CA18105

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Risk-based meat inspection and integrated meat safety assurance

RIBMINS WG2/WG3 Training school: Farm and abattoir interventions in a risk-based meat safety assurance system

Dragan Antic | 29-Jun-22 | virtual, UK

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Funded by the 2020 Framework Programme of the European Union

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WG3 Abattoir level: controls + risk categorization

- Results from ongoing work -

leader:

Dragan Antic
[Univ. of Liverpool | UK]

vice-leader:

Kurt Houf
[Univ. Gent | BE]

WG3 Specific objectives

Controls:

- 3.1 Assessment of effectiveness of new tools | methods for detection of carcass contamination
- 3.2 Assessment of the significant intervention strategies and alternative methods for the slaughtering | the carcass dressing

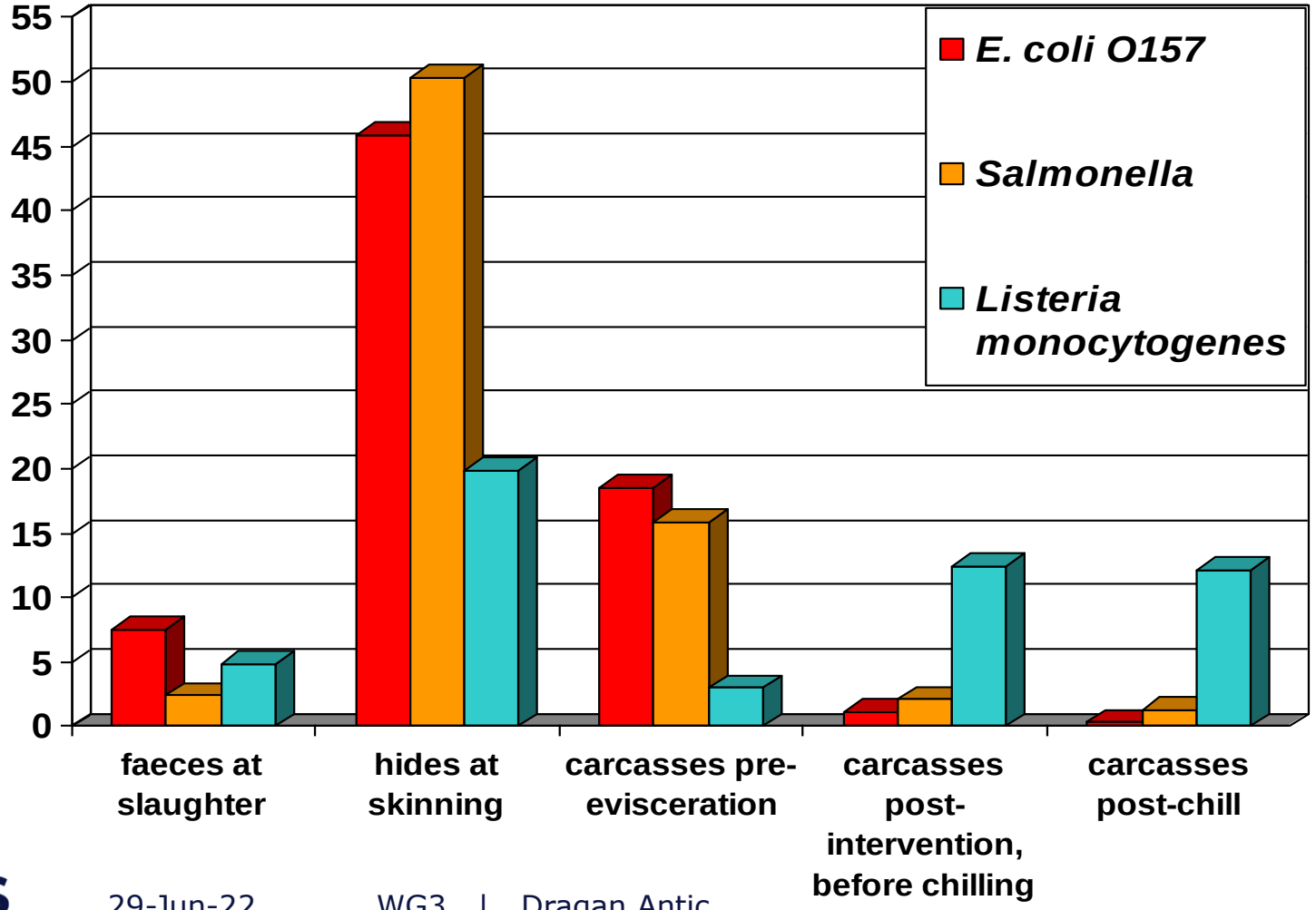
Years 1 & 2

Risk categorisation:

- 3.3 Assessment of the performance of food safety management systems
- 3.4 Harmonised Epidemiological Indicators in risk categorisation of abattoirs

Years 3 & 4

Prevalence of the main foodborne pathogens at abattoir
(mean prevalence from selected studies)



WG3 ongoing activities

- performing systematic literature reviews coupled with meta-analysis on:
  - interventions for the reduction of bacterial load on **pig** | **beef** | **sheep** | **chicken** carcasses at abattoirs

Meat Science 182 (2021) 108622

Contents lists available at ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

Review

Beef abattoir interventions in a risk-based meat safety assurance system

Dragan Antic [a,*], Kurt Houf [b], Eleni Michalopoulou [a], Bojan Blagojevic [c]

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Article

Systematic review and meta-analysis of the efficacy of interventions applied during primary processing to reduce microbiological contamination on pig carcasses

Nevijo Zdolec [1], Aurelia Kotsiri [2], Kurt Houf [3], Avelino Alvarez-Ordóñez [4], Bojan Blagojevic [5], Nedjeljko Karabasil [6], Morgane Salines [7] and Dragan Antic [2*]

WG3 Recommendations for risk management decisions

LTTC burgers (FSA Board, March 2020)

- "it can be expected that the 4 logs performance criterion can be achieved in the minced beef production chain, at the FBOs which supply meat for LTTC burgers"
- "most promising interventions to reduce microbial load on beef: cattle **hide** interventions (including FSA's '**clean livestock** policy'), carcass **pasteurisation** treatments and **organic acid** washes ... **multiple** interventions reduce microbiological load by up to 3 log (99.9%)"
- recommendations: the sequential use of general hygiene practice and hazard-based interventions at the pre-slaughter, slaughter and post-slaughter stages, as an integral part of intervention-based HACCP


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[c] University of Novi Sad, Faculty of Agriculture, Department of Veterinary Medicine, Trg D. Obradovica 8, 21000 Novi Sad, Serbia

WG3 Interventions

- Interventions are actions taken during slaughter and processing to reduce microbial contamination of carcasses
- Hazard based interventions:
  - Any intervention that has a significant and persistent effect in reducing carcass microbial contamination
  - Cattle hide interventions: chemical washes with vacuuming and immobilisation treatments
  - Carcass interventions: thermal interventions (hot water washes, pasteurisation treatments), organic acid washes
- GHP-based control measures:
  - lack of evidence (e.g. cattle hide removal practices, bunging/rodding);
  - have shown inconsistent results in reducing microbial contamination (particularly in respect to pathogens, e.g. hide cleanliness assessment, hide clipping, chilling);
  - no processing parameters can be clearly established (e.g. environment sanitation, equipment and tools sanitation, and trimming)
  - Steam vacuuming ? – rely on due diligence, manual application

Interventions - legislation

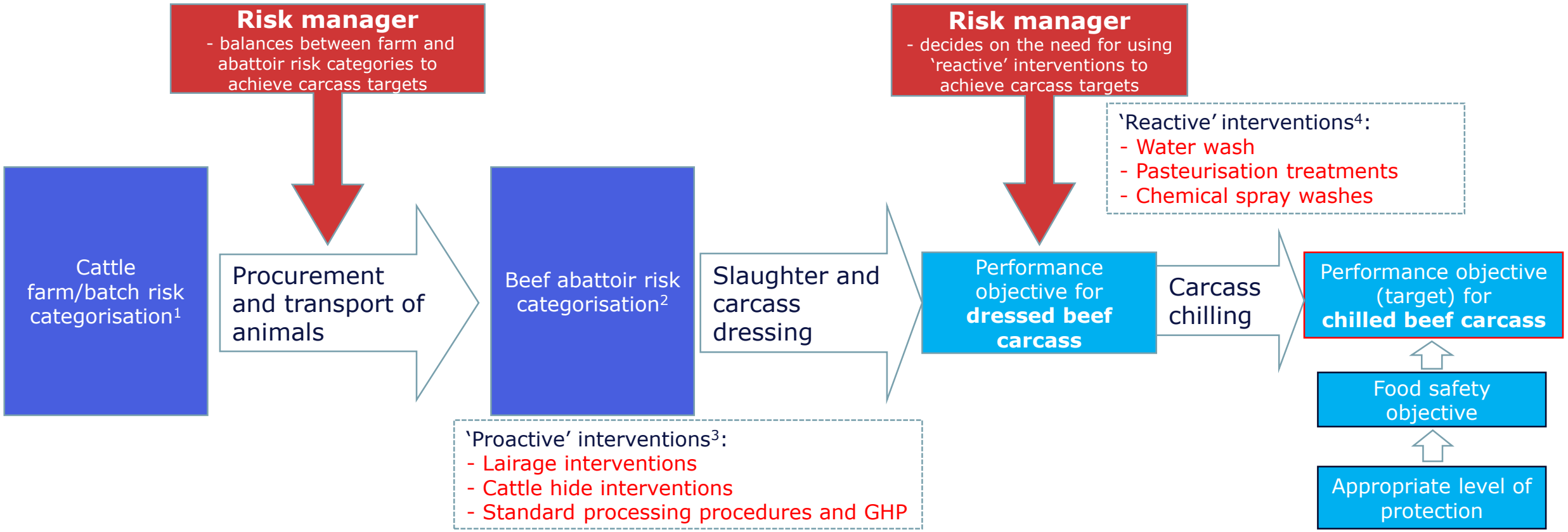
EU (Regulation (EC) No. 853/2004: Interventions with substances other than potable water are permissible but subject to regulatory authorisation and following a risk assessment by the EFSA

Regulation 101/2013 allows the use of lactic acid to reduce microbiological surface contamination on bovine carcases

However,

Good Hygiene Practice must be implemented first, as interventions must not be a substitute for GHP, only an additional measure

WG3 Risk-based meat safety assurance system (RB-MSAS)



[1]grouping in high or low risk categories based on food chain information/epidemiological indicators (e.g. high risk are those with high *Salmonella* and/or VTEC prevalence)
[2]grouping in high or low risk categories based on process hygiene criteria/epidemiological indicators (e.g. high risk are those with poor process hygiene, i.e. GMP/GHP and HACCP-based procedures not sufficient to meet PHC or other targets)
[3] aimed at preventing carcass microbial contamination: help to "lower" abattoir risk category at the same time
[4] aimed at removing/eliminating hazards from carcasses: applied only in "high risk scenario" (high risk farm + high risk abattoir), i.e. when targets cannot otherwise be met

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WG3 Interventions – reducing the food safety risks

- Average probability of illness per serving of ground beef, non-intact beef cuts, and intact beef cuts for each beef intervention scenario as determined using Monte Carlo simulation

- Public health risks, expressed as average probability of illness per serving, were reduced by:
  - 31%-72% - for single pre-harvest interventions (on farm)
  - 44%-96%, - for single processing interventions (at slaughter)
  - 95%-99.9% - for combinations of interventions (both on farm and at slaughter)

  relative to a worst-case scenario where no interventions were applied

Food Control 29 (2013) 364–381

Contents lists available at SciVerse ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

A risk assessment model for *Escherichia coli* O157:H7 in ground beef and beef cuts in Canada: Evaluating the effects of interventions

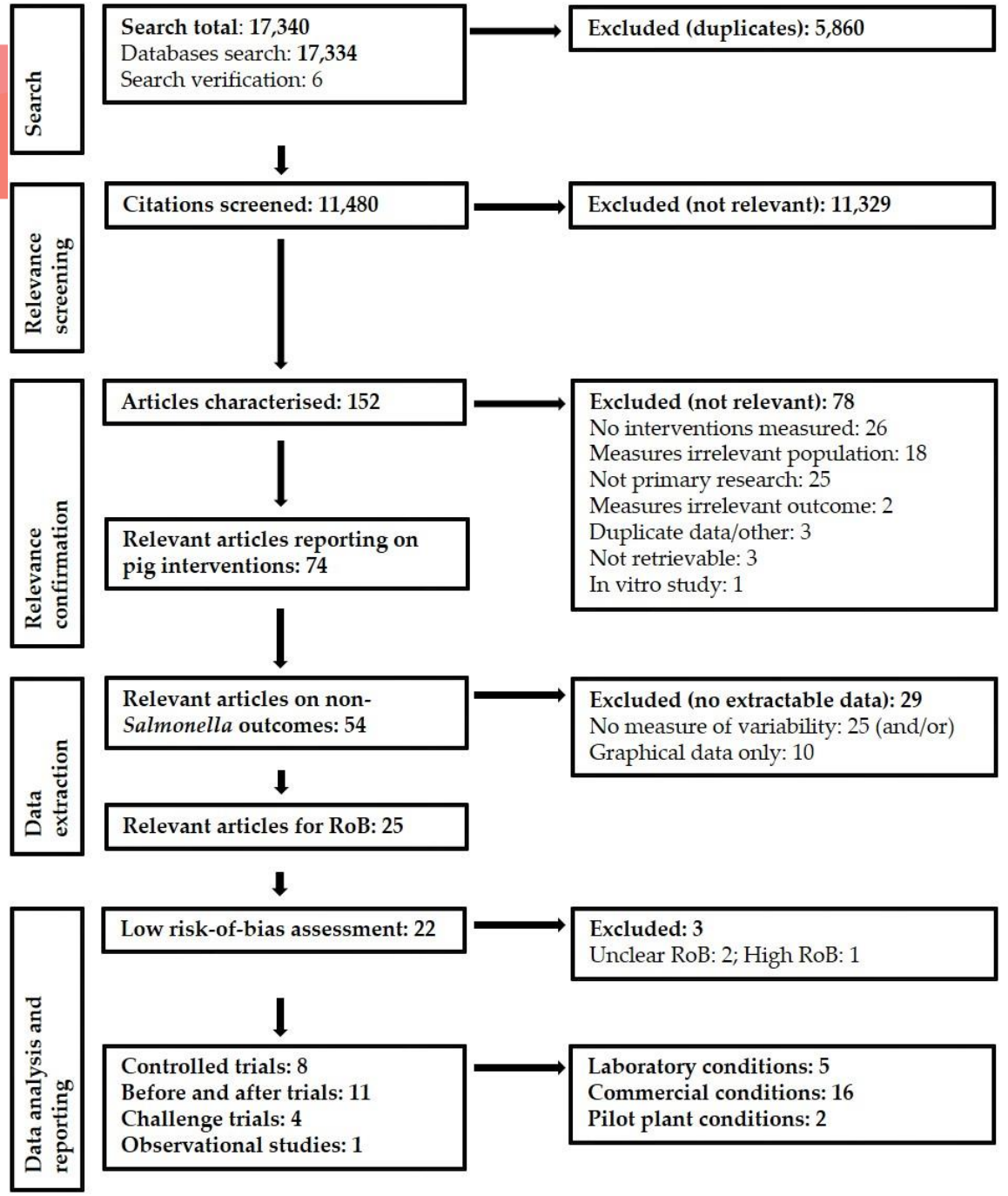
Ben A. Smith*, Aamir Fazil, Anna M. Lammerding

Science to Policy Division, Laboratory for Foodborne Zoonoses, Public Health Agency of Canada, 206-160 Research Lane, Guelph, Ontario, Canada N1G 5B2

Intervention type	Scenario (Sc.)	Description	Average probability of illness		
			Ground beef	Non-intact beef cuts	Intact beef cuts
None	1	No Interventions	1.78×10^{-4}	6.97×10^{-7}	6.00×10^{-8}
Single	2	Probiotics	9.62×10^{-5}	4.31×10^{-7}	3.71×10^{-8}
	3	SRP vaccine	1.23×10^{-4}	4.39×10^{-7}	3.88×10^{-8}
	4	Type III protein vaccine	6.77×10^{-5}	2.69×10^{-7}	1.67×10^{-8}
	5	Carcass wash (≤50 °C)	9.71×10^{-5}	3.88×10^{-7}	3.36×10^{-8}
	6	Hot water wash (>85 °C)	4.13×10^{-5}	1.29×10^{-7}	1.12×10^{-8}
	7	Pre-wash intervention followed by wash	5.74×10^{-5}	2.08×10^{-7}	1.83×10^{-8}
	8	Steam pasteurization	4.37×10^{-5}	1.55×10^{-7}	1.28×10^{-8}
	9	Acid spray chill	1.36×10^{-5}	3.13×10^{-8}	2.08×10^{-9}
	10	Dry-aged chill	5.37×10^{-5}	1.70×10^{-7}	1.45×10^{-8}
	11	Water spray chill	1.90×10^{-4}	8.84×10^{-7}	6.68×10^{-8}
Combination	12	Current Practices	8.66×10^{-6}	3.29×10^{-8}	2.92×10^{-9}
	13	Sc. 12 + Probiotics	3.75×10^{-6}	2.39×10^{-8}	2.76×10^{-9}
	14	Sc. 12 + SRP vaccine	3.81×10^{-6}	1.52×10^{-8}	1.15×10^{-9}
	15	Sc. 12 + Type III protein vaccine	1.90×10^{-6}	1.14×10^{-8}	4.62×10^{-10}
	16	Pre-evis. Hot water wash + post-evis. Hot water wash + Acid spray chill	5.15×10^{-6}	4.67×10^{-9}	5.64×10^{-10}
	17	Pre-evis. Hot water wash + post-evis. Hot water wash + post-evis. Steam pasteurization + Acid spray chill	3.99×10^{-6}	2.59×10^{-9}	3.22×10^{-10}
	18	Sc. 17 + Probiotics	2.09×10^{-6}	1.20×10^{-9}	1.61×10^{-10}
	19	Sc. 17 + SRP vaccine	2.09×10^{-6}	1.14×10^{-9}	1.32×10^{-10}
	20	Sc. 17 + Type III protein vaccine	6.71×10^{-7}	8.06×10^{-10}	6.33×10^{-11}

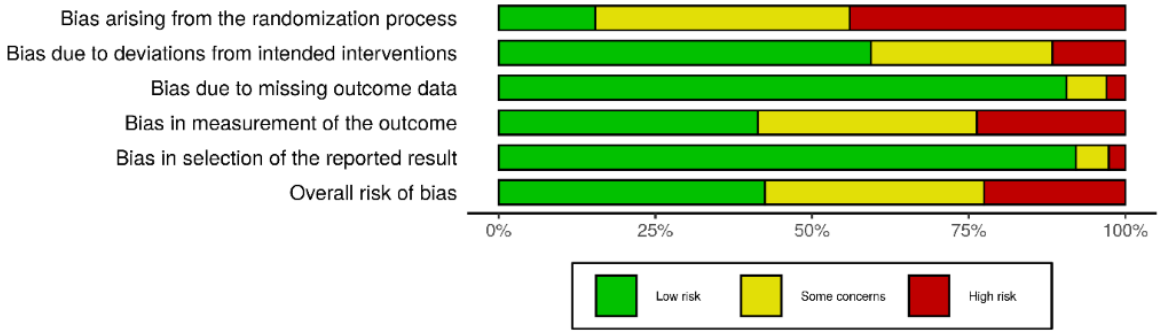
WG3 Methodology

- Systematic reviews:
  - PICO framework,
  - From lairage to chilled carcasses
  - Scopus & CAB Direct (1990-2021), SciELO (2002-2021)
  - All stages, two reviewers, third to resolve discrepancies
  - Risk of bias performed to see which studies are suitable for meta-analysis
- Meta-analysis:
  - Data stratified by study design/conditions, intervention (sub)category, outcomes and measures (prevalence, concentration: mean log CFU)
  - Meta-analysis performed when an intervention group had three or more trials with a low risk of bias
  - A mixed-effects model was used to create pooled summary statistics and then presented as Forest plots.
  - Tests for heterogeneity of study groups were performed.



WG3 Results – Risk of Bias and MA grade

- Relevant studies were identified, and then
  - 'low risk of bias' studies selected for meta-analysis.
- Three or more trials – forest plots generated:
  - with meta-analysis summary effects
- Test for heterogeneity:
  - homogenous ($p>0.05$ on the test for heterogeneity),
  - moderately heterogeneous ($p<0.05$, $I^2<=60\%$),
  - highly heterogeneous ($p<0.05$, $I^2>60\%$).
- Meta-analysis grade:
  - Significant positive effect
  - No effect
  - Significantly homogenous studies



WG3 Beef interventions (progressed to meta-analysis)

- **Lairage interventions**
- Lairage cleaning
- Cattle handling in lairage
- Hide cleanliness assessment
- Pre-slaughter cattle hide interventions (washing, clipping, bacteriophage spray)

- **Cattle hide interventions**
- Water wash
- Chemical wash (organic acids, chlorine, sanitiser)
- Chemical dehairing, thermal
- Shellac hide coating

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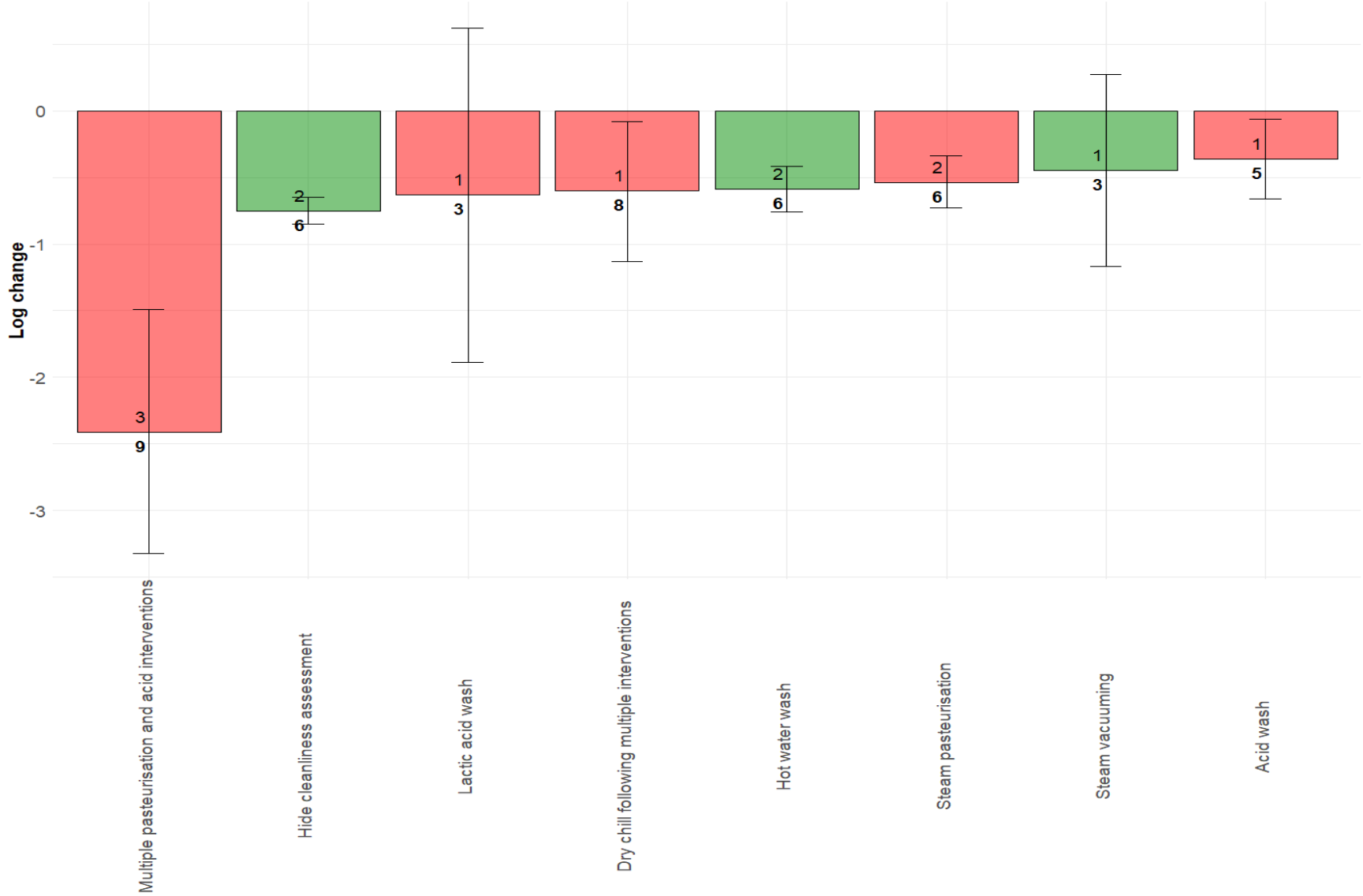
- **Beef carcass interventions**
- SPP & GHP:
  - knives sanitation; hide removal; bung bagging
- Pre-chill carcass treatments:
  - Water wash
  - Knife trimming
  - Hot water wash
  - Steam pasteurisation
  - Steam vacuuming
  - Lactic acid wash
  - Other organic acids wash
  - Other chemicals
- Chilling
  - Dry chilling
  - Dry aging
  - Water spray chilling
  - Spray chilling with chemicals
- Multiple interventions
  - Pasteurisation and acid washes

WG3 Results – overall beef carcass interventions for **generic** *E. coli*

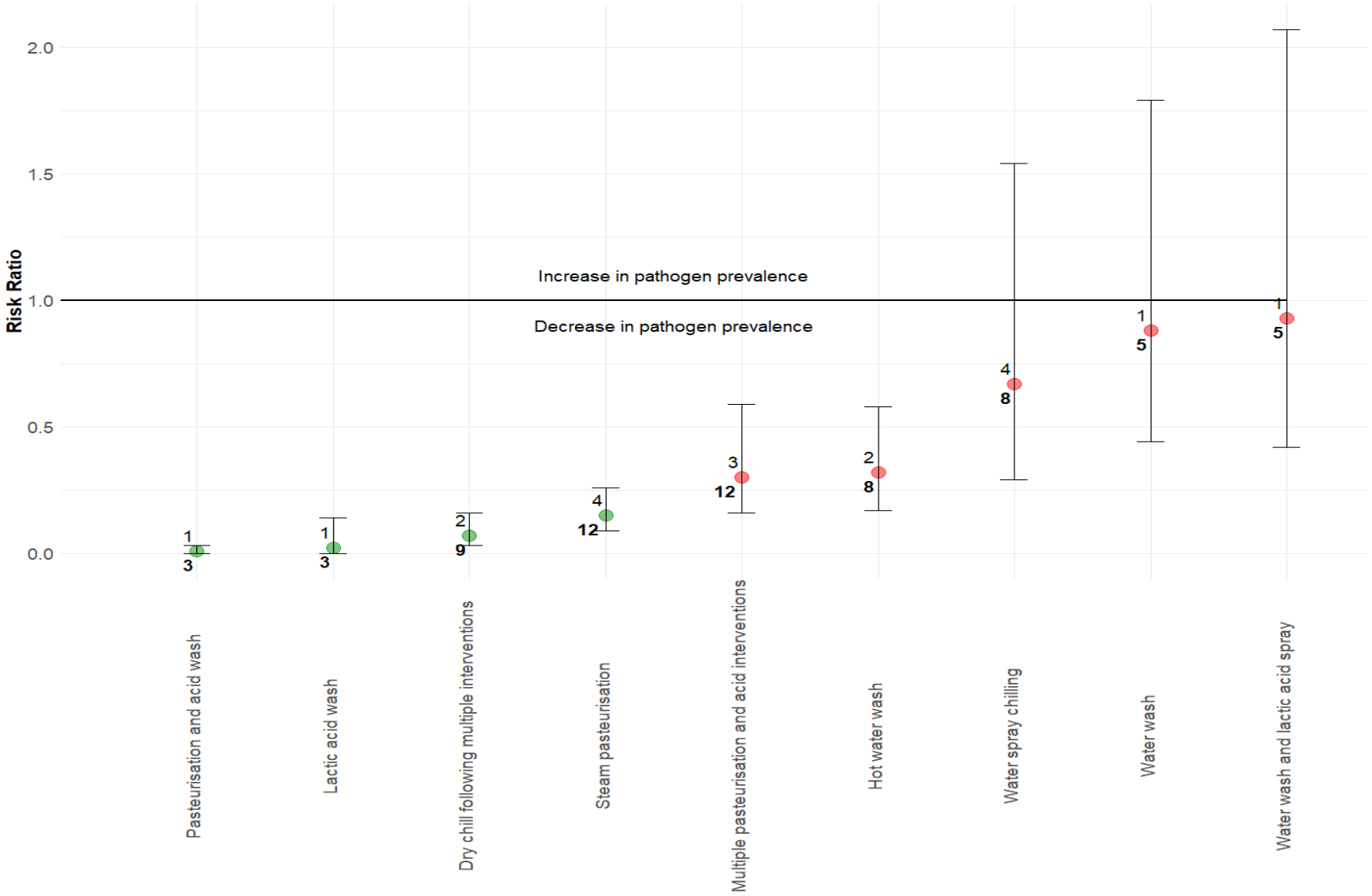


A comparison of meta-analyses of cattle hide and beef carcass processing interventions on **generic *E.coli* counts** (pooled **log** change) on beef carcasses under **commercial abattoir** conditions

Green: Homogenous trials
Red: Heterogeneous trials

Numbers in bar chart:
Top number = Number of studies,
Bottom number = Number of trials

WG3 Results – overall beef carcass interventions for **generic** *E. coli*

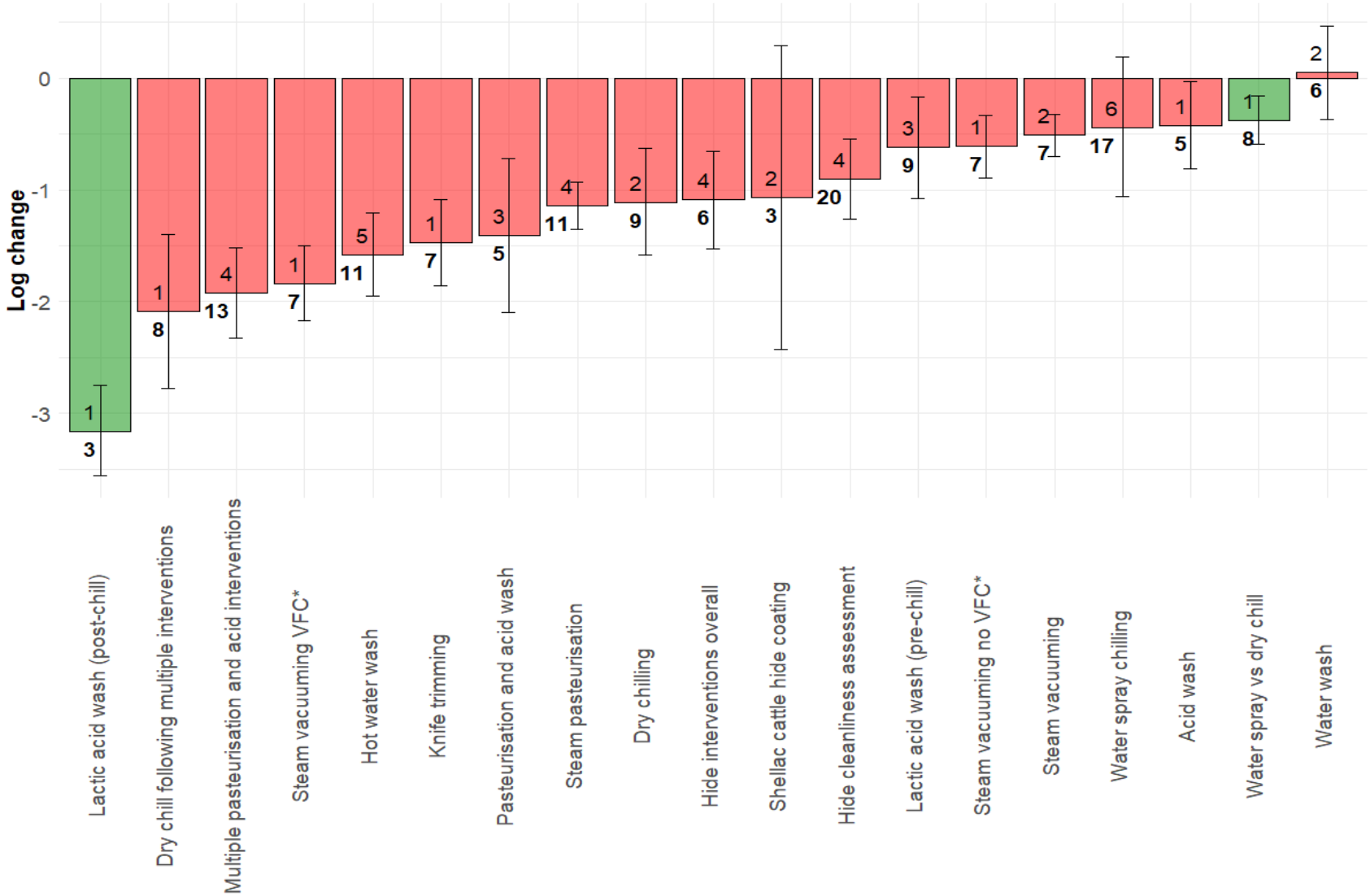


A comparison of meta-analyses of beef carcass processing interventions on **generic *E.coli* prevalence** (pooled **risk ratios**) on beef carcasses under **commercial abattoir** conditions

Green: Homogenous trials
Red: Heterogeneous trials

Numbers in bar chart:
Top number = Number of studies,
Bottom number = Number of trials

WG3 Results – overall beef carcass interventions for **ACC**



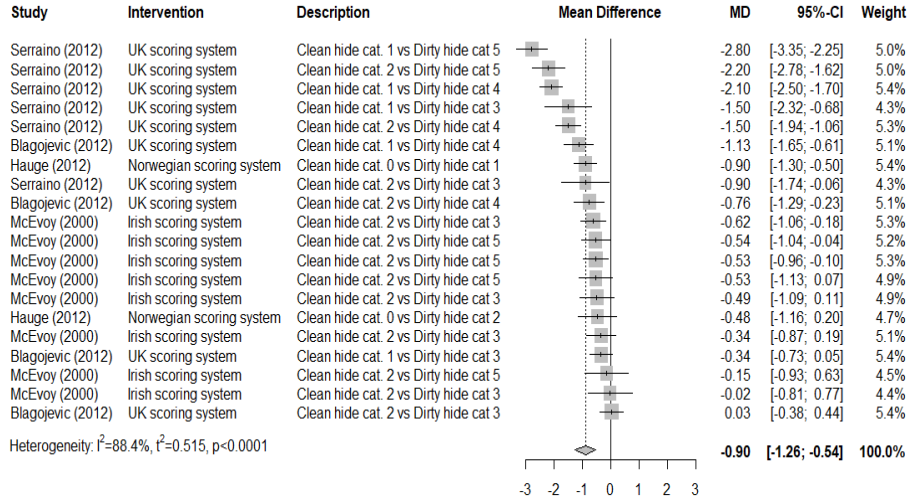
A comparison of meta-analyses of cattle hide and beef carcass processing interventions on **aerobic colony counts** (pooled **log** change) on beef carcasses under **commercial abattoir** conditions

Green: Homogenous trials
Red: Heterogeneous trials

Numbers in bar chart:
Top number = Number of studies,
Bottom number = Number of trials

WG3 Beef abattoir interventions – Hide cleanliness assessments

- Using hide cleanliness scores led to:
  - Aerobic colony count (ACC) reduction:
    - **0.90** log CFU/cm², 95%CI 0.54-1.26, I^2=88.4%
  - Enterobacteriaceae count (EBC) reduction:
    - **0.71** log CFU/cm², 95%CI 0.36-1.05, I^2=88.4%
  - *E. coli* reduction:
    - **0.75** log CFU/cm², 95%CI 0.65-0.85, I^2=0%



Study	Intervention	Description	MD	95%-CI	Weight
Serraino (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 5	-2.80	[-3.35; -2.25]	5.0%
Serraino (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 5	-2.20	[-2.78; -1.62]	5.0%
Serraino (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 4	-2.10	[-2.50; -1.70]	5.4%
Serraino (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 3	-1.50	[-2.32; -0.68]	4.3%
Serraino (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 4	-1.50	[-1.94; -1.06]	5.3%
Blagojevic (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 4	-1.13	[-1.65; -0.61]	5.1%
Hauge (2012)	Norwegian scoring system	Clean hide cat. 0 vs Dirty hide cat 1	-0.90	[-1.30; -0.50]	5.4%
Serraino (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 3	-0.90	[-1.74; -0.06]	4.3%
Blagojevic (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 4	-0.76	[-1.29; -0.23]	5.1%
McEvoy (2000)	Irish scoring system	Clean hide cat. 2 vs Dirty hide cat 3	-0.62	[-1.06; -0.18]	5.3%
McEvoy (2000)	Irish scoring system	Clean hide cat. 2 vs Dirty hide cat 5	-0.54	[-1.04; -0.04]	5.2%
McEvoy (2000)	Irish scoring system	Clean hide cat. 2 vs Dirty hide cat 5	-0.53	[-0.96; -0.10]	5.3%
McEvoy (2000)	Irish scoring system	Clean hide cat. 2 vs Dirty hide cat 5	-0.53	[-1.13; 0.07]	4.9%
McEvoy (2000)	Irish scoring system	Clean hide cat. 2 vs Dirty hide cat 3	-0.49	[-1.09; 0.11]	4.9%
Hauge (2012)	Norwegian scoring system	Clean hide cat. 0 vs Dirty hide cat 2	-0.48	[-1.16; 0.20]	4.7%
McEvoy (2000)	Irish scoring system	Clean hide cat. 2 vs Dirty hide cat 3	-0.34	[-0.87; 0.19]	5.1%
Blagojevic (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 3	-0.34	[-0.73; 0.05]	5.4%
McEvoy (2000)	Irish scoring system	Clean hide cat. 2 vs Dirty hide cat 5	-0.15	[-0.93; 0.63]	4.5%
McEvoy (2000)	Irish scoring system	Clean hide cat. 2 vs Dirty hide cat 3	-0.02	[-0.81; 0.77]	4.4%
Blagojevic (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 3	0.03	[-0.38; 0.44]	5.4%
Heterogeneity: I^2=88.4%, t^2=0.515, p<0.0001			**-0.90**	**[-1.26; -0.54]**	**100.0%**

Mean Difference: -3 -2 -1 0 1 2 3

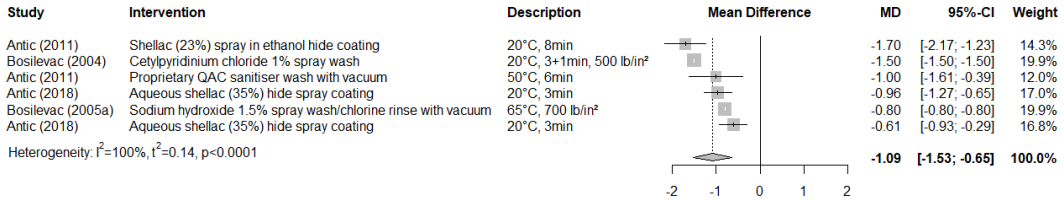
Study	Intervention	Description	MD	95%-CI	Weight
Serraino (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 3	-1.50	[-2.61; -0.39]	5.1%
Serraino (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 3	-1.50	[-2.61; -0.39]	5.1%
Serraino (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 5	-1.10	[-1.56; -0.64]	11.1%
Serraino (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 5	-1.10	[-1.56; -0.64]	11.1%
Blagojevic (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 4	-0.71	[-1.10; -0.32]	11.8%
Serraino (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 4	-0.70	[-1.21; -0.19]	10.5%
Serraino (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 4	-0.70	[-1.21; -0.19]	10.5%
Blagojevic (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 4	-0.68	[-1.17; -0.19]	10.7%
Blagojevic (2012)	UK scoring system	Clean hide cat. 2 vs Dirty hide cat 3	-0.05	[-0.36; 0.26]	12.7%
Blagojevic (2012)	UK scoring system	Clean hide cat. 1 vs Dirty hide cat 3	-0.02	[-0.44; 0.40]	11.5%
Heterogeneity: I^2=74.0%, t^2=0.175, p<0.0001			**-0.71**	**[-1.05; -0.36]**	**100.0%**

Mean Difference: -2 -1 0 1 2

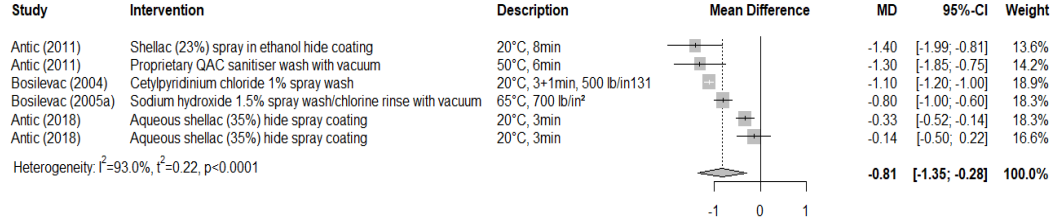
WG3 Beef abattoir interventions – Cattle hide interventions overall

- Under commercial abattoir conditions:
  - Shellac spray hide coating
  - Cetylpyridinium chloride spray wash
  - Sanitizer spray wash
  - Sodium hydroxide spray wash

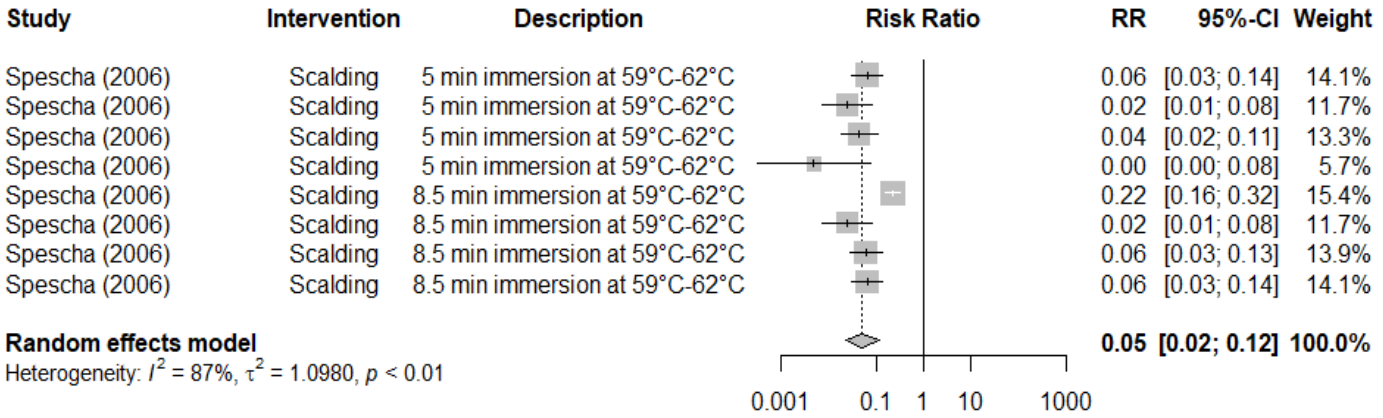
- Together these studies showed:
  - ACC reduction:
    - 1.09 log CFU/cm², 95%CI 0.65-1.53, I^2=100%



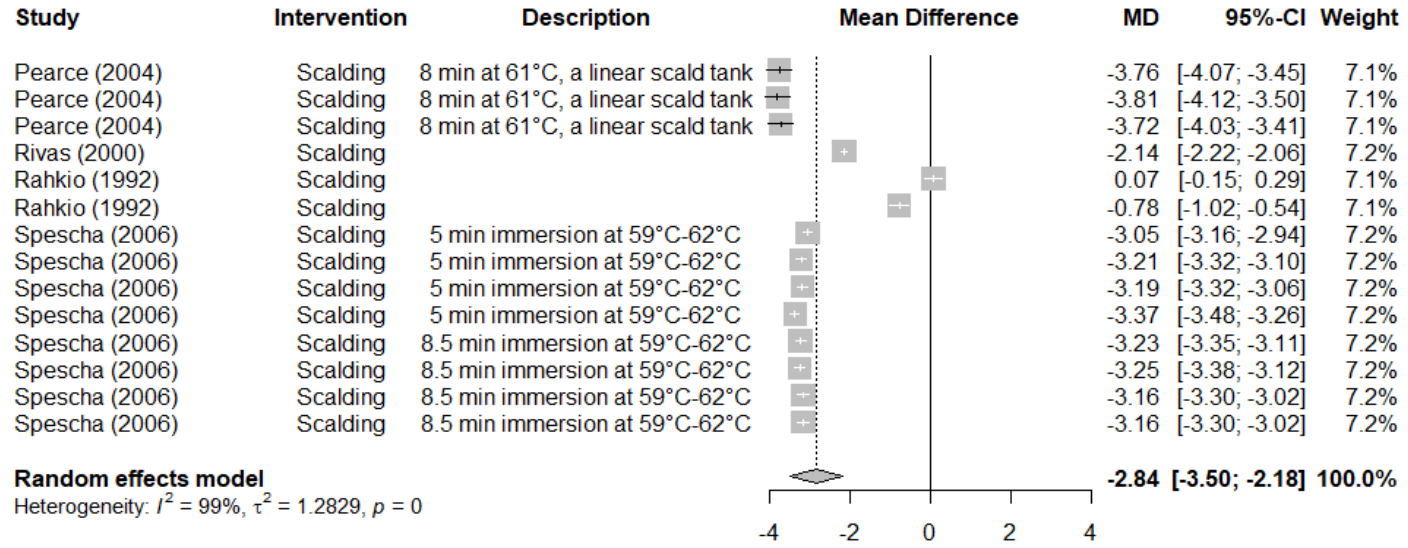
  - EBC reduction:
    - 0.81 log CFU/cm², 95%CI 0.28-1.35, I^2=9



WG3 Results – standard processing procedures: pig **scalding**

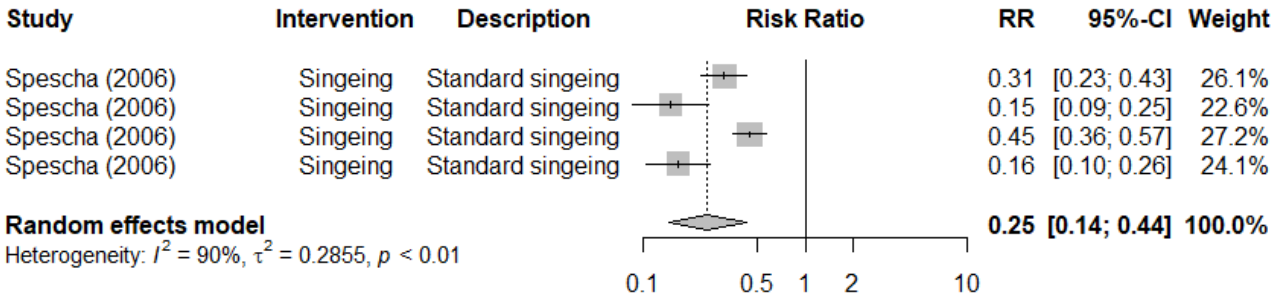


Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of scalding in reducing *Enterobacteriaceae* prevalence on pig carcasses

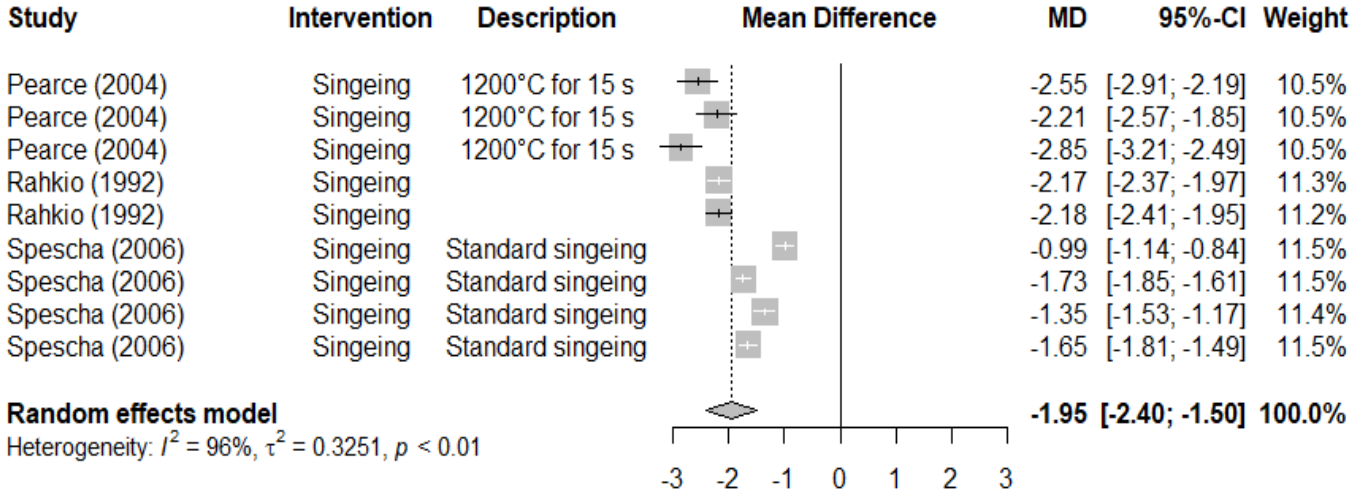


Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of scalding in reducing aerobic colony count (log_{10} CFU) on pig carcasses

WG3 Results – standard processing procedures: pig **singeing**



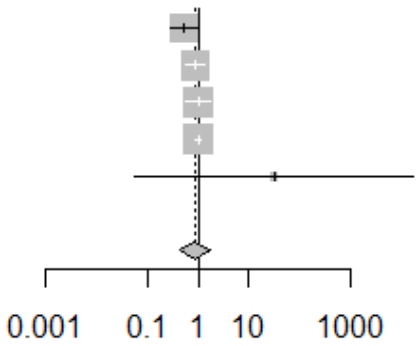
Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of singeing in reducing *Enterobacteriaceae* prevalence on pig carcasses



Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of singeing in reducing aerobic colony count (log_{10} CFU) on pig carcasses

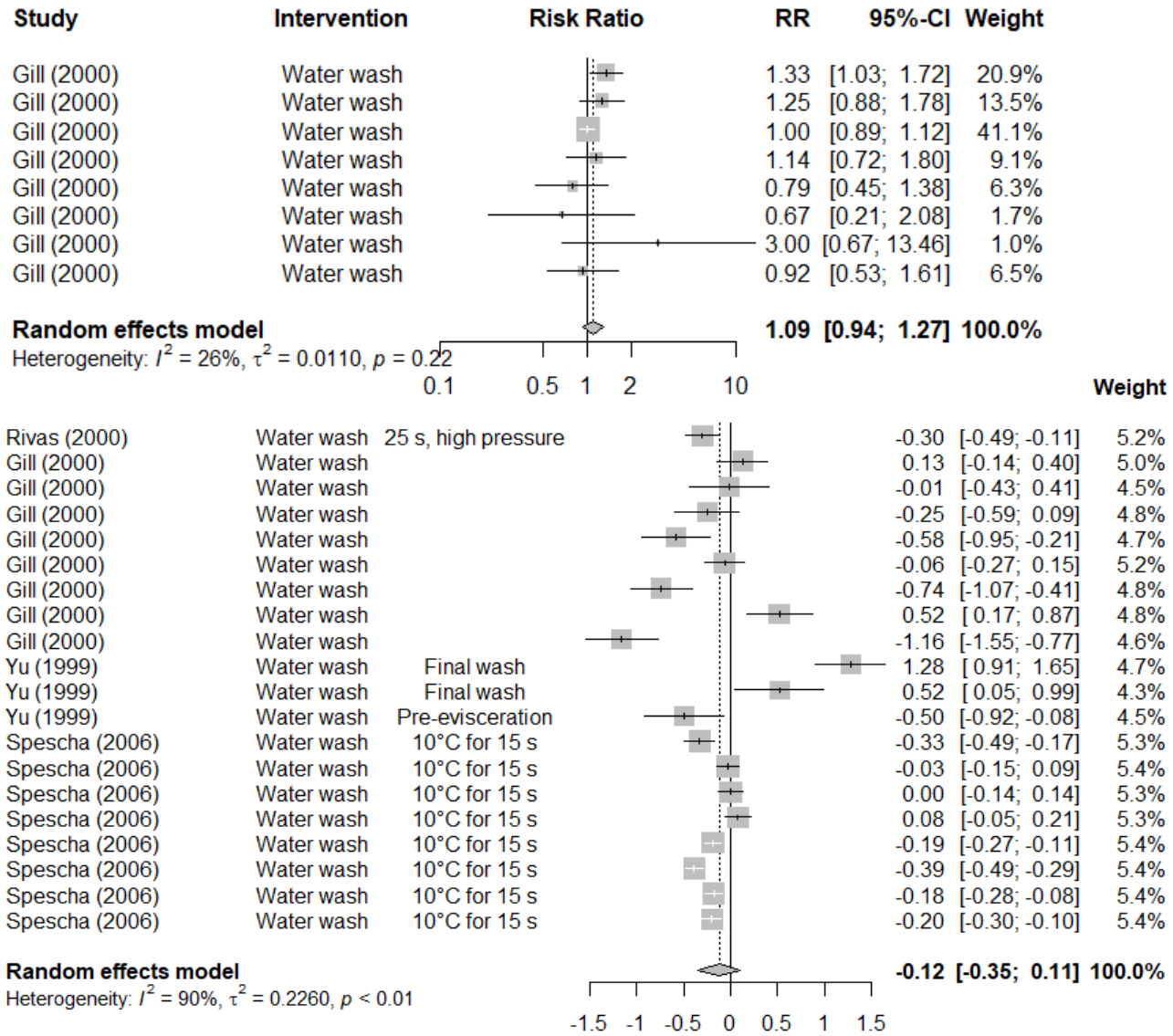
WG3 Pre-chill beef carcass SPPs: **water wash**

Study	Intervention	Description	RR	95%-CI	Weight
Gill & Landers (2003b)	Water wash	Post-evisceration cabinet, 40°C, 280 psi, 25 s	0.53	[0.28; 1.03]	22.8%
Gill & Landers (2003b)	Water wash	Post-evisceration cabinet, 40°C, 280 psi, 25 s	0.88	[0.58; 1.34]	25.1%
Gill & Landers (2003b)	Water wash	Post-evisceration cabinet, 40°C, 280 psi, 12 s	1.00	[0.59; 1.70]	24.0%
Gill & Landers (2003b)	Water wash	Post-evisceration cabinet, 40°C, 280 psi, 25 s	1.00	[0.85; 1.18]	26.6%
Gill & Landers (2003b)	Water wash	Cold water at 2°C, 140 psi	31.00	[0.06; 16428.28]	1.5%
Heterogeneity: I^2=14.7% t^2=0.61, p=0.32			**0.88**	**[0.44; 1.79]**	**100.0%**



Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of water wash in reducing **generic *E. coli* prevalence** on beef carcasses (low heterogeneity, no effect)

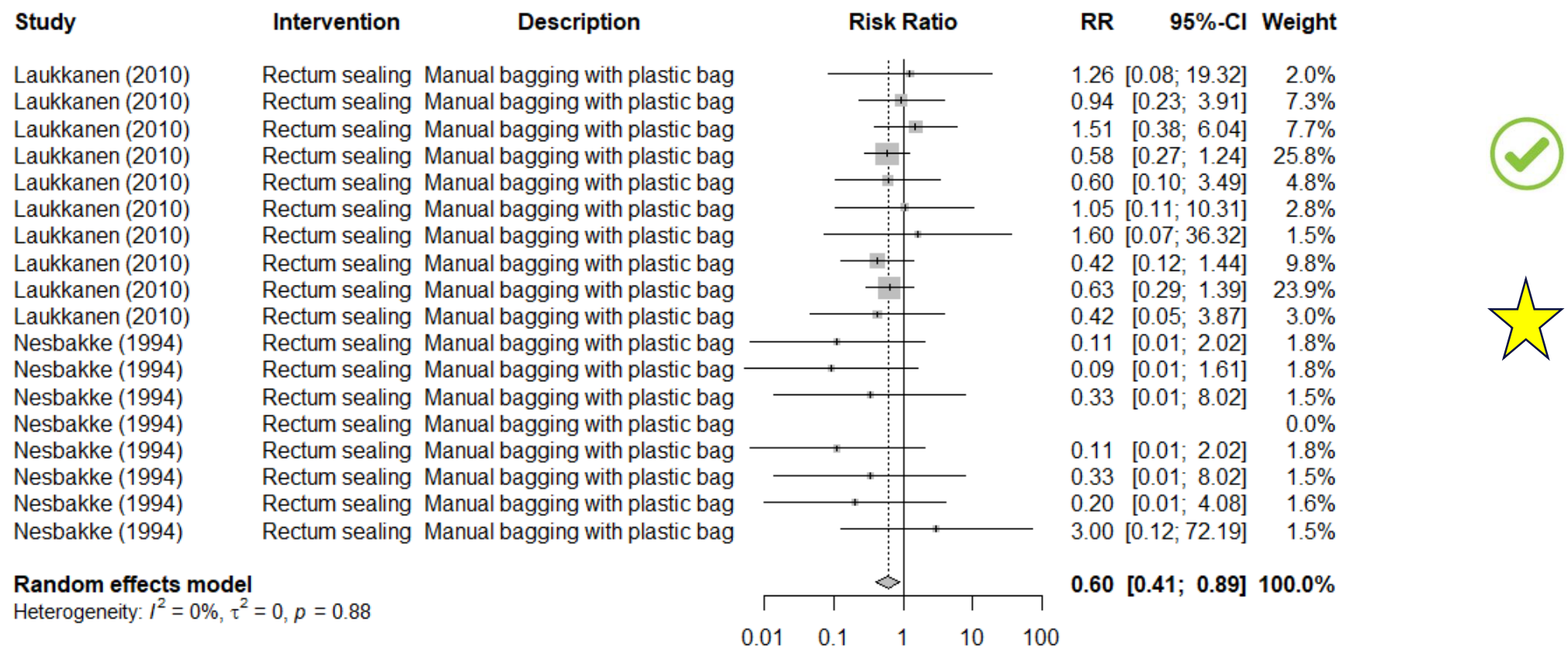
WG3 Results – SPPs: pig carcass **water wash**



Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of singeing in reducing generic *E. coli* prevalence on pig carcasses

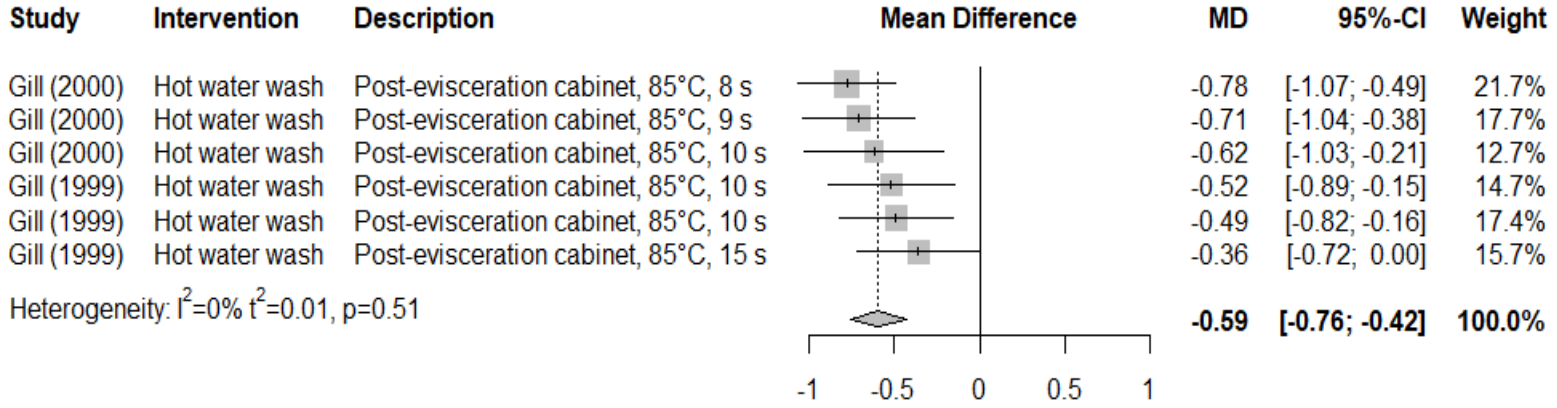
Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of water wash in reducing aerobic colony count (log_{10} CFU) on pig carcasses

Results – SPP: pig carcass **rectum sealing**

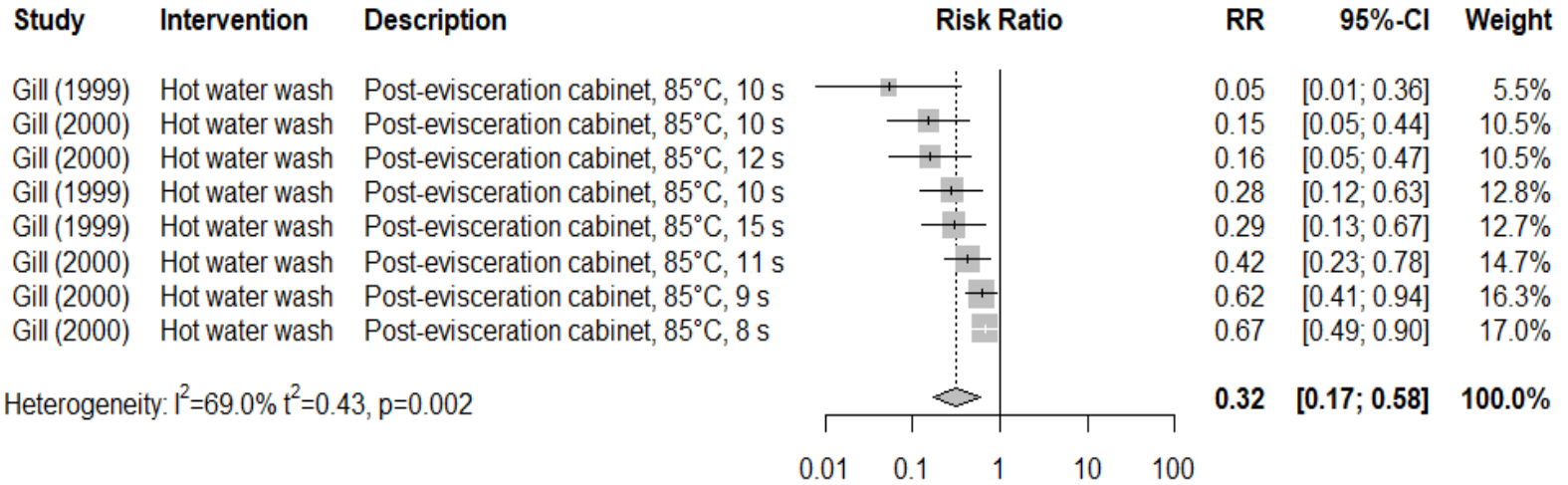


Forest plot of the results of controlled trials performed under commercial abattoir conditions to investigate the efficacy of rectum sealing in reducing ***Yersinia enterocolitica*** **prevalence** on pig carcasses

WG3 Beef pre-chill carcass interventions: **hot water wash**



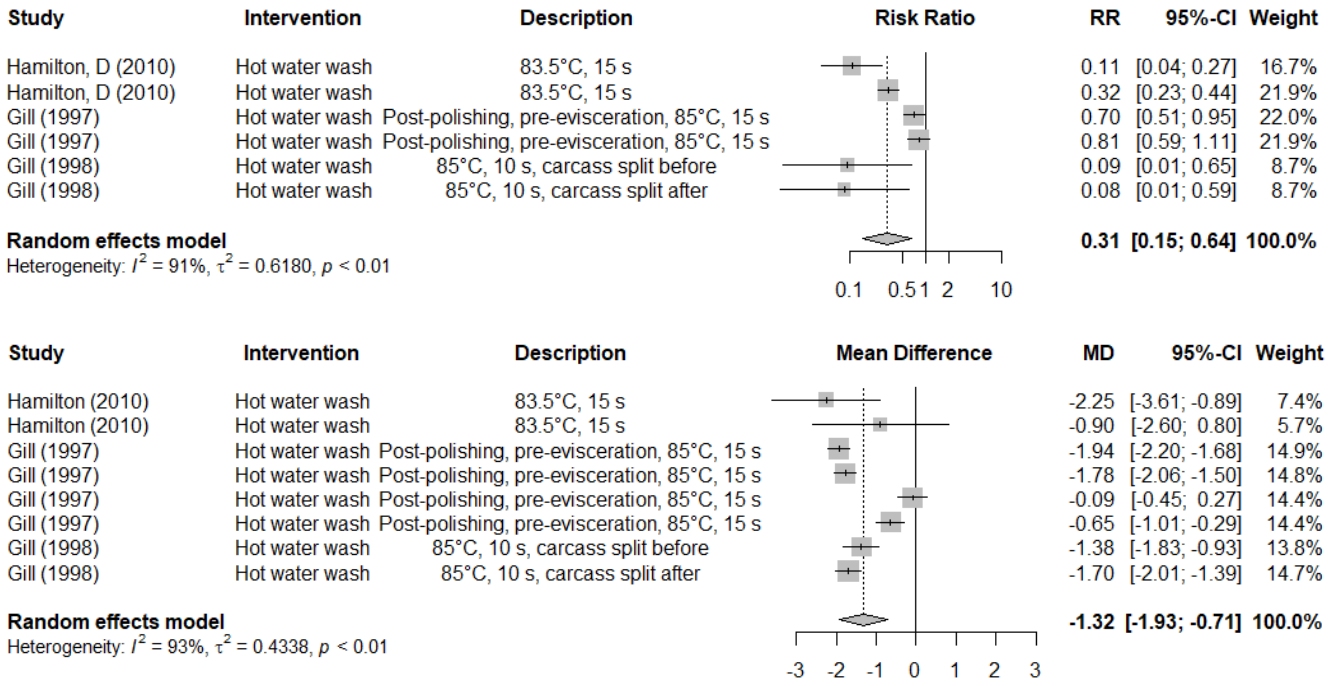
Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of hot water wash in reducing **generic *E. coli* counts** (log_{10} CFU) on beef carcasses (low heterogeneity, positive effect)



Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of hot water wash in reducing **generic *E. coli* prevalence** on beef carcasses (high heterogeneity, positive effect)

WG3 Pig abattoir interventions – Hot water washing

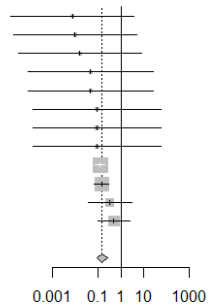
- Hot water washing effect:
  - ***E. coli*** prevalence reduced (RR 0.31, 95% CI 0.15-0.64) and counts (1.2 log CFU/cm²; 95% CI 0.34-0.73)
  - **ACC** reduced by 1.32 log CFU/cm² (95% CI 0.71-1.93)



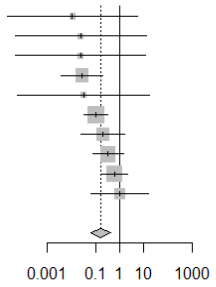
WG3 Beef abattoir interventions – Carcass steam pasteurisation

- Steam pasteurisation effect:
  - ***E. coli*** prevalence (RR 0.15, 95% CI 0.09-0.26) and counts (0.54 log CFU/cm²; 95% CI 0.34-0.73)
  - **Enterobacteriaceae** prevalence (RR 0.17, 95% CI 0.07-0.43) and counts 1.04 log CFU/cm² (95% CI 0.60-1.48)
  - **ACC** reduced by 1.14 log CFU/cm² (95% CI 0.93-1.35)

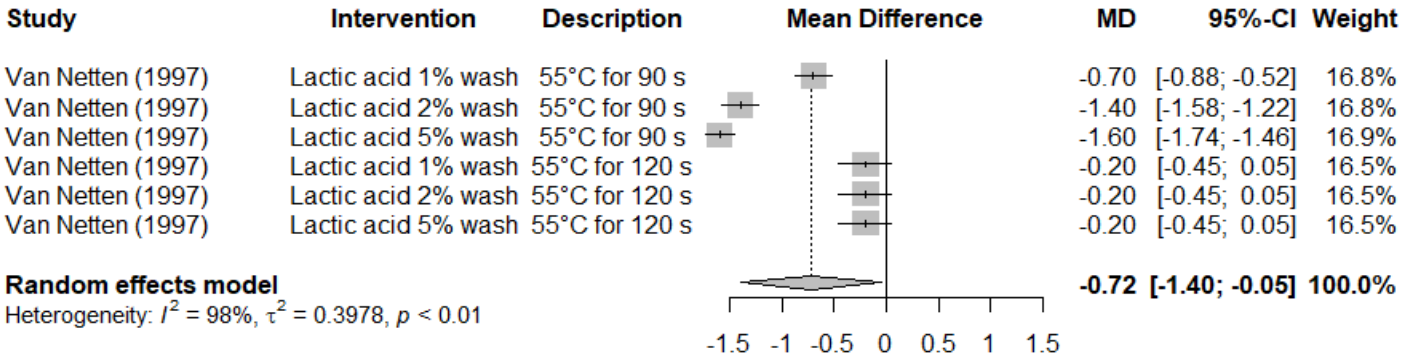
Study	Intervention	Description	RR	95%-CI	Weight
Nutsch (1997)	Steam pasteurisation	82.2°C, pressurised, 8 s; then cold water spray (4.4°C) at 40 lb/in2, 10 s	0.01	[0.00; 3.81]	1.6%
Nutsch (1997)	Steam pasteurisation	82.2°C, pressurised, 8 s; then cold water spray (4.4°C) at 40 lb/in2, 10 s	0.01	[0.00; 4.98]	1.6%
Retzlaff (2005)	Steam pasteurisation	85.0°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.02	[0.00; 8.22]	1.6%
Nutsch (1997)	Steam pasteurisation	82.2°C, pressurised, 6 s; then cold water spray (4.4°C) at 40 lb/in2, 10 s	0.05	[0.00; 25.34]	1.5%
Retzlaff (2005)	Steam pasteurisation	82.2°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.05	[0.00; 26.29]	1.5%
Nutsch (1997)	Steam pasteurisation	82.2°C, pressurised, 6 s; then cold water spray (4.4°C) at 40 lb/in2, 10 s	0.09	[0.00; 55.81]	1.5%
Retzlaff (2005)	Steam pasteurisation	76.7°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.09	[0.00; 57.17]	1.5%
Retzlaff (2005)	Steam pasteurisation	87.8°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.09	[0.00; 57.17]	1.5%
Corantin (2005)	Steam pasteurisation	74.5°C, 95 to 100 psi, 5 s	0.13	[0.08; 0.20]	34.1%
Gill & Bryant (1997b)	Steam pasteurisation	105°C, pressurised, 6.5 s	0.14	[0.07; 0.31]	28.7%
Retzlaff (2005)	Steam pasteurisation	73.9°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.33	[0.04; 2.94]	9.9%
Retzlaff (2005)	Steam pasteurisation	79.4°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.50	[0.10; 2.43]	15.3%
Heterogeneity: I^2=0% t^2=0.42, p=0.90			**0.15**	**[0.09; 0.26]**	**100.0%**



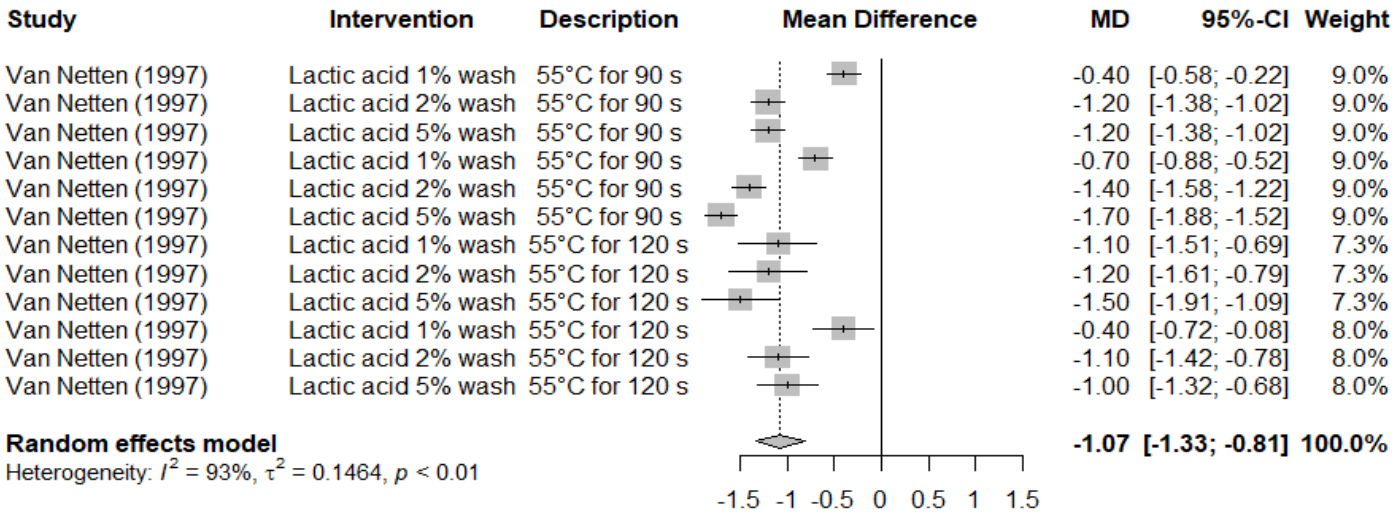
Study	Intervention	Description	RR	95%-CI	Weight
Retzlaff (2005)	Steam pasteurisation	85.0°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.01	[0.00; 5.42]	2.4%
Nutsch (1997)	Steam pasteurisation	82.2°C, pressurised, 6 s; then cold water spray (4.4°C) at 40 lb/in2, 10 s	0.02	[0.00; 12.23]	2.4%
Nutsch (1997)	Steam pasteurisation	82.2°C, pressurised, 6 s; then cold water spray (4.4°C) at 40 lb/in2, 10 s	0.02	[0.00; 12.08]	2.4%
Nutsch (1997)	Steam pasteurisation	82.2°C, pressurised, 8 s; then cold water spray (4.4°C) at 40 lb/in2, 10 s	0.03	[0.00; 0.20]	13.3%
Retzlaff (2005)	Steam pasteurisation	87.8°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.03	[0.00; 16.99]	2.4%
Nutsch (1997)	Steam pasteurisation	82.2°C, pressurised, 8 s; then cold water spray (4.4°C) at 40 lb/in2, 10 s	0.10	[0.03; 0.32]	19.8%
Retzlaff (2005)	Steam pasteurisation	73.9°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.20	[0.03; 1.56]	12.6%
Retzlaff (2005)	Steam pasteurisation	79.4°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.33	[0.08; 1.46]	17.0%
Retzlaff (2005)	Steam pasteurisation	76.7°C, pressurised, 11 s; then cold water spray (1°C), 12 s	0.60	[0.17; 2.18]	18.5%
Retzlaff (2005)	Steam pasteurisation	82.2°C, pressurised, 11 s; then cold water spray (1°C), 12 s	1.00	[0.07; 14.90]	9.2%
Heterogeneity: I^2=23.8% t^2=1.00, p=0.22			**0.17**	**[0.07; 0.43]**	**100.0%**



WG3 Results – hazard-based, pre-chill carcass interventions: **lactic acid wash**

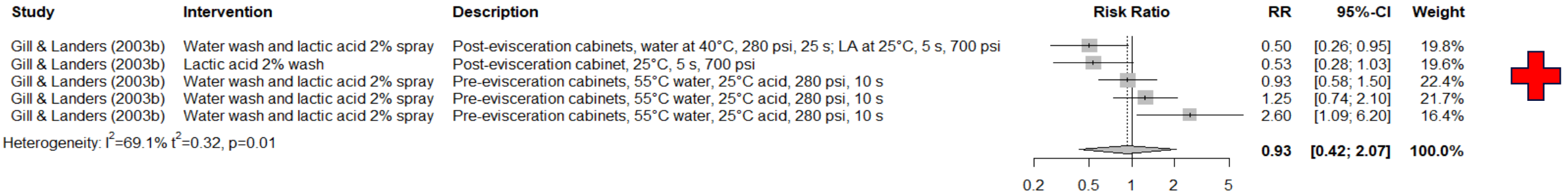


Forest plot of the results of **challenge trials** performed under **laboratory** conditions to investigate the efficacy of lactic acid wash in reducing ***Enterobacteriaceae* count** (log_{10} CFU) on pig carcass meat

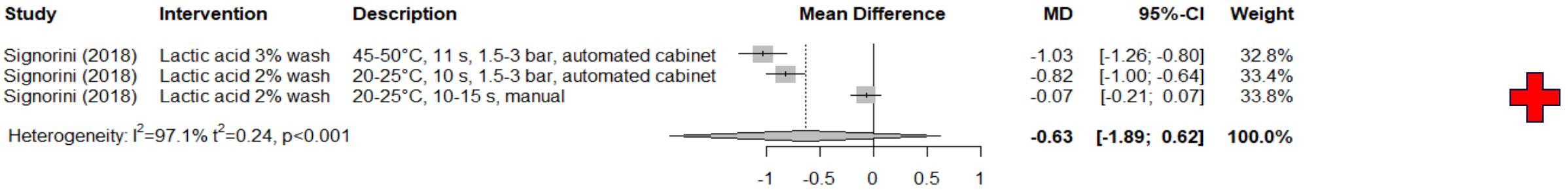


Forest plot of the results of **challenge trials** and performed under **laboratory** conditions to investigate the efficacy of hot water wash in reducing **aerobic colony count (log_{10} CFU)** on pig carcasses

WG3 Results – hazard-based, pre-chill carcass interventions: **lactic acid wash**



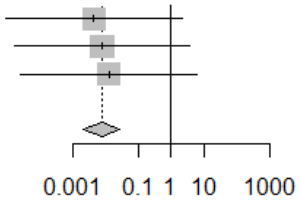
Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of lactic acid spray wash in reducing **generic *E. coli* prevalence** on beef carcasses (high heterogeneity, no effect)



Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of lactic acid spray wash in reducing **generic *E. coli* counts** (log_{10} CFU) on beef carcasses (high heterogeneity, no effect)

WG3 Results – hazard-based, pre-chill beef carcass interventions: **pasteurization & acid**

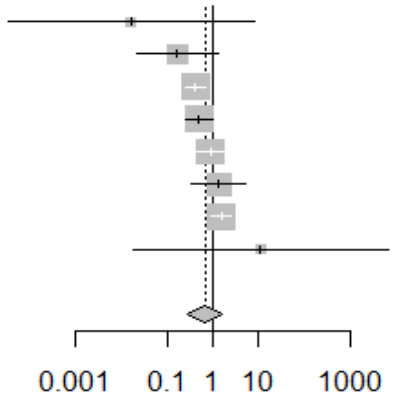
Study	Intervention	Description	Risk Ratio	RR	95%-CI	Weight
Gill & Landers (2003b)	Steam pasteurisation and lactic acid 2% spray	Post-evisceration cabinets, steam at 88-94°C, 12 s, LA at 700 psi		0.00	[0; 2.10]	33.5%
Gill & Landers (2003b)	Peroxyacetic acid spray and steam pasteurisation	Post-evisceration cabinets, PAA 200 ppm, 700 psi, steam at 88-94°C, 12 s		0.01	[0; 3.75]	33.3%
Gill & Landers (2003b)	Hot water and lactic acid 2% wash	Post-evisceration cabinet, water at 85°C, 10 s, 280 psi; LA at 25°C, 5 s, 700 psi		0.01	[0; 6.15]	33.2%
Heterogeneity: I^2=0% t^2=0.005, p=0.97				**0.01**	**[0; 0.03]**	**100.0%**



Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of pasteurisation and subsequent acid spray washes in reducing **generic *E. coli* prevalence** on beef carcasses (low heterogeneity, positive effect)

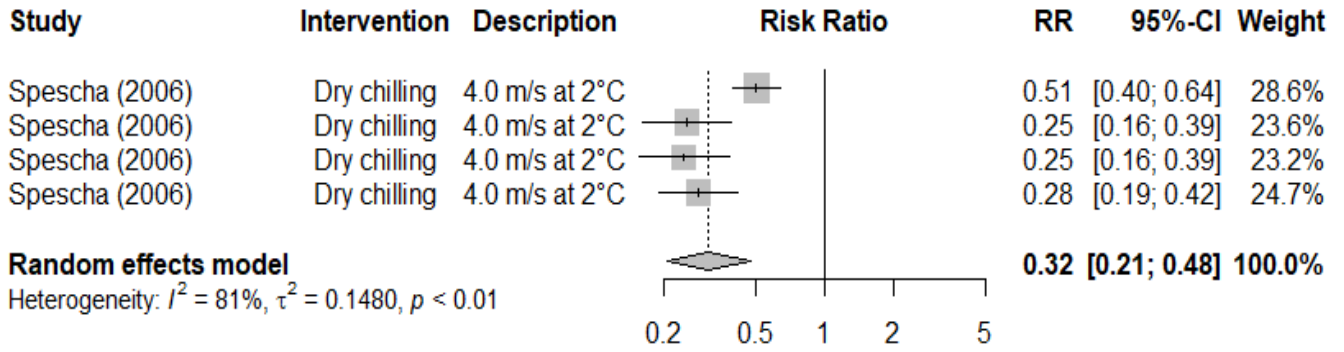
WG3 Results – chilling: beef carcass **water spray chilling**

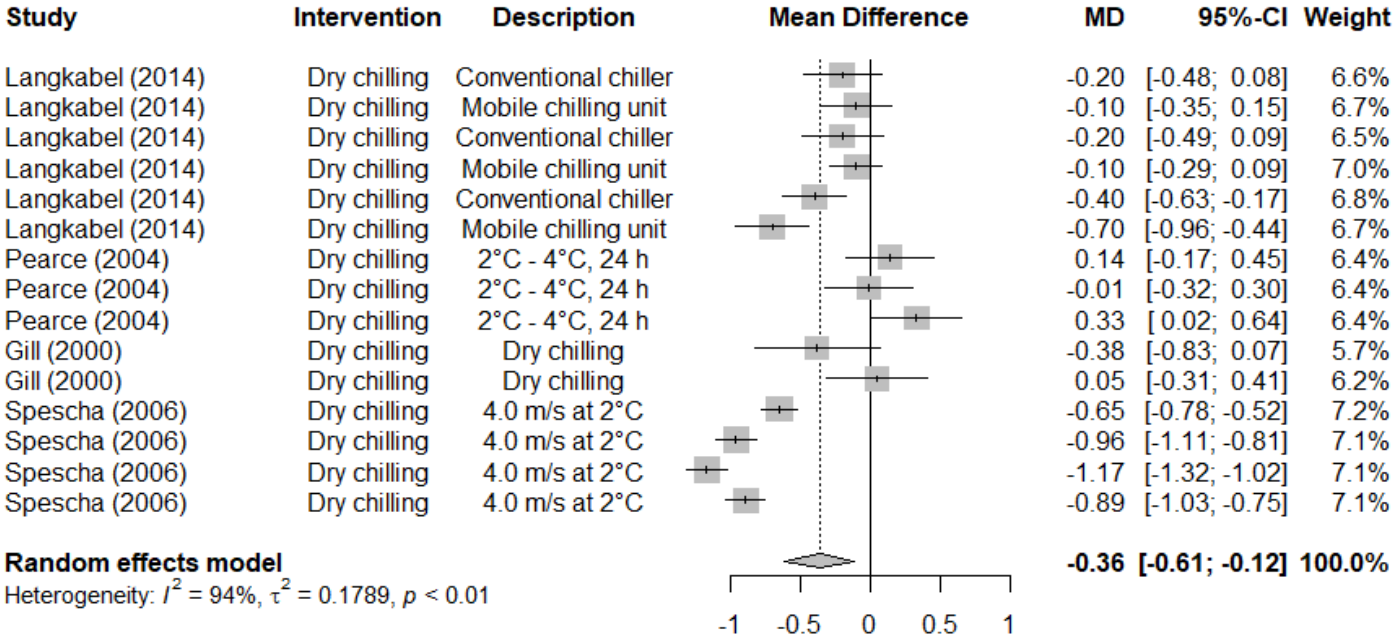
Study	Intervention	Description	RR	95%-CI	Weight
Gill & Bryant (1997b)	Water spray chilling	Intermittent (4°C water, 2°C air for 8 h), then dry air, -5°C, 22 h	0.02	[0.00; 8.38]	2.0%
Gill & Landers (2003a)	Water spray chilling	Intermittent for 8 h at 0°C, then dry air at 0°C, 24 h in total	0.17	[0.02; 1.29]	10.0%
Gill & Bryant (1997a)	Water spray chilling	Intermittent (4°C water, 2°C air for 8 h), then dry air, -5°C, 22 h	0.42	[0.26; 0.68]	18.7%
Gill & Bryant (1997a)	Water spray chilling	Intermittent (4°C water, 2°C air for 8 h), then dry air, -5°C, 22 h	0.50	[0.24; 1.03]	17.6%
Corantin (2005)	Water spray chilling	24 h, after steam pasteurisation	0.89	[0.46; 1.73]	17.8%
Gill & Landers (2003a)	Water spray chilling	Intermittent for 8 h at 2°C, then dry air at 2°C, 24 h in total	1.33	[0.33; 5.36]	13.6%
Gill & Landers (2003a)	Water spray chilling	Intermittent for 10 h at -2°C, then dry air at -1°C, 24 h in total	1.55	[0.92; 2.59]	18.5%
Gill & Landers (2003a)	Water spray chilling	Intermittent for 8 h at 2°C, then dry air at -2°C, 36 h in total	11.00	[0.02; 6958.77]	1.9%
Heterogeneity: I^2=63.9% t^2=1.12, p=0.007			**0.67**	**[0.29; 1.54]**	**100.0%**



Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of water spray chilling in reducing **generic *E. coli* prevalence** on beef carcasses (high heterogeneity, no effect)

WG3 Results – chilling: pig carcass **conventional dry chilling**

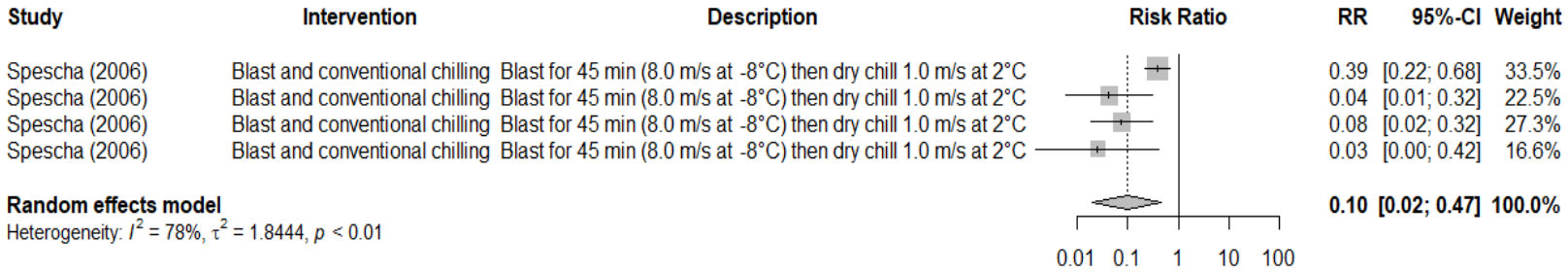




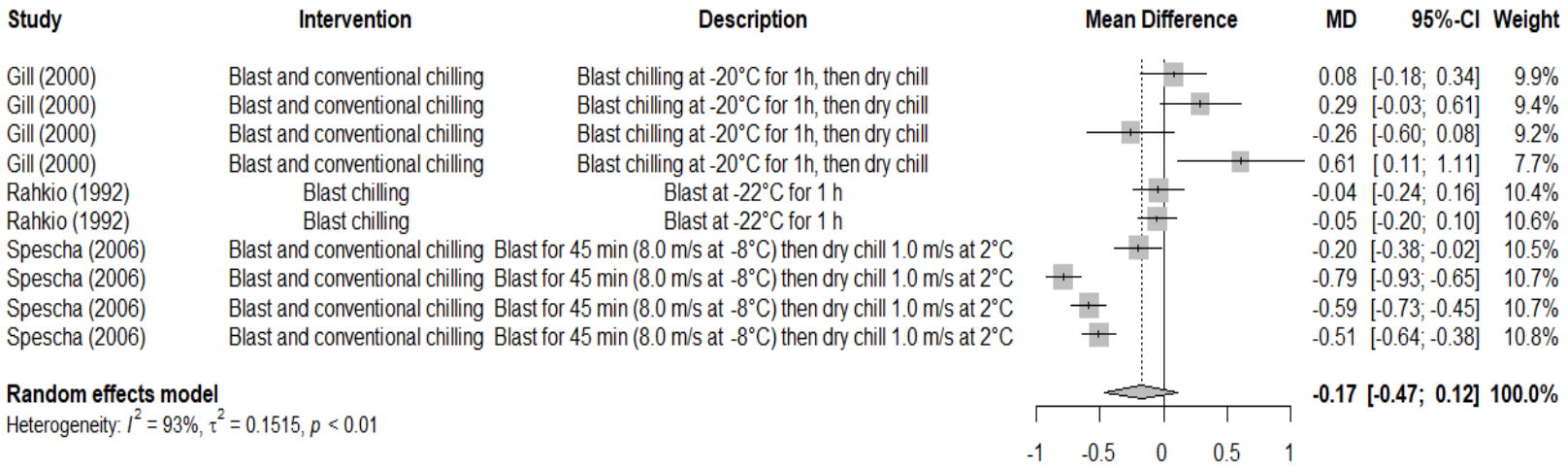
Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of dry chilling in reducing *Enterobacteriaceae* prevalence on pig carcasses

Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of dry chilling in reducing aerobic colony count (log_{10} CFU) on pig carcasses

WG3 Results – chilling: **blast chilling**



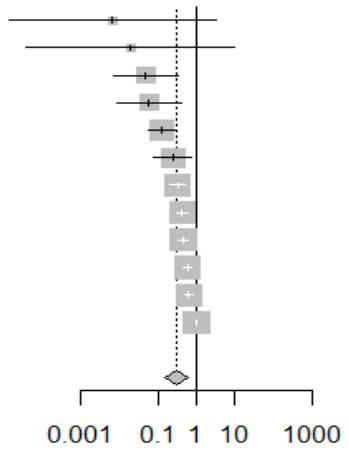
Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of blast and conventional chilling in reducing *Enterobacteriaceae* prevalence on pig carcasses



Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of blast and conventional chilling in reducing aerobic colony count (log_{10} CFU) on pig carcasses.

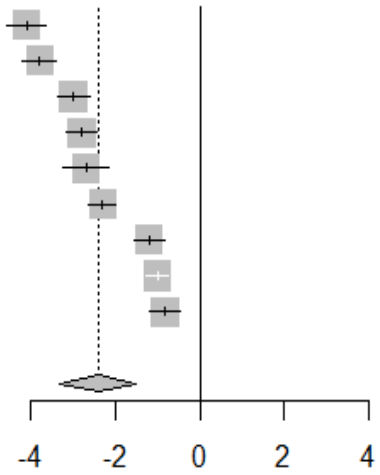
WG3 Results – beef carcass **multiple pasteurization and acid interventions**

Study	Intervention	Description	RR	95%-CI	Weight
Gill & Landers (2003b)	Pasteurisation and acid treatment system G		0.01	[0.00; 3.24]	1.1%
Gill & Landers (2003b)	Pasteurisation and acid treatment system F		0.02	[0.00; 10.00]	1.1%
Gill (2003)	Pasteurisation and acid treatment system F		0.05	[0.01; 0.33]	6.0%
Gill (2003)	Pasteurisation and acid treatment system F		0.06	[0.01; 0.41]	5.9%
Bacon (2000b)	Pasteurisation and acid treatment system C		0.13	[0.06; 0.29]	9.9%
Gill & Landers (2003b)	Pasteurisation and acid treatment system H		0.25	[0.08; 0.78]	8.7%
Bacon (2000b)	Pasteurisation and acid treatment system C		0.33	[0.21; 0.51]	11.0%
Bacon (2000b)	Pasteurisation and acid treatment system A		0.43	[0.30; 0.61]	11.1%
Bacon (2000b)	Pasteurisation and acid treatment system C		0.45	[0.32; 0.63]	11.2%
Bacon (2000b)	Pasteurisation and acid treatment system A		0.59	[0.45; 0.77]	11.3%
Bacon (2000b)	Pasteurisation and acid treatment system A		0.63	[0.49; 0.80]	11.3%
Bacon (2000b)	Pasteurisation and acid treatment system A		1.00	[0.98; 1.02]	11.5%
Heterogeneity: I^2=92.4% t^2=1.05, p=0.002			**0.30**	**[0.16; 0.59]**	**100.0%**



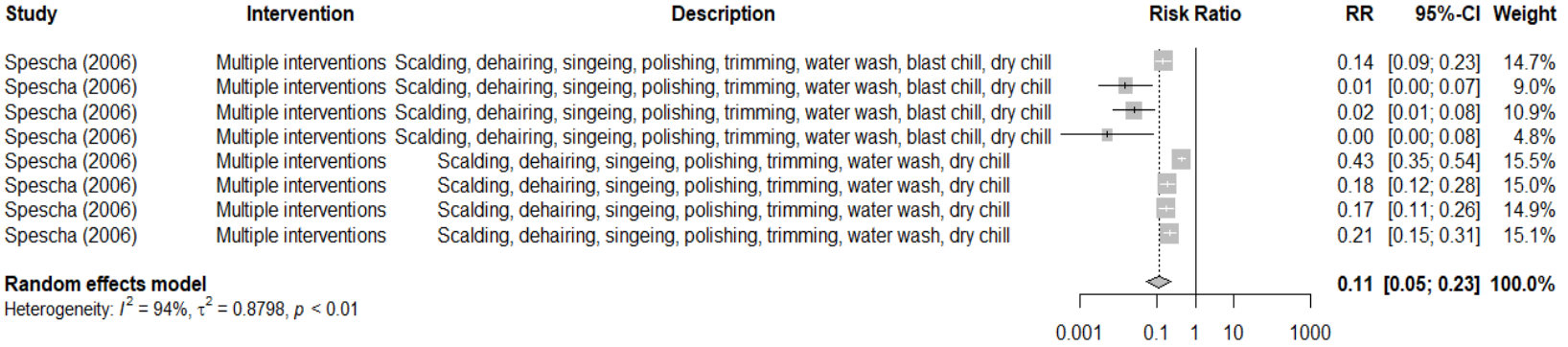
Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of multiple pasteurisation and acid interventions in reducing **generic *E. coli* prevalence** on beef carcass sides (high heterogeneity, positive effect)

Study	Intervention	Description	MD	95%-CI	Weight
Bacon (2000b)	Pasteurisation and acid treatment system C		-4.10	[-4.57; -3.63]	11.0%
Bacon (2000b)	Pasteurisation and acid treatment system A		-3.80	[-4.20; -3.40]	11.1%
Bacon (2000b)	Pasteurisation and acid treatment system C		-3.00	[-3.38; -2.62]	11.1%
Bacon (2000b)	Pasteurisation and acid treatment system A		-2.80	[-3.17; -2.43]	11.2%
Bacon (2000a)	Pasteurisation and acid treatment system A		-2.70	[-3.24; -2.16]	10.8%
Bacon (2000b)	Pasteurisation and acid treatment system C		-2.30	[-2.62; -1.98]	11.2%
Bacon (2000b)	Pasteurisation and acid treatment system A		-1.20	[-1.57; -0.83]	11.2%
Bacon (2000b)	Pasteurisation and acid treatment system A		-1.00	[-1.26; -0.74]	11.3%
Gill (2003)	Pasteurisation and acid treatment system F		-0.83	[-1.21; -0.45]	11.1%
Heterogeneity: I^2=97.5% t^2=1.37, p<0.0001			**-2.41**	**[-3.32; -1.49]**	**100.0%**

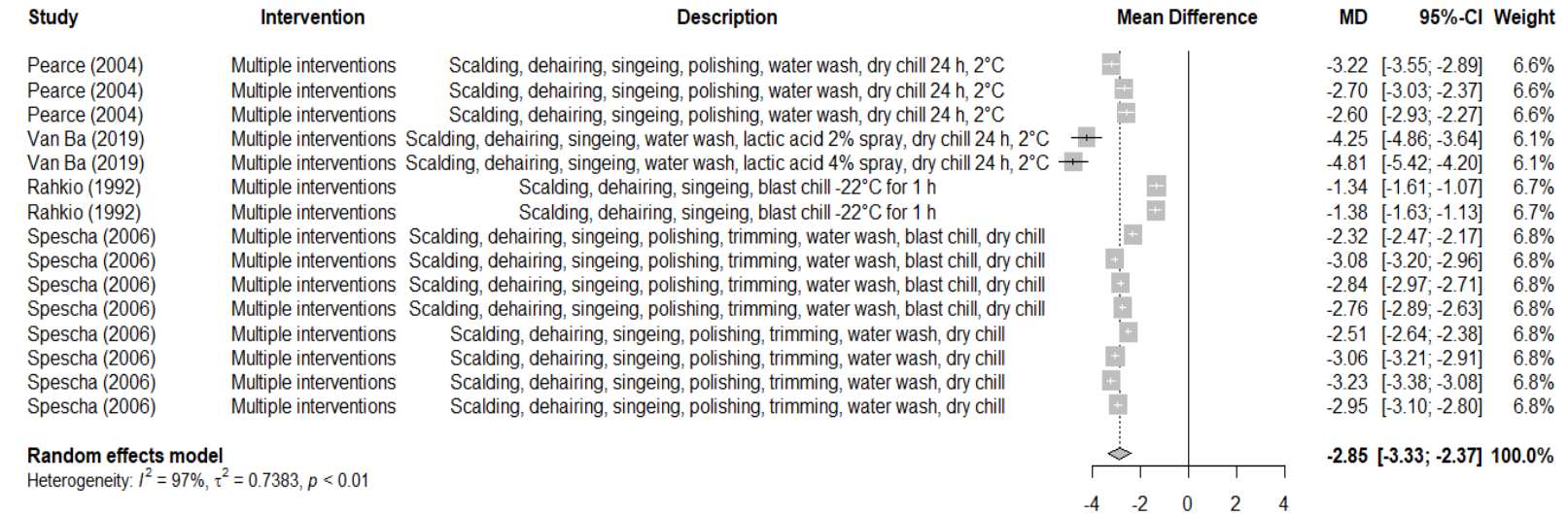


Forest plot of the results of before-and-after trials performed under **commercial abattoir** conditions to investigate the efficacy of multiple pasteurisation and acid interventions in reducing **generic *E. coli* counts** (log_{10} CFU) on beef carcass sides (high heterogeneity, positive effect)

WG3 Results – pig carcass **multiple interventions**



Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of multiple interventions in reducing *Enterobacteriaceae* prevalence on pig carcasses



Forest plot of the results of before-and-after trials performed under commercial abattoir conditions to investigate the efficacy of multiple interventions in reducing aerobic colony count (log_{10} CFU) on pig carcasses.

WG3 Conclusions

- Beef interventions can control microbial contamination on beef carcasses
  - cattle hide interventions including cleanliness assessments (can produce ~1 $\log_{10}$ reduction in microbial transfer each)
  - carcass steam pasteurisation, hot water washing, multiple (up to 2.5 $\log_{10}$ reduction)
- Pig interventions can control microbial contamination on beef carcasses
  - scalding, singeing, rectum sealing, hot water washing and dry chilling are effective
- Interventions integrated in RB-MSAS:
  - used to prevent carcass microbial contamination: help to "lower" abattoir risk category at the same time
  - used to remove/eliminate hazards from carcasses: applied only in "high risk scenario" (high risk farm + high risk abattoir), i.e. when targets cannot otherwise be met

WG3 Systematic review and Meta-analysis of beef, pig, sheep and poultry interventions

- Big thanks to all contributors in these tasks (2019-2022) and co-authors of past and future publications
- Beef project was commissioned and funded by the UK Food Standards Agency (FS430388)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