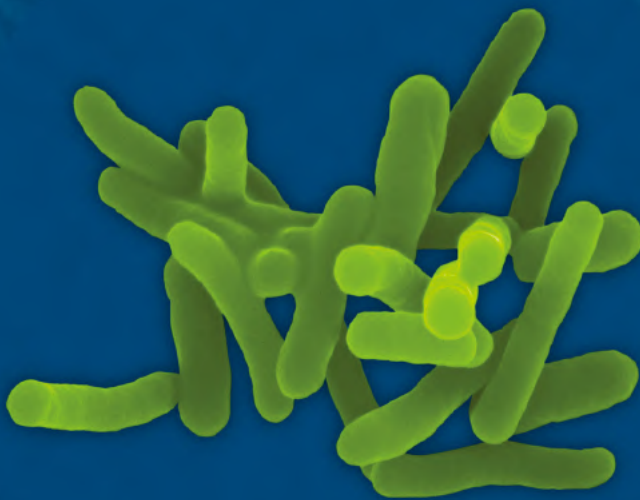




Measures for the control of non-typhoidal *Salmonella* spp. in poultry meat

Meeting report



45

MICROBIOLOGICAL RISK
ASSESSMENT SERIES

Measures for the control of non-typhoidal *Salmonella* spp. in poultry meat

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Required citation:

FAO & WHO. 2023. *Measures for the control of non-typhoidal Salmonella spp. in poultry meat – Meeting report*. Microbiological Risk Assessment Series, No. 45. Rome. <https://doi.org/10.4060/cc9026en>

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ISSN 1726-5274 [Print]

ISSN 1728-0605 [Online]

ISBN 978-92-5-138447-3 [FAO]

ISBN 978-92-4-007882-6 (electronic version) [WHO]

ISBN 978-92-4-007881-9 (print version) [WHO]

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Acknowledgements

The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) would like to express their appreciation to all those who contributed to the preparation of this report through the provision of their time and expertise, data and other relevant information before, during and after the meeting. Special appreciation is extended to all the members of the expert committee for their dedication to this project, to Dr Catherine M. Logue for her expert chairing of the committee and to Dr Marianne Chemaly for her excellent support as Rapporteur. All contributors are listed in the following page.

Appreciation is also extended to all those who responded to the calls for data that were issued by FAO and WHO.

The preparatory work and expert meeting convened to prepare this report was coordinated by the Secretariat of the Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment (JEMRA).

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Declaration of interest

All participants completed a Declaration of Interest in advance of the meeting. Two of the experts declared interest in the topic under consideration: Stan Bailey declared significant interest connected with his employment and James Dickson declared a closely related consultancy work. It could not be excluded that the declared interests might be perceived as potential conflicts of interest. Therefore, while the two persons mentioned above were invited to the meeting, they participated as technical resource people only and were excluded from the decision-making process regarding final recommendations. All remaining experts were not considered by FAO and WHO to have declared any interest that might be perceived as a potential conflict of interest with regard of the objectives to the meeting.

All the declarations, together with any updates, were made known and available to all the participants at the beginning of the meeting.

All the experts participated in their individual capacities and not as representatives of their countries, governments or organizations.

Abbreviations

ACP	atmospheric cold plasma
AMR	antimicrobial resistance
C&D	cleaning and disinfection
DR	dose response
FAO	Food and Agriculture Organization of the United Nations
GA	gallic acid
GHP	good hygiene practices
JEMRA	Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment
LA	lactic acid
MDR SH	Multidrug-resistant <i>Salmonella</i> Heidelberg
MIA	medically important antimicrobial
NT- <i>Salmonella</i>	non-typhoidal <i>Salmonella</i>
PSC	photosensitizer curcumin
QMRA	quantitative microbial risk assessment
SCFA	short-chain fatty acid
SD	standard dose
SDS	sodium dodecyl sulphate
SE	<i>Salmonella</i> enterica ser. Enteritidis
ST	<i>Salmonella</i> enterica ser. Typhimurium
WHO	World Health Organization
WOAH	World Organisation for Animal Health

Executive summary

Scope and objectives

In response to a request from the 52nd Session of the Codex Committee on Food Hygiene (CCFH), the FAO/WHO Joint Expert Meetings on Microbiological Risk Assessment (JEMRA) convened a meeting in Geneva, Switzerland from 12 to 16 September 2022, to collate and assess the most recent scientific information relating to the control of non-typhoidal (NT)-*Salmonella* spp. in chicken meat, including a review of the Codex *Guidelines for the Control of Campylobacter and Salmonella in Chicken Meat* (CXG 78-2011).¹ The group of subject matter experts reviewed the available data on NT *Salmonella* spp. control in the broiler production chain, including scientific literature published since 2008 and data submitted in response to a call for data for this meeting. The experts: 1) determined the extent to which various control measures, good hygiene practices (GHPs) or hazard-based control measures (targeted to reduce NT-*Salmonella* spp.), provided adequate evidence for assessing their efficacy; 2) evaluated the impact or efficacy of control measures relevant to NT-*Salmonella* spp. in the broiler production chain, noting the variability of the impact reviewed and recommended revisions to the *Guidelines for the Control of Campylobacter and Salmonella in Chicken Meat* (CXG 78-2011), Paragraphs 1 to 114, based on the evidence currently available (Annex 3).

Based on evaluation criteria such as the number, quality, applicability and representativeness of reports and research on a particular intervention available for screening, many control measures lacked sufficient evidence to allow the experts to assess their effectiveness.

Conclusions

The expert consultation noted that no single control measure was sufficiently effective in reducing either the prevalence or the level of contamination of broilers and poultry meat with NT-*Salmonella* spp. Instead, it was emphasized that control strategies based on multiple intervention steps (multiple or multi-hurdle) would have the greatest impact on controlling NT-*Salmonella* spp. in the broiler

1 https://www.fao.org/fao-who-codexalimentarius/sh-proxy/de/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252Fstandards%252FCXG%2B78-2011%252FCXG_078e.pdf

production chain.

The expert consultation concluded the following:

Primary production interventions for the control of NT-*Salmonella* spp.

Biosecurity and management approaches for the control of NT-*Salmonella* spp.

- At all levels of farm production, stringent biosecurity measures including sanitation and hygiene are important factors for preventing and controlling NT-*Salmonella* spp. in flocks.
- It is important for breeding flocks to be NT-*Salmonella*-free, and this begins at the parent/grandparent flock level and in the production environment.

Vaccination-based approaches for the control of NT-*Salmonella* spp.

- Vaccine-based strategies reduce the prevalence and/or level of shedding of NT-*Salmonella* spp. in flocks but do not eliminate NT-*Salmonella* spp.

Antimicrobial approaches for the control of NT-*Salmonella* spp.

- There was no strong evidence that the use of substances with antimicrobial activity, such as additives in feed and water, resulted in effective control of NT-*Salmonella* spp. in broilers.

Competitive exclusion/probiotic approaches for the control of NT-*Salmonella* spp.

- A promising strategy for NT-*Salmonella* spp. control was a combination of different competitive exclusion products (e.g. probiotics and prebiotics), but there was a limited number of published studies using naturally contaminated chicks and/or under commercial conditions to allow adequate conclusions to be drawn.

Feed and water characteristics and management approaches for the control of NT-*Salmonella* spp.

- The efficacy of specific feed- and water-based strategies were study-specific and dependent upon the physiological status of both the pathogen and the animal, the broiler gastrointestinal tract environment, the concentration of the additive, and the method for its application.
- The use of feed modifications, including the acidification of feed and water, are not stand-alone hazard-based control measures for the control of NT-*Salmonella* spp. in poultry. However, feed-based strategies, when used in conjunction with good hygiene practices, may further reduce

NT-*Salmonella* spp. in poultry.

- Based on the information available, further studies are needed to assess how extensive scale application of modified feed and management approaches could impact NT-*Salmonella* spp. levels

Bacteriophage-based approaches for the control of NT-*Salmonella* spp.

- There is limited information as to the effectiveness of bacteriophage-based control of NT-*Salmonella* spp. at the farm level. Further research is needed, especially on the long-term efficacy of bacteriophage-based control.

Processing interventions for the control of NT-*Salmonella* spp.

- Good hygienic practices are important in minimizing the risk of NT-*Salmonella* spp. contamination during slaughter and processing.
- The effect of processing interventions on NT-*Salmonella* spp. is influenced by a variety of conditions, including but not limited to the characteristics of the NT-*Salmonella* strain, pH, agent concentration, temperature, contact time, absorbed dose, product characteristics, and processing parameters.
- There was extensive information on the use of water additives, but the current scientific literature is not sufficient to draw objective conclusions regarding the effectiveness of some of them. However, chlorine-based compounds and organic acids (lactic acid, peracetic acid (PAA), and acidified chlorate solutions) showed potential effectiveness.
- High pressure processing may be effective in reducing NT-*Salmonella* spp. in poultry meat.
- An extensive body of scientific evidence suggested that ionizing radiation can achieve any level of NT-*Salmonella* spp. reduction from pasteurization to complete sterility.
- Other interventions or combinations of interventions, including but not limited to novel additives, thermal processes and physical treatments applied to the meat, still require further refinement.

Post-processing interventions for the control of NT-*Salmonella* spp.

- Control measures applied during processing may extend shelf-life and control the growth of NT-*Salmonella* spp. at the retail or consumer level; however, the literature in this area is sparse and the application of post-processing interventions needs further examination to assess its feasibility.
- Emphasis should be placed on encouraging a positive food safety culture through human behaviour and consumer education as it applies to transport,

storage, handling and cooking practices.

The experts highlighted several paragraphs in the *Guidelines for the Control of Campylobacter and Salmonella in Chicken Meat* (CXG 78-2011) that could benefit from an update (Annex 2).

Other factors considered by the expert panel that have the potential to impact NT-*Salmonella* spp. control strategies in the future included changes in climate, human behaviour and awareness, and interactions between pathogens and their hosts; innovations in the broiler value chain; and improvements in food safety culture. With the advent of next generation technologies and methodologies, including machine learning, omics, tools for traceability and a better understanding of the interactions between *Salmonella* and the microbiome circulating in food systems will lead to more accurate quantitative microbial risk assessments (QMRA) and improved One Health.



Introduction

1.1 REQUEST FROM CODEX

Salmonellosis and campylobacteriosis are among the most frequently reported foodborne diseases worldwide (EFSA and ECDC, 2021; Havelaar *et al.*, 2015; Tack *et al.*, 2019). In response to the requests from Codex for scientific advice, FAO and WHO have undertaken a risk assessment of foodborne pathogens in several foods since 1999 (FAO and WHO, 1999). The Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment (JEMRA) has previously evaluated *Salmonella* spp. in eggs and broiler chickens (FAO and WHO, 2002a, 2002b), powdered infant formula (FAO and WHO, 2006a), chicken meat (FAO and WHO, 2009a), bivalve molluscs, and beef and pork (FAO and WHO, 2016), to inform risk assessments and recommend effective interventions for the control of this foodborne pathogen. For *Campylobacter* spp., JEMRA has conducted risk assessments on broiler chickens (FAO and WHO, 2008, 2009b) and evaluated the intervention measures being used in the production of chicken meat (FAO and WHO, 2009a).

In its report on the global burden of foodborne disease, WHO estimated that in 2010, foodborne NT-*Salmonella enterica* caused more than 78 million cases of illness, 59 153 deaths, and nearly 4 068 000 Disability Adjusted Life Years (DALYs) (Havelaar *et al.*, 2015). While there are numerous potential vehicles of transmission, commercial poultry meat has been identified as one of the most important food vehicles for NT-*Salmonella* spp.

At its 52nd session in 2022, the Codex Committee on Food Hygiene (CCFH) requested that JEMRA collate relevant scientific information on *Salmonella* and *Campylobacter* in chicken meat in preparation for a potential update of the

existing Guidelines for the Control of *Campylobacter* and *Salmonella* in Chicken Meat (CXG 78-2011).

To meet the request of the CCFH, FAO and WHO convened this expert meeting on the pre- and post-harvest control of non-typhoidal *Salmonella* spp. in poultry meat, from 12 to 16 September 2022 at the WHO headquarters, Geneva. The goal of the meeting was to gather and evaluate recent data, evidence and scientific opinions on the topic.

1.2 CONSUMPTION AND PRODUCTION

1.2.1 Global consumption of poultry

According to FAO, the global poultry population was 27.9 billion head in 2019, with chickens accounting for 93 percent. The number of chickens worldwide has more than doubled since 1990, with poultry accounting for more than 40 percent of all meat produced (OECD and FAO, 2021).

The global consumption of meat protein is also projected to increase by 14 percent by 2030, the exceeding 2018–2020 projections, and the Agricultural Outlook 2021-2030 suggests that the global meat supply will continue to expand over the next projection period, reaching 374 million tonnes by 2030 (OECD and FAO, 2021). In addition, Africa produced a total of 5.7 million tonnes of chicken meat in 2018, an increase of 4.2 percent compared with 2017 (Poultry World, 2020). This expansion is driven by production in China, the Americas and Africa. China alone is expected to account for the greatest increase in meat production, followed by Brazil and the United States of America. Poultry protein availability is expected to grow by 17.8 percent due to its relative affordability for mid-income consumers who can afford a more diverse meat basket. International trade has also helped improve access to poultry worldwide with trade in Asia and the Middle East where demand has outpaced production.

Factors influencing meat consumption include population growth and demographics, urbanization, income, price, cultural norms, environmental aspects, animal welfare and health. Other reasons for growth in poultry as a commodity are explained by the maturity rate of birds, which is significantly shorter than other meat-producing animals, the ability to raise birds in small areas, which can help in raising the quality of life for lower income families, and the increased demand based on the population growth and income level. As the primary drivers are linked to population growth and income, the per capita meat consumption rates are expected to

continue to increase, including poultry consumption, reflecting the significant role it plays in the people's diet. As a result of the continued growth of the poultry market for the foreseeable future, it is necessary to review best practices in poultry production from hatching to final product to help ensure the safety and quality of this important protein for the world's population.

1.2.2 Intensification of production to meet growing needs

With a growing worldwide population, there is an increased need for animal protein. In many high-income countries, poultry production has been intensified by increasing farm and flock sizes, developing specific and rapidly growing chicken breeds, creating a global supply of parental stock, and investing in optimal feeding (Shaoting *et al.*, 2021; Jeni *et al.*, 2021). Typically, these commercial farms receive day-old chicks, raise them to maturity and transport them to an abattoir. In many low- and middle-income countries, small to medium-size enterprises, backyard farming and live-bird markets still dominate domestic poultry meat production (Delabougliise *et al.*, 2019; Wong *et al.*, 2017). These less intensive poultry production systems rarely apply strict biosecurity and good husbandry practices. Biosecurity is a challenge for the entire poultry production industry, but especially when birds are raised in backyard systems and sold at live-bird markets. Education and motivation of farmers in management and biosecurity are crucial for successful intensification.

In the commercial systems, market forces such as demand for organic products, animal welfare considerations, diversification of parental stock, and housing requirements need to be considered when designing *Salmonella* control strategies. Such control strategies should be designed, implemented and monitored taking into account the specific production conditions of the business operation.

1.3 SCOPE OF THIS REPORT

The purpose of this meeting was to collect, review and discuss relevant measures for control of non-typhoidal (NT) *Salmonella* spp. from primary production to consumption of poultry meat.

The scope of the meeting included, but was not limited to, aspects of primary production, processing, distribution, handling, preparation, retail and consumption of poultry meat. Emphasis was placed on the identification and evaluation of control measures to reduce salmonellosis associated with consumption of poultry meat, taking into consideration their effectiveness and practicalities.

The objectives of this meeting included:

- To review publicly available literature and guidelines provided by the competent authorities and industry associations (e.g. compliance guidelines, code of practices, etc.) to assess the current state of knowledge about controlling NT- *Salmonella* spp. in poultry meat.
- To review the mitigation/intervention measures being used at different points along the food chain and assess their effectiveness at reducing NT- *Salmonella* spp. in poultry meat.

1.4 LITERATURE SURVEY

A review of the available scientific literature targeting changes in knowledge since 2008 was used to develop a bibliography. Scientific articles were only selected from two databases (Web of Science and PubMed), yet, as there was a need to consider studies published in languages other than English, data from member countries and expert opinions were also relied upon.

The records from Web of Science (n = 5 695) were added into Distiller (n = 4 051), which contained the database of articles identified in PubMed. The function “Duplication Detection” was used by comparing the Title, Author and Abstract. A total of 1 948 duplicate articles were found. The “Smart Quarantine” feature in Distiller was used to remove these duplicates resulting in $5695+4051-1948 = 7798$ publications which were used to establish the database. The search was carried out on 1 June 2022. The keywords used for searching the literature are detailed in Annex 1.

The database was further refined using a two-step process for the relevance screening and confirmation of the 7 798 articles. After that, 1 402 publications were left for the experts to review. The detail of this procedure is included in Annex 2.

The experts made a further review of these 1 402 publications during the meeting, to reach a final decision on whether the literature contain control measures or not, and they provided the recommendation and conclusion based on these scientific publications and their expert opinion. The final reviewed papers are not necessarily cited, but are listed in the bibliography at the end of the report.

The experts relied on the following criteria to assess the articles found in the literature search: quality of evidence, measure of effectiveness, scalability and applicability, and geographical representation of the studies.

Quality of evidence: A limited number of controlled yet experimental studies meet the quality threshold. Few serotypes (predominantly *Salmonella* Enteritidis or Typhimurium) have been explored in the in-feed challenge studies evaluating the acidification effect on *Salmonella*.

The measure of effectiveness: Qualitatively, a reduction in *Salmonella* shedding based on feed acidification was very much study-specific and showed a wide range of variability ranging from 0 percent reduction in shedding up to 80 percent across selected experimental studies. Quantitatively, the impact of feed and water acidification on the recovery of *Salmonella* in poultry carcasses was not reported.

Scalability or applicability: Further studies are recommended for extensive scale application.

Geographical representation of the studies: The studies were represented by many world regions.



Control measures

2.1 CONTROL DURING PRIMARY PRODUCTION

2.1.1 Biosecurity and management approaches for the control of *Salmonella* spp.

The experts reviewed 63 papers and publications in the area of biosecurity and management and found 16 of them to be relevant. Biosecurity entails various measures to prevent birds from getting infected, beginning from breeder flocks (great grandparents, grandparents, and parents) (Cox and Pavic, 2010; Van Hoorebeke *et al.*, 2010). A previously infected flock on the poultry premises is a risk factor for consecutive flocks. A general biosecurity plan requires a thorough knowledge of the various routes of transmission. In the control of NT-*Salmonella* spp., and other microbes, biosecurity is the first line of defence. Chicks may acquire NT-*Salmonella* spp. through vertical transmission within the egg, from externally contaminated eggs or via horizontal transmission from pre-existing or resident contamination on the premises, including cross-contamination or via feed or water (Cox and Pavic, 2010, Volkova *et al.*, 2011).

At all levels of flock management, contact with any potential carriers, notably wild birds, rodents, insects (such as beetles and flies) and humans, should be minimized. Poultry houses must be designed to incorporate stringent biosecurity measures. A pest-control strategy needs to be established and regularly evaluated. Persons working or visiting poultry houses need to understand the importance of stringent biosecurity measures. For the breeding flock, measures such as change-in-change-out (farm or shed-based apparel) or even shower-in-shower-out

(shower prior to and post entry to the farm) may be needed (Cox and Pavic, 2010).

A review of the scientific evidence for broiler chickens with outdoor access and the occurrence of NT-*Salmonella* spp. is inconclusive; however, there is conclusive evidence that high stocking density, larger farms, thinning and stress of birds can result in the increased occurrence, persistence and spread of NT-*Salmonella* spp. in poultry flocks (Volkova *et al.*, 2011; Kloska *et al.*, 2017; EFSA Panel on Biological Hazards, 2019). Movement of employees and goods between houses of layers and broilers are also risk factors for NT-*Salmonella* spread (Volkova *et al.*, 2011; Kloska *et al.*, 2017; Greening *et al.*, 2020). Successful NT-*Salmonella* spp. control includes actions taken to strengthen biosecurity measures at the breeding flock level, such as culling *Salmonella* positive flocks, and vaccination. The success of on-farm biosecurity enhancement policies based on their voluntary adoption by farmers and in particular, financial incentives or penalties for farmers could be necessary to facilitate the adoption of biosecurity measures.

Effective cleaning and disinfection (C&D) protocols are essential and must involve critical locations in broiler houses such as drinking cups, drain holes and floor cracks (Luyckx *et al.*, 2015; Kloska *et al.*, 2017). C&D protocols consist of different steps starting from thorough manual removal of organic material (e.g. manure, feed, straw, bedding), prior to cleaning with water and overnight soaking of the broiler house with water. After cleaning and disinfection, there needs to be enough time for the poultry house to dry before a new flock is introduced. For this intervention, the experts weighed all the available information and concluded the following:

For breeders, it is pivotal that breeding flocks be *Salmonella*-free, and this begins at the parent/grandparent flock level. The best approaches to ensure high quality flocks and progeny should include continuous monitoring to ensure *Salmonella*-free breeders and parents (Namata *et al.*, 2009; Volkova *et al.*, 2011).

Implementing good hygiene practices (GHPs) at the hatchery may assist in decreasing the transmission of NT-*Salmonella* spp. to progeny and ultimately to the final product (Cox and Pavic, 2010).

Management on poultry farms: the experts considered that there was conflicting evidence regarding the use of outdoor access for flocks and its potential impact on the prevalence of NT-*Salmonella* spp. in broilers.

The experts also concluded that one of the most important risk factors for NT-*Salmonella* spp. in broiler houses that warrants consideration is external staff with access to the farm. Contaminated feed is also a potential source of NT-*Salmonella* spp. (Le Bouquin *et al.*, 2010).

The use of cleaning and disinfection were considered to be GHPs.

The experts also reviewed the use of economic incentives (from both a positive or negative perspective) as a means to enhance control of NT-*Salmonella* spp.. In particular, financial incentives or penalties for farmers could be useful in facilitating the adoption and maintenance of biosecurity measures.

2.1.2 Vaccination-based approaches for the control of NT-*Salmonella* spp.

The experts reviewed 16 publications on vaccination-based approaches for the control of NT-*Salmonella* spp..

Vaccine regimes and maternal antibody protection will ensure the health of poultry and decrease contamination of poultry products with foodborne pathogens. Vaccination against *S. Gallinarum* is common in some regions for targeting the eradication of systemic infection by this host-specific serovar. Vaccination against NT-*Salmonella* is largely limited to serovars *S. Enteritidis* (SE) and *S. Typhimurium* (ST). Both live (e.g. *aroA*-deficient) and killed vaccines have been developed and are employed in some regions (Groves *et al.*, 2021).

There are currently no commercially available inactivated vaccines against NT-*Salmonella* for oral administration. There are commercially available killed *Salmonella* vaccines for broilers and/or layers, and the administration route is an intramuscular injection (Neto *et al.*, 2008). Commercially available live vaccines for broilers, breeders or layers can be administered either via sprays or orally. Inactivated NT-*Salmonella* spp. vaccines are available for the control of several serovars, mainly SE and ST, in breeders and laying hens and they may help reduce the presence of *Salmonella* in birds and in eggs; however, the results vary in terms of efficacy.

Attenuated live vaccines may also offer a competitive exclusion effect and tend to better stimulate the cell-mediated immune system; however, a combination vaccine, using attenuated and killed *Salmonella* serovars, which stimulated both cell-mediated and humoral immune systems, may result in higher protection rates than vaccinations based on only one strategy. In addition, live vaccines may show cross-protection against other serovars than those included in their formulation (Bearson *et al.*, 2019; Eeckhaut *et al.*, 2018; Crouch *et al.*, 2020). Low *Salmonella* prevalence in broiler chicks can occur due to protection acquired from vaccinated breeders. Farms populated with chicks from vaccinated breeders tend to have fewer environmental samples containing *Salmonella* (Armwood *et al.*, 2019; Dórea *et al.*, 2010).

For this intervention, the experts weighed all the available information and concluded the following:

The experts concluded from the evidence that vaccine-based strategies can reduce the prevalence and the level of shedding of NT-*Salmonella* spp. in birds but cannot necessarily eliminate the pathogen from flocks and farms.

Thus, vaccination is considered a useful aid in addition to other control measures such as biosecurity and farm hygiene. Most vaccine studies target serovars Enteritidis and/or Typhimurium. There was limited evidence as to cross-protection against other serovars due to a limited number of studies on multiple serovars or serogroups. In addition, the available commercial vaccines primarily target the two abovementioned serovars, but various subunit-based vaccines with promising results in controlled trials are being developed.

Vaccination of breeders (grandparents or parents) against NT-*Salmonella* serovars may be useful in lowering the risk of vertical transmission of invasive serovars (or strains) as well as in reducing shedding. The vaccine studies were typically done on breeders, although some studies have investigated broilers. Vaccination of broilers is not common in many countries, and it may be linked to the short lifespan of the bird, and to the costs of the vaccine. Another issue of concern is the timing of vaccination in order to avoid its potential entry into processing, where it could result in false positive results for the flock (WOAH, 2022b, 2022c; Desin *et al.*, 2013).

2.1.3 Antimicrobial-based approaches for the control of NT-*Salmonella* spp.

The experts reviewed 42 papers, including 5 reviews, from 397 publications retrieved pertaining to the use of antimicrobial-based control of NT-*Salmonella* spp.

According to WHO, antimicrobials are medicines used to prevent and treat infections in humans, animals and plants. They include antibiotics, antivirals, antifungals and antiparasitic agents (WHO, 2021). For the purposes of this report, the term “antimicrobial” has been expanded in order to include other agents not considered as medicine but rather as agents that can control or inhibit NT-*Salmonella* spp. or other such pathogens.

However, antimicrobials for the control of NT-*Salmonella* spp. in poultry described in the literature include a wide group of molecules. Most of the papers refer to botanicals, also known as phytobiotics. Moreover, there are papers describing the effects of short-chain fatty acids (SCFAs) and antimicrobial peptides.

Among phytobiotics, essential oils are the most investigated, due to their antimicrobial and growth promotion properties. However, results on the precise mechanisms of the antimicrobial action of phytobiotics as well as the physiological impact of these active compounds on animal performance are limited. The plant extracts which are effective against pathogenic bacteria such as NT-*Salmonella* spp. include oregano (carvacrol), thyme (thymol), clove (eugenol), mustard (allyl isothiocyanate), cinnamon (cinnamaldehyde), and garlic (allicin) (Venkitanarayanan *et al.*, 2013; Al-Mnaser *et al.*, 2022; El-Saadony *et al.*, 2022; Diaz-Sanchez *et al.*, 2015).

SCFAs include acetic, propionic, and butyric acids. They are produced by the normal anaerobic intestinal flora as end products of metabolism and have both bacteriostatic and bactericidal effects on Gram-negative bacteria, including NT-*Salmonella* spp. (El-Saadony *et al.*, 2022).

Antimicrobial peptides, represented by small molecules with a molecular mass of 1 to 5 kDa, are also described in the literature because of their effect on NT-*Salmonella* spp. caused by interacting with the negatively charged membrane of the pathogen (Vandeplas *et al.*, 2010).

The experts weighed the available information concerning the use of antimicrobials (not including antibiotics) and concluded that there was no strong evidence regarding the use of any products tested as efficient interventions to control NT-*Salmonella* spp. in broilers.

Should antibiotics be used?

Over the years, the way animals are raised for food, including the increased global demand for poultry-sourced products, has resulted in more efficient production practices. In tandem, these practices have resulted in greater volumes of antibiotics being used to maintain food animal health in intensively reared poultry, pigs, feedlot cattle and dairy cows. The emergence of antimicrobial resistance (AMR) as a major threat to human health and the dramatic social and economic consequences of the spread of AMR have triggered the re-evaluation of antimicrobial usage and led to a call for action on the part of multiple countries to reduce the emergence and spread of AMR.

Many countries have already taken action to reduce use, increase stewardship and oversight and ban drugs that are used in human healthcare. Poultry producers have come under similar pressure to reduce on-the-farm use in alignment with consumer and industry pressure. However, antimicrobial resistant *Salmonella* and *Campylobacter* strains continue to persist. Studies have found a greater diversity in the gene families involved in the degradation of starch, cellulose, and

hemicellulose in chickens that did not receive antibiotic supplements compared with those that did (Clavijo and Flórez, 2018) This supports the hypothesis that antibiotic use can lead to negative effects on chickens' health by disrupting the commensal microbiota of the gastrointestinal tract. The progressive increase in the number of multi-drug resistant bacteria and the complete ban on the use of antibiotics in livestock feed in the European Union, as well as the partial ban in the United States of America, have led to the growth of research on the use of alternative antimicrobial agents to combat bacterial infections in poultry (Moyane *et al.*, 2013; AccessScience, 2017; More, 2020; Pinto Ferreira *et al.*, 2022; WOA, 2022a).

Consequently, multiple countries have adopted practices for prudent and responsible stewardship in the therapeutic use of all antimicrobials and for the phasing out of antimicrobials, particularly those important for human medicine and for growth promotion in food animals. Examples of prudent and responsible stewardship of antimicrobials are included in the World Organisation for Animal Health (WOAH) documents as a frame of reference.

Current status on practices regarding the use of antibiotics as growth promoters in different countries

Australia: Five antibiotics not currently used in human medicine can be used as growth promoters for poultry, pigs, cattle, and sheep, while those that are used in human medicine are not licensed for use as animal growth promoters.

Canada: The use of growth promotion claims on medically important antimicrobials (MIAs) is no longer permitted. Ionophore and coccidiostat product use has changed in some regions, while in others they are not considered as MIAs.

China: All antibiotic growth promoters except herbal medicine have been banned.

European Union: The use of antibiotics for preventative measures is illegal across Europe and regulations to ban the importation of meat and dairy goods produced using antibiotic growth promoters are pending.

New Zealand: No banning claim has been found. If antibiotics are used in food-producing animals, the regulator must also be satisfied that the antibiotic will not leave residues above the maximum residue level in food from treated animals.

United States of America: Medically important antimicrobials are banned; however, bacitracin and carbadox, which are classified as medically important by the WHO, are still used as growth promoters.

Africa: In many African countries, antibiotics can be purchased over the counter, and in some areas, the law does not ban farmers from using antibiotics as growth

promoters. Although antimicrobials may be used for the treatment of diseases that do not target *Salmonella*, there are inherent risks of antimicrobial resistance emergence and selection of the pathogen. Therefore, the use of antimicrobials should not be considered a food safety recommendation (Wernicki *et al.*, 2017; Clavijo *et al.*, 2022; Hashem and Parveen, 2016; Rahman *et al.*, 2022; Van *et al.*, 2020; Van den Hornert *et al.*, 2018; Wen *et al.*, 2022; Plata *et al.*, 2022; USDA, 2012).

Where antimicrobials are used in poultry production, the guidance from WOAHT Terrestrial Aquatic Animal Health is recommended.

2.1.4 Bacteriophage-based approaches for the control of *Salmonella* spp. in live birds

The experts reviewed 14 publications in the area of bacterial viruses (bacteriophages) for the control of NT-*Salmonella* spp. For this intervention, the experts weighed all the available information and concluded the following.

Most available studies have focused on a limited number of serovars. The efficacy of these bacteriophages needs evaluation across several serovars to assess their true efficacy. There were no longitudinal studies available for bacteriophages, thereby limiting knowledge as to their long-term effectiveness or subsequent impact.

Bacteriophages are often strain-specific in their target thereby limiting their effectiveness against a diversity of NT-*Salmonella* spp.

Bacteriophages can be classified antimicrobial agents because of their natural ability to control specific bacteria by lysing cells.

Experimental studies have demonstrated that phage cocktails can reduce *Salmonella* counts in drinking water, on shavings, and on plastic surfaces on poultry farms (Evran *et al.*, 2022), while other studies, some using successive dosing regimens, have demonstrated reductions in *Salmonella* colonization of the poultry gut or flock level reductions and have typically targeted SE or ST (Adhikari *et al.*, 2017; Borie *et al.*, 2008).

Bacteriophages may be very effective in the elimination of specific *Salmonella* serovars and strains under specific conditions; however, based on the available peer-reviewed scientific literature, it could not be concluded whether bacteriophages can protect against NT-*Salmonella* spp., as the efficacy of bacteriophages varies according to factors such as the environment, the type of bacteriophage and how it is applied.

While bacteriophages may provide an effective alternative to antibiotics in the

future, concerns remain, as there is insufficient or limited data from studies with respect to bacteriophages' stability and effectiveness, genotoxicity, oral toxicity, exposure of users via inhalation, irritancy to eyes and skin, safety for the environment and field efficacy.

The experts also noted that few studies were carried out at the farm level, thereby limiting further comment as to their effectiveness as a control agent. The experts commented, based on their own experience, that resistance to bacteriophages can develop relatively fast and that a *Salmonella* control-based approach may only have transient effects.

In conclusion, the experts considered that there is still limited information as to the effectiveness of bacteriophage-based control for NT-*Salmonella* spp. and further research is needed.

2.1.5 Exploitation of the microbiome of the chick and of the environment

Competitive exclusion/probiotic approaches for the control of NT-*Salmonella* spp.

The experts screened 170 publications, including 8 reviews on the use of competitive exclusion and probiotics for the control of NT-*Salmonella* spp. There were many studies addressing the impact of probiotics (e.g. lactic acid bacteria, alone or in combination with other bacteria, *Bacillus* spp., primarily *B. subtilis*, yeasts, primarily *Saccharomyces*) and prebiotics (e.g. fermented sugars) on *Salmonella* control in broilers. A few papers were found that address synbiotics and phytobiotics (e.g. plant extracts). Most of the studies reviewed consisted of *in vivo* trials to test the effect of products added primarily to feed, with the animal challenge using either SE or ST.

The impact of the control measures was assessed according to the following criteria: (a) no effect, (b) reduction of the prevalence of NT-*Salmonella* spp. and/or (c) reduction of the concentration of *Salmonella* spp. in the caeca or other organs.

The studies reviewed a wide geographic range of countries.

The experts concluded that the most promising strategy for NT-*Salmonella* spp. control was a combination of multiple control measures (e.g. probiotics and prebiotics, probiotics and vaccination of parent flocks).

The experts also concluded the following:

- Studies with naturally contaminated chicks and/or under commercial conditions are scarce.

- The experts noted that there are only a few studies using novel control measures to prevent colonization or to reduce NT-*Salmonella* spp. prevalence or load in chicks, but the variability among the studies did not allow adequate conclusions to be drawn as to their potential as an intervention to control NT-*Salmonella* spp. in broilers.

Effects of the litter (environmental) microbiome

Fresh vs reused litter. While the reuse of litter is common in some poultry operations, it also comes with its own challenges – some growers prefer reuse, as the litter itself houses its own unique microbiome that contributes to the health of a bird. The application of control/ treatment strategies for litter reuse varies (poultry litter treatment (PLT), acidification, heat, etc.) (Cox and Pavic, 2010). At the same time, reused litter may pose a risk for bacterial pathogens, including NT-*Salmonella* spp. (Cox and Pavic, 2010). The type of litter may also impact its microbiome.

In addition, fresh and reused litter were found to affect the composition of the gut microbiome in broiler chickens differently, especially at an early age. The microbiome of reused litter may serve as a competitive exclusion culture (Cox and Pavic, 2010). Oladeinde *et al.*, (2022) found that reused litter can limit the horizontal gene transfer associated with antimicrobial resistance and may harbour beneficial organisms associated with biosynthesis of organic and antimicrobial molecules. The microbiological risk associated with recycled litter is dependent on the efficacy of the management system applied to inactivate residual microorganisms and to preserve the health of successive broiler flocks.

The use of probiotic-based cleaning products for the microbial decontamination of reused litter warrants further investigation. Preliminary results suggest that probiotic interventions on the litter improve broilers' caeca stability, thereby enhancing animal health and preventing the shedding of foodborne pathogens such as NT-*Salmonella* spp. (Clavijo and Flórez, 2018).

Litter management also has an impact beyond bird health and has the potential to impact the environment; in contrast, litter reuse has the potential to reduce some of that environmental impact.

Microbiome on competitive exclusion

There is a need to move to a holistic approach to fight NT-*Salmonella* spp. in the poultry food chain, identifying control measures promoting the circulation of positive microbiomes that are able to prevent pathogen colonization and spread both in the poultry houses (i.e. in the chicken gut, and in the environment, e.g. in the air, feed, drinking water, litter, etc.) and at the slaughterhouse (e.g. in the

air, water, food contact surfaces, etc.). The dynamics of interaction between the microbiomes circulating in the poultry food chain and NT-*Salmonella* spp. can be investigated using metagenomic sequencing approaches; however, more data are needed to understand the impact of different interventions on the microbiome, as are better reference databases for analysing sequencing outputs to accurately identify any key organisms present.

A better understanding of the interactions between NT-*Salmonella* spp. and the gut microbiome may help to improve the design of competitive exclusion-based control measures (either defined or undefined microflora), prebiotics, tailor-made probiotics, etc.

There should be a specific focus on the interactions between NT-*Salmonella* spp. and *Campylobacter* spp. in the future in order to identify new control measures for targeting the outcomes of the interactions.

Longitudinal studies are needed to assess the efficacy of each control measure from the farm to the fork.

2.1.6 Feed and water acidification approaches for the control of NT-*Salmonella* spp.

The experts reviewed 27 publications in the area of feed and water acidification-based approaches for the control of NT-*Salmonella* spp. in chickens. Lowering feed and water pH through acidification can affect poultry intestinal health in multiple ways. Studies report improvements in the digestibility and hygienic quality of feed, overall gut health of chickens, and intestinal microbiome composition. Some acids may also have antimicrobial qualities by targeting bacterial cytoplasmic membranes. The activity of organic acids is variable and potentially dependent on the physiology of the targeted microorganism, the physiology of the bird, and the localized gastrointestinal tract environment (Wales *et al.*, 2010).

A review of the data and literature on feed and water acidification showed that there was good geographical representation of the studies from many world regions. However, there were a limited number of studies that met the quality threshold, with few examples addressing commercial/in-field applications. The NT-*Salmonella* spp. serovars studied were primarily Enteritidis or Typhimurium, and it is not known if the findings can be generalized to other serovars. There was substantial variability in the experimental design of the studies. Variations in the acid type, acid form, acid dose, and the method of application were noted. Several studies showed that the timing and length of acid feeding also affected *Salmonella* spp. presence in the caeca qualitatively and quantitatively (Kollanoor-Johny *et*

al., 2009; Wales *et al.*, 2013; Bourassa *et al.*, 2018; Hernandez-Patlan *et al.*, 2019). Thus, a comparative analysis across methods and approaches was not feasible. Reductions in NT-*Salmonella* spp. colonization and shedding were study-specific and showed a wide range of efficacy. Based on the reported information, it is not clear which acid concentrations and administration protocols would be practical for facilitating reductions in the recovery of NT-*Salmonella* spp. from chicken meat.

Overall, the experts agreed that because of limitations to the data, further studies are recommended to assess the impacts of the commercial application of acid-based approaches. In concluding their observations, the experts did not recommend using feed and water acidification as a stand-alone *Salmonella*-reduction intervention at broiler farms. Nevertheless, feed and water acidification could be considered in conjunction with other practices as part of an integrated good hygiene programme to control NT-*Salmonella* spp. on broiler farms.

2.1.7 Feed characteristics and management approaches for the control of NT-*Salmonella* spp.

The experts reviewed 77 publications in the area of feed characteristics and management approaches for the control of NT-*Salmonella* spp. Concomitant with the reduction or elimination of antimicrobial agent use on broiler farms, many alternatives are being assessed to promote animal health and to reduce the colonization of *Salmonella* in chickens. Chicken feed can be modified in many ways to achieve these goals. Tested feed modifications vary extensively, across various regions in the world, and can include herbal and plant supplements, food and fermentation by-products, yeast cell fragments, and mineral supplements, from a variety of unique sources, including commercial formulations. Additives can also vary in dose, size and format. The activity of specific modifications is variable and potentially dependent on the physiological status of the microorganism, the chicken, and its surrounding localized alimentary tract environment. A large class of feed additives included by-products of food production that can serve as sources of acids or oligosaccharides, which can exert prebiotic functions to modulate the intestinal microbiome and improve overall intestinal and immune health.

The experts noted the following specific points regarding the current state of evidence on feed characteristics and management as a potential pre-harvest *Salmonella* intervention. There was good geographical representation of the studies with coverage from multiple regions. A limited number of studies met the quality threshold, with no field studies. The studies primarily focused on NT-*Salmonella* serovars Enteritidis and Typhimurium and it is not known

whether the findings can be generalized to other members of the genus. Study outputs to measure the impact of feed modification were given as differences in NT-*Salmonella* prevalence or concentration in caeca, feces, or other organs. There was considerable variation in experimental design, primarily in the type, form, and dose of feed modifications used. Several studies showed that the timing and length of feed modification had an impact on the *Salmonella* levels (Biloni *et al.*, 2013; Cerisuelo *et al.*, 2014; Liu *et al.*, 2014; Donato *et al.*, 2015). Given this variability, a comparative analysis of these studies was not possible, and the results were largely study-specific. The types of responses were variable, ranging from some modifications favouring the treatment group and others favouring the control groups. Reductions, when seen, were marginal. Despite some promising experimental results, it is not clear how they would translate to commercial settings, and it is not known which specific feed modifications/protocols would be practical for facilitating reductions in the recovery of NT-*Salmonella* in chicken meat. It was also noted that some feed modifications might only be applicable to intensive production systems, whereas others may be better suited to non-intensive production systems.

Based on the information available, further studies are needed to assess how extensive scale application of modified feed and management approaches could impact NT-*Salmonella* spp. levels in chicken meat. The experts did not recommend using feed modifications as a stand-alone NT-*Salmonella*-reduction intervention on broiler farms. Nevertheless, feed modification could be considered along with other practices as part of an integrated good hygiene programme to control NT-*Salmonella* spp. on broiler farms.

2.1.8 Poultry transportation to slaughter

Transporting poultry to the slaughterhouse affects *Salmonella* shedding and modifies the faecal microbiota. Information routinely collected at the slaughterhouse is usually used to assess the effects of transport risk factors on deaths on arrival (DOA) and carcass rejection rates for broiler chickens transported to a slaughterhouse. Overall, results highlight the value of slaughter records to produce information useful to reduce the impact of transport risk factors, improve broiler chicken welfare, and improve slaughterhouse economic results (Averós, 2020). Broiler chicken performance, during transport, can also be related to road conditions, and it is difficult to evaluate the real impact of seasons and distances on animal welfare. Load microclimate can compromise broiler chicken welfare during transport, and it does not necessarily reflect significant losses pre- and post-slaughter (Ehuwa *et al.*, 2021).

The arrival of poultry at a slaughterhouse is the first step in the slaughter process

and it includes all activities from the moment the truck arrives at the slaughterhouse until the containers and crates are unloaded from the truck. The condition of birds at arrival represents the cumulative result of the state of animals on the farm, including husbandry, and how the birds were caught, crated and transported (EFSA Panel on Animal Health and Welfare, 2019).

Factors such as transport cost, haulers, truck specifications, micro-environment conditions, loading density, route planning, vehicle accidents and journey length need to be considered and evaluated to minimize animal losses, which may have been underestimated in the past.

Transportation often takes place during the day without shade or isolation, which can result in weight loss and increased deaths on arrival due to stress. One study relied on red blood cell and white blood cell profiles, a stress index, and chicken performance to determine that three hours of travel resulted in the highest levels of stress but had no effect on body weight or mortality (Ulupi *et al.*, 2018).

Transporting broiler chickens from farms to slaughterhouses and its potential impact depends on the time of day of the journey. In conclusion, the experts found there was limited information as to the impact of transportation on *Salmonella* associated with poultry transport. Evidence does suggest that transport has an effect on overall bird health from the perspective of stasis, stress, weight, etc. Longer transportation times had a greater impact on bird health overall (Miranda-de la Lama *et al.*, 2014; Dos Santos *et al.*, 2020; Arikian *et al.*, 2017). The committee concluded that additional studies are required to better understand the impact of transport on bird health and *Salmonella* status as well as its impact on carcass and bird contamination and potential entry into the processing plant.

2.2 CONTROL DURING PROCESSING

Poultry processing has been continuously modified over the years to reduce the level of microbial contamination of the edible portion of the carcass, both to reduce pathogenic bacteria and to increase shelf life. Treatments applied to poultry carcasses or parts include water, steam, and chemical solutions. Many of these chemical solution studies involve the addition of organic and inorganic chemical compounds to water used for scalding and at various washing steps throughout the slaughter process. The experts noted that there were many process variables with these compounds, including chemistry, concentration and the method of application. While the full details of these process variables are beyond the scope of this review, there are certain generalities regarding NT-*Salmonella* spp. which can be stated based on the available scientific evidence.

The experts noted substantial variability in experimental design, primarily in the type of processing conditions, methods, chemistries and concentrations used across the published literature. It is not clear which specific processing modifications would be practical for facilitating reductions in the recovery of NT- *Salmonella* spp. on all poultry carcasses and for all processing environments.

The experts pointed out the following specific points regarding the current state of evidence on processing as potential *Salmonella* interventions.

A few controlled experimental studies meet the quality threshold. Few serovars (predominantly *Salmonella* Typhimurium) have been explored in challenge studies evaluating the effect on NT-*Salmonella* spp.

Qualitatively, a reduction in NT-*Salmonella* spp. concentration and occurrence based on process modifications was very much study-specific and showed a wide range of variability. Quantitatively, the impact of processing modifications on the recovery of NT-*Salmonella* spp. on poultry carcasses has been reported under experimental conditions.

The experts concluded that further studies are recommended for an extensive scale application of these interventions. Some processing modifications may only be applicable to intensive production systems, while others may only be applicable to non-intensive production systems. The studies reviewed were represented by many world regions.

2.2.1 Chlorine and acid water additives

There is extensive scientific literature on the use of different chemistries in wash or rinse waters, including but not limited to chlorine-based compounds and organic acids. These chemistries are used commercially in intensive poultry processing in some parts of the world, based on their perceived effectiveness. The panel noted that collectively, the evidence supports an approximate 1 log₁₀ reduction in NT- *Salmonella* spp. when chlorine was used in conjunction with either lactic acid or peracetic acid (Kataria *et al.*, 2020; Vaddu *et al.*, 2021; Zhang *et al.*, 2019; Carpenter *et al.*, 2011). Other acids which have been tested and shown to be effective include citric and propionic acids (Over *et al.*, 2009). Caprylic acid, a medium-chain fatty acid, is an effective natural processing aid against multidrug-resistant *Salmonella* Heidelberg (MDR SH) in chicken products (Manjankattil *et al.*, 2021). A disinfectant consisting of citric acid, lactic acid, and sodium dodecyl sulphate (SDS) exerted an *in vitro* synergistic bactericidal effect (Bai *et al.*, 2022). The reductions attributable to chlorine-based compounds are, however, highly variable, although acidified chlorate solutions appear to be more

effective than hypochlorous acids. Concentration, pH, temperature and contact time were the major variables in the application of this intervention (Bauermeister *et al.*, 2008).

2.2.2 Other water additives

There are many other additives for use in wash or rinse water that have been tested, but the current scientific literature and the expert panel considered that there was not sufficient information to draw objective conclusions regarding their effectiveness in commercial operations. Essential oils from various herbs and spices have been shown to be effective in some cases, as well as lauric arginate (Punchihewage-don *et al.*, 2021). Sequential spraying cycles with ozonated water of 8 ppm reduced a heavy *Salmonella* load below the detectable limit on the skin surface and the subcutis of drumsticks, respectively. Addition of lactic acid (LA) was found to increase the microbial killing capacity of aqueous O₃ (Megahed, Aldridge and Lowe, 2020). Sequential treatment with LA or gallic acid (GA) and atmospheric cold plasma (ACP) (a novel non-thermal technology) to inactivate the serovar Typhimurium resulted in synergistic interactions and a significantly higher level of membrane permeability and membrane lipid peroxidation in challenged cells (Yadav and Roopesh, 2022). The antimicrobial efficacy of 200 ppm of the water-soluble photosensitizer curcumin (PSC) on liquid media and chicken skin led to a maximum 3.6 log reduction in *Salmonella* spp. (Gao and Matthews, 2020; Yadav and Roopesh, 2022).

2.2.3 High hydrostatic pressure processing

High pressure processing may be effective in controlling NT-*Salmonella* spp. in poultry meat. The effect of the technology is dependent on pressure, exposure time and temperature. High hydrostatic pressure processing may cause changes in raw poultry meat which can result in undesirable characteristics for consumers and requires advanced processing equipment and technical skill.

2.2.4 Irradiation

There is an extensive body of scientific evidence on the use of ionizing radiation to control *Salmonella* spp. in poultry. The technical objective is to achieve any level of NT-*Salmonella* spp. reduction determined to be necessary, from pasteurization to complete sterility. The impact of the technology is dependent upon the absorbed dose, and the absorbed dose is affected by many parameters of the product and process (Gao and Matthews, 2020). Irradiation requires an advanced level of technical facilities and skill and is not suitable for many applications.

2.2.5 Other interventions during processing

There were several other interventions included in the literature, including but not limited to direct addition of additives to the meat, bacteriophages, thermal processes, ultrasound, ultraviolet radiation, electrolyzed water and cold plasma. Some of the proposed interventions are incorporated into product packaging, including edible packaging materials, and packaging and pads that incorporate antimicrobial compounds, nanomaterials, or a modified atmosphere to provide a sustained effect over the distribution chain of the meat. Although several of these interventions show promise, the experts concluded that most still require further development to be consistently effective and to have their ability to be practically applied in the poultry industry assessed.

The experts recommend using integrated process modifications as interventions for reducing the prevalence of NT-*Salmonella* spp. in poultry meat for consumers. Process modifications can be considered along with other practices, such as good hygiene practice to control NT-*Salmonella* spp. on poultry meat. The effectiveness of specific process modifications is variable and potentially dependent in the status and condition of the live birds as they are delivered to the slaughter establishment, the individual processing environment, and the concentration or method of application.

2.2.6 Good hygiene practices

Good hygiene practices (GHPs) are important in minimizing the risk of NT-*Salmonella* spp. contamination during slaughter and processing. With the rapid growth of the poultry industry, the growth in production directly reflects an increase in poultry consumption. Hygiene in poultry processing is a major issue. GHPs will increase the quality and shelf-life of meat by reducing contamination of carcasses.

Poultry meat processing is the term used by poultry industry to describe the conversion of live birds into raw poultry products. It is carried out in series of steps including receiving - stunning – bleeding and scalding - defeathering - singeing - washing - neck slitting and removal of feet and oil glands - evisceration - giblet harvest-cutting - washing - chilling. During these steps, implementing of GHPs helps to maintain quality and prevent the spread of foodborne pathogens such as NT-*Salmonella* spp. via poultry meat.

Horizontal transmission, that is the introduction of infectious agents from the environment, including via feed, hatchery equipment, staff movements and contaminated farm equipment; however, this remains a key route for pathogen exposure. If NT-*Salmonella* spp. is present in chickens reared for meat, the likelihood that the poultry meat produced from these chickens will be contaminated with this organism is increased. It is important to reduce the potential risk of contamination at all steps in the production chain from farm to fork, notably during processing (EC, 2020).

Indeed, processing should include all appropriate GHPs measures to avoid cross-contamination between flocks during processing. The process flow should be designed to reduce the risk of contamination of meat with faecal matter. Respect for GHPs in abattoirs could play a key role in the reduction of NT-*Salmonella* spp. during poultry processing; it is then necessary to emphasize the implementation of effective measures/guidelines in the slaughter process.

Several studies have indicated poor hand washing and contact with infected matter as some of the common contamination routes for carcass contamination (Mama and Alemu, 2016; Eng *et al.*, 2015). Slaughter equipment must be cleaned and disinfected using appropriate schedules (e.g. end of shift, between flocks, and end of day).

GHPs must be applied to all points of production on the farm from transport and entry of the live bird into the plant to the final product (whole carcass or pieces), and from plant to retail and the consumer table (FAO and WHO, 2011; Mama and Alemu, 2016). Several studies indicated that some carcass rinse solutions can aid in the reduction of NT-*Salmonella* spp. contamination in chicken carcasses or pieces (Cox and Pavic, 2010). GHPs must include the training of abattoir personnel from the reception step to the final finished carcasses or post-processing of pieces.

In 2018, WHO provided recommendations for the control of NT-*Salmonella* spp. that cover the whole food chain from farm to fork (WHO, 2020). These efforts are aimed at strengthening food safety standards that enhance NT-*Salmonella* spp. surveillance efforts, educating consumers and training food handlers in good hygiene practices for preventing NT-*Salmonella* spp. and other foodborne diseases. Indeed, contamination depends on how healthy the food handlers are, their personal hygiene and their knowledge and application of food hygiene rules (Ehuwa *et al.*, 2021).

2.3 POST-PROCESSING CONTROL OF NT-SALMONELLA SPP. IN POULTRY MEAT

The experts screened over 196 potential articles and reviewed 42 publications on post-process interventions for the control of NT-*Salmonella* spp. Post-processing interventions (encompassing transport, wholesale, retail and consumers) largely consist of temperature control during transport, providing cooking, handling, and storage guidelines, and other consumer education initiatives as well as treating poultry meat with agents to decrease the microbial load, thus extending the product shelf-life. NT-*Salmonella* spp. control at retail and distribution level relies on appropriate storage and handling. The experts noted that many agents used at the processing level (e.g. organic acids, or plant extracts) may also be applied at the retail or consumer level; however, the literature in this area is sparse and needs to be examined for further feasibility. When reported, the addition of some agents, such as organic acids, or plant extracts, can extend the shelf-life of cooked products. Practices such as marination in acidic or natural antimicrobial foods (e.g. spices) have also produced marginal reductions in NT-*Salmonella* spp. levels (Baltić *et al.*, 2015). Post-processing physical interventions, for example, light-emitting diodes for cooked products may reduce levels of NT-*Salmonella* spp. but this is not encouraged as a post-processing control measure. Rather, the emphasis should be placed on consumer education on appropriate transport, storage, handling, cooking guidelines and strategies to avoid cross-contamination (e.g. cleaning cutting boards) (Khalid *et al.*, 2020; Ravishankar *et al.*, 2010; Roccato *et al.*, 2015).

The experts noted the following specific points regarding the current state of evidence on post-processing interventions for the control of NT-*Salmonella* spp. in chicken meat. A limited number of controlled, experimental studies met the quality threshold. There was good geographical representation among the articles reviewed with multiple world regions represented. However, there was a lack of studies done in settings relevant to post-processing. The effectiveness of the interventions was presented as log changes in NT-*Salmonella* spp. counts on chicken meat following treatment (e.g. application of an aid such as essential oils in the packaging (Lin *et al.*, 2019), or various time-temperature situations) (Osaili *et al.*, 2013; Roccato *et al.*, 2015)). Marginal changes in NT-*Salmonella* spp. counts were observed across some of the publications. All studies were done at laboratory scale with a focus on a limited number of serovars (Typhimurium, Enteritidis), and limited types of chicken meat (primarily raw chicken breast, or ground). Further studies on different types of chicken meat and in different settings (e.g. retail and home settings) are recommended in order to examine applicability.

To maintain the microbiological quality of chicken meat, the experts noted that the transportation of chicken meat from retail to consumers is a critical step because of the potential for *Salmonella* to grow under non-refrigerated/temperature abuse conditions. Consumer education programmes on the safe transport, storage, handling, and cooking of chicken meat, and measures to avoid cross-contamination are required for the implementation of GHPs in the home.

2.4 OTHER CONSIDERATIONS FOR CONTROL

2.4.1 Role of sampling in NT-*Salmonella* spp. control

Laboratory analyses of samples collected at various points during the poultry production and processing chain is a method both for monitoring the process as well as verifying the effectiveness of interventions applied throughout the poultry process system. The analysis of samples collected at various stages of production and processing do not control or mitigate NT-*Salmonella* spp. but serve to inform the decisions which may ultimately control the organism. The results of a sampling programme are an important part of the poultry system for identifying sources of variation within the system as well as areas which can be improved upon to reduce the prevalence of NT-*Salmonella* spp. (EC, 2020).

As with many foodborne pathogens, NT-*Salmonella* spp. may occur at a very low prevalence and is not uniformly distributed within a flock or lot of a product. (Zweifel and Stephan, 2011; Ehuwa *et al.*, 2021) The plan to collect samples in any part of the poultry system, whether it is live bird production, processing or distribution must take this into account. In many cases, a sampling plan may not have sufficient sensitivity to allow the acceptability of a given flock or lot of a product to be determined because of the low prevalence of the target organism and the operating characteristic curve of the sampling plan.

Another factor to be considered is the sensitivity and specificity of the method for collecting and analysing the samples. The methods for sample collection will vary depending on the sampling location, but the method of collection may affect the outcome of the analyses. Some sample collection methods may be better than others at collecting representative samples (e.g. boot socks vs. drag swabs in poultry production facilities). The method for laboratory analysis may also affect the outcome, as laboratory methods differ in their respective sensitivity and specificity. While molecular methods of detection may be the most sensitive currently available, they may not be cost effective for all applications and may not

be accurate where population levels of the target organism are low, or there are interfering agents that impede analysis. In addition, molecular methods may not be targeted to all serovars. Many microbiological methods require some degree of sample enrichment, and the enrichment medium and growth conditions may selectively favour some NT-*Salmonella* serovars over others (WOAH, 2022b).

The value of the results from a sampling programme does not come from the individual results but from trend analysis over time. Trend analysis of the results over time, when combined with other operating factors, including but not limited to the source of the live birds, environmental conditions during rearing, processing parameters and distribution controls, can help to identify sources of variation within the system (See also Section 4.5 Traceability). Sampling points which demonstrate wide variation over time may be associated with other operating factors and together, these may help identify areas for improvement or the need for an additional intervention.

NT-*Salmonella* spp. originates primarily during the production of live birds, and so efforts to reduce its prevalence in live birds have the potential for the greatest impact on the prevalence of NT-*Salmonella* in the final product destined for the consumer. This would suggest that monitoring should be primarily focused on the aspects of live bird production, including breeders, hatcheries, feed and the grow-out environment. A sampling (monitoring) plan should focus on these areas, although sampling should also occur during processing and distribution as per the relevant state and governmental guidelines.

2.4.2 What to do with NT-*Salmonella* spp. in breeder flocks?

Protecting poultry flocks from microbial contamination is an extremely important component of commercial poultry production. The introduction of a pathogenic, contagious disease organism into poultry flocks could result in serious economic consequences for society as a whole (EC, 2020).

Good management and biosecurity can reduce the risk of introduction and persistence of infection to minimal levels. *Salmonella* control in the poultry breeder sector and in feed production has greatly reduced the risk from these sources, although contaminated feed is still one of the main routes for the introduction of new NT-*Salmonella* spp. infections onto a farm, along with resident hatchery contamination, personnel and other factors (e.g. rodents, beetles, etc.) (WOAH 2022c; EC, 2020).

The introduction of NT-*Salmonella* spp. into breeder flocks raises different issues such as the location and characteristics of the farm (geographical, environment,

surrounding area), the characteristics of the strain or the serovar of *Salmonella* involved, and the routes and traceability of contamination of breeder flocks (identification of the source of contamination, contamination routes, type of transmission, vertical or horizontal, feeds, fomites, vermin, other animal species such wild birds) and must be managed by following appropriate guidelines and by applying strict biosecurity measures (quarantine, clean and disinfect poultry houses and remove infected vermin present on the farm, or slaughter the infected breeder flocks) (EC, 2020).

Animal keepers are strongly encouraged to incorporate appropriate state and governmental guidelines (or a modification of WOAHA guidelines as appropriate) into their standard management practices. These guidelines must be drawn up to take into account that most chickens reared for meat are produced in controlled (temperature, air ventilation system, light) environment housing systems. The measures outlined in the guidelines should form the cornerstone of *Salmonella* control and, if rigorously applied, they may substantially contribute to preventing and controlling and help to take some decisions vis-a-vis *Salmonella* disease in flocks of chickens reared for meat production (EC, 2020).

The application of these guidelines is, however, limited to specific measures that would apply to free-range or small-scale rearing systems. Nevertheless, many of the basic principles are applicable and could be reasonably implemented (EC, 2020).

The decision-making process, in the case of NT-*Salmonella* spp. in breeder flocks, must be based on local regulation body laws or guidelines. Several low- and middle-income countries are currently developing *Salmonella* control programmes. The coordinated *Salmonella* control programmes implemented by the European Union are one of the most significant in the control of zoonotic diseases. Since these programmes were implemented, the number of notified human cases of salmonellosis has decreased in the European Union.

However, prerequisite aspects are required for the effectiveness of programmes for *Salmonella* control. This approach should involve stakeholders at top government level and appropriate legislative bodies. The European Union took a drastic step to curtail the spread of *Salmonella* by applying extended control programmes and legislation that include the routes of *Salmonella* exposure (WHO, 2020; Zweifel and Stephan, 2012; EFSA, 2021; Ehuwa *et al.*, 2021; EC, 2020; Islam *et al.*, 2021; Edel, 1994; McIlroy *et al.*, 1989).

A large, stylized number '3' is overlaid on a background illustration of hands being washed with soap suds. The hands are rendered in a light, sketchy style, and the number '3' is a large, dark grey font.

Review of the Code of Practice

The review committee were tasked with looking at the current code of practice with a view to assessing whether the current code of practice requires updates in light of new information or research or changes that require addressing or revision.

3.1 CONTROLLING SPECIFIC SEROTYPES VS NT-SALMONELLA SPP.

Target serovars should be defined based on their public health significance, reported frequency, virulence, infection route, etc. The criteria should be elaborated on a case-by-case basis. Source attribution studies can help to identify target serovars. Targeting all the serovars would be effective but needs to be balanced with economic considerations (EFSA, 2019; EC, 2003).

3.2 SPECIFIC COMMENTS

The experts evaluated the impact or efficacy of control measures relevant to NT-*Salmonella* spp. in the broiler production chain, noting the variability of the impacts reviewed, and recommended revisions to the Guidelines for the Control of *Campylobacter* and *Salmonella* in Chicken Meat (CXG 78-2011), Paragraphs 1 to 114 based on the currently available evidence (Annex 3).

A large, light gray illustration of hands being washed with soap suds. A large, dark gray number '4' is overlaid on the right side of the hands, indicating the chapter number.

4

Summary and synthesis

4.1 MULTI-HURDLE APPROACH NEEDED

The interventions described in this document are intended to control the levels of *Salmonella* spp. at specific steps of the chicken meat production chain. The scientific evidence shows they have varying efficacies and they target different aspects of *Salmonella* physiology. The implementation of multiple interventions (hurdles) is more effective in controlling *Salmonella* levels in chicken meat, as this approach incorporates potentially additive or synergistic effects of multiple pathogen reduction steps and is likely to counteract the resistance of *Salmonella* to any single intervention.

4.2 BENEFITS OF APPLYING QMRA

There is a need to update the 2011 quantitative microbial risk assessment (the web-based risk management tool for the control of *Salmonella* and *Campylobacter* in chicken meat) refine certain steps in the model and refine the dose response model – including differences between serotypes and dose response (DR), including different parameters of DR models, providing information on key interventions, including the most likely log reduction and standard dose (SD) with variability and uncertainty (FAO and WHO, 2011) – in order to allow users to add new control measures to the model.

Additional guidance for risk assessors in member countries to collect data which are fit for this model is very useful, including the consumer stage, e.g. growth during storage, frequency and *Salmonella* transfer during cross-contamination.

4.3 CLIMATE CHANGE

Extreme weather events and climate change may increase the spread of *Salmonella*, as it grows better at higher temperatures, potentially leading to higher concentrations of *Salmonella* in the poultry supply during the warmer months (Zdragas *et al.*, 2012; Mahmud *et al.*, 2011; Li *et al.*, 2020; Morgado *et al.*, 2021).

Climate change leads to extreme heat and can induce stress in chickens. It has emerged as a serious threat to the global poultry industry. Heat stress can negatively impact the growth, gut health and immune function of chickens, which can expose poultry to infection by several bacteria such as *Salmonella* spp.. Climate elements can have an impact on *Salmonella* infection at poultry farms. In one study humidity was noted as being the most important variable associated with *Salmonella* prevalence.

To conclude, a suitable environment is needed to reduce *Salmonella* contamination. The ongoing vertical and horizontal spread of NT-*Salmonella* spp. in poultry infecting humans via direct contact with the environment, infected animals or eating contaminated animal products requires further assessment.

Food business operators need to take climate change into consideration, when designing and managing the production environment.

The impact of climate on consumer handling and storage practices during extreme weather events also warrants consideration.

4.4 FUTURE CONSIDERATIONS

The scalability and adaptability of control measures in intensive production in low- and middle-income countries warrants further consideration. The integration between several control measures and their combined added value for *Salmonella* reduction in chicken meat during the consumer phase should be encouraged and investigated further. Scientific evidence is crucial for proposing *Salmonella* control measures with a coordinated One Health approach that involves all stakeholders. The use of next generation omics-based technologies (e.g. whole genome sequencing and microbiome analysis) to inform evidence-based source attribution, risk assessment, and ultimately informing the development of serotype-specific *Salmonella* control measures is an area of critical consideration for the future.

There is the opportunity to implement/promote the use of machine learning (artificial intelligence) to predict the *Salmonella* risk level associated with each chicken meat lot using farm to fork integrated datasets, which can be established

by taking advantage of: (1) automatically retrieving data systems, such as sensors, probes and cameras (for instance to detect vectors etc.), applicable at farm, transport and slaughterhouse level; (2) microbiome and whole genome sequencing data; and (3) production, processing and environmental data and metadata.

Data analysis should be performed in an aggregated form at the national/international level. Data provided by food business operators can be anonymized by the companies before making them available. Technology (data) transfers between countries should be encouraged as a means to enhance information databases and address data gaps.

4.5 TRACEABILITY, FOOD CHAIN INFORMATION AND BLOCKCHAIN

The International Standards Organization (ISO, 2007) defines traceability as the “ability to follow the movement of a feed or food through specified stage(s) of production, processing and distribution”. Traceability is an important component of every stage of the poultry system, whether it is live birds and feed or processed poultry for the consumer. The ability to trace products is important not only from a food safety standpoint but also from an animal health perspective. As an example, an outbreak of highly pathogenic Avian Influenza or Newcastle disease would require the identification and isolation of the infected flocks as well as any vehicles which may have been on the production sites. A foodborne disease outbreak associated with poultry would also require a thorough trace-back of the contaminated product throughout the system.

The fundamental principles of a traceability system include, but are not limited to, defining the ingredient(s) or product(s) covered, the flow of the ingredient through the process and the required information to establish and maintain the traceability system. These principles are described in a specific Codex document on food traceability (CAC/GL 60-2006) (FAO and WHO, 2006b). Traceability in the food system is also discussed in the General Principles of Food Hygiene (CXC 1-1969) (FAO and WHO, 2011), and there is an ISO Standard on traceability in the feed and food chain (ISO, 2007).

4.6 CRITICAL RESEARCH GAPS

Virulence factors and dose response curves: The expert committee did not address these two issues because it was considered that the current state of the

science is incomplete. Therefore, these topics should be reviewed at a future date. The committee recognized that there were substantial differences in virulence both between serovars and, in some cases, within serovars, which are attributable to the presence or absence of specific genetic elements. In addition, the behaviour of serovars in the poultry host and human host differs in terms of infectious dose, and the health status of host. Processing and selection also likely impact serovar behaviour. However, at the present time, the science of the virulence of NT-*Salmonella* spp. is still evolving and it may be premature to draw conclusions based on current knowledge. These remain important topics and should be reviewed in the future.

Reviews of the performance of interventions in natural field settings are currently limited and often consist of single studies which do not lend themselves well to comparative analysis or allow for accurate measurement of the impacts of interventions in the field. Further studies in these areas will likely continue and at a future date will warrant full review.

The need for consumer education programmes and activities is clearly required (from the transport of purchased products to handling them in the kitchen), but how to integrate the effects of education into risk assessment models requires further work; due to the limitation of the meeting time, it was not adequately covered as part of this meeting report. Therefore, the panel did not address consumer education as it was considered to be outside the scope of the review.

The experts also considered that ground chicken (and other raw poultry products that appear to be ready to eat, e.g. breaded poultry products) may not be covered under current codex documents and will need to be addressed under CXG 78-2011.

Another limitation of the work reviewed was that the focus remained on the broiler chain alone and issues regarding ducks, turkeys and other avian species were not considered in this review.



5

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Annexes

Annex 1

THE KEYWORDS

Table A1. The keywords used for searching the control measures of *Salmonella* in poultry.

Parameter	Search
1 (poultry)	poultry OR chicken* OR hen* OR broiler* OR “ <i>Gallus gallus</i> ” OR “ <i>Gallus domesticus</i> ” OR “ <i>G gallus</i> ” OR “ <i>G domesticus</i> ” OR “ <i>Gallus gallus domesticus</i> ” OR “ <i>G gallus domesticus</i> ” OR duck* OR turkey* OR goose OR geese OR guineafowl* OR pigeon* OR “quail” NOT layer*
2 (<i>Salmonella</i>)	<i>Salmonella</i>
3 (intervention)	intervention* OR antibiotic* OR antimicrobial* OR antibacterial* OR bacteriophage* OR bifidobac* OR biosecur* OR boning OR chlorine OR chill* OR “competitive exclusion”

3 (intervention)	OR contamination OR control OR cool* OR cut* OR debon* OR decontaminat* OR decreas* OR dehid* OR dehair* OR disinfect* OR dress* OR efficacy OR eviscerat* OR fabricat* OR grind* OR "hot water" OR hygiene OR immunis* OR immuniz* OR inactiv* OR irradiat* OR lactob* OR "lactic acid bacteria" OR mitigat* OR pasteuriz* OR phage* OR probiotic* OR reduce* OR reducing OR reduction OR rins* OR skin* OR "sodium chlorate" OR spray* OR steam OR treatment* OR storage OR trial OR trim* OR vaccin* OR vaccum* OR wash*
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4	Title/Abstract (1 AND 2 AND 3)
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Annex 2

THE QUESTIONS FOR THE TWO-STEP RELEVANCE SCREENING AND CONFIRMATION

Table A2.1. Relevance screening

Question	Options	Key definitions
<p>1. Does this citation describe research evaluating the efficacy and/or effectiveness (including costs or practicality of implementation) of interventions to control <i>Salmonella</i> in poultry at any stage from primary production to consumption?</p> <p>Selections 1-3 will pass the citation to the next review stage and the article will be procured.</p>	<ul style="list-style-type: none"> <input type="checkbox"/> Yes, primary research <input type="checkbox"/> Yes, systematic review/meta-analysis <input type="checkbox"/> Yes, risk assessment, risk profile, or other risk-based tool (e.g. cost-benefit analysis) <input type="checkbox"/> No or it is a narrative literature review on the subject (exclude) 	<p>Primary research is collection of new data in a single study.</p> <p>Risk assessment is a scientifically-based process consisting of the following steps (i) hazard identification, (ii) hazard characterization, (iii) exposure assessment, and (iv) risk characterization.</p> <p>Risk profile presents the current state of knowledge relating to a food safety issue, describes potential options that have been identified to date (if any), and the food safety policy context that will influence further possible actions. Other risk-based tools could include cost-benefit analyses, risk ranking, or risk prioritizations.</p> <p>Systematic review is a structured review of a clearly defined question with a transparent search strategy, relevance screening process, data extraction, risk-of-bias assessment and synthesis of results. Meta-analysis is a statistical technique that can be used on data collected in a systematic review.</p> <p>Exclude research on feral animals (e.g. feral pigs not produced for human consumption), and <i>in vitro</i> lab experiments.</p>

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2. What commodity is investigated?
- Chicken
 - Duck
 - Turkey
 - Goose
 - Guineafowl
 - Pigeon
 - Quail
 - Other
-

Table A2.2. Relevance confirmation

Question	Options	Key definitions
Did the study investigate outcomes other than <i>Salmonella</i> ?	<ul style="list-style-type: none"> <input type="checkbox"/> Yes, <i>E. coli</i> (generic and/or pathogenic strains) <input type="checkbox"/> Yes, <i>Campylobacter</i> <input type="checkbox"/> Yes, other bacteria <input type="checkbox"/> No 	
In what setting was the study carried out?	<ul style="list-style-type: none"> <input type="checkbox"/> Commercial/field conditions <input type="checkbox"/> Research farm/pilot plant <input type="checkbox"/> Smallholder farm/abattoir conditions <input type="checkbox"/> Laboratory conditions <input type="checkbox"/> Not reported 	
In what country was the study conducted?	<ul style="list-style-type: none"> <input type="checkbox"/> The information is in the abstract, which is: (COMMENT) <input type="checkbox"/> Cannot tell from the abstract 	Specify country name only (not sub-regions, states, provinces, etc.)
How many logarithm reductions?	<ul style="list-style-type: none"> <input type="checkbox"/> The information is in the abstract, which is (COMMENT) <input type="checkbox"/> Cannot tell from the abstract <input type="checkbox"/> Other ways to reflect the efficiency (COMMENT) 	

<p>Is it at farm?</p> <p><input type="checkbox"/> Yes</p> <p><input type="checkbox"/> No</p>	<p>What is the intervention?</p> <p><input type="checkbox"/> Biosecurity/management practices</p> <p><input type="checkbox"/> Vaccination</p> <p><input type="checkbox"/> Antimicrobials</p> <p><input type="checkbox"/> Competitive exclusion/probiotics</p> <p><input type="checkbox"/> Feed/water acidification</p> <p><input type="checkbox"/> Feed characteristics/management</p> <p><input type="checkbox"/> Bacteriophages</p> <p><input type="checkbox"/> Other (COMMENT)</p>	<p>Antimicrobials: Examples include: Fluoroquinolones, cephalosporins, gentamicin, ampicillin, tetracyclines, spectinomycin, ciprofloxacin, and ceftriaxone. These may be administered via feed.</p> <p>Biosecurity: includes, but is not limited to, sanitation, biosafety, disinfection, hygiene and hygiene barriers, all-in-all-out production, depopulation, staff and the environment, litter testing and treatment, pest control, etc.</p>
<p>Is it from transport to slaughter?</p> <p><input type="checkbox"/> Yes</p> <p><input type="checkbox"/> No</p>	<p>What is the intervention?</p> <p>(COMMENT)</p>	<p>Competitive exclusion: May also be referred to as probiotics, prebiotics or synbiotics. May include <i>Lactobacillus</i> spp., bacteroides, <i>Bifidobacterium</i> spp., <i>Enterococcus faecium</i>, <i>Aspergillus oryzae</i>, and <i>Saccharomyces</i> spp. (<i>S. cerevisiae</i>, <i>S. boulardii</i>). May be caecal contents or other materials from animals or the environment that contain many different or unknown bacterial species.</p>
<p>Is it Processing?</p> <p><input type="checkbox"/> Yes</p> <p><input type="checkbox"/> No</p>	<p>What is the intervention?</p> <p><input type="checkbox"/> Segregated/logistic slaughter</p> <p><input type="checkbox"/> Cleaning/disinfection of equipment/environments</p> <p><input type="checkbox"/> Carcass/product washes, rinses, sprays</p> <p><input type="checkbox"/> Standard processing procedures/good hygienic practices (GHPs)</p> <p><input type="checkbox"/> Irradiation</p> <p><input type="checkbox"/> Modified packaging</p> <p><input type="checkbox"/> bacteriophages</p> <p><input type="checkbox"/> Other (COMMENT)</p>	<p>Feed/water acidification: Addition of organic acids, such as lactic acid, to feed or water. Would include 'nutraceuticals' such as copper, chromium, zinc, betaine or carnitine.</p> <p>Feed management: E.g. comparisons of coarse/finely ground feed, fermented feed, or liquid feed.</p>
<p>Is it from post-processing to consumer?</p> <p><input type="checkbox"/> Yes</p> <p><input type="checkbox"/> No</p>	<p>What is the intervention?</p> <p><input type="checkbox"/> (Biosecurity/management practices</p> <p><input type="checkbox"/> Vaccination</p> <p><input type="checkbox"/> Antimicrobials</p> <p><input type="checkbox"/> Competitive exclusion/probiotics</p> <p><input type="checkbox"/> Feed/water acidification</p> <p><input type="checkbox"/> Feed characteristics/management</p> <p><input type="checkbox"/> Bacteriophages</p> <p><input type="checkbox"/> Other (COMMENT)</p>	<p>Segregated/logistic slaughter = slaughtering/processing of more highly contaminated lots after less contaminated lots.</p> <p>Standard processing procedures/good hygienic practices (GHP) refers to steps such as singeing, de-hiding, cooling, chilling, etc.</p>

Annex 3

REVIEW OF THE CODEX GUIDELINES

There is evidence that new products, e.g. frozen raw products, were the source of *Salmonella* in some recent outbreaks, so both the FAO/WHO web-based risk assessment model and the scope of CXG 78-2011 should be expanded to take account of new products that were not available during the previous development or review of the code.

Table A3.1. Recommended revisions to the Guidelines for the Control of *Campylobacter* and *Salmonella* in Chicken Meat (GXG 78-2011), as they relate specifically to the control of NT-*Salmonella* spp.

Para.	CAC/GL 78-2011	JEMRA Recommendations
3.	<p>Good hygienic practice (GHP)-based. They are generally qualitative in nature and are based on empirical scientific knowledge and experience. They are usually prescriptive and may differ considerably between countries.</p> <p>Hazard-based. They are developed from scientific knowledge of the likely level of control of a hazard at a step (or series of steps) in a food chain, have a quantitative base in the prevalence and/or concentration of <i>Campylobacter</i> or <i>Salmonella</i>, and can be validated as to their efficacy in hazard control at the step. The benefit of a hazard-based measure cannot be exactly determined without a specific risk assessment; however, any significant reduction in pathogen prevalence and/or concentration is expected to provide significant human health benefits.</p>	<ul style="list-style-type: none"> • To align the definition of GHPs with the definition provided within the General Principles of Food Hygiene (CXC 1-1969). • To consider revising the definition of hazard base to read, “...of <i>Campylobacter</i> and/or <i>Salmonella</i>...; ... significant reduction in hazard prevalence and/or concentration...”; and • To review the statement “any significant reduction in pathogen prevalence is expected to provide significant human health benefits”.

Para.	CAC/GL 78-2011	JEMRA Recommendations
9.	Scope	<ul style="list-style-type: none"> To expand the scope to include ground chicken meat, organ meat, and chicken products made from comminuted meat.
Section 4. Definition – Competitive exclusion	Probiotics are defined as competitive exclusion products (footnote 7)	<ul style="list-style-type: none"> To consider changing the text in the footnote to read, “<i>Probiotics may be competitive exclusion products</i>”. To verify the alignment with WOH’s definition of complete exclusion in Chapter 6.6 To consider including a definition for a production lot as per the Guidelines on the management of biological foodborne outbreaks (For adoption at Step 8 - Report of the 52nd session of the CCFH.) <i>Lot: A definite quantity of ingredients or of a food that is intended to have uniform character and quality, within specified limits, is produced, packaged and labelled under the same conditions, and is assigned a unique reference identification by the food business operator. It may also be referred to as a “batch”.</i>
18.	<p>Food Safety Risk Profile for <i>Salmonella</i> species in broiler (young) chicken, June 2007.</p> <p>Food Safety Risk Profile for <i>Campylobacter</i> species in broiler (young) chicken, June 2007.</p>	<ul style="list-style-type: none"> To verify that the links referenced in the footnote are current and active. To evaluate paragraph 18 and to consider updating it, if needed.

Para.	CAC/GL 78-2011	JEMRA Recommendations
24.	Control of <i>Campylobacter</i> and <i>Salmonella</i> in grandparent flocks is strengthened by the application of a combination of biosecurity and personnel hygiene measures. The particular combination of control measures adopted at a national level should be determined in consultation with relevant stakeholders.	<ul style="list-style-type: none"> • To consider including a definition for biosecurity that includes personal hygiene. • May want to align with the WOAHA definition: https://www.woah.org/fileadmin/Home/eng/Health_standards/tahc/current/glossaire.pdf. • To consider changing the text to read “...by the application of effective biosecurity measures.”
26.	Where a flock is found to be <i>Salmonella</i> -positive a range of responses, detailed in the OIE Terrestrial Animal Health Code ¹⁹ , Chapter 6.5 “Prevention, Detection and Control of <i>Salmonella</i> in Poultry”, should be taken.	<ul style="list-style-type: none"> • To update the WOAHA reference “Terrestrial Animal Health Code, Chapter 6.6 - Prevention, Detection and Control of <i>Salmonella</i> in Poultry”.
29.	Only eggs from <i>Salmonella</i> -negative flocks should be sent for hatching. When this is not practical, the eggs from <i>Salmonella</i> -positive flocks should be transported separately from other eggs.	<ul style="list-style-type: none"> • To consider revising the guidance so that “Only eggs from <i>Salmonella</i>-negative flocks should be transported for hatching. The eggs from <i>Salmonella</i>-positive flocks should be transported separately and discarded/not used for propagation/handled according to competent authority. “
31.	Where the use of eggs from flocks that are known to be contaminated is unavoidable, they should be kept separate and hatched separately from eggs from other flocks. Trace back of contamination to the infected breeding flocks should be performed and control measures should be reviewed.	<ul style="list-style-type: none"> • To verify that the guidance is aligned with the most recent version of WOAHA. Several references identified egg disinfection as a means of reducing <i>Salmonella</i> in chicks after hatching. • A suggestion for reformulation: “Where the use of eggs from flocks that are known to be infected is unavoidable” (thus replacing the word contaminated with infected).

Para.	CAC/GL 78-2011	JEMRA Recommendations
35.	Where the use of eggs from flocks that are known to be contaminated is unavoidable, they should be kept separate and hatched separately from eggs from other flocks and the chicks should be kept isolated from other flocks. Trace back of contamination to the infected breeding flocks should be performed and control measures should be reviewed.	<ul style="list-style-type: none"> • To verify that the guidance is aligned with the most recent version of WOH. Several references identified egg disinfection as a means of reducing <i>Salmonella</i> in chicks after hatching. • To consider revising the text to read, “<i>Where the use of eggs from flocks that are known to be infected is unavoidable</i>”, thus replacing the word contaminated with infected.
37.	Personnel should follow appropriate biosecurity procedures to avoid cross contamination of day old chicks during loading and unloading. All live bird transport crates and modules should be cleaned, disinfected and dried to the greatest extent practicable before re-use.	<ul style="list-style-type: none"> • To consider revising the text to read, “<i>All live bird transport trucks, crates and modules should be effectively cleaned, disinfected and dried on site to the greatest extent practicable, before reuse.</i>”
44.	All live bird transport crates and modules should be cleaned, disinfected and dried to the greatest extent practicable, before reuse.	<ul style="list-style-type: none"> • To consider revising the text to read, “<i>All live bird transport trucks, crates and modules should be effectively cleaned, disinfected and dried on site to the greatest extent practicable, before reuse.</i>”
46.	Flocks, where practical, should be slaughtered after 8-12 hours feed withdrawal in order to reduce the likelihood of contamination of carcasses by faecal material and ingesta.	<ul style="list-style-type: none"> • To consider aligning the text with recent scientific studies on proper fasting time, which could reduce the goal of carcass contamination.
54.	Washing with abundant potable running water	<ul style="list-style-type: none"> • To consider replacing potable water with fit-for-purpose water to align with CXG1-1969, paragraph 70. Text should be adjusted to fit for purpose water.

Para.	CAC/GL 78-2011	JEMRA Recommendations
60.	Cross contamination at defeathering can be minimised by:	<ul style="list-style-type: none"> To consider revising the text to read, “<i>Washing carcasses prior to scalding can reduce contamination prior to defeathering.</i>”
64.	Spray applications of 20-50 ppm chlorinated water following defeathering and carcass evisceration have been shown to reduce the prevalence of <i>Salmonella</i> -positive broiler carcasses from 34% to 26% and from 45% to 36% respectively.	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73. To also consider replacing references to trisodium phosphate (TSP) with the following text: “<i>Several different chemistries have been demonstrated to be effective in reducing carcass contamination at different washing steps.</i>”
65.	Immersion in Tri Sodium Phosphate (TSP) has been shown to reduce prevalence of <i>Salmonella</i> - positive carcasses from 72% to 4%	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73.
66.	The inside and outside of all carcasses should be thoroughly washed, using pressure sufficient to remove visible contamination. Appropriate equipment should be used to ensure direct water contact with the carcass. The removal of contaminants may be aided by the use of brushing apparatus installed in line with the inside/outside wash.	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73.
68.	Inside/outside washing using a spray application of 20-50 ppm chlorinated water has been shown to reduce the prevalence of <i>Salmonella</i> -positive broiler carcasses from 25% to 20%. A second inside/outside washing following upon the first resulted in a reduction of <i>Salmonella</i> -positive broiler carcasses from 16% to 12%.	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73.

Para.	CAC/GL 78-2011	JEMRA Recommendations
69.	An on-line reprocessing spray system incorporating ASC has been shown to reduce <i>Campylobacter</i> in the whole carcass rinse sample by about 2.1 log ₁₀ CFU/ml and to reduce the prevalence of <i>Salmonella</i> -positive carcasses from 37% to 10%.	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73.
70.	Dipping carcasses in 10% TSP reduced Campy by 1.7 log ₁₀ CFU/g neck skin and the MPN of <i>Salmonella</i> was reduced from 1.92 log ₁₀ CFU neck skin to undetectable levels.	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73.
71.	The use of ASC (750ppm, pH 2.5, spray application) has in one industrial setting been shown to reduce <i>Salmonella</i> prevalence on carcasses from about 50% to levels below detection. In another industrial setting <i>Salmonella</i> prevalence was reduced by 18% (700-900ppm, pH 2.5, spray application).	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73.
72.	A pre-chill ASC spray reduced the <i>Salmonella</i> prevalence on carcasses from 17% to 9%. Dipping carcass parts in ASC reduced the <i>Salmonella</i> prevalence from 29% to 1%.	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73.
73.	Spray application of 8-12% TSP immediately before carcass chilling was shown to reduce <i>Salmonella</i> from 10% to 3%.	<ul style="list-style-type: none"> To consider including a generic statement rather than specific processing parameters for paragraphs 64-73.
79.	Water (including recirculated water) should be potable and the chilling system may comprise of one or more tanks. Chilled water can be used or ice may be added to it. Water flow should be counter-current and may be agitated to assist cooling and washing action.	<ul style="list-style-type: none"> To consider replacing potable water with fit for purpose water to align with CXG1-1969, paragraph 70.

Para.	CAC/GL 78-2011	JEMRA Recommendations
83.	Immersion chilling in water treated with 20ppm or 34 ppm chlorine or 3ppm or 5 ppm chlorine dioxide reduced <i>Salmonella</i> prevalence from 14% in controls to 2% (20ppm Cl ₂), 5% (34ppm Cl ₂), 2% (3ppm ClO ₂) and 1% (5 ppm ClO ₂) respectively.	<ul style="list-style-type: none"> • To consider including a generic statement rather than specific processing parameters for paragraphs 83-88. • To consider revising the text to read “<i>Immersion chilling in water treated with chemical disinfectants (e.g. chlorinated compounds, organic acids) can reduce Salmonella prevalence.</i>”
85.	The use of ASC (750 ppm, pH ≈ 2.5, immersion dip) post-chill has been shown to reduce prevalence of <i>Salmonella</i> positive carcasses from 16% to a level below detection. ⁵	<ul style="list-style-type: none"> • To consider including a generic statement rather than specific processing parameters for paragraphs 83-88.
86.	Spray applications of 20-50 ppm chlorinated water have been shown to reduce the prevalence of <i>Salmonella</i> -positive carcasses from 10% to 4%.	<ul style="list-style-type: none"> • To consider including a generic statement rather than specific processing parameters for paragraphs 83-88.
87.	A chlorine dioxide generating system applied as a dip at 5ppm post-chill resulted in 15-25% reduction in <i>Salmonella</i> prevalence. ⁵	<ul style="list-style-type: none"> • To consider including a generic statement rather than specific processing parameters for paragraphs 83-88.
88.	Spraying carcasses immediately after spin chilling with 10% TSP resulted in a reduction of <i>Salmonella</i> from 50 to 6 %	<ul style="list-style-type: none"> • To consider including a generic statement rather than specific processing parameters for paragraphs 83-88. • To consider also replacing references to trisodium phosphate (TSP) with the following text “<i>Several different chemistries have been demonstrated to be effective in reducing carcass contamination at different washing steps.</i>”
89.	Chilled carcasses should be held in temperature controlled environments and processed as soon as possible, or with the addition of ice to minimise the growth of <i>Salmonella</i> .	<ul style="list-style-type: none"> • To consider water and ice references in conjunction with CXG1-1969, paragraph 70.

Para.	CAC/GL 78-2011	JEMRA Recommendations
92.	Chilled carcasses should be held in temperature controlled environments and processed as soon as possible or with the addition of ice to minimise the growth of <i>Salmonella</i> .	<ul style="list-style-type: none"> To consider water and ice references in conjunction with CXG1-1969, paragraph 70.
97.	For GHP-based control measures for all aspects of transport, refer to the Code of Practice – General Principles of Food Hygiene (CAC/RCP 1-1969) and the Code of Hygienic Practice for Meat (CAC/RCP 58- 2005).	<ul style="list-style-type: none"> To consider water and ice references in conjunction with CXG1-1969, paragraph 70.
Section 10.1	Step 25: Transport	<ul style="list-style-type: none"> To consider also including the same text for temperature under the transport step. <i>“Products should be transported at temperatures preventing the growth of Salmonella.”</i>
99.	Hygiene measures should be in place to prevent cross-contamination between raw chicken meat and other food.	<ul style="list-style-type: none"> To consider revising the text to read, <i>“Hygienic measures should be in place to prevent cross-contamination between raw chicken meat, surfaces, utensils, and other food.”</i>
100.	Retailers should separate raw and cooked products.	<ul style="list-style-type: none"> To consider revising the text to read, <i>“Retailers should separate raw and cooked, ready-to-eat products.”</i>
103. and footnote 28 in 104.	For GHP-based control measures, also refer to the Code of Hygienic Practice for Precooked and Cooked Foods in Mass Catering (CAC/RCP 39-1993).	<ul style="list-style-type: none"> To consider updating the codes, CAC/RCP 39-1993 and CAC/RCP 8-1976.
108.	Chicken meat should be cooked according to a process that is capable of achieving at least a 7 log reduction in both <i>Campylobacter</i> and <i>Salmonella</i> .	<ul style="list-style-type: none"> To consider revising the text to read, <i>“Chicken meat should be cooked according to a process that is capable of reaching an internal temperature that can inactivate Salmonella, for example 74 °C.”</i>

Para.	CAC/GL 78-2011	JEMRA Recommendations
109.	<p>Consumer education should focus on handling, hand washing, cooking, storage, thawing, prevention of cross contamination, and prevention of temperature abuse. The WHO Five keys to safer food³⁰ assists in this process.</p>	<ul style="list-style-type: none"> • To consider revising the text to read, <i>“Consumer education should focus on handling, hand washing, cooking, storage, thawing, prevention of cross-contamination, and prevention of temperature abuse including during transport.”</i>
110.	<p>Special attention should be paid to the education of all persons preparing food, and particularly to persons preparing food for the young, old, pregnant and immuno-compromised.</p>	<ul style="list-style-type: none"> • To consider revising the text to read, <i>“Special attention should be paid to the education of all persons preparing food, and particularly to persons preparing food for vulnerable populations (e.g. the young, the elderly, and those with compromised immunity)”</i>.
111.	<p>The above information to consumers should be provided through multiple channels such as national media, health care professionals, food hygiene trainers, product labels, pamphlets, school curriculae and cooking demonstrations.</p>	<ul style="list-style-type: none"> • To consider revising the text to read, <i>“The above information for consumers should be provided in appropriate languages and forms. Multiple channels such as the internet, media, public health providers, healthcare professionals, food hygiene trainers, product labels, posters and pamphlets, school curricula and cooking demonstrations should be considered when disseminating educational information.”</i>
112.	<p>Washing of raw chicken in the kitchen should be discouraged so as to minimise the possibility of contamination of other foods and surfaces that come in contact with food and humans. Where deemed necessary washing of raw chicken carcasses and/or chicken meat, should be carried out in a manner which minimises the possibility of contamination of other foods and surfaces that come in contact with other foods and humans.</p>	<ul style="list-style-type: none"> • To consider removing the following text <i>“Where deemed necessary, washing of raw chicken carcasses and/or chicken meat, should be carried out in a manner which minimizes the possibility of contamination of other foods and surfaces that come into contact with other foods and humans.”</i>

Para.	CAC/GL 78-2011	JEMRA Recommendations
114.	Products should be stored at temperatures preventing growth of <i>Salmonella</i> .	<ul style="list-style-type: none"> To consider revising the text to read, “<i>Products should be transported and stored at temperatures preventing the growth of Salmonella.</i>”
115.	Chicken meat should be cooked according to a process that is capable of achieving at least a 7 log reduction in both <i>Campylobacter</i> and <i>Salmonella</i> .	<ul style="list-style-type: none"> To consider revising the text to read, “<i>Chicken meat should be cooked according to a process that is capable of reaching an internal temperature that can inactivate Salmonella, for example 74 °C.</i>”

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- 45 FAO and WHO. 2023. Measures for the control of non-typhoidal *Salmonella* spp. in poultry meat, meeting report.

In response to a request from the 52nd Session of the Codex Committee on Food Hygiene (CCFH), the FAO/WHO Joint Expert Meetings on Microbiological Risk Assessment (JEMRA) convened this meeting, to collate and assess the most recent scientific information relating to the control of non-typhoidal (NT)-*Salmonella* spp. in chicken meat. The assessment included a review of the Codex *Guidelines for the Control of Campylobacter and Salmonella in Chicken Meat* (CXG 78-2011). The *Campylobacter* will be reviewed by another meeting.

The expert consultation noted that no single control measure was sufficiently effective in reducing either the prevalence or the level of contamination of broilers and poultry meat with NT-*Salmonella* spp. Instead, it was emphasized that control strategies based on multiple intervention steps would have the greatest impact on controlling NT-*Salmonella* spp. in the broiler production chain. This report describes the output of this expert meeting and the advice herein is useful for both risk assessors and risk managers, at national and international levels and those in the food industry working to control the hazard in poultry.

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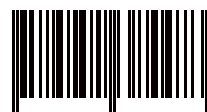
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20 Avenue Appia 1211 Geneva 27,

Switzerland

ISBN 978-92-5-138447-3 ISSN 1726-5274



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CC9026EN/1/12.23

Microbiological Risk Assessment Series