Salmonella control in food-animals: Focus on chicken and pork

Andrijana Rajić
PHAC/University of Guelph

Story

• Epidemiology and ecology of Salmonella
  – Food animal chain
• Salmonella control
  – Conventional wisdom
  – International approaches
• Evidence-informed approach
  – Case study: Efficacy of farm-to-processing interventions for Salmonella in broiler chicken
• Summary/Canadian context/
Salmonella in food-animals

- Common foodborne illness
- 11 million food-borne illness each year in Canada (Thomas, 2009)
- Costs US $2.9 billion annually (USDA)

- Disease in food animals
- Common infection
- Serovar distribution / overlap
- Food safety/public health
  - Disease in humans
  - Vulnerable populations
  - AMR
- Economic impact
  - Production, trade

Complexity of Salmonella ecology

From Ray and Davies
Complexity of food-animal chain

Food can be contaminated at any point, from farm inputs to fork

Farm/Transport

• Risk Factors
  – Feed, breeding, hatching
  – Production practices
    • Replacement animals, mixing, transport stress
  – Animals as reservoirs
  – Environment
    • Litter, feed, water, dust, rodents, wildlife, …
  – Equipment
  – Humans
    • Visitors, workers …

• Recommended practices
  – Feed control/dietary interventions
  – Quarantine/testing
  – Good hygiene & bio-security programs, training
  – Transport in separate containers
  – Sanitation
  – Integrated control programs

Key aspects: persistence, unique farm/production system ecology?
Slaughter/Processing

- **Risk factors**
  - Lairage/holding pens
  - Contaminated feathers/hides
  - Carcass contamination
    - Pre-post evisceration
  - Plant building, equipment and environment
  - Human carriers
  - Initial contamination of row materials
  - Production, processing, food handling, distribution and preparation
  - Level of sanitation

- **Interventions**
  - HACCP/Microbial testing
  - Holding in pens separated by concrete
  - Facility design, production flow
  - Covering the bungs with a plastic bag
  - Various decontamination procedures
  - Large scale monitoring and surveillance
  - Personnel training
  - Logistic slaughter

Key aspects: pathogen/food matrix/plant ecology?

International approaches

- Scandinavian
  - Sweden, Denmark
- EU Zoonoses legislation
  - Farm level
  - Main Targets: Typhimurium, Enteritidis
- US
  - HACCP/PR at processing
- Canada
  - HACCP/PR at processing
  - OFFS programs
    - No pathogen targeted monitoring/control
Denmark success

- *Salmonella* program in broiler chicken chain
  - Number of positive flocks reduced considerably
- *Salmonella* program in pork chain
  - Considerable incremental reduction reported along with the program modification
- *Salmonella* reduction in humans
  - Domestic human cases reduced
  - Import/travel-related cases
- Cost-effectiveness? Applicability to other countries?

Contextual factors

- History of major outbreaks
- Regulatory aspects
- Trust in government
- Consumer preferences
- Industry size and organization
- Trade aspects
- Overall food safety/public health priorities
- Resources, cost-effectiveness
- Long-term sustainability
- Transparency, accountability
  - Risk and science-based approach to food safety
- Partnership
  - Multi-stakeholder approach, partnership
- Health, nutrition trends
  - Food safety objectives part of public health objectives
- Long-term sustainability

Evidence-informed policy/decision making in food safety
Evidence-informed approach: Systematic review-meta-analysis

Case study: Salmonella in chicken

Study rationale

- **Chicken: main source of *Salmonella***
- **Canada/Ontario (CIPARS, 08)**
  - Serovar overlap?
  - **Humans**
    - Typhimurium, Enteritidis, Heidelberg
  - **Chicken (abattoir)**
    - Kentucky, Enteritidis, Typhimurium
  - **Chicken (retail):**
    - Kentacky, Enteritidis, Typhimurium
- **Control options**
  - Different
  - Experts disagree
- **International risk management guidelines**
  - WHO/FAO/Codex Committee for Food Hygiene
- **Need to assess intervention effectiveness (farm to processing)**
  - Optimal combination of interventions?
Evidence-informed approach

• Knowledge synthesis and translation science
• Long tradition in health sector
• Systematic review-meta-analysis
  – Transparent and replicable methodology
  – ‘All available knowledge’ rather than a single study
  – Frequently used to evaluate
    • Intervention efficacy
    • Diagnostic test accuracy, risk factor consistency, prevalence extent
  – Identify knowledge gaps, inform future research

Study objective

• Evaluate all publicly available primary research investigating the efficacy of various interventions, from farm to processing, for *Salmonella* in broiler chicken
  – Using evidence mapping, systematic review and meta-analysis methodology (SR-MA)
    • Which specific interventions are effective or more promising?
    • Overall quality and relevance of publicly available intervention research knowledge
Evidence-informed approach

Review team
Protocol/Broad topic
Salmonella, Broilers
Interventions/Risk factors/Prevalence

Literature search
Simple algorithm
5 Databases/Verification

Characterization
Intervention type
PIC/Time period
Outcome
Continent

Relevance
Intervention
Risk factor
Prevalence

Evidence maps
Prioritize questions

Evidence-informed approach

MA/MR
Intervention
Outcome
Study design

DE
By sub-topic

SR/QA
By study design

Evidence summary

RS 2
978 studies

Interventions
748 studies

Risk factors
30 studies

Prevalence
200 studies
CE evidence summary

- 18% published after 2000
- 69% conducted in Canada/USA
- 96% used day old chicks
- 78% CE administered one time only
- 72% only received CE treatment
- 28% in combination with:
  - Other additives (66%)
  - Vaccination (15%)
  - Antimicrobials (11%)
  - Feed withdrawal (7%)
  - Bacteriophages (1%)
- 15 unique products
- 9 routes of administration
  - Oral gavage (65%)
- 16 sample types
  - Cecal contents (28%)
- Time outcome measured
  - Range 1-13 weeks
  - 8-14 days post-treatment (28%)
- Serovar
  - Typhimurium (47%)
  - Enteritidis (29%)
  - Infantis (13%)

(n=2,789 trials)
### Studied CE products

<table>
<thead>
<tr>
<th>CE TYPE</th>
<th>FREQUENCY</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undefined, chicken source</td>
<td>1743</td>
<td>62.5</td>
</tr>
<tr>
<td>Other</td>
<td>304</td>
<td>10.9</td>
</tr>
<tr>
<td>Containing lactobacillus</td>
<td>200</td>
<td>7.17</td>
</tr>
<tr>
<td>Undefined, unknown source</td>
<td>95</td>
<td>3.41</td>
</tr>
<tr>
<td>Aviguard</td>
<td>76</td>
<td>2.72</td>
</tr>
<tr>
<td>Vermicompost</td>
<td>69</td>
<td>2.47</td>
</tr>
<tr>
<td>FM-B11</td>
<td>67</td>
<td>2.40</td>
</tr>
<tr>
<td>Broilact</td>
<td>66</td>
<td>2.37</td>
</tr>
<tr>
<td>Primilac</td>
<td>47</td>
<td>1.69</td>
</tr>
<tr>
<td>CF3</td>
<td>43</td>
<td>1.54</td>
</tr>
<tr>
<td>Avian Pac Plus</td>
<td>30</td>
<td>1.08</td>
</tr>
<tr>
<td>Preempt</td>
<td>24</td>
<td>0.86</td>
</tr>
<tr>
<td>MSC</td>
<td>11</td>
<td>0.39</td>
</tr>
<tr>
<td>Simbiotico</td>
<td>8</td>
<td>0.29</td>
</tr>
<tr>
<td>Avifree</td>
<td>6</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>2789</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

### Efficacy of CE: Meta-Analysis

#### Prevalence Outcome

<table>
<thead>
<tr>
<th>Publication date</th>
<th>OR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-42 days</td>
<td>0.05 (0.04, 0.07)</td>
<td>0.04</td>
</tr>
<tr>
<td>Overall</td>
<td>0.05 (0.04, 0.07)</td>
<td>0.03</td>
</tr>
</tbody>
</table>

#### Concentration Outcome

<table>
<thead>
<tr>
<th>Publication date</th>
<th>OR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-42 days</td>
<td>-2.83 (-3.09, -2.57)</td>
<td>0.02</td>
</tr>
<tr>
<td>Overall</td>
<td>-2.83 (-3.09, -2.57)</td>
<td>0.01</td>
</tr>
</tbody>
</table>
More intuitive knowledge translation

• *CF3 reduced the risk of Salmonella colonization by 47% out of 100 chickens treated with CE when compared to the control group*

• *On average CF3 reduced Salmonella in treated broiler groups by $2.83 \log_{10} \text{cfu/g}$ of cecal material when compared to the control group*

### Chilling evidence summary

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th># studies</th>
<th># trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study design</td>
<td>Controlled trials</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Challenge trials</td>
<td>8</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>Before-and-after (no challenge)</td>
<td>7</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Before-and-after (challenge)</td>
<td>9</td>
<td>46</td>
</tr>
<tr>
<td>Setting</td>
<td>Laboratory</td>
<td>7</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>Pilot</td>
<td>9</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Commercial</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Chilling types</td>
<td>Immersion with agitation</td>
<td>17</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Immersion no agitation</td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Air</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Simulated / Other</td>
<td>3</td>
<td>123</td>
</tr>
<tr>
<td>Disinfectants</td>
<td>Chlorine</td>
<td>10</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>Acetic acid</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Lactic acid</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Potable water</td>
<td>6</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>20</td>
<td>99</td>
</tr>
</tbody>
</table>

*Only some data shown*
Efficacy of immersion chilling with agitation-chlorine: Meta-analysis

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>OR (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stopforth et al., 2007</td>
<td>1.40 (0.55, 3.60)</td>
<td>17.52</td>
</tr>
<tr>
<td>James et al., 1992</td>
<td>0.33 (0.17, 0.63)</td>
<td>20.25</td>
</tr>
<tr>
<td>Knivett, 1971</td>
<td>0.02 (0.00, 0.50)</td>
<td>4.86</td>
</tr>
<tr>
<td>Knivett, 1971</td>
<td>0.03 (0.00, 0.72)</td>
<td>4.93</td>
</tr>
<tr>
<td>Knivett, 1971</td>
<td>1.00 (0.02, 55.27)</td>
<td>3.17</td>
</tr>
<tr>
<td>Knivett, 1971</td>
<td>0.07 (0.01, 0.84)</td>
<td>7.06</td>
</tr>
<tr>
<td>Knivett, 1971</td>
<td>0.01 (0.00, 0.21)</td>
<td>4.37</td>
</tr>
<tr>
<td>Bauermeister et al., 2008</td>
<td>0.36 (0.21, 0.62)</td>
<td>21.21</td>
</tr>
<tr>
<td>Northcutt et al., 2000</td>
<td>0.89 (0.31, 2.44)</td>
<td>16.63</td>
</tr>
<tr>
<td>Overall (I-squared = 65.1%, p = 0.003)</td>
<td>0.31 (0.15, 0.68)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

NOTE: Weights are from random effects analysis

Before-and-after Trials (ChT)

Summary: some on-farm practices

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Promising practices</th>
<th>Efficacy est./CI</th>
<th>CGR</th>
<th>PTR</th>
<th>GR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitive exclusion</td>
<td>Preempt</td>
<td>OR=0.05 (0.04, 0.07) / MD range -0.12, 6.43</td>
<td>72%</td>
<td>11%</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>FM-B11</td>
<td>OR=0.13 (0.1, 0.18)† / MD range 0.05, 3.19</td>
<td>81%</td>
<td>36%</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>Broilact</td>
<td>OR=0.06 (0.02, 0.17)†</td>
<td>2.78</td>
<td>n/a</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>33%</td>
<td>3%</td>
<td>***</td>
</tr>
<tr>
<td>Feed/water additives</td>
<td>Organic acids</td>
<td>OR range 0.00, 7.67</td>
<td>28%</td>
<td>1-26%</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>Lactose</td>
<td>OR=0.22 (0.13, 0.37) / MD range -0.53, 6.60</td>
<td>94%</td>
<td>77%</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6.10</td>
<td>n/a</td>
<td>*</td>
</tr>
<tr>
<td>Vaccination</td>
<td>Live ST</td>
<td>OR 0.21 (0.06, 0.77) / OR range 0.09, 1.75 / OR range 0.15, 0.87</td>
<td>21%</td>
<td>1%</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>Killed SE</td>
<td></td>
<td>50%</td>
<td>8-64%</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>Killed SE + ST</td>
<td></td>
<td>78%</td>
<td>35-76%</td>
<td>**</td>
</tr>
<tr>
<td>Bio-security</td>
<td>H₂O₂ eggs</td>
<td>OR=0.13 (0.06-0.30)†</td>
<td>75%</td>
<td>28%</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>PHMB/eggs</td>
<td>OR=0.07 (0.02-0.30)†</td>
<td>68%</td>
<td>12%</td>
<td>**</td>
</tr>
</tbody>
</table>

OR=odds ratio; MD=mean difference; †=significant heterogeneity; GR=GRADE=* very low quality to **** high quality evidence; CGR=control group risk; PTR=predicted treated risk; n/a= not applicable
### Summary: some processing practices

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Promising practice</th>
<th>Efficacy est./CI</th>
<th>CGR</th>
<th>PTR</th>
<th>GR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carcass sprays</td>
<td>Potable water</td>
<td>MD range 0.01, 1.59</td>
<td>6.55</td>
<td>n/a</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Trisod. phosphate 10%</td>
<td>MD=1.31 (0.7, 1.92)†</td>
<td>5.94</td>
<td>n/a</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Cetylpyrid. chloride 0.1%</td>
<td>MD=0.85 (0.51, 1.18)†</td>
<td>6.10</td>
<td>n/a</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Lactic acid 1%</td>
<td>MD=0.91 (0.55, 1.27)†</td>
<td>5.80</td>
<td>n/a</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Sodium bisulfate</td>
<td>MD range 0.97, 2.58</td>
<td>5.01</td>
<td>n/a</td>
<td>*</td>
</tr>
<tr>
<td>Carcass dips</td>
<td>Lactic acid</td>
<td>OR range 0.001, 0.51</td>
<td>59%</td>
<td>4%</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>Trisodium phosphate</td>
<td>OR 1.16 (0.59, 2.26)</td>
<td>20%</td>
<td>22%</td>
<td>***</td>
</tr>
<tr>
<td>Chilling</td>
<td>Air chilling</td>
<td>OR=0.7 (single trial)</td>
<td>25%</td>
<td>18%</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>Immersion/agitation + H₂O</td>
<td>OR=0.08 (0.04, 0.17)</td>
<td>84%</td>
<td>29%</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>Immersion/agitation + Cl</td>
<td>OR range 0.02, 49.63</td>
<td>52%</td>
<td>2-98%</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>Immersion + cl</td>
<td>OR range 0.02, 1.5</td>
<td>61%</td>
<td>3-70%</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>Immersion + LA acid</td>
<td>OR range 0.004, 0.05</td>
<td>79%</td>
<td>2-16%</td>
<td>***</td>
</tr>
</tbody>
</table>

OR=odds ratio; MD=mean difference; †=significant heterogeneity; GR=GRADE=* very low quality to **** high quality evidence; CGR=control group risk; PTR=predicted treated risk; n/a= not applicable

### Modelling control options

**SOURCE** → **INPUTS** → **MODULES** → **OUTPUTS**

- **SOURCE**
  - Individual studies
  - SR-MA

- **INPUTS**
  - WF/BF Prevalence
  - Competitive exclusion
  - Lactose water additive
  - Prior flock carry-over
  - Within-flock spread

- **MODULES**
  - FARM
    - Externally contaminated? Y/N
  - TRANSPORT
    - Contaminated post-transport? Y/N
    - CFU on exterior post-transport
  - PROCESSING
    - Contaminated? Y/N
    - Scalding
    - Defeathering
    - Evisceration
    - Post evisc. wash
    - Pre-chill spray
    - Chilling

- **OUTPUTS**
  - CFU post-scald
  - CFU post-feathering
  - CFU post-evisceration
  - CFU post-evisceration wash
  - CFU post-spray
  - CFU post-chill
Model scenarios

• Two baseline populations/fresh & frozen product market

• Farm interventions (WFP)
  – CE culture CF3, 2-2.5% lactose water additive

• Processing intervention package (CFU/carcass)
  – 1% NaOH scald water additive, 500ppm Cl₂ post-evisceration spray, 10% TSP pre-chill spray, 20ppm Cl₂ chilling or air chilling

• Single farm + processing intervention package
  – CF3 + scalding, post-evisceration spray + pre-chill spray + chilling

• Hypothetical reductions
  – 50% reduction in flock-level prevalence
  – 50% reduction in Salmonella cfu/carcass post-transport

• Sensitivity analysis: relative impact/model parameters

Intervention impact/\textit{Salmonella} prevalence
(Broiler carcasses/fresh product market/+ve flocks)
Food safety intervention research

- Overall, globally and within Canada:
  - Lack of robust, powerful research
    - Both at the farm and processing level
    - This applies to other priority food safety pathogens
    - Lack of large, well-designed and reported field trials for all interventions
    - Lack of specific bio-security intervention protocols
    - Lack of strong contextual research
  - Food safety research: Priority?
    - Verbal priority vs. really funded research priority
    - Funding multi-disciplinary teams?
  - Empirical evidence, proprietary data?
  - Importance of multi-stakeholder partnership, multi-disciplinary knowledge sharing approach
Future of *Salmonella* control

- *International trends* indicate:
  - Burden of salmonellosis can be reduced in humans
  - Pathogen reduction plans
    - multi-faceted control options at the most critical stages in the food chain/importance of contextual relevance
- Incremental risk reduction is possible
  - with continuous modification of surveillance approaches
  - sustainability?
- Public health objectives
  - Food safety objectives (FSO)
    - Tolerable levels of the pathogens and regular review of FSO

Impact on Canada

- *International trends*
  - EU, USA
    - Stringent standards
  - Market demands
  - Consumer pressures

- *Options*
  - Do nothing?
  - React if/when necessary
    - Adopt / modify approaches from others
  - Pro-active
    - Develop own policy?
Acknowledgements

All reviewers, collaborators, OMAFRA, PIC and PHAC for funding