured by people called “catchers,” placed into cages, and transported to the slaughtering facilities. Once delivered to the slaughterhouse, the broilers are removed from the cages and shackled to semi-automated slaughter lines by people called “live hangers.” Thus, growing, catching, and hanging are the three tasks with the most intensive live-animal exposures. For example, a catcher will capture and cage thousands of chickens in a single workday ([Goodman 2006](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2137113/#b11-ehp0115-001738)).

# Racicot et al., (2013) - Assessing most practical and effective protocols to sanitize hands of poultry catching crew members. When hands were highly contaminated, the alcohol-based gel alone was less effective than the degreasing cream combined with the alcohol-based gel.

Youssef et al. (2020) - The effectiveness of biosecurity interventions in reducing the transmission of bacteria from livestock to humans at the farm level: A systematic literature review Two main types of biosecurity interventions in poultry farms:

(a) hand washing, sanitization and hygienic measures;

(b) personal protective equipment (PPE);

Ridley et al. (2011) - Enhanced biosecurity measures in poultry farms (Campylobacter):

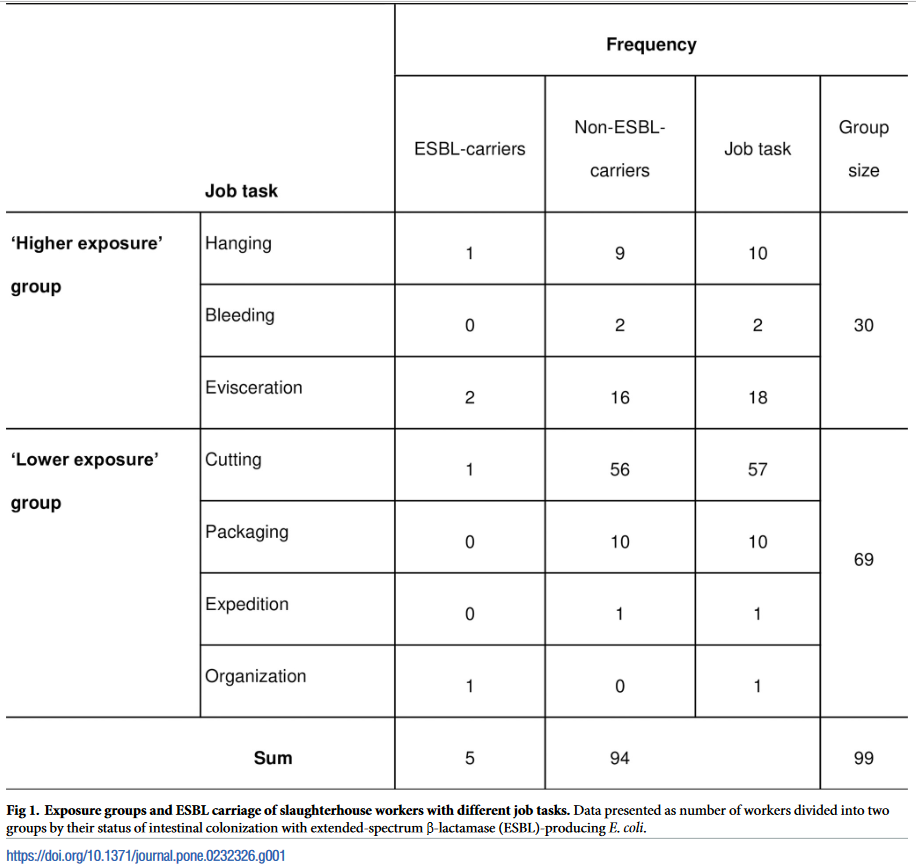
(a) Cleaning and disinfection

(b) Provision of a mobile mess ⁄ changing room for the catching crew

(c) A requirement for catchers to bring with them fresh clothing, dedicated footwear and any ancillary equipment, including face masks and gloves

Mo et al. (2016) – Norwagien poultry farm questionnaire on hygiene practices

# Wadepohl et al. (2020) Association of intestinal colonization of ESBL-producing *Enterobacteriaceae* in poultry slaughterhouse workers with occupational exposure—A German pilot study This study is the first of its kind to collect data on the occupational exposure of slaughter house workers to ESBL-producing Enterobacteriaceae in Europe.



Fastl et al. (2023) Animal sources of antimicrobial-resistant bacterial infections in humans: a systematic review. Review paper.

# De Freitas Costa (2022) Multidirectional dynamic model for the spread of extended-spectrum-β-lactamase-producing Escherichia coli in the Netherlands Risk of AMR colonization of Farmers from chickens using the probability of colonization from the below paper.

# Huijbers et al. (2014) Extended-spectrum and AmpC b-lactamase-producing Escherichia coli in broilers and people living and/or working on broiler farms: prevalence, risk factors and molecular characteristics Questionnaire sampling of farms to estimate the prevalence of different group of farmers/employees and study the relation of their respective exposure time/contact time to broilers.

# Adhikari et al. (2020) Quantitation of Risk Reduction of E. coli Transmission after Using Antimicrobial Hand Soap.

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Chen et al. (2001) Quantification and Variability Analysis of Bacterial Cross-Contamination Rates in Common Food Service Tasks Transfer rate from chicken to finger tips: the normal distributions in log percent transfer rate from chicken to hand (0.94 +- 0.68). These turns out to be lognormal parameters.

# Lopez et al. (2013) Transfer Efficiency of Bacteria and Viruses from Porous and Nonporous Fomites to Fingers under Different Relative Humidity Conditions Transfer rate form cutting board/knife to finger tips

Gibson et al. (2002) Quantitative assessment of risk reduction from hand washing with antibacterial soaps Transfer rate from finger tips to lips

Depoorter et al. (2012) Assessment of human exposure to 3rd generation cephalosporin resistant E. coli (CREC) through consumption of broiler meat in Belgium QMRA farm to fork, with meat to hand transfer rate from the following paper, assuming *Salmonella* and *E. coli* has same attaching properties

Montville et al. (2000) Glove barriers to bacterial cross-contamination between hands to food chicken to hand transfer rate (%) through gloves, gamma (5.91, 0.40, -5) and chicken to bare hand, normal (0.71, 0.42); for *Salmonella* substitute

Leonas et al. (2003) The Relationship of Fabric Properties and Bacterial Filtration Efficiency for Selected Surgical Face Masks Average over the 6 different Bacterial Filtration Efficiency (BFT) was used as the q\_mask parameter in the model

# King et al. (2020) Bacterial transfer to fingertips during sequential surface contacts with and without gloves Although previous studies have investigated the transfer efficiency of various microorganisms during a single contact from fomite to finger[18](https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12682#ina12682-bib-0018), [19](https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12682#ina12682-bib-0019), [23](https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12682#ina12682-bib-0023) and finger to fomite,[23](https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12682#ina12682-bib-0023)-[25](https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12682#ina12682-bib-0025) only a small number of studies have considered more than one surface contact.[21](https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12682#ina12682-bib-0021), [26](https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12682#ina12682-bib-0026) Repeated contact with a surface covered in fluorescent powder shows that skin became saturated after six contacts,[27](https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12682#ina12682-bib-0027) while a separate study using fluorescent particles found an equilibrium after five contacts.

Julian et al. (2009) A Model of Exposure to Rotavirus from Nondietary Ingestion Iterated by Simulated Intermittent Contacts stochastic-mechanistic model of exposure to rotavirus from nondietary ingestion iterated by simulated intermittent fomes-mouth, hand-mouth, and hand-fomes contacts typical of a child.   
The transfer is assumed to occur instantaneously and uniformly, and the duration of contact is assumed to not affect transfer. The latter is based on the work of Cohen-Hubal et al., who found that duration does not increase the amount of both lipophilic uvitex and nonlipophilic riboflavin tracer residues transferred between surfaces on contact.(25) It is assumed that, after transfer, virus is distributed evenly over the en tire surface.

### [An Examination of Broiler Growth](https://getd.libs.uga.edu/pdfs/morris_jonathan_a_201505_ms.pdf) gives the constant for the Meeh’s formula used to compute the broilers surface area from its weight.

Explanation of ECDF at hanging stage:

For hanging stage we use the foodborne module output C\_prod as the concentration on the birds. The sudden peak is due to very low sd for the negatve flocks.